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Interdisciplinary Research in Science and Engineering

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Dr. Ranjan Kumar
Abhishek Dhar
Dr. Ashes Banerjee
Dr. Kazi Hasibur Rahman

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<u>Editors</u>

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Preface

In an era characterized by rapid technological advancement and complex global challenges, the need for interdisciplinary research has never been more pressing. "Interdisciplinary Research in Science and Engineering" aims to illuminate the pivotal role that collaborative efforts across various scientific and engineering domains play in addressing contemporary issues. This book serves as a comprehensive exploration of the methodologies, innovations, and implications of interdisciplinary research, emphasizing the convergence of ideas, techniques, and perspectives from diverse fields.

The landscape of modern research is evolving. Traditional disciplinary boundaries are increasingly blurred, as scholars and practitioners recognize that complex problems—ranging from climate change and public health to artificial intelligence and renewable energy require multifaceted approaches. By fostering collaboration among disciplines such as physics, biology, computer science, engineering, and social sciences, we can develop holistic solutions that are both innovative and effective. Each chapter of this book presents case studies and theoretical frameworks that exemplify successful interdisciplinary collaborations. The contributors renowned experts in their respective fields bring a wealth of knowledge and experience, shedding light on the challenges and triumphs encountered in their research endeavors. Readers will find a rich tapestry of insights that illustrate how integrating knowledge from different domains can lead to ground-breaking discoveries and advancements.

Moreover, this book emphasizes the importance of cultivating an interdisciplinary mindset among students, researchers, and professionals. The future of science and engineering hinges on our ability to embrace diverse perspectives, foster creativity, and encourage open dialogue among disciplines. It is our hope that this book inspires a new generation of researchers to pursue collaborative endeavours that transcend traditional boundaries. As we embark on this exploration of interdisciplinary research, we invite you to engage with the ideas presented herein, reflect on the interconnectedness of knowledge, and consider how you might contribute to the growing body of work that seeks to harness the power of collaboration in addressing the challenges of our time.

We extend our deepest gratitude to all the contributors, reviewers, and supporters who have made this book possible. Together, we can pave the way for a future where interdisciplinary research not only thrives but also transforms the landscape of science and engineering for the betterment of society.

Dr. Ranjan Kumar

Associate Professor, Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, West Bengal, India

Acknowledgment

I extend my heartfelt gratitude to Swami Vivekananda University, Kolkata, India, for their steadfast support and encouragement throughout the creation of “Interdisciplinary Research in Science and Engineering" The University’s dedication to fostering education and research has been instrumental in shaping the content and direction of this publication. We deeply appreciate the collaborative spirit and resources provided by Swami Vivekananda University, Kolkata, which have enabled us to explore and share the latest innovations and technologies across various fields.

We hope that this book serves as a valuable resource for this esteemed institution and the broader academic community, reflecting our shared dedication to knowledge, progress, and the pursuit of excellence.

I extend my deepest appreciation to each of the external reviewers mentioned below for their unwavering commitment to excellence and their indispensable role in ensuring the scholarly merit of this work.

With sincere appreciation,

List of reviewers

1. Prof. (Dr.) Vinayak Ranjan, Department of Mechanical Engineering, Rowan University, Glassboro, NJ 08028, United States
2. Dr. Shamim Haidar, Department of Mechanical Engineering, Aliah University, Kolkata- 700156, India
3. Prof. (Dr.) Somendra Nath Roy, Ex-Scientist, CSIR-CGCRI, Kolkata- 700032, India

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Investigating the Particle Size Distribution of Soil and Rock Dust for Civil Engineering Applications

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Chapter - 1

Investigating the Particle Size Distribution of Soil and Rock Dust for Civil Engineering Applications

Santanu Karmakar, Rahul Kumar Shaw and Ashes Banerjee

Abstract

This study investigates the application of sieve analysis, a standardized technique governed by the IS-2720(P-4) 1985 standard. Sieve analysis offers a simple yet effective method for quantifying the particle size distribution of granular materials, which are fundamental building blocks in numerous civil engineering projects. This experiment employs sieve analysis to analyze both soil and rock dust samples. By determining the distribution of particle sizes within each sample, we gain valuable insights into their suitability for various civil engineering applications. Understanding particle size distribution is a critical aspect of material selection in civil engineering. The size and gradation (range) of particles significantly influence the engineering properties of a material, such as permeability, drainage characteristics, shear strength, and ultimately, its overall performance within a structure. By employing sieve analysis, engineers can ensure they select materials with a particle size distribution that aligns with the specific requirements of a project. This not only optimizes the performance of the final structure but also contributes to factors like construction efficiency and cost-effectiveness.

Keywords: Granular materials, sieve analysis, particle size distribution, civil engineering, soil compaction, permeability.

Introduction

The behavior of granular materials, such as soil and rock dust, plays a critical role in the success of civil engineering projects. These materials form the foundation, embankments, and various structural elements within civil infrastructure. Their properties, particularly particle size distribution, exert a significant influence on factors like stability, drainage, and bearing capacity (Lambe & Whitman, 1979). For instance, soil with a high percentage of fines (silt and clay particles) can exhibit poor drainage characteristics, leading to waterlogging and potential structural issues (Das, 2016). Conversely, well-graded materials with a mix of particle sizes often demonstrate superior performance in terms of strength and permeability (Coduto, 2010).

Understanding the composition and distribution of these particles is essential for civil engineers to make informed decisions regarding the use and treatment of granular materials in construction. Poorly graded materials, where particle sizes are uniform, may lead to excessive settlement and instability, while well-graded materials can enhance the mechanical properties of the structure (Holtz, Kovacs, & Sheahan, 2010). The specific gravity, shape, and texture of particles also contribute to the overall behavior of the material under different loading conditions (Bowles, 1996).

Sieve analysis emerges as a reliable and straightforward technique for quantifying the particle size distribution of granular materials (ASTM International, 2017). This method offers a valuable tool for civil engineers by providing a detailed breakdown of the various particle sizes present within a sample (Head, 2006). By understanding this distribution, engineers can gain crucial insights into the material's suitability for different civil engineering applications. The information obtained from sieve analysis helps in designing foundations, assessing soil compaction needs, predicting settlement behavior, and evaluating drainage capabilities (Fang & Daniels, 2006).

This paper delves into the details of sieve analysis, outlining the experimental procedure, the apparatus required, and the calculation methods employed. The procedure involves passing a soil or rock dust sample through a stack of sieves with progressively smaller mesh sizes. The amount of material retained on each sieve is weighed, and the cumulative percentage of material passing through each sieve is calculated to determine the particle size distribution curve (ASTM International, 2017). This curve is critical in identifying the grading characteristics of the material.

The apparatus required for sieve analysis includes a set of standard sieves, a mechanical shaker, a balance, and a brush for cleaning the sieves. The mechanical shaker ensures consistent and repeatable results by vibrating the sieves and sample for a specified period. Accurate weighing of the retained material on each sieve is crucial for reliable results (British Standards Institution, 2009).

Following this, we present the results obtained from analyzing soil and rock dust samples, along with a discussion on their significance in the context of civil engineering projects. The results section includes graphical representations of particle size distribution curves for the samples tested. These curves illustrate the gradation of the materials, highlighting the percentage of fines, sand, and gravel present in each sample.

In the discussion, we interpret the implications of these findings for various civil engineering applications. For example, a sample with a high percentage of fines may require additional drainage measures or stabilization techniques to ensure structural integrity. On the other hand, a well-graded sample with a diverse range of particle sizes might be ideal for use in constructing stable embankments and load-bearing structures (Bowles, 1992).

Overall, sieve analysis provides a fundamental understanding of granular material properties, enabling engineers to make data-driven decisions in the design and construction of civil infrastructure. Through careful analysis and interpretation of particle size distribution data, civil engineers can enhance the performance, safety, and longevity of their projects (Murthy, 2002).

Materials and sample preparation

Soil samples were collected from the Kalyani site, and rock dust samples were obtained from the Birbhum location. To eliminate moisture content variations that could affect the results, all samples were oven-dried for 24 hours before testing.

Apparatus

The experiment utilized a set of standard sieves with mesh sizes conforming to the chosen standard (IS-2720(P-4) 1985). The specific sieve sizes used in this experiment were 4.75mm, 2.36mm, 1.18mm, 0.600mm, 0.300mm, 0.150mm, 4.75micron, and 2.0mm. Additionally, a sieve shaker was employed to facilitate the sieving process, ensuring efficient and consistent separation of particles.

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Fig 1: Instrument used in the study (a) Sieve Shaker (b) Set of Sieve

Methodology and calculations

The following calculations were used to determine the particle size distribution from the collected sieve data:

- **Percentage retained:** This value represents the portion of the sample retained on a specific sieve. It is calculated using the formula:

Percentage Retained = (Weight Retained on Sieve / Total Sample Weight) x 100%

- **Cumulative Percentage passing (finer):** This parameter indicates the percentage of particles smaller than a particular sieve size. It is determined by subtracting the cumulative percentage retained from 100%.

- **Percentage passing:** This value signifies the portion of the sample passing through a specific sieve. It is calculated using the formula:

Percentage Passing = (Total Weight Below Current Sieve / Total Sample Weight) x 100%

Results and Discussion

Sieve analysis of soil and rock dust

The results obtained from the sieve analysis performed on both the soil and rock dust samples are presented in separate tables (Table 1 and Table 2). The corresponding particle size distribution charts are depicted in Figures 1 and 2, respectively. These figures visually represent the gradation (percentage) of various particle sizes within each sample.

Table 1: Sieve Analysis of Soil (As Per IS 2720, Part - IV)

Type of material	Soil							
			Weight of sample taken (W)			300	gm	
Sl no	Sieve Size	Wt. Retained	% Weight Retained	Cumulative % weight Retained	Cumulative % Passing	Remarks		
	(mm)	(gms)	(%)	(%)	(%)			
A	100	0	0.00	0.00	100.00	GRAVEL CONTENT (B - D)	0.12	%
B	75	0	0.00	0.00	100.00			
C	19	0	0.00	0.00	100.00	SAND CONTENT (D - G)	23.26	%
D	4.75	0.35	0.12	0.12	99.88			
E	2.00	5.05	1.68	1.80	98.20	SILT & CLAY CONTENT (G)	76.62	%
F	0.425	11.93	3.98	5.78	94.22			
G	0.075	52.81	17.60	23.38	76.62			

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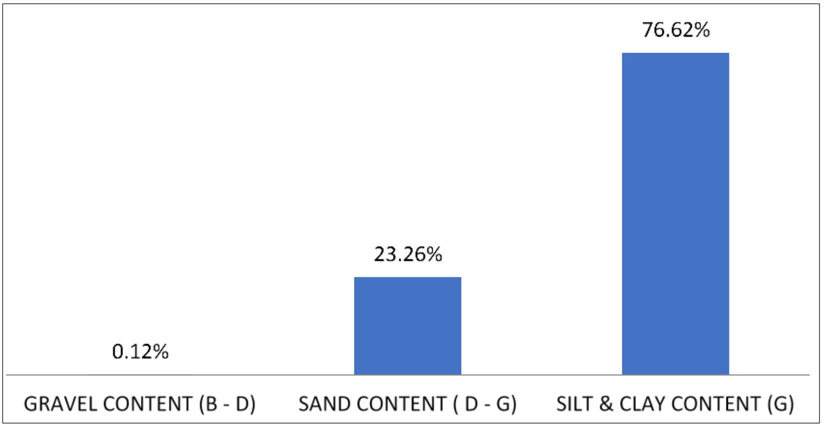

Fig 1: Soil grade percentage

Table 4: Sieve analysis of rock dust (As Per IS 2720, Part - IV)

Type of material	Stone Dust							
				Weight of sample taken (W)		**300**	gm	
Sl no	Sieve Size	Wt. Retained	% Weight Retained	Cumulative % weight Retained	Cumulative % Passing	Remarks		
	(mm)	(gms)	(%)	(%)	(%)			
A	100	0	0.00	0.00	100.00	GRAVEL CONTENT (B - D)	4.44	%
B	75	0	0.00	0.00	100.00			
C	19	0	0.00	0.00	100.00	SAND CONTENT (D - G)	82.13	%
D	4.75	13.31	4.44	4.44	95.56			
E	2.00	70.83	23.61	28.05	71.95	SILT & CLAY CONTENT (G)	13.43	%
F	0.425	120.04	40.01	68.06	31.94			
G	0.075	55.53	18.51	86.57	13.43			

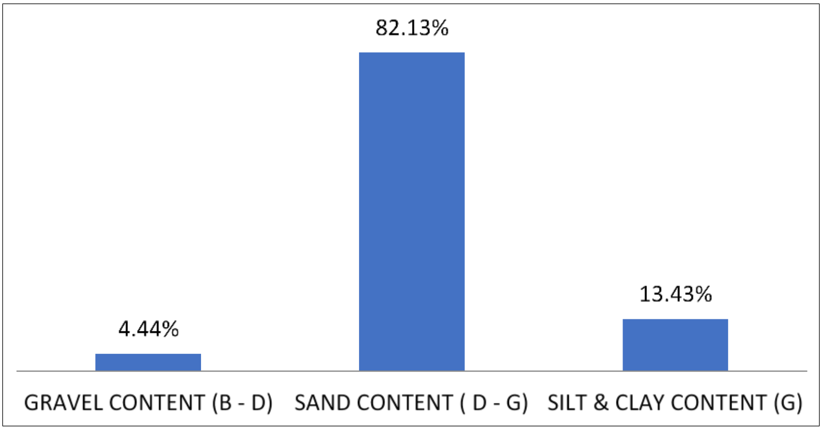

Fig 2: Rock dust grade percentage

As observed from the data and figures, the soil sample exhibits a significantly higher percentage of silt and clay particles (76.62%) compared to the rock dust sample (13.43%). Conversely, the rock dust sample demonstrates a considerably higher proportion of sand particles (82.13%) compared to the soil sample (23.26%). This variation in particle size distribution highlights the distinct characteristics of these two materials.

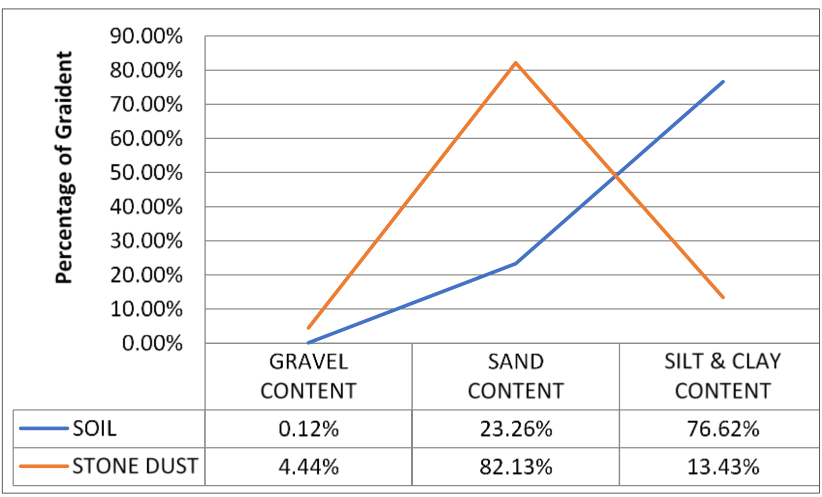

Fig 3: Rock dust grade percentage

Significance in civil engineering

In civil engineering, particularly highway construction, the sub-base material plays a critical role. Improper compaction and gradation (particle size distribution) of this layer can lead to severe consequences, including cracking, moisture absorption, and ultimately, structural failure. The functional performance of soil is governed by several factors, including compaction, water content, particle size distribution, and overall strength. Understanding these factors is essential for selecting appropriate materials and ensuring optimal performance in infrastructure development. The current study paves the way for further investigations into the potential for improving the bearing capacity of weak soils through partial replacement with rock dust, a technique frequently employed in various civil engineering applications.

Conclusion

Sieve analysis is a valuable tool for characterizing the particle size distribution of granular materials used in civil engineering projects. The information obtained from this analysis aids in selecting suitable materials for specific applications and ensures optimal performance in infrastructure development. This study demonstrates the distinct particle size distributions of soil and rock dust samples. The soil sample possessed a higher percentage of fines (silt and clay), while the rock dust sample contained a greater proportion of sand particles. This understanding of particle size distribution is crucial for selecting appropriate materials in various civil engineering applications.

Future research

This research lays the groundwork for further investigations into the potential of utilizing rock dust for improving the bearing capacity of weak soils. Here are some potential areas for future exploration:

- **Mixing ratios:** Experimenting with different mixing ratios of soil and rock dust to determine the optimal combination for enhancing bearing capacity.
- **Strength testing:** Conducting compression tests or other relevant strength tests on samples prepared with varying soil-rock dust mixtures to quantify the improvement in bearing capacity.
- **Geotechnical properties:** Evaluating the impact of rock dust incorporation on other geotechnical properties of the soil, such as permeability and susceptibility to erosion.

By investigating these aspects, future research can establish a more comprehensive understanding of the effectiveness of rock dust in fortifying weak soils and its potential applications in civil engineering projects.

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Chapter - 2

Plasticity and Free Swell Characteristics of Soil and Stone Dust

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Chapter - 2

Plasticity and Free Swell Characteristics of Soil and Stone Dust

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Abstract

This study explores the geotechnical properties of soil and stone dust, focusing on plasticity and free swell behavior, which are critical factors influencing their performance in civil engineering applications. The investigation employs standard procedures outlined in IS codes (IS 2720 (Part 5), 1985 and IS 2720 (Part 40), 1977) to determine the liquid limit (LL), plastic limit (PL), and free swell index (FSI) of both materials. The results reveal significant differences in these properties between soil and stone dust, highlighting their varying suitability for specific civil engineering projects. By understanding these fundamental geotechnical characteristics, engineers can make informed decisions regarding material selection and optimize construction practices. This research contributes to the selection of appropriate materials for various civil engineering applications, promoting safe, efficient, and cost-effective infrastructure development.

Keywords: Soil, stone dust, plasticity, free swell index, geotechnical properties, civil engineering.

Introduction

In the realm of civil engineering, the successful execution of projects hinges critically on the behavior of granular materials, such as soil and rock dust. These materials serve as the bedrock for various structural elements within civil infrastructure, forming foundations, embankments, and essential components (Das & Sivakumar, 2015). Their inherent properties, particularly the distribution of particle sizes, exert a profound influence on factors like stability, drainage efficiency, and the overall bearing capacity (Yoon & Santamarina, 2002). For instance, soil with a high concentration of fines (silt and clay particles) can exhibit poor drainage characteristics. This arises due to the reduction in pore spaces within the soil matrix, potentially leading to waterlogging and subsequent structural issues (Koerner, 1994). Conversely, well-graded materials, characterized by a mix of various particle sizes, often demonstrate superior performance. The interlocking nature of these diverse particle sizes enhances the overall strength of the material and allows for improved water permeability (Feng *et al*., 2018).

Understanding and quantifying particle size distribution are paramount for selecting appropriate materials in civil engineering applications. Sieve analysis emerges as a reliable and standardized technique (ASTM D422-63, 2007) for achieving this objective. This method offers a valuable tool by providing a detailed breakdown of the various particle sizes present within a granular material sample. By meticulously analyzing this distribution, civil engineers gain crucial insights into the material's suitability for specific project requirements. The subsequent sections of this paper delve into the specifics of sieve analysis, outlining the experimental procedure, the necessary apparatus, and the employed calculation methods. Following this, we will present the results obtained from analyzing soil and rock dust samples, along with a comprehensive discussion on their significance within the context of civil engineering projects. By exploring the impact of particle size distribution on the performance of granular materials, this research aims to contribute to the selection of optimal materials for various civil engineering applications, ultimately promoting the development of safe, efficient, and cost-effective infrastructure.

Methodology

This section details the experimental procedures employed to evaluate the plasticity characteristics (liquid limit, plastic limit, and plasticity index) and free swell index of the collected soil and stone dust samples. All tests were conducted in accordance with the relevant Indian Standard (IS) specifications.

Plasticity characteristics

Plasticity is a crucial property of fine-grained soils, influencing their behavior under load. It is quantified by the liquid limit (LL), plastic limit (PL), and plasticity index (PI).

Liquid Limit (LL): The minimum water content at which the soil exhibits flow behavior is defined as the liquid limit. It is determined using the Casagrande cone penetration test (ASTM D4318, 2017).

Plastic Limit (PL): The minimum water content at which the soil crumbles when rolled into thin threads (diameter of 3 mm) is defined as the plastic limit. A rolling device or a hand-rolling technique can be employed for this test (ASTM D4318, 2017).

Plasticity Index (PI): The PI is calculated using the following formula:

PI = LL - PL

Apparatus used

- Balance (accuracy of 0.01 g)
- Casagrande Liquid Limit Device (Fig. 1a)
- Grooving Tool (Fig. 1b)
- Mixing Dishes
- Spatula
- Electric Oven (maintained at 105°C ± 5°C)
- Squeeze Bottle with distilled water
- 425-micron IS Sieve

Sample preparation

- Disturbed soil samples were collected from the Kalyani site, and stone dust samples were obtained from Birbhum, West Bengal.
- The samples where prepared following IS 2720 (Part 5) 1985 (Fig.2). This involved air-drying the samples and sieving them through a 425-micron IS sieve to remove any particles larger than the specified size.
- All organic materials like leaves and roots were meticulously removed from the samples.

Liquid limit test procedure

1. A portion of the prepared soil or stone dust sample (approximately 100 g) was placed in a mixing dish and thoroughly mixed with distilled water to achieve a pasty consistency.
2. The sample was placed in the Casagrande liquid limit device (Fig. 1) and leveled with a spatula to create a flat surface with a groove in the center.
3. The Casagrande cup was raised and dropped repeatedly at a rate of two drops per second using a standardized mechanism. The number of drops required for the groove to close along a distance of 10 mm was recorded.

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4. This procedure was repeated with the sample at different water contents until two consecutive readings within a range of 10 drops were obtained.
5. The moisture content corresponding to the average of these two readings was considered the liquid limit of the sample.

Fig 1: The device used in the study (a) Liquid Limit Device (b) Grooved Soil

Fig 2: Sample preparations for plastic limit test

Calculation of liquid limit

The water content (W%) of the soil or stone dust sample at the liquid limit was determined using the following formula:

W% = [(W2 - W3) / (W3 - W1)] x 100

where:

W1 = Weight of container + liquid (g)

W2 = Weight of container + liquid + wet sample (g)

W3 = Weight of container + liquid + dry sample (g)

Plastic limit test procedure

1. A portion of the prepared soil or stone dust sample (approximately 20 g) was placed on a clean glass plate and mixed with distilled water to obtain a moldable consistency.
2. The moist soil or stone dust was rolled out by hand or using a rolling device (optional) on the glass plate, applying moderate pressure to form a uniform sheet.
3. The sheet of soil or stone dust was continuously rolled and folded until it reached a thickness of approximately 3 mm. Throughout the rolling process, portions of the sample losing moisture were discarded to maintain the required consistency.
4. Threads of approximately 3 mm in diameter were rolled out from the soil or stone dust sheet. The rolling was continued until the threads crumbled when attempting to roll them further.
5. The water content of the crumbled threads was determined by oven-drying the sample at 105°C ± 5°C for 24 hours and calculating the moisture content using the same formula employed for the liquid limit test.

Plasticity index calculation

The plasticity index (PI) for each sample was calculated using the following formula:

PI = LL - PL

where:

- LL = Liquid Limit (%)
- PL = Plastic Limit (%)

Free swell index

The free swell index (FSI) signifies the increase in soil volume upon immersion in water without any external pressure. A higher FSI indicates a greater potential for swelling, which can be detrimental to civil engineering structures. The FSI was determined following the guidelines outlined in IS 2720 (Part 40), 1977.

Apparatus used

Two 100-ml capacity graduated glass cylinders

425-micron IS Sieve

Glass Rod for stirring

Balance with a capacity of 500 grams and a sensitivity of 0.01 gram

Sample preparation

Two test samples, each weighing approximately 10 grams, were prepared from the oven-dried soil or stone dust passing through a 425-micron IS sieve (Fig.3).

1. One of the graduated cylinders was filled with 100 ml of distilled water.
2. The other graduated cylinder was filled with 100 ml of kerosene oil.
3. Each prepared soil or stone dust sample was carefully poured into the respective graduated cylinder containing either water or kerosene oil.
4. A glass rod was used to gently stir the contents of each cylinder to remove any trapped air. The initial volume occupied by the soil or stone dust sample in each cylinder was recorded.
5. Both cylinders were allowed to stand undisturbed for a period of 24 hours to permit complete immersion and potential volume change of the samples.

Calculation of free swell index

After 24 hours, the final volume occupied by the soil or stone dust sample in each cylinder was recorded. The free swell index (FSI) was calculated using the following formula:

$$FSI = [(V_d - V_k) / V_k] \times 100$$

where:

- V_d = Volume of soil sample in the cylinder containing distilled water (ml) after 24 hours.
- V_k = Volume of soil sample in the cylinder containing kerosene oil (ml) after 24 hours.

Fig 3: Sample preparation of FSI

Results

This section presents the findings obtained from the laboratory tests conducted to evaluate the plasticity characteristics (liquid limit, plastic limit, and plasticity index) and free swell index of the collected soil and stone dust samples.

Free swell index

The free swell index (FSI) results for both soil and stone dust samples are summarized below:

- **Average Free Swell Index (%):**
  - Soil: 27.27%
  - Stone Dust: 10.00%

These results are visually depicted in Figure 4 (Average Free Swell Index Chart). As evident from the data, the soil exhibits a significantly higher FSI compared to stone dust, indicating a greater potential for swelling when saturated with water. This behavior can pose challenges in civil engineering applications where the soil serves as a foundation material.

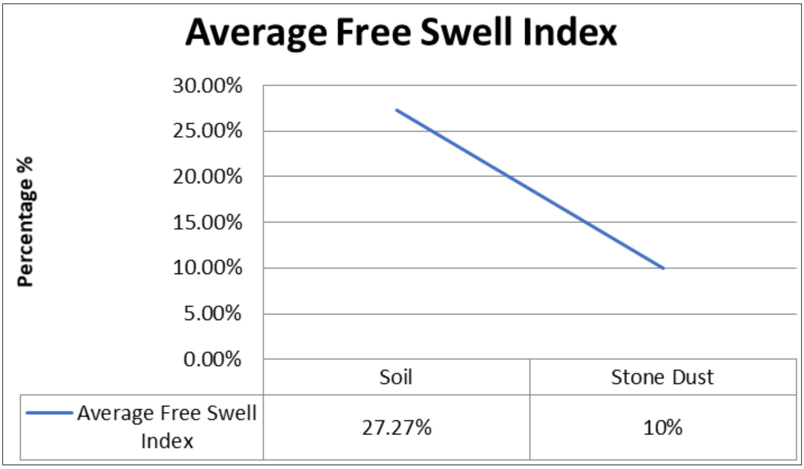

Fig 4: Average free swell index chart

Atterberg's limits

Soil

The liquid limit (LL), plastic limit (PL), and plasticity index (PI) for the soil sample are summarized in Table 1 (Atterberg's Limits (Soil)). The corresponding data is also presented graphically in Figure 5 (Liquid Limit Chart (Soil)).

- Liquid Limit (LL): 32.50%
- Plastic Limit (PL): 21.12%
- Plasticity Index (PI): 11.38%

Table 1: Atterberg's limits [As per IS 2720, (Part-V)]

Type of material	Soil					
	Liquid Limit				Plastic Limit	
Determination No.	1	2	3	4		
Container No.	18	19	20	21	22	23
Empty Wt.of Container (W1) gm	16.49	13.12	15.45	15.59	15.47	18.61
Wt.of Container and Wet material (W2) gm	36.84	33.46	37.15	35.25	29.14	31.06
Wt.of Container and Dry material (W3) gm	32.54	28.77	31.52	29.72	26.81	28.84
Wt.of Moisture (W4=W2-W3) gm	4.3	4.69	5.63	5.53	2.33	2.22
Wt.of dry material (W5=W3-W1) gm	16.05	15.65	16.07	14.13	11.34	10.23
Moisture Content w = 100 x W4/W5 %	26.79	29.97	35.03	39.14	20.55	21.70
No of Blows	32	28	22	17	Avg	21.12

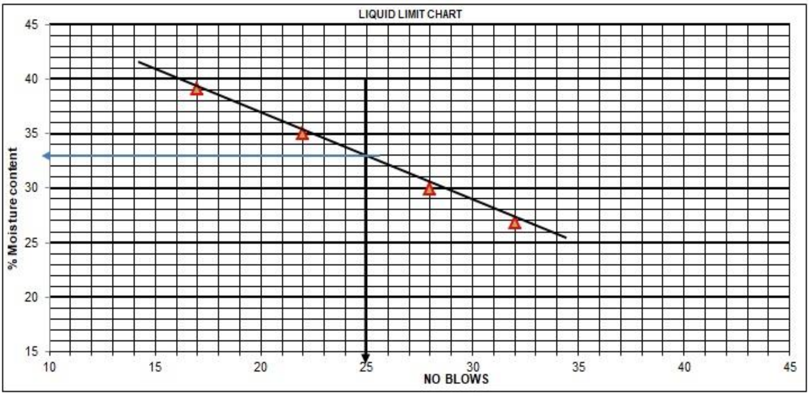

Fig 5: Liquid limit chart (Soil)

Stone dust

The liquid limit (LL) results for the stone dust sample are presented in Table 2 (Atterberg's Limits (Stone Dust)) and Figure 6 (Liquid Limit Chart (Stone Dust)).

Table 2: Atterberg's Limits (by cone penetrometer) [As per IS 2720, (Part-V)]

Type of material	Stone Dust				
	Liquid Limit				Plastic Limit
Determination No.	1	2	3	4	NA
Container No.	17	30	3	21	
Empty Wt.of Container (W1) gm	15.34	13.29	13.68	15.59	
Wt.of Container and Wet material (W2) gm	44.52	39.9	46.86	49.8	
Wt.of Container and Dry material (W3) gm	39.63	34.81	39.52	41.75	
Wt.of Moisture (W4=W2-W3) gm	4.89	5.09	7.34	8.05	
Wt.of dry material (W5=W3-W1) gm	24.29	21.52	25.84	26.16	
Moisture Content w = 100 x W4/W5 %	20.13	23.65	28.41	30.77	
Penetration	15	18	22	24	

It is important to note that the plastic limit (PL) and plasticity index (PI) are not applicable (NA) for stone dust because it exhibits non-plastic behavior.

- Liquid Limit (LL): 26.00%
- Plastic Limit (PL): Not Applicable (NA)
- Plasticity Index (PI): Non-Plastic (NP)

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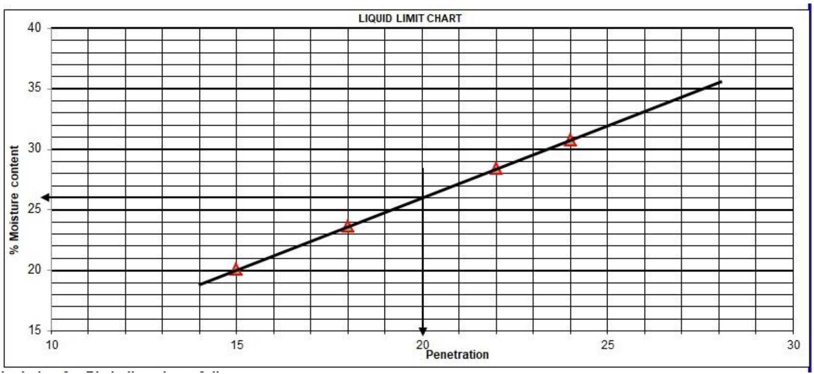

Fig 6: Liquid limit chart (Stone dust)

A comparative analysis of the Atterberg's limits for both soil and stone dust is presented in Figure 7 (Atterberg's Limits Chart (Soil + Stone Dust)).

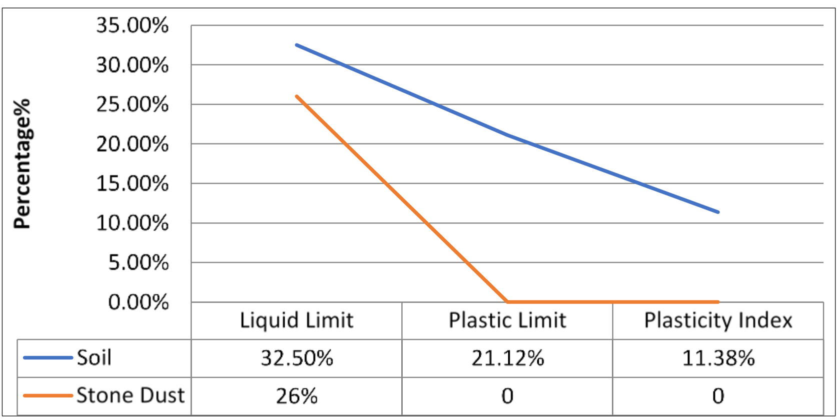

Fig 7: Atterberg's limit chart (Soil + Stone Dust)

This chart clearly illustrates the contrasting behavior of the two materials. Soil exhibits a measurable plasticity index, indicating its ability to deform plastically within a certain moisture content range. Conversely, stone dust exhibits non-plastic behavior, with a negligible or no plastic range.

These findings suggest that the soil sample possesses moderate plasticity, while the stone dust is essentially non-plastic. This information is crucial for selecting suitable materials in various civil engineering projects. For instance, soils with high plasticity may not be ideal for foundation construction due to potential swelling and shrinkage problems.

Conclusion

This research investigated the geotechnical properties of soil and stone dust samples, focusing on plasticity characteristics (liquid limit, plastic limit, and plasticity index) and free swell index. The findings highlight significant differences between these materials, influencing their suitability for various civil engineering applications.

The soil sample exhibited a moderate plasticity index (11.38%) and a relatively high free swell index (27.27%). This indicates the soil's potential for deformation and volume change upon exposure to moisture, which can be detrimental in foundation construction or other applications requiring dimensional stability.

In contrast, the stone dust sample displayed non-plastic behavior (no measurable plastic limit or plasticity index) and a lower free swell index (10.00%). This suggests minimal volume change and limited susceptibility to deformation under varying moisture conditions.

By understanding these fundamental geotechnical properties, engineers can make informed decisions regarding material selection for specific civil engineering projects. For instance, stone dust, with its superior dimensional stability, may be preferable for applications requiring a less expansive material, while soil with moderate plasticity might be suitable for specific purposes after proper stabilization techniques are employed.

This study emphasizes the importance of characterizing granular materials like soil and stone dust before their utilization in civil engineering projects. The knowledge gained from these evaluations contributes to the selection of optimal materials, promoting safe, efficient, and cost-effective infrastructure development.

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Chapter - 3

Compaction Characteristics of Soil and Stone Dust: An Investigation into Civil Engineering Applications

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Chapter - 3

Compaction Characteristics of Soil and Stone Dust: An Investigation into Civil Engineering Applications

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Abstract

This research provides a comprehensive investigation into the compaction characteristics of soil and stone dust samples, with a focus on their implications for civil engineering applications. The study employs the Modified Proctor Compaction Test to evaluate the maximum dry density (MDD) and optimum moisture content (OMC) for optimal compaction. It explores the individual compaction behavior of soil and stone dust, as well as the effects of incorporating stone dust into the soil sample at varying ratios. The findings contribute valuable insights into the selection and modification of materials for achieving optimal compaction in construction projects, leading to improved infrastructure stability, durability, and cost-effectiveness. Furthermore, the results contribute to the growing body of research on the utilization of waste products like stone dust in civil engineering applications, promoting environmentally conscious construction practices. The methodology includes detailed experimental procedures and data analysis, and the results and discussion section presents the findings from the Modified Proctor Density Tests conducted on soil, stone dust, and various soil-stone dust mixtures. The research concludes that the incorporation of stone dust into soil samples can significantly influence their compaction characteristics, offering potential benefits for cost-effective and sustainable construction practices.

Keywords: Soil compaction, stone dust, civil engineering, modified proctor compaction test, infrastructure stability, sustainable construction practices.

Introduction

Soil compaction is an essential process in civil engineering, directly influencing the stability and performance of various infrastructure projects, including foundations, embankments, roads, and dams (Das, 2018). A well-compacted soil layer possesses superior strength, lower permeability, and enhanced resistance to settlement and deformation (Nelson & Nelson, 2015). Understanding the compaction behavior of soils is critical for selecting suitable materials and optimizing compaction procedures to achieve the desired engineering properties (Koerner, 2016). Improper compaction can lead to a multitude of problems, including excessive settlement, cracking, and even structural failure (Hausmann, 1990).

This research investigates the compaction characteristics of soil and stone dust samples obtained from designated locations in West Bengal, India. The Modified Proctor Compaction Test, a standardized method outlined in IS 2720 (Part VIII) [5], serves as the primary tool for evaluating the maximum dry density (MDD) and optimum moisture content (OMC) for optimal compaction. The MDD represents the highest dry density achievable for a given soil at a specific compactive effort, while the OMC signifies the moisture content at which this MDD is attained (IS 2720 (Part VIII), 1980).

The study explores not only the individual compaction behavior of soil and stone dust but also delves into the effects of incorporating stone dust into the soil sample at varying ratios. Stone dust, a by-product generated during the crushing of rocks, has garnered increasing interest as a potential modifier for influencing soil properties (Shahin, 2005). By analyzing the MDD and OMC variations across these mixtures, the research aims to assess the potential of stone dust as a modifier to influence the compaction properties of soil for civil engineering applications. Understanding how stone dust affects compaction characteristics can provide valuable insights for its potential use in cost-effective and sustainable construction practices.

The findings of this investigation contribute valuable insights into the selection and modification of materials for achieving optimal compaction in construction projects. This knowledge can lead to improved infrastructure stability, durability, and cost-effectiveness. Furthermore, the results can contribute to the growing body of research on the utilization of waste products like stone dust in civil engineering applications, promoting environmentally conscious construction practices.

Methodology

This section details the experimental procedures employed to evaluate the compaction characteristics of the collected soil and stone dust samples, along with various soil-stone dust mixtures (Fig.1). The Modified Proctor Compaction Test was chosen as the standard for this investigation due to its applicability in simulating the compaction achieved by heavy construction equipment in field applications. The test procedures adhered to the guidelines outlined in IS 2720 (Part VIII).

(a)

(b)

(c)

(d)

Fig 1: (a) The raw soil (b) sample preparation (c) St proctor mould (d) sample preparation of st proctor test

Modified proctor compaction test

Preparation of Samples:

1. An oven-dried soil sample was obtained from the Kalyani site.
2. Stone dust samples were collected from Birbhum, West Bengal.
3. Both soil and stone dust samples were sieved through a 4.75-mm IS sieve to eliminate any particles exceeding the designated size.

Moisture content variation

Portions of the prepared soil and stone dust samples were weighed and then mixed with varying amounts of distilled water to create a range of moisture contents. The initial water content estimations were adjusted based on the observed behavior of the materials during mixing.

Compaction

The moistened soil or stone dust samples were compacted within a standard Proctor mold using the specified compactive effort of the Modified Proctor Test. This involves employing a 2.6 kg rammer with a drop height of 18 inches for a predetermined number of blows per layer.

Density measurement

1. The weight (W) of the compacted soil or stone dust in the mold was measured after each compaction stage.
2. The volume (V) of the mold is constant and known.
3. The bulk density (ρb) of the compacted material was calculated using the following formula:

$\rho b = W / V$ (g/cm^3)

4. A small sample of the compacted soil or stone dust was collected from each layer for moisture content determination.
5. The collected samples were oven-dried at 105°C ± 5°C for 24 hours.
6. The moisture content (W%) of each sample was determined by calculating the weight difference before and after oven-drying.
7. The dry density (ρd) of the compacted material was calculated using the following formula: $\rho d = \rho b / (1 + W\%)$ (g/cm^3)

Data analysis

The dry density (ρd) values obtained for each moisture content level were plotted against their corresponding moisture content (W%) values. This generated a compaction curve for the tested material (soil, stone dust, or mixture). The peak of this curve represents the maximum dry density (MDD), and the moisture content at this peak signifies the optimum moisture content (OMC) for achieving optimal compaction.

Compaction of soil-stone dust mixtures

The influence of incorporating stone dust into the soil sample on compaction characteristics was investigated. Three separate mixtures were prepared by dry weight blending the soil with stone dust at ratios of 15%, 25%, and 35%. The Modified Proctor Compaction Test was conducted on each mixture following the same procedures described above for individual soil and stone dust samples. The MDD and OMC values for each mixture were determined and compared to those of the original soil sample.

Results and discussion

This section presents the findings obtained from the Modified Proctor Density Tests conducted on soil, stone dust, and various soil-stone dust mixtures, following the guidelines outlined in IS 2720 (Part-VIII).

Materials

Soil

The results of the Modified Proctor Density Test for the soil sample are summarized in Table 1 and visually represented in Figure 2. The test revealed a maximum dry density (MDD) of 1.854 gm/cc at an optimum moisture content (OMC) of 11.70%. As depicted in Figure 26, the dry density of the soil increases with increasing water content up to the OMC point. Beyond this point, further water addition leads to a decrease in dry density due to the presence of excess water in the voids, hindering effective particle packing.

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Table 1: Modified proctor's density test [As per IS 2720, (Part-VIII)]

	Type of material	SOIL						
B	Mould No. :-	3	Wt.of mould (A) =	4654	gm	Volume of mould (V)=	1000	cc
C	**Trial No.**	**I**	**II**	**III**	**IV**	**V**	**VII**	**VII**
D	Wt.of wet sample + mould. gm	6512	6604	6678	6730	6702		
E	Wt.of wet sample (E = D-A). gm	1858	1950	2024	2076	2048		
F	Wet density of sample (F = E/V). gm/cc	1.86	1.95	2.02	2.08	2.05		
G	Container No.	45	1	22	34	47		
H	Wt.of Empty container. gm	52.08	51.62	42.93	42.27	44.28		
I	Wt.of wet sample+Cont. gm	200.40	199.28	193.08	191.99	191.63		
J	Wt.of dry sample+Cont. gm	191.85	188.09	179.22	175.53	172.96		
K	Wt.of water(K=I-J). gm	8.55	11.19	13.86	16.46	18.67		
L	Wt.of dry sample(L=J-H). gm	139.77	136.47	136.29	133.26	128.68		
M	Water content [M = 100X(K/L)]%	6.12	8.20	10.17	12.35	14.51		
N	Dry density[N=100x(F/(100+M))]. gm/cc	1.75	1.80	1.84	1.85	1.79		

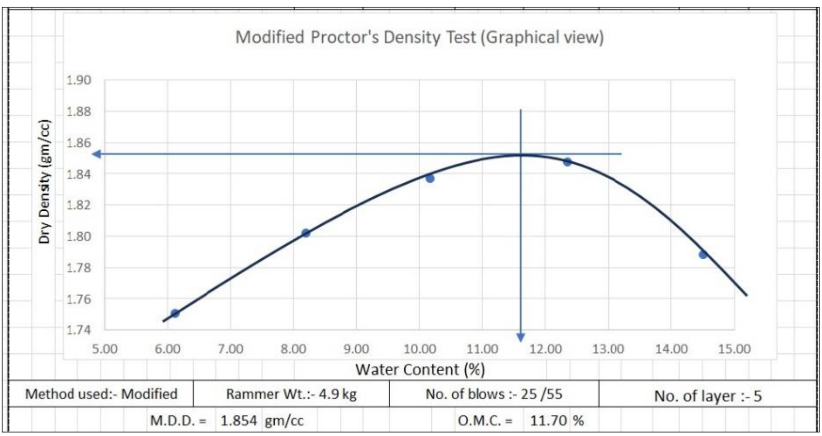

Fig 2: Modified proctor density test (Soil)

Stone dust

The results for the stone dust sample, presented in Table 2 and Figure 3, demonstrate a higher MDD (2.235 gm/cc) compared to the soil, with an OMC of 8.05%. Similar to the soil, the dry density of stone dust increases with increasing water content until the OMC, followed by a decrease with further moisture addition. This behavior can be attributed to the same principle of reduced particle interaction and increased water film thickness at higher moisture contents.

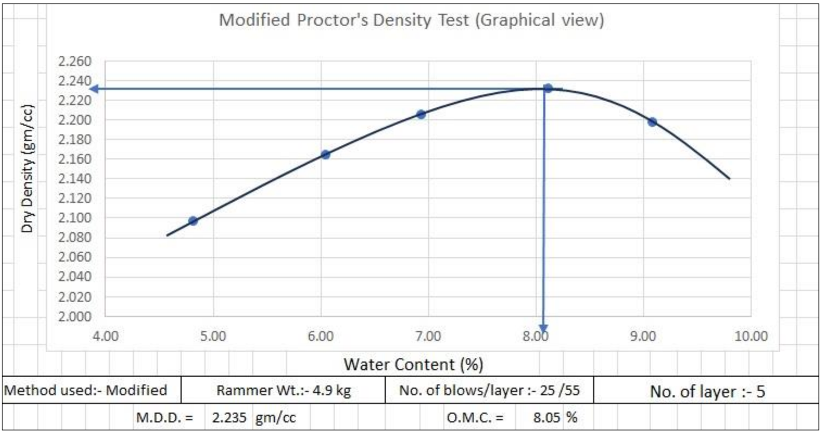

Fig 3: Modified proctor density test (Stone dust)

Soil-stone dust mixtures

The effects of incorporating stone dust into the soil sample at varying percentages (15%, 25%, and 35%) were investigated through Modified Proctor Density Tests. The detailed results for each mixture, including MDD, OMC, and corresponding figures, are presented in Tables 3-5 and Figures 4-6, respectively.

Table 2: Modified proctor's density test [As per IS 2720, (Part-VIII)]

Type of material		Stone Dust						
B	Mould No. :- 2	Wt.of mould (A) =	3930	gm	Volume of mould (V)=		1000	cc
C	**Trial No.**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
D	Wt.of wet sample + mould. gm	6128	6225	6289	6343	6328		
E	Wt.of wet sample (E = D-A). gm	2198	2295	2359	2413	2398		
F	Wet density of sample (F = E/V). gm/cc	2.20	2.30	2.36	2.41	2.40		
H	Wt.of Empty container. gm	50.40	51.96	41.12	53.98	53.20		
I	Wt.of wet sample+Cont. gm	217.94	222.37	203.44	193.72	205.74		
J	Wt.of dry sample+Cont. gm	210.25	212.66	192.92	183.24	193.04		
K	Wt.of water(K=I-J). gm	7.69	9.71	10.52	10.48	12.70		
L	Wt.of dry sample(L=J-H). gm	159.85	160.70	151.80	129.26	139.84		
M	Water content [M = 100X(K/L)]%	4.81	6.04	6.93	8.11	9.08		
N	Dry density[N=100x(F/(100+M))]. gm/cc	2.097	2.164	2.206	2.232	2.198		

Table 3: Modified proctor's density test [As per IS 2720, (Part-VIII)]

Type of material		SOIL+ Stine Dust (85%:15%)						
B	Mould No. :- 3	Wt.of mould (A) =	4654 gm		Volume of mould (V)=		1000 cc	
C	**Trial No.**	**I**	**II**	**III**	**IV**	**V**	**VII**	**VII**
D	Wt.of wet sample + mould. gm	6665	6743	6837	6890	6866		
E	Wt.of wet sample (E = D-A). gm	2011	2089	2183	2236	2212		
F	Wet density of sample (F = E/V). gm/cc	2.01	2.09	2.18	2.24	2.21		
H	Wt.of Empty container. gm	52.76	53.28	45.87	52.49	50.46		
I	Wt.of wet sample+Cont. gm	198.54	196.87	192.15	199.49	195.89		
J	Wt.of dry sample+Cont. gm	195.88	191.76	183.86	188.85	182.75		
K	Wt.of water(K=I-J). gm	2.66	5.11	8.29	10.64	13.14		
L	Wt.of dry sample(L=J-H). gm	143.12	138.48	137.99	136.36	132.29		
M	Water content [M = 100X(K/L)]%	1.86	3.69	6.01	7.80	9.93		
N	Dry density[N=100x(F/(100+M))]. gm/cc	1.97	2.01	2.06	2.07	2.01		

Table 4: Modified proctor's density test [As per IS 2720, (Part-VIII)]

Type of material		SOIL + STONE DUST (75%:25%)						
B	Mould No. :- 3	Wt.of mould (A) =	4654 gm		Volume of mould (V)=		1000 cc	
C	**Trial No.**	**I**	**II**	**III**	**IV**	**V**	**VII**	**VII**
D	Wt.of wet sample + mould. gm	6670	6752	6853	6917	6883		
E	Wt.of wet sample (E = D-A). gm	2016	2098	2199	2263	2229		
F	Wet density of sample (F = E/V). gm/cc	2.02	2.10	2.20	2.26	2.23		
H	Wt.of Empty container. gm	51.54	50.40	49.37	50.74	52.53		
I	Wt.of wet sample+Cont. gm	191.56	192.43	188.14	192.99	189.27		
J	Wt.of dry sample+Cont. gm	188.67	187.39	180.26	182.28	176.99		
K	Wt.of water(K=I-J). gm	2.89	5.04	7.88	10.71	12.28		
L	Wt.of dry sample(L=J-H). gm	137.13	136.99	130.89	131.54	124.46		
M	Water content [M = 100X(K/L)]%	2.11	3.68	6.02	8.14	9.87		
N	Dry density[N=100x(F/(100+M))]. gm/cc	1.97	2.02	2.07	2.09	2.03		

Table 5: Modified proctor's density test [As per IS 2720, (Part-VIII)]

Type of material		SOIL + STONE DUST (65%:35%)						
B	Mould No. :- 3	Wt.of mould (A) =	4654 gm		Volume of mould (V)=		1000 cc	
C	**Trial No.**	**I**	**II**	**III**	**IV**	**V**	**VII**	**VII**
D	Wt.of wet sample + mould. gm	6694	6789	6869	6934	6902		
E	Wt.of wet sample (E = D-A). gm	2040	2135	2215	2280	2248		
F	Wet density of sample (F = E/V). gm/cc	2.04	2.14	2.22	2.28	2.25		
H	Wt.of Empty container. gm	51.62	52.76	49.56	53.61	42.94		
I	Wt.of wet sample+Cont. gm	194.05	189.57	190.03	194.65	190.16		
J	Wt.of dry sample+Cont. gm	191.60	184.49	182.28	184.03	176.73		
K	Wt.of water(K=I-J). gm	2.45	5.08	7.75	10.62	13.43		
L	Wt.of dry sample(L=J-H). gm	139.98	131.73	132.72	130.42	133.79		
M	Water content [M = 100X(K/L)]%	1.75	3.86	5.84	8.14	10.04		
N	Dry density[N=100x(F/(100+M))]. gm/cc	2.00	2.06	2.09	2.11	2.04		

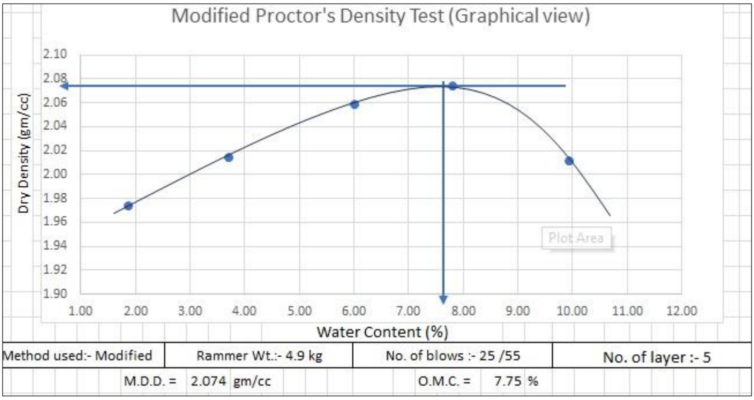

Fig 4: Modified proctor density test (Soil & stone dust)

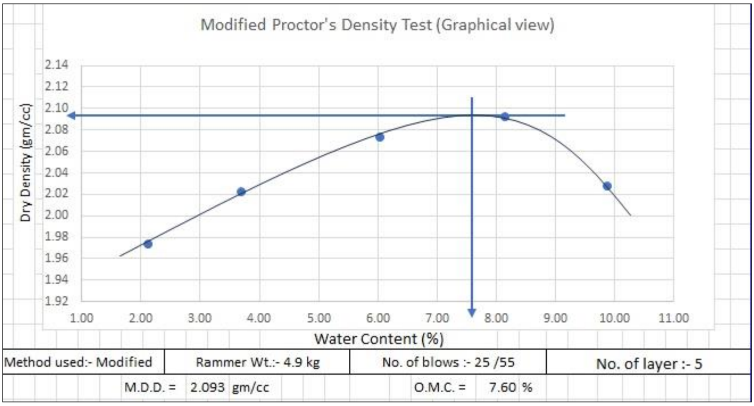

Fig 5: Modified proctor density test (Soil & stone dust)

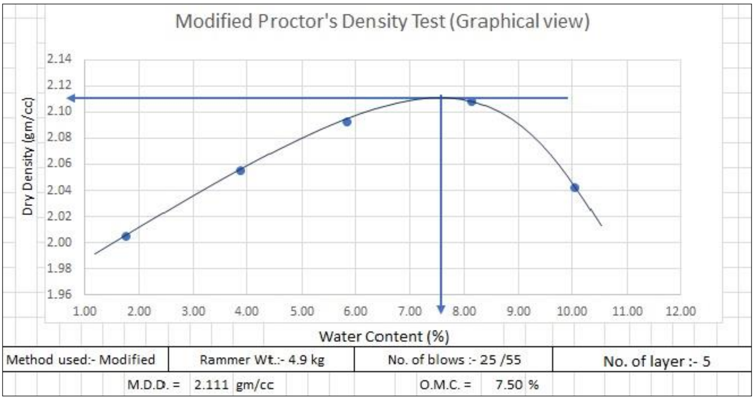

Fig 6: Modified proctor density test (Soil & stone dust)

A key observation across all the mixtures is an increase in MDD compared to the original soil sample. The MDD values for the mixtures with 15%, 25%, and 35% stone dust content were 2.074 gm/cc, 2.093 gm/cc, and 2.111 gm/cc, respectively. This suggests that stone dust inclusion contributes to a denser packing of particles within the mixture, leading to a higher achievable MDD.

Interestingly, the OMC values for the mixtures exhibited a decreasing trend with increasing stone dust content. The OMC values for the 15%, 25%, and 35% stone dust mixtures were 7.75%, 7.60%, and 7.50%, respectively. This can be explained by the lower water absorption capacity of stone dust compared to soil. As the stone dust content increases in the mixture, less water is required to achieve the same degree of saturation within the soil particles, leading to a lower overall OMC for the mixture.

Figure 7 provides a comparative analysis of the MDD and OMC values for all tested materials. This visual representation effectively summarizes the observed trends.

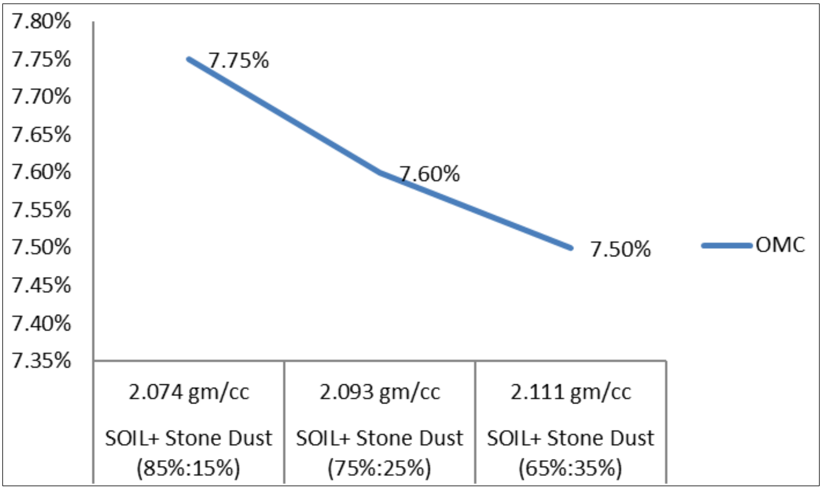

Fig 7: Modified proctor density test result (Compare between OMC & MDD)

Discussion

The experimental investigation highlights the potential of stone dust as a modifier for improving the compaction characteristics of soil. The inclusion of stone dust in the soil-stone dust mixtures resulted in a significant increase in MDD compared to the original soil sample. This indicates the potential for achieving denser and potentially stronger compacted layers in civil engineering applications when incorporating appropriate amounts of stone dust.

However, it is crucial to consider the trade-off between MDD and OMC. While MDD increases with increasing stone dust content, the OMC values decrease. This may necessitate using a larger amount of water during compaction in practical scenarios to achieve the desired workability of the mixture. Using excessive water can be counterproductive, as it can lead to a reduction in the achieved dry density and compromise the overall strength and stability of the compacted soil.

Further research is recommended to explore the influence of particle size distribution and gradation of both soil and stone dust on the compaction behavior of their mixtures. Additionally, investigating the mechanical properties (e.g., strength and permeability) of these compacted mixtures would provide valuable insights into their suitability for various civil engineering applications.

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Chapter - 4

Evaluating the Impact of Stone Dust on the California Bearing Ratio (CBR) of Soil-Stone Dust Mixtures

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Chapter - 4

Evaluating the Impact of Stone Dust on the California Bearing Ratio (CBR) of Soil-Stone Dust Mixtures

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Abstract

The California Bearing Ratio (CBR) test is pivotal for evaluating subgrade materials in construction. This study explores the influence of stone dust on the CBR characteristics of soil-stone dust mixtures, aiming to enhance subgrade stability and strength. Soil compaction is fundamental in civil engineering, impacting infrastructure stability significantly. Stone dust, a byproduct of rock crushing, holds promise as a soil modifier, particularly in West Bengal, India. The research employs the Modified Proctor Compaction Test to analyze the maximum dry density (MDD) and optimum moisture content (OMC) necessary for optimal compaction. By varying stone dust ratios in soil samples, the study assesses its potential as a modifier for soil compaction properties. The findings contribute insights into material selection and modification for achieving optimal compaction in construction projects. Stone dust demonstrates potential as a cost-effective additive to enhance soil engineering properties, especially in subgrade construction for roads and pavements. The research underscores the need for further validation through field testing and additional studies to explore broader applications of soil-stone dust mixtures in geotechnical engineering projects. This study aims to promote sustainable construction practices by optimizing soil-stone dust mixtures for superior performance and longevity of civil engineering structures.

Keywords: California Bearing Ratio (CBR), soil-stone dust mixtures, compaction characteristics, geotechnical engineering, sustainable construction, subgrade materials.

Introduction

Soil compaction serves as a fundamental process in the realm of civil engineering, intricately woven into the fabric of infrastructure development.

It plays a pivotal role in shaping the stability and performance of critical structures like foundations, embankments, roads, and dams (Das, 2018). A well-executed compaction process yields a soil layer endowed with superior strength, reduced permeability, and enhanced resistance to settlement and deformation (Nelson & Nelson, 2015). Consequently, understanding the nuances of soil compaction is paramount for selecting suitable materials and optimizing compaction procedures to achieve the desired engineering properties (Koerner, 2016). Conversely, the repercussions of improper compaction practices can be dire, leading to a myriad of issues such as excessive settlement, cracking, and even structural failure (Hausmann, 1990).

Against this backdrop, our research delves into the compaction characteristics of soil and stone dust mixtures sourced from designated locales in West Bengal, India. Stone dust, a byproduct generated during the crushing of rocks, has captured increasing attention due to its potential as a modifier capable of influencing soil properties (Shahin, 2005). Our study aims to elucidate the capacity of stone dust to enhance the compaction behavior of soil, thereby contributing to the development of denser and potentially stronger compacted layers in various civil engineering applications.

Central to our investigation is the utilization of the Modified Proctor Compaction Test, a standardized methodology outlined in IS 2720 (Part VIII), as the primary tool for evaluating the maximum dry density (MDD) and optimum moisture content (OMC) requisite for optimal compaction (IS 2720 (Part VIII), 1980). The MDD denotes the highest dry density achievable for a given soil-stone dust mixture at a specific compactive effort, while the OMC signifies the corresponding moisture content at which this MDD is attained.

Our study ventures into the repercussions of incorporating stone dust into soil samples at varying ratios on the MDD and OMC parameters. Through a meticulous analysis of these variations, we endeavor to assess the potential of stone dust as a modifier capable of influencing the compaction properties of soil in diverse civil engineering applications. A comprehensive understanding of how stone dust impacts compaction characteristics holds promise for its potential utilization in fostering cost-effective and sustainable construction practices.

The findings garnered from our investigation furnish valuable insights into the selection and modification of materials to achieve optimal compaction in construction projects. This knowledge stands to enhance infrastructure stability, durability, and cost-effectiveness, thus bolstering the resilience of vital structures. Moreover, our results contribute to the burgeoning body of research surrounding the utilization of waste products such as stone dust in civil engineering endeavours, thereby promoting environmentally conscious construction methodologies.

Methodology

The California bearing ratio is a test used to determine the shear strength of soil under specific conditions of density and moisture content. This test is conducted in accordance with IS 2720 (P-16) 1987. The soil must pass through a 20mm sieve and be retained by a 4.75mm sieve. The soil sample is obtained through sieve analysis and placed in a CBR mould. The sample is filled in three steps and each layer is uniformly compacted with 55 blows. The un-soaked CBR test is conducted immediately after the three-step filling process, while the soaked CBR test is performed after four days of soaking. The soil sample is soaked in water for four days as per IS specifications. The load values observed from the dial gauge at penetrations of 2.5mm, 5mm, 7.5mm, 10mm, and 12.5mm provide important data for the test.

California bearing ratio is an experimental test that gives an indication of the shear strength of soil, under control density and moisture content. This test conduct as per IS 2720 (P-16) 1987. The soil should be pass through a 20mm sieve and retain 4.75 mm. This soil sample is collected by sieve analysis and placed in a CBR mould. This sample fill in three steps and uniformly ram each layer (55 blows). The un-soaked CBR performed immediately after three steps filling material. But soaked CBR test will be performed after four days of soaking. The soil sample placed in water for 4 days as per IS specification. Observed load values of sample from dial gauge evidence regarding dial gauge concerning 2.5mm, 5mm, 7.5mm, 10mmand 12.5mm penetration.

Determine the CBR of soil (CBR%) = Pt / Ps *100.

Pt= Penetration Load.

Ps= Standard Load.

Apparatuses used

The apparatus used in this study comprises a 150mm diameter cylindrical mould, sieves, a rammer, mixing tools, a loading machine, and a penetration piston. The cylindrical mould, with a diameter of 150mm, serves as the container for soil samples during testing. Sieves are employed for separating soil particles to obtain the desired particle size distribution. A rammer is utilized to compact soil layers uniformly within the mould, ensuring consistent density throughout the sample. Mixing tools facilitate the blending of soil and stone dust mixtures to achieve the desired compositions. A loading machine applies vertical pressure to the penetration piston, which penetrates the soil sample during testing. The penetration piston measures the load values observed at various penetrations, providing crucial data for the California Bearing Ratio (CBR) test. Together, these apparatuses enable the accurate evaluation of soil-stone dust mixtures' CBR characteristics under controlled conditions, contributing valuable insights to geotechnical engineering research.

(a) (b)

Fig 1: Apparatus used in the study (a)CBR Testing Machine (b) CBR Mould

Result and discussion

The CBR values at 2.5mm and 5mm penetrations were documented for each sample as follows: Sample 1 exhibited values of 4.60% and 4.82% respectively; Sample 2 showed values of 5.04% and 5.45% respectively; and Sample 3 displayed values of 5.89% and 5.45% respectively. According to the CBR test protocol, the higher of these values was considered as the final CBR value, resulting in final CBR values of 4.82%, 5.45%, and 5.45% for Samples 1, 2, and 3 respectively.

For the stone dust under soaked conditions, the CBR values at 2.5mm and 5mm penetrations were ascertained. Sample 1 yielded values of 24.74% and 25.21% respectively; Sample 2 returned values of 24.96% and 25.30% respectively; and Sample 3 exhibited values of 20.58% and 22.77%

respectively. The final CBR values for stone dust were determined as 25.21%, 25.30%, and 22.77% for Samples 1, 2, and 3 respectively.

In the case of soil-stone dust mixtures, Sample 1 (85% soil and 15% stone dust) displayed CBR values of 11.09% and 11.14% at 2.5mm and 5mm penetrations respectively; 10.73% and 10.80% respectively; and 11.31% and 11.48% respectively. The final CBR values for this mixture were 11.14%, 10.80%, and 11.48%.

For Sample 2 (75% soil and 25% stone dust), the recorded values were 20.44% and 25.55% at 2.5mm and 5mm penetrations respectively; 21.90% and 27.64% respectively; and 20.36% and 24.33% respectively. The final CBR values for Sample 2 were 25.55%, 27.64%, and 24.33%.

Regarding Sample 3 (65% soil and 35% stone dust), the CBR values obtained were 31.09% and 29.93% at 2.5mm and 5mm penetrations respectively; 30.07% and 29.83% respectively; and 30.29% and 29.05% respectively. The final CBR values for Sample 3 were 31.09%, 30.07%, and 30.29%.

Through our study, we observed a correlation between the percentage of stone dust in the mixtures and the resulting CBR values. Notably, an increase in the stone dust ratio led to higher CBR values, indicating improved stability and bearing capacity of the sub-grade. Specifically, we observed a significant increase in CBR values when the stone dust percentage increased from 15% to 25%. This trend underscores the potential for enhancing the quality and performance of sub-grade materials by optimizing the stone dust content. These findings are depicted in Figure 2.

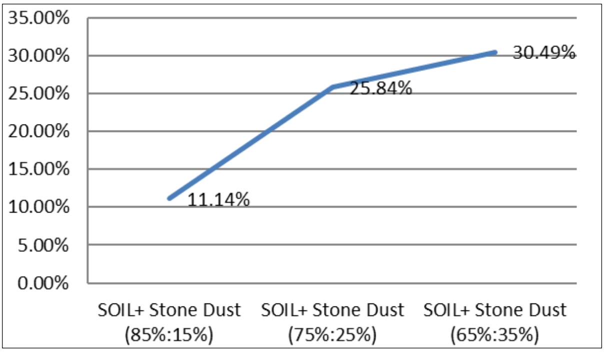

Fig 2: California bearing ratio test result [Compare between stone dust percentage & CBR percentage]

Conclusion

In conclusion, the California Bearing Ratio (CBR) tests conducted on soil, stone dust, and their mixtures provided valuable insights into their engineering properties and suitability for various applications. The results revealed distinct trends in CBR values corresponding to different compositions of soil and stone dust. For the pure soil samples, the CBR values ranged from 4.82% to 5.89%, indicating their moderate to good bearing capacity under specified conditions. In contrast, the stone dust exhibited higher CBR values, ranging from 20.58% to 25.21%, suggesting its potential as a stabilizing agent for sub-grade materials. Moreover, the mixtures of soil and stone dust demonstrated varying CBR values, with notable improvements observed with increasing proportions of stone dust. Specifically, mixtures containing higher percentages of stone dust, such as 25% and 35%, exhibited significantly enhanced CBR values compared to pure soil samples. This underscores the effectiveness of stone dust in augmenting the strength and stability of soil matrices. Overall, the study highlights the importance of stone dust as a cost-effective additive for enhancing the engineering properties of soil, particularly in the construction of sub-grade layers for roads and pavements. By optimizing the composition of soil-stone dust mixtures, engineers can achieve superior performance and longevity of civil engineering structures, thereby contributing to sustainable infrastructure development. Further research and field testing are recommended to validate these findings and explore additional applications of soil-stone dust mixtures in geotechnical engineering projects.

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Chapter - 5

Effect of Fine Sand on the Strength Properties of Laterite Soil: A Geotechnical Investigation

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Chapter - 5

Effect of Fine Sand on the Strength Properties of Laterite Soil: A Geotechnical Investigation

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Abstract

The study explores the stabilization of lateritic soil by incorporating varying proportions of fine sand (12%, 24%, 36%, and 48% by weight) to enhance its engineering properties. Lateritic soils, commonly found in tropical regions, often suffer from poor bearing capacity and high moisture susceptibility, posing challenges for construction projects. Fine sand, readily available and cost-effective, has been identified as a potential stabilizing agent that can improve soil gradation and load-bearing characteristics. The research involved a series of laboratory tests including Grain Size Analysis, Free Swell Index, and Atterberg Limits to assess the impact of sand stabilization on lateritic soil. The findings indicate that fine sand incorporation reduces the plasticity and swelling potential of lateritic soil, while enhancing its compaction and overall stability. Specifically, the addition of fine sand significantly alters the soil's particle size distribution, decreases its Free Swell Index, and lowers the Atterberg Limits, thereby improving its geotechnical properties. This investigation demonstrates that fine sand can effectively stabilize lateritic soil, making it more suitable for use in foundation, roadway, and embankment construction. The optimal sand proportions identified in this study provide a practical and economical solution for soil stabilization, contributing to safer and more durable infrastructure development in regions with prevalent lateritic soils. Further research is recommended to validate these findings under various environmental conditions and to explore the long-term performance of the stabilized soil.

Introduction

Soil stabilization is crucial in geotechnical engineering, aiming to improve soil's physical properties for specific engineering requirements (Das, 2006). This enhancement is essential for safe, durable, and cost-effective construction of foundations, roadways, embankments, and other infrastructure projects (Consoli *et al*., 2007). Lateritic soils, with high iron and aluminum content, pose unique challenges due to their moisture susceptibility and variable mechanical properties (Oluremi *et al*., 2012). These soils, prevalent in tropical regions, often exhibit poor bearing capacity and excessive swelling, leading to structural instability and significant maintenance costs (Fredlund & Rahardjo, 1993).

Recent research has explored various materials and techniques for lateritic soil stabilization. One promising approach involves incorporating sand as a stabilizing agent (Shayan *et al*., 2016). Sand's ready availability and cost-effectiveness make it attractive for improving the gradation and load-bearing characteristics of lateritic soils (Michalowski & Rozanski, 2010). The granular nature of sand helps reduce plasticity, enhances compaction, and improves the overall stability of the soil (Mooney *et al*., 2017). However, determining the optimal sand proportions and their impact on the stabilized soil's mechanical properties requires detailed investigation for practical implementation in construction projects.

This study investigates the stabilization of lateritic soil using different proportions of fine sand. The primary objective is to evaluate how the strength properties of lateritic soil change with the addition of graded sand in varying percentages (12%, 24%, 36%, and 48% by weight). The research focuses on conducting a series of laboratory tests, including Grain Size Analysis, Free Swell Index, and Atterberg Limits, to assess the impact of sand stabilization on the engineering properties of lateritic soil. By systematically analyzing these properties, the study seeks to provide insights into the feasibility and efficiency of using sand as a stabilizing agent for lateritic soils.

The findings of this research are expected to contribute significantly to the field of soil stabilization, offering practical solutions for infrastructure development in regions with prevalent lateritic soils. Enhanced understanding of soil-sand interactions will aid in the design and implementation of more robust and sustainable construction practices, thereby mitigating the risks associated with poor soil conditions. This study not only addresses the immediate need for improved soil stabilization techniques but also sets the stage for further research into innovative and cost-effective methods for enhancing soil properties.

Collection & preparation of materials

Laterite

The natural reddish-brown soil designated as LAT used in the present study was obtained from borrow pits in Kharagpur, Medinipur (West), West Bengal, India. The samples were collected following the standard specification IS-2720 (Part-1)-1983. This fine-grained residual lateritic soil was excavated using a spade and shovel from a depth of 400mm below the surface to avoid humus and roots. The collected samples, shown in Fig. 1, were placed in five cement bags and transported to the laboratory by public transport for various tests. The soil was air-dried for seven days using GI trays in the laboratory. Subsequently, the red soil aggregates were carefully broken up with a rubber mallet, and the soil was characterized by laboratory tests as per Indian standards.

Fig 1: Preparation of lateritic soil samples

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Sand

In this study, the sand samples used to stabilize the natural lateritic soil were collected from the near banks of the Ganges River, Kalyani, Nadia, West Bengal, India. The samples were collected as per standard specification IS-2720 (Part-1)-1983. The sand was excavated using a spade and shovel from a depth of 400 mm below the riverbank surface, as shown in Fig. 9. The samples were collected in five cement bags and transported to the laboratory for various tests. In the laboratory, the sand was air-dried using GI trays and sieved through a 4.75 mm test sieve to ensure uniformity of particle size and remove impurities.

Fig 2: Preparation of fine sand samples

Laboratory investigation

This study aims to bridge knowledge gaps in the field of laterite soil stabilization using sand. Past research has demonstrated the potential of sand as a stabilizing agent for laterite (e.g., Shayan *et al*., 2016). However, a comprehensive understanding of the optimal sand content and its influence on the mechanical properties of laterite-sand mixtures is still required.

To address this gap, this research will investigate the strength properties of laterite stabilized with graded sand at varying replacement percentages. Specifically, laterite will be partially replaced with 12%, 24%, 36%, and 48% (by weight) of sand. The chosen sand percentages encompass a wide range, allowing for the identification of a potential "sweet spot" between maximizing the stabilizing effect and maintaining economic feasibility (sand acquisition and transportation costs).

To achieve this objective, the following laboratory tests will be conducted:

- **Grain Size Analysis (GSA):** This test determines the particle size distribution of both laterite and sand. It is crucial for understanding how well the two materials pack together, influencing factors like density, porosity, and ultimately, the strength of the stabilized mixture.
- **Free swell index:** This test measures the volume increase of laterite soil when submerged in water. Lateritic soils are known for their high swelling potential, which can compromise the stability of structures built upon them. The Free Swell Index will help assess how sand incorporation affects the swelling behavior of the laterite, indicating its potential to mitigate this issue.
- **Atterberg limits:** These tests (Liquid Limit, Plastic Limit, and Plasticity Index) quantify the plasticity characteristics of laterite soil. Plasticity is undesirable in construction materials as it can lead to excessive deformations and cracking. By measuring the Atterberg Limits of laterite-sand mixtures, we can evaluate how sand addition influences plasticity, potentially reducing the risk of these problems.

The results of these tests will be analyzed to establish the relationships between sand content, grain size distribution, swelling behavior, plasticity, and ultimately, the strength properties of the stabilized laterite. This will provide valuable insights into the effectiveness of sand stabilization for lateritic soils and inform practical recommendations for geotechnical engineering applications.

Grain size analysis (Sieve analysis)

In the realm of geotechnical engineering, grain size analysis, also known as sieve analysis, reigns supreme as a foundational classification test for soils, particularly those dominated by coarse particles. This meticulous procedure unveils the relative proportions of various sized particles residing within a soil sample. By meticulously dissecting the soil's composition, grain size analysis sheds light on whether the soil is primarily comprised of gravel, sand, silt, or clay. This knowledge is instrumental in predicting the soil's potential engineering behavior and suitability for various construction projects.

The experiments conducted in this study strictly adhered to the guidelines outlined in the IS code IS: 2720 (Part-4) - 1985. To ensure accurate representation, a substantial sample of 6 kg of soil was oven-dried to eliminate any moisture content that might influence the analysis. Following this initial drying phase, the soil underwent a 24-hour submersion period to facilitate the complete dispersion of individual particles, preventing them from clinging together and skewing the results.

After the soaking process, the soil was strategically placed on a 75-micron sieve, the finest mesh size used in the experiment. A gentle stream of water then meticulously washed the soil, meticulously removing any adhering fines that could distort the analysis. This washing step ensured a more accurate representation of the actual particle size distribution. The retained material on the 75-micron sieve was then subjected to a controlled drying process within an oven for 24 hours, maintaining a precise temperature range of 105 ± 5°C.

Once the essential drying step was complete, the sieving process commenced. A series of I.S. sieves, meticulously arranged in descending order of mesh size, awaited the soil sample (Fig.3). The largest sieve, boasting a mesh opening of 100mm, occupied the top position, while the 75-micron sieve, the finest in the lineup, patiently waited at the bottom. The prepared soil sample was then strategically placed on the topmost sieve, ready for the sieving action. The sieves were then vigorously shaken, ensuring a thorough separation of particles as they trickled through the progressively finer mesh openings.

Following the sieving process, meticulous data collection commenced. The weight of the material meticulously retained on each individual sieve was scrupulously documented. This captured data provided a crucial foundation for the analysis phase. To arrive at a comprehensive understanding of the soil's composition, the percentage of the total sample weight that passed through each sieve size was meticulously calculated. This calculation yielded the critical information - the percentage of particles smaller than the corresponding sieve opening.

By meticulously analyzing the grain size distribution obtained from the sieve analysis, we can glean valuable insights into the soil's behavior and suitability for various engineering applications. This information plays a pivotal role in the lateritic soil stabilization process using sand. The data empowers us to comprehend how effectively the sand particles will interact with the native soil particles, ultimately influencing properties like density, porosity, and the most crucial factor - the strength of the stabilized mixture. Understanding these interactions is paramount for achieving optimal results in the lateritic soil stabilization process.

Fig 2: Testing of grain size analysis

Free swell index

The Free Swell Index test measures the increase in the volume of soil without any external constraint when submerged in water, providing a valuable assessment of the swelling characteristics of bentonite clay. The experiments were conducted according to IS code IS: 2720 (Part-40)-1977 provisions (Fig.3). The objective of this test is to determine the free swell index of soils. The apparatus used includes a 425-micron IS sieve, an oven controlled at a temperature of 105°C to 110°C, a balance sensitive to 0.01 g, two 100 ml capacity glass graduated cylinders, distilled water, and kerosene. The procedure involves taking two 10-gram oven-dry soil specimens passing through a 425-micron IS sieve and pouring each specimen into separate 100 ml graduated cylinders. One cylinder is filled with kerosene and the other with distilled water up to the 100 ml mark. After stirring the soil samples and allowing them to settle for 24 hours, the final volume of the soils in each cylinder is read.

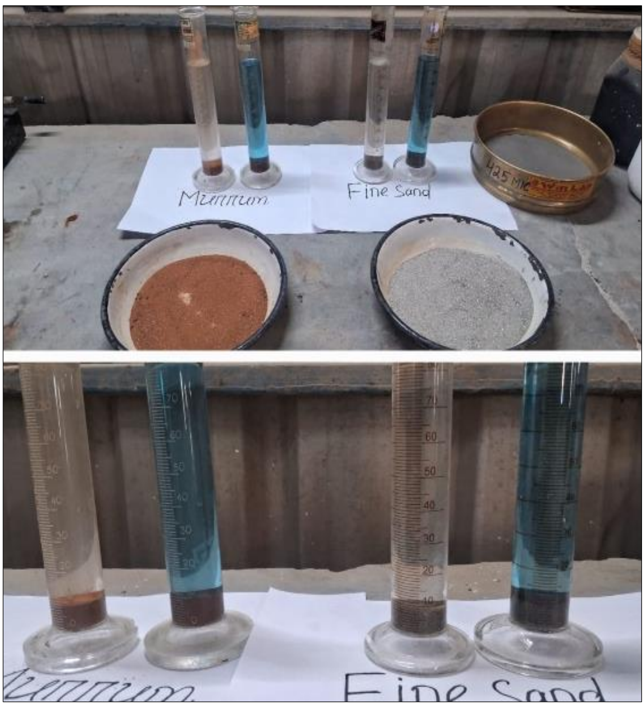

Fig 3: Testing of free swell index

Atterberg limits

The Atterberg Limits tests determine the behavior of fine-grained soils in the presence of water, including the Liquid Limit and Plastic Limit, which help define the soil's consistency, plasticity, and adhesion properties. The Liquid Limit is the moisture content at which soil transitions from the liquid state to the plastic state, measured using either Casagrande's apparatus or a cone penetrometer. The experiments were conducted as per IS code IS: 2720

(Part-5)-1985 provisions. For Casagrande's apparatus, 120 g of soil passing through a 425-micron sieve is weighed and made into a homogeneous paste, placed in the cup, and a groove is cut. The handle is rotated at 2 revolutions per second, and the number of blows until the groove closes is counted, followed by determining the moisture content near the closed groove. For the cone penetrometer, 400 g of soil passing through a 425-micron sieve is weighed, mixed thoroughly, ensuring the first reading is around 15 mm, filled in the cup with excess soil struck off, and the cone is released, recording the penetration after 5 seconds. The moisture content is then determined from the penetrated area.

Fig 4: Testing of liquid limit by casagrande's apparatus

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Fig 5: Testing of liquid limit by cone penetrometers apparatus

Fig 6: Testing of plastic limit

Results

Index properties of fine sand

The index properties of the fine sand used in this study are crucial for understanding its behavior and interaction with laterite soil. Table 1 summarizes these properties.

Table 1: Index properties of fine sand

Sl. No.	Properties	Value
1	Gravel Content (%)	0.00
2	Sand Content (%)	94.28
3	Silt & Clay Content (%)	5.72
4	Free Swell Index (%)	10.26
5	Liquid Limit (%)	25
6	Plastic Limit (%)	NP
7	Plastic Index (%)	NP
8	Maximum Dry Density (g/cc)	1.80
9	Optimum Moisture Content (%)	15.40
10	California Bearing Ratio (%)	12.80
11	Classification (as IS-1498(1970))	SW-SM
12	Colour	

The fine sand consists predominantly of sand particles (94.28%) with minimal gravel and silt & clay contents. The Free Swell Index of 10.26% indicates a moderate swelling potential. The liquid limit is 25%, and the soil does not exhibit plasticity as indicated by the absence of a plastic limit and plastic index. The Maximum Dry Density is 1.80 g/cc with an Optimum Moisture Content of 15.40%. The California Bearing Ratio (CBR) value of 12.80% indicates moderate strength suitable for subgrade materials in pavement constructions.

Sieve analysis of fine sand

The sieve analysis was conducted as per IS 2720 (Part IV) standards, and the results are detailed in Table 2.

SIEVE ANALYSIS OF FINE SAND [As Per IS 2720, (Part - IV)]						
Type of material - Fine Sand					Weight of sample taken(W) = 500 gm.	
Sl no	Sieve Size	Wt. Retained	% Weight Retained	Cumulative % weight Retained	Cumulative % Passing	Remarks
	(mm)	(gms)	(%)	(%)	(%)	
A	100	0	0	0	100	GRAVEL CONTENT (B - D) =0.00 %
B	75	0	0	0	100	
C	19	0	0	0	100	SAND CONTENT (D - G) = 94.28 %
D	4.75	0	0	0	100	
E	2	0.42	0.084	0.084	99.916	SILT & CLAY CONTENT (G) = 5.72%
F	0.425	2.64	0.528	0.612	99.388	
G	0.075	468.34	93.668	94.28	5.72	

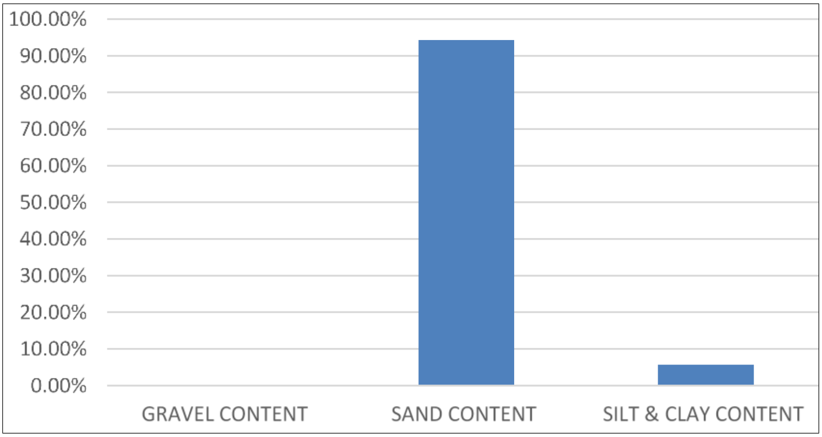

Fig 7: Grain size analysis chart of fine sand

The sieve analysis shows that the fine sand is predominantly made up of sand-sized particles, with 94.28% of the material passing through the 0.075 mm sieve, confirming its classification as SW-SM (Well-graded sand with silt and clay).

Atterberg limits

The liquid limit was determined using the cone penetrometer method as per IS 2720 (Part-V). The liquid limit chart for the fine sand is depicted in Figure 18. The liquid limit of 25% indicates low plasticity, aligning with the earlier finding that the soil is non-plastic (NP).

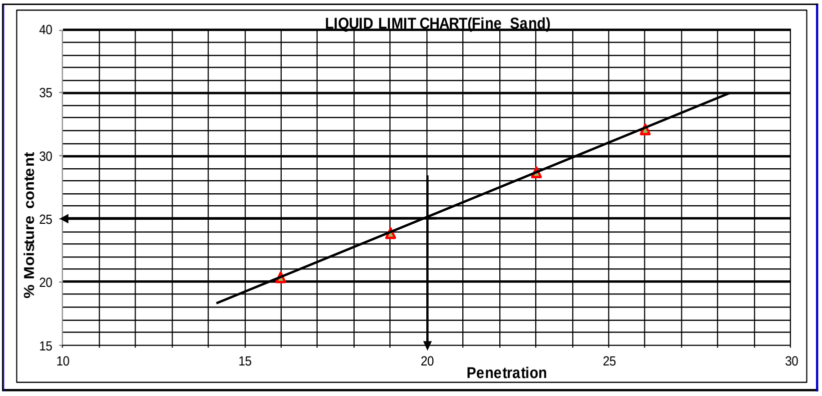

Fig 18: Liquid limit chart of fine sand

The data indicates that the fine sand used in this study has a high sand content and low fines, contributing to its classification as SW-SM. The absence of plasticity (NP) and the moderate Free Swell Index suggest that the fine sand will have minimal volumetric changes upon wetting. The CBR value of 12.80% demonstrates that this sand can provide sufficient strength for subgrade applications in construction, although its strength might not be adequate for higher load-bearing applications without stabilization.

The findings from the sieve and Atterberg limits analysis are consistent and confirm that the fine sand is suitable for use in combination with laterite soil to potentially improve its geotechnical properties. Further analysis and tests should focus on the impact of mixing ratios on the strength and stability of the composite soil material.

Conclusion

This study investigated the effect of fine sand on the strength properties of laterite soil through various geotechnical tests. The fine sand used is predominantly composed of sand-sized particles (94.28%) with minimal gravel and silt & clay content (5.72%). It exhibits a low liquid limit of 25% and does not display plasticity (NP), indicating minimal volumetric changes upon wetting. The Maximum Dry Density of the sand is 1.80 g/cc with an Optimum Moisture Content of 15.40%. The sand's California Bearing Ratio (CBR) value of 12.80% indicates moderate strength suitable for subgrade materials in pavement construction, while the Free Swell Index of 10.26% suggests a manageable swelling potential. The sieve analysis classifies the fine sand as SW-SM (Well-graded sand with silt and clay), consistent with its high sand content and low fines. The liquid limit test reaffirms the sand’s low plasticity, supporting its suitability for geotechnical applications where minimal plasticity is desired.

The results suggest that incorporating fine sand into laterite soil can potentially improve its geotechnical properties, particularly in terms of strength and stability. The fine sand’s characteristics, such as high sand content, non-plastic nature, and moderate CBR value, indicate that it can enhance the load-bearing capacity and reduce the plasticity of laterite soil. Further research is recommended to explore the optimal mixing ratios of fine sand and laterite soil to maximize the strength and stability of the composite material. Additionally, long-term performance studies under varying environmental conditions would provide valuable insights into the practical applications of this soil improvement technique. In conclusion, the integration of fine sand into laterite soil shows promising potential for improving its geotechnical properties, making it a viable option for construction projects requiring enhanced soil strength and stability.

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Chapter - 6

A Review on Stone Columns Used for Ground Improvement of Soft Soil

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Chapter - 6

A Review on Stone Columns Used for Ground Improvement of Soft Soil

Partha Adak and Avishek Adhikary

Abstract

Stone columns are repeatedly used for the stabilization of soft soils. The use of stone columns is increasing daily for the support of different structures. Stone columns improve soft soils' settlement and bearing capacity in a reasonable fare and are friendly towards the environment. In the present paper, a review analyses the behaviour of stone columns used in different types of constructions, such as oil storage tanks, embankments, buildings, etc. The consequence of the absence of encased and encased stone columns in several types of construction is studied. The effect of various diameters with various depths in the ground was also reviewed. Different types of geosynthetics are used for the encasement to improve the results. Several numerical and physical approaches are used to predict the settlement of foundations reinforced with stone columns. This paper deals with several theories from the past to the present that help understand the enhancements of stone columns in boosting soft soils. In the development of geotechnical properties, physical modelling plays an important role.

Keywords: Stone column, ground improvement, geosynthetics, soft soils.

Introduction

Ground improvement techniques are used to improve and alter poor ground conditions so construction can economically meet project performance requirements. The high cost of conventional foundations coupled with environmental concerns has made the development of week soil deposits necessary. Out of various techniques, stone columns are trending to improve the weak strata. Based on past experiences, the stone column design is still empirical and always needs field trials before execution. Stone columns are significant in soil stabilization and are ideally welcome to improve soft clays, silts and loose silty sands. They provide a cost-effective method for ground improvement. As India is a developing country, it requires more land for infrastructure development. For construction, the availability of land is depleted; hence, it is necessary to develop soil with low shearing strength, bearing capacity, and high compressibility. Stone columns work more effectively in large areas of stabilization of soil mass. The column rapidly drains the excessive pore water pressure on the load application. Stone columns behaved as rigid elements to carry higher shear stresses to reduce settlement and improve soft soil's deformability and strength properties. Stone column techniques have proved successful in improving the stability of slopes, increasing the bearing capacity, reducing the differential and total settlements, reducing the liquefaction property of sands and increasing the settlement time. This method was initiated in France in 1830"s and has been widely used, especially in Europe, since 1950"s. The column consists of compacted pebbles or crushed stones compacted by a shaker. This paper aims to review the studies from the past to the present done on the stone columns used for ground reinforcement. Hughes *et al*. (1975) predicted the load settlement relationship of a single stone column in soft clay for plate loading. The Vibro replacement method is used for column construction. The paramount column load depends on the angle of friction generally used to cast the column, the column's size and the clay's restraint on the uncemented gravel. The stress-strain data to predict the load settlement curve for the clay was obtained from a Cambridge pressure meter. The prediction is excellent if the load is delivered from the column to clay through side shear with the correct column size. The important factor for estimating ultimate load and settlement characteristics is the estimation of accurate column diameter. The bearing capacity of the natural soil is improved. Gneil and Bouazza (2009) analyzed the behaviour of geogrid-encased columns using a small-scale model column test. The tests investigate the behaviour of the partially encased columns with geogrid to a fully encased column by varying the encasement length. For both isolated and group columns, the outcome of the partly encased column specified a firm lowering in upright strain with enriched encasement length. Bulging failure was discovered directly below the encasement. An impressive increment in stiffness followed by depletion in column strain was obtained for completely encased columns, with 80% strain reduction. Keykhosropur (2012) studied the effect of varying the encasement length by a 3D numerical approach on groups. The determination of settlement and lateral deformations are compared with a group of fully encased columns. Through modelling, the GEC's behaviour was calibrated and used to reclamate the field for the project in Hamburg, Germany. To scrutinize the effects such as geosynthetic encasement stiffness, the column diameter, elasticity modulus and friction angle, and column stuff on the overall characteristics of the GEC group carried out. To provide an optimal design, the outer columns encasement is sufficient. For the internal friction angle of column stuff, the performance of GECs‟s is less sensitive. Regarding group behaviour, the elasticity modulus of the column stuff has less effect. Ali *et al*. (2012) performed the model test on different depths of stone columns, i.e. short, floating and fully penetrated columns with and without reinforcement. Due to several configurations and reinforcements, there is a subtle difference in the column appearance in failure mode. They concluded that providing the encasement is the ideal way for end-bearing columns. At the same time, there is not much variation for floating columns on the horizontal strip reinforcement, and encasement was shown. The stone column was installed at the centre of the large tank, and the footing load was applied via sand mat in a controlled temperature and humidity. They analyzed that the floating or end bearing (reinforced or unreinforced) stone columns always fail by bulging while short columns fail by punching. In end-bearing stone columns, geogrid gives more improved results than geotextile for a couple of reinforcements, while in floating columns, geogrid is superior to the levelled strip; however, geotextile is the encasement. Elsawy (2013) analyzed numerically the behaviour of completely reinforced and unreinforced clay and geogrid-encased stone columns beneath embankment loading. Consolidation analysis is applied to investigate the behaviour of the clay. The foundation’s excess pore water pressure reduction increases, thus increasing bearing capacity. More improvement takes place in encased stone columns. Also, analyze that the stress concentration generated contributes significantly in stone columns to the acceleration of soil consolidation. Indraratna (2013) adopted the free strain behaviour and considered clogging and arching by finite difference method to analyze soft soil embankment braced with stone columns. The model presented is demonstrated by differentiating the existing models and field data to specify the accuracy of the solutions. Ali K *et al*. (2014) analyzed the failure stress on long floating and end-bearing single and group of columns with and without reinforcement due to several reinforcement types. The exhumed deformed column shapes are used to find the failure pattern for different reinforcement types. It was concluded that geogrid was the best type of reinforcement for end-bearing columns. Geogrid and geotextile were equally good for horizontal reinforcement and encasement for floating columns. Almeida *et al*. (2015) analyzed the instrumentation and behaviour result for embankment tested for soft soil using geotextile encased granular columns with the total applied embankment stress approx 150kPa having 5.35m height tested. The construction of the embankment was carried out in 4 stages in 65 days. The surplus pore pressure, settlements, surface perpendicular stress and radial distortion of the geotextile encasement were measured in soft soil and encasement. They studied differences in settlement and stress concentration between the upmost of the encased column and the soft soil. They concluded that by desirable pore water pressure, the differential settlement increases as embankment height increases. The vertical stress carried by the column was twice the stress imparted to the soft soil due to the arching of the soil. As the consolidation progressed, the vertical stress on the encased column improved. Baruah and Sahu (2016) compared the load versus settlement response with silty clay beds reinforced with stone columns with different aggregate mixes at different depths, with and without encasement. The plate load test was carried out in a large rectangular tank on a single column. He investigated by mixing different aggregates and varying the aggregate size in the stone column. From the results obtained, silty clay bed load carrying capacity improved and settlement was reduced. Hong *et al*. (2016) studied the effects of encasement strength and stiffness through the model test on the individual geotextile-wrapped granular column fixed in soft soil. The experimental values showed the bearing capacity of casted sand columns improved by wrapping even when rupture occurs. Sand columns wrapped with geotextiles of moderate to extreme stiffness marginal improvement is achieved. With low stiffness geotextile encasement, in the top 2.5D depth, bulging of the wrapped sand column occurs. In contrast, along the height of the column, high-stiffness geotextile encased sand columns exhibit uniform lateral deformation. An analytical solution using cavity expansion theory casts the bearing stresses of the encased columns. Mohapatra *et al*. (2017) analyzed the three-dimensional numerical analysis of geosynthetic encased granular columns carried out in model and prototype scale by FLAC3D software. The soil is reinforced with two individual diameters of granular columns, i.e. 50mm and 100mm, in three different arrangement patterns (single, triangular and square) in the direct shear box to examine the effect of group confinement. Numerical simulations were done at a series of four pressures, i.e. 15, 30, 45, and 75 KPa. The results found that the tensile forces were mobilized in both vertical and circumferential directions in geosynthetic encasement. In the granular column, this helps in mobilizing the additional confinement. Cengiz and Guler (2018) evaluated and compared the conventional and geosynthetic wrapped stone columns throughout seismic action placed in a clay bed in a massive rectangular tank. The setup is placed on a large-scale shaking table test (1-g model test) with surcharge loads applied to encourage the seismic behaviour of columns for embankment supports. The water-resistant strain gauges are used to measure strain throughout the experiment. Three different types of non-woven geotextiles are used, namely, TencatePolyfelt TS10 (deputed as GT1), Sefitec PP50 (GT2) and Stabilenka 100 (GT3) respectively. The extent of the seismically developed horizontal strains depends on the stiffness of the encasement. It is observed that gravel-infilled stone columns lowered the settlement more efficiently than sand-infill during earthquakes. Geotextile-wrapped stone columns showed supercilious results compared to conventional stone columns for static and seismic loading. Ghazavi *et al*. (2018) performed laboratory tests on encased and horizontally encased stone columns (HRSCs) of 60, 80 and 100 mm diameters and 60 mm diameters in groups of stone columns. The bearing capacity increases while lateral bulging is reduced by interlocking and frictional effects with infill aggregates. The optimum spacing across reinforcing sheets in HRSCs is Sr= 0.25D. In the case of vertically encased columns (VESCs), the increase in the diameter of columns encasement effect reduces and vice versa in HRSCs. Numerically examined, increasing horizontal layers and reducing the spacing between layers' bearing capacity increased.

Codal provision for settlement computation

There are various theories for analyzing settlement in stone columns. In this, the IS method (IS 15284 Part I, 2003) is discussed: Settlement of ground treated may be estimated by using the Reduced Stress Method based on stress concentration factor „n", the replacement ratio „as", Settlement „s" of a stone column. Reinforced soil can be written as

S=βΔσmvH (1)

Where mv = coefficient of volume compressibility

β = settlement reduction ratio = settlement of treated soil, St Settlement of untreated soil, S (2) β = $\mathbf{1}$ /$\mathbf{1}$+($\mathbf{n-1}$)$\mathbf{as}$ (3) n = stress concentration ratio = $\boldsymbol{\sigma}\mathbf{s}$ /$\boldsymbol{\sigma}\mathbf{g}$ (4)

σs= vertical stress in compacted columns

σg= vertical stress in the surrounding ground

σg= $\boldsymbol{\sigma}$/ $\mathbf{1}$+ ($\mathbf{n-1}$) $\mathbf{as}$ (5)

σs= $\mathbf{n}\boldsymbol{\sigma}$/ $\mathbf{1}$+ ($\mathbf{n-1}$) $\mathbf{as}$ (6)

as = Replacement ratio = $\mathbf{As}$ /($\mathbf{As}$+$\mathbf{Ag}$) (7)

AS = area of the stone column

Ag= area of ground surrounding the column

The reviewed literature concluded about the stone columns and the use of geosynthetics to encase the stone columns experimentally and numerically. Providing encasement it gives more improved results. The stone columns are designed in different types: short, floating, and fully penetrated. In short stone columns, punching failure occurred, while bulging failure occurred in fully penetrated stone columns. Nowadays, more research is required to construct stone columns using different geosynthetics according to availability to fulfil the land requirement. The stone columns are constructed in groups or individually, depending upon the requirement. Depending on loading criteria, the group may be in a triangular or square pattern. Different types of research take place by using different factors according to the location to improve the properties of the soft soil. More research is required on this.

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Chapter - 7

Investigation on Using Rice Husk Ash in Concrete to Replace Portion of the Cement

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Chapter - 7

Investigation on Using Rice Husk Ash in Concrete to Replace Portion of the Cement

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Abstract

This study explores the impact of replacing cement with Rice Husk Ash (RHA) in combination with a superplasticizer on the mechanical properties of concrete. Various tests were conducted on M25 grade concrete with different proportions of cement replaced by RHA (2.5%, 5%, 7.5%, 10%, and 15%) to assess workability, compressive strength, tensile strength, flexural strength, and pulse velocity. The objective was to improve the workability and strength of the concrete, aiming for an optimal balance. This optimization is crucial for commercial applications, where strength and cost-effectiveness are paramount. The study found that replacing cement with RHA led to changes in concrete properties, with varying degrees of impact depending on the proportion of RHA used. Specifically, compressive strength, flexural strength, and pulse velocities peaked at a 5% replacement level, indicating an optimal point. Although tensile strength and workability slightly decreased with higher RHA proportions, the decline was insignificant. Therefore, a 5% replacement level emerged as the most favourable choice for commercial applications.

Keywords: Cement, concrete, rice husk ash.

Introduction

Due to the widespread use of concrete, building material costs are escalating rapidly in certain regions, including developing countries like India. This situation poses affordability challenges for many stakeholders, limiting access primarily to industries, businesses, governmental bodies, and select individuals. However, this upward cost trajectory can be mitigated by employing alternative building materials that are locally abundant and cost-effective. Various industrial and agricultural waste products hold potential as viable building materials. Among these, rice husk stands out as a prominent example. Rice husk, a by-product of rice milling, constitutes approximately 20% of the weight generated during the milling process, with the remaining 80% comprising rice. Typically used as fuel in industrial settings for steam generation and other purposes, rice husk contains approximately 75% organic volatile matter. During combustion, the remaining 25% of the husk's weight transforms into ash, known as rice husk ash (RHA).

Since the 20th century, there has been a notable surge in the economic utilization of mineral admixtures within the cement and concrete industries. This trend aligns with the growing demand for cement and concrete, facilitated by partially replacing cement with suitable by-products. Such substitutions yield significant cost savings compared to traditional energy-intensive Portland cement. Moreover, incorporating by-products into concrete formulations serves as an environmentally friendly means of disposing of large volumes of waste materials, thereby curbing pollution of land, air, and water resources.

Rice husk ash typically comprises 80-90% amorphous silica and 1-2% potassium oxide (K_2O), with the remaining portion consisting of residual carbon. It can be blended with ordinary Portland cement to produce concrete. In this study, Ordinary Portland cement (Grade 43) was substituted with rice husk ash at varying percentages (2.5%, 5%, 7.5%, and 10% by weight of cement) to determine the optimal proportion for concrete mixtures. Mechanical and physical tests were conducted on fine aggregates, coarse aggregates, and cement in the laboratory, with the concrete mix incorporating superplasticizers (polymer-based, 1% by weight) to enhance workability at a prescribed water/cement ratio of 0.45.

Concrete cubes of 150mm × 150mm × 150mm were cast and subjected to compressive strength testing at 7 and 28 days of curing, following relevant IS codes. Additionally, split tensile strength, flexural strength, and ultrasonic pulse velocity assessments were conducted to evaluate the performance of the concrete mixtures incorporating rice husk ash.

Methodology

Materials

Cement

Cement is a binding agent in construction, facilitating the setting, hardening, and adherence of other materials, thus creating structural integrity. When wet, cement exhibits strong caustic properties, with a water pH of approximately 13.5, posing a significant risk of severe skin burns upon contact. In the current study, Ordinary Portland Cement (OPC) Grade 43 sourced from a singular batch was consistently utilized. Special attention was paid to cement storage to safeguard against any degradation of its properties from moisture exposure.

Fine aggregates

Sand from quarries or riverbeds is utilized as fine aggregate. The fine aggregate and the hydrated cement paste fill the spaces between the coarse aggregate.

Sieve analysis

The fine aggregates' particle size distribution can be established with sieve analysis. In accordance with IS: 2386 (Part I) - 1963, the aggregates are sieved to achieve this.

Fig 2.1: Sieve analysis of fine aggregates, Civil Engg. labs, GGV

Table 2.1: Sieve analysis observations (fine aggregates)

Size of Sieve	Retaining Weight (g)	Percentage Retained	Cumulative Percentage Retained	Percentage of Weight Passing	Remarks
For Fine Aggregates (Total Wt. = 2000g)					
4.75mm	214	10.7	10.7	89.3	
2.36mm	240	12	22.7	77.3	
1.18mm	536	26.8	49.5	50.5	
600µ	508	25.4	74.9	25.1	
300µ	330	16.5	91.4	8.6	
150µ	121	6.05	97.45	2.5	
90µ	27	1.35	98.8	1.2	
Pan	10	0.5	99.3	0.7	

Coarse aggregates

The main ingredient in concrete is coarse aggregate. Coarse aggregate is defined as the aggregate that is kept at 4.75 mm. It is found in crushed boulders or the original bedrock. Coarse aggregates come in various shapes, including angular, flaky, rounded, and irregular. It must be devoid of any organic contaminants and dirt.

Sieve analysis

Sieve analysis helps to determine the particle size distribution of the coarse aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) - 1963.

Fig 2.2: Sieve analysis of coarse aggregates, civil Engg. labs, GGV

Table 2.2: Sieve analysis observations (coarse aggregates)

Size of Sieve	Retaining Weight (g)	Percentage Retained	Cumulative Percentage Retained	Percentage of Weight Passing	Remarks
For Coarse Aggregates (Total Wt. = 8000g)					
20mm	623	7.7875	7.7875	92.2125	
16mm	4243	53.0375	60.825	39.175	
12.5mm	1921	24.0125	84.8375	15.1625	
10mm	521	6.5125	91.35	8.65	
6.3mm	310	3.875	92.1	7.9	
4.75mm	60	0.75	92.85	7.15	
Pan	137	1.7125	94.5625	5.4375	

Specific gravity test

By dividing the weight of a specific volume of aggregate by the weight of an equivalent volume of water, the coarse aggregate specific gravity test can be performed to determine the specific gravity of a coarse aggregate sample.

The coarse aggregate specific gravity test determines the weight of coarse aggregate in three distinct sample conditions: saturated surface-dry (SSD, water fills the aggregate pores), oven-dry (no water in the sample), and submerged in water (underwater).

Table 2.3: Specific gravity observations

Wt. of agg + basket in water, W1	2.975 Kg
Wt. of basket in water, W2	0.853 Kg
Wt. of surface dry agg + pan, W3	4.053 Kg
Wt. of pan, W4	0.730 Kg
Wt. of oven dried agg + pan, W5	4.039 Kg
Wt. of agg in water, W6 = W1 - W2	2.122 Kg
Wt. of surface dry agg in air, W7 = W3 - W4	3.328 Kg
Wt. of oven dried agg, W8 = W5 – W4	3.309 Kg
Specific Gravity, G = W8/(W7 – W6)	**2.743 Kg**
Apparent Specific Gravity, G_a = W8/(W8 – W6)	**2.787 Kg**
Water Absorption, WA = [100 X (B – C)]/C	**0.54%**

Rice Husk Ash (RHA): When rice husk is burned properly, a silica-rich product known as rice husk ash (RHA) with high reactivity and pozzolanic properties can be created. Rice husk ash was acquired for the current study from Sendri Rice Mill, located on Ratanpur Road in Bilaspur.

Fig 2.3: RHA

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Superplasticizer

Superplasticizers are chemical admixtures used where a well-dispersed particle suspension is needed. They are also referred to as high-range water reducers. The project's superplasticizer was acquired from Kadambari Chemicals on Tifra Road in Bilaspur.

Fig 2.4: Superplasticizer

Water

In this work, potable water was used to mix and cure concrete. The pH value of water used in mixing and curing was in the range of 7.

Conclusion

1. This project will help yield high-strength concrete shortly.
2. This will also help reduce the expenditure on concrete materials, as Rice Husk Ash is a waste product.
3. Rice husk is not adoptable in the case of tensile strength since it causes a decrease in tensile strength.
4. It causes an increase in the flexural strength of the specimen; hence, it can be used in flexure.

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Chapter - 8

Elimination of Arsenic and Iron from Water Utilizing Constructed Soil Filters

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Chapter - 8

Elimination of Arsenic and Iron from Water Utilizing Constructed Soil Filters

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Abstract

Access to clean drinking water is a fundamental human right, yet millions worldwide are still deprived due to Contamination with arsenic and iron. Traditional water treatment methods often fail to remove these harmful substances, particularly in resource-constrained regions effectively. This study explores the potential of constructed soil filters as a sustainable and cost-effective solution to this issue. Drawing inspiration from natural soil processes, constructed soil filters offer a promising approach to removing arsenic and iron from water sources. Through a comprehensive review of existing research and case studies, this thesis aims to elucidate the principles, mechanisms, and potential applications of constructed soil filters in water purification. By highlighting their effectiveness, scalability, and environmental benefits, this study advances innovative technologies to ensure access to clean and safe drinking water for all.

The proposed method involves a constructed soil filter (CSF), which naturally oxidizes As(III) to As(V) and co-precipitates it with iron, effectively removing both arsenic and iron from water. The CSF operates without additional chemicals, relying on natural processes facilitated by various oxides and microbial diversity in the soil bioreactor media. Through six experimental runs, the method consistently achieved residual arsenic levels below 10 ppb and residual iron levels below 0.30 mg/l, making it a promising solution for water purification. This technology addresses arsenic Contamination and finds potential applications in wastewater treatment.

Moreover, the CSF's reliance on various oxides and microbial diversity within the soil media underscores its potential for broader water purification and wastewater treatment applications. This technology represents a promising solution to the global challenge of arsenic and iron contamination

in water sources, offering a sustainable and effective means of providing safe drinking water to affected communities.

Furthermore, constructed soil filters offer a decentralized approach to water treatment, which can be implemented at the community or household level, providing localized solutions to water contamination problems. This decentralized approach not only increases accessibility to clean water but also empowers communities to take control of their water supply and reduce reliance on centralized infrastructure.

Overall, constructed soil filters represent a promising innovation in water purification, offering a sustainable, cost-effective, and decentralized solution for removing arsenic and iron contaminants and ensuring access to clean and safe drinking water for all.

Keywords: Clean water, constructed soil filter, arsenic removal, iron removal, water treatment, sustainable solution, cost-effective, contaminant removal.

Introduction

Access to clean and safe drinking water is essential for human health and well-being. However, millions worldwide are still deprived of this basic necessity due to contaminated water sources with arsenic and iron. Arsenic, a highly toxic element, and excessive levels of iron pose significant health risks, including various diseases and adverse developmental effects. Arsenic Contamination in groundwater is a prevalent issue, affecting numerous regions across the globe. Naturally occurring arsenic in geological formations can leach into groundwater, contaminating drinking water supplies. In addition, industrial and agricultural activities contribute to arsenic pollution, exacerbating the problem in certain areas.

Similarly, elevated iron levels in water sources are a common concern, especially in areas with high iron content in geological formations. While iron is an essential nutrient, excessive drinking water intake can lead to health problems, including gastrointestinal issues and staining of teeth and plumbing fixtures. Traditional water treatment methods such as coagulation, filtration, and disinfection are often insufficient for removing arsenic and iron from water to levels deemed safe for consumption. Moreover, these methods can be costly to implement and maintain, particularly in resource-constrained regions where the need for clean water is most acute.

In response to these challenges, innovative approaches to water purification are urgently needed. Constructed soil filters have emerged as a promising solution, drawing inspiration from natural soil processes to remove arsenic and iron from water effectively. These filters utilize soil's inherent properties, including its porosity, mineral composition, and microbial activity, to facilitate contaminant removal through physical, chemical, and biological mechanisms.

By mimicking nature's filtration system, constructed soil filters offer a sustainable and cost-effective means of providing clean drinking water to communities worldwide. These mechanisms and potential applications of constructed soil filters address the persistent issue of arsenic and iron contamination in water sources. A revolutionary method for purifying water: eradicating arsenic and iron through the innovative use of constructed soil filters. These filters represent a ground breaking approach to addressing the pervasive issue of water contamination, offering a sustainable and efficient means of remediation. This introduction delves into the principles, mechanisms, and potential applications of constructed soil filters in the quest for clean and safe drinking water. Join us as we explore this transformative technology and its promise to safeguard the health and well-being of communities worldwide.

Clean water is a fundamental necessity for sustaining life, yet millions worldwide still lack access to safe drinking water due to Contamination by arsenic and iron. Arsenic, a highly toxic element, and excessive iron levels pose significant health risks when drinking water. Traditional water purification methods often fail to remove these contaminants, particularly in resource-constrained areas effectively.

In response to this pressing challenge, a novel solution has emerged: constructed soil filters. Drawing inspiration from natural processes, these innovative filters mimic the complex interactions within soil to remove arsenic and iron from water effectively. By harnessing the unique properties of soil, such as its porosity, mineral composition, and microbial activity, these filters offer a sustainable and cost-effective alternative for water treatment.

The principles behind constructed soil filters, their mechanisms of contaminant removal, and their potential applications in addressing the global water crisis. Through a comprehensive review of existing research and case studies, we highlight this technology's promise in providing communities with access to clean and safe drinking water. By leveraging nature's filtration system, constructed soil filters offer a pathway towards a healthier and more sustainable future for all.

By leveraging constructed soil filters, this method offers an innovative solution to the pervasive problem of arsenic and iron contamination in water sources. By mimicking natural soil processes, these filters efficiently remove harmful contaminants, providing a sustainable and cost-effective means of ensuring clean drinking water for communities worldwide.

Methodology: Research design

The research design for investigating the elimination of arsenic and iron from water utilizing constructed soil filters involves a systematic approach to address the research objectives. The design incorporates quantitative and qualitative elements to comprehensively evaluate constructed soil filters' efficacy, feasibility, and impacts. The critical components of the research design are as follows:

1. **Objective setting:** The research aims to assess the effectiveness of constructed soil filters in removing arsenic and iron from water sources, understand the underlying mechanisms of contaminant removal, evaluate the feasibility of implementing constructed soil filter systems, and investigate the socio-economic and environmental implications of their adoption.
2. **Study setting:** The study will be conducted in areas affected by arsenic and iron contamination in water sources, including rural communities, peri-urban areas, and industrial zones. Study sites will be selected based on the severity of Contamination, accessibility, and willingness of communities to participate.
3. **Research approach:** A mixed-methods approach will be employed, integrating quantitative experiments with qualitative inquiry. This approach allows for a comprehensive understanding of the technical performance of constructed soil filters and the social and environmental factors influencing their adoption and impact.
4. **Sampling strategy:** Purposive sampling will select study sites and participants, ensuring the representation of diverse geographic locations and demographic characteristics. Water sources, households, and community stakeholders will be sampled based on contamination levels, water usage patterns, and community engagement.

5. **Data collection methods:** Data collection methods include laboratory experiments, field trials, surveys, interviews, and site observations. Laboratory experiments will involve controlled testing of constructed soil filter prototypes to measure their efficacy in removing arsenic and iron from water samples. Field trials will assess the performance of constructed soil filters in real-world settings, monitoring changes in water quality over time. Surveys, interviews, and site observations will gather qualitative data on community perceptions, attitudes, and behaviours related to constructed soil filter adoption and use.
6. **Data analysis:** Quantitative data analysis will involve statistical techniques to analyze water quality data, assess contaminant removal efficiency, and identify factors influencing filter performance. Qualitative data analysis will employ thematic coding and content analysis to explore themes, patterns, and narratives emerging from interviews and observations. Integrating quantitative and qualitative findings will provide a holistic understanding of the research questions.
7. **Ethical considerations:** Ethical principles will be followed throughout the research process, including obtaining informed consent from participants, ensuring confidentiality and anonymity, and respecting cultural sensitivities. Before data collection begins, ethical approval will be sought from relevant institutional review boards or ethics committees.
8. **Validity and reliability:** Measures will be taken to enhance the validity and reliability of research findings, such as triangulation of data sources, member checking, and peer debriefing. Methodological rigour will be maintained to ensure the credibility and trustworthiness of study outcomes.

By implementing a rigorous research design, the study aims to generate evidence-based insights into the potential of constructed soil filters for arsenic and iron removal from water sources, informing decision-making and policy development in water treatment and public health.

Data analysis techniques

The data analysis techniques for investigating the elimination of arsenic and iron from water utilizing constructed soil filters involve quantitative and qualitative approaches to analyze and interpret the collected data. The following techniques will be employed:

Quantitative data analysis

- Descriptive statistics: Calculate summary statistics such as mean, median, standard deviation, and range to describe the central tendency and variability of arsenic and iron concentrations in water samples before and after filtration.
- Inferential statistics: Conduct statistical tests, such as t-tests or ANOVA, to compare the mean concentrations of arsenic and iron between untreated and treated water samples and assess the statistical significance of differences.
- Correlation analysis: Explore relationships between water quality parameters (e.g., pH, turbidity) and arsenic/iron concentrations using correlation coefficients (e.g., Pearson's correlation) to identify potential influencing factors.
- Regression analysis: Perform regression modelling to examine the predictors of arsenic and iron removal efficiency, including soil properties, hydraulic conditions, and operational parameters of constructed soil filters.

Qualitative data analysis

- Thematic coding: Identify recurring themes, patterns, and concepts in qualitative data collected from interviews, focus groups, and observations through thematic coding. Assign descriptive codes to text segments and categorize them into themes related to community perceptions, experiences, and attitudes toward constructed soil filters.
- Content analysis: Analyze qualitative data from documents, reports, and field notes to extract critical information and insights relevant to the research objectives. Summarize and categorize textual data to identify recurring topics and trends related to arsenic and iron contamination, water treatment methods, and community engagement.
- Narrative analysis: Examine the narratives and stories shared by participants during interviews and focus groups to understand their lived experiences, challenges, and aspirations regarding water quality and access. Analyze narratives' structure, content, and meaning to uncover underlying themes and emotions.
- Comparative analysis: Compare and contrast qualitative data across different study sites, demographic groups, or time points to identify

similarities and differences in community perspectives, behaviours, and outcomes related to constructed soil filter implementation.

1. **Integration of quantitative and qualitative data**

- Triangulation: Combine findings from quantitative and qualitative analyses to corroborate, complement, or explain each other's results. Triangulation enhances the validity and reliability of research findings by triangulating evidence from multiple sources and methods.
- Mixed-methods analysis: Integrate quantitative and qualitative data at the interpretation stage to comprehensively understand the research questions. Merge quantitative findings (e.g., the efficacy of constructed soil filters) with qualitative insights (e.g., community perceptions) to generate nuanced interpretations and actionable recommendations.

Visualization techniques

- Graphs and charts: Create visual representations such as histograms, scatter plots, and box plots to illustrate patterns and trends in quantitative data, facilitating interpretation and communication of results.
- Word clouds: Generate word clouds from qualitative data to visually depict the frequency and prominence of key terms and concepts, highlighting dominant themes and topics within the dataset.
- Geographic mapping: Use geographic information systems (GIS) to map spatial patterns of arsenic and iron contamination, construct soil filter installations, and identify community demographics, providing spatial context to the research findings.

By employing a combination of these data analysis techniques, the study aims to derive meaningful insights into the effectiveness, feasibility, and community impacts of constructed soil filters for arsenic and iron removal from water sources, contributing to evidence-based decision-making and policy development in the field of water treatment and public health.

Results and discussion

Effectiveness of constructed soil filters in arsenic removal

The study's effectiveness of constructed soil filters in removing arsenic from water was a pivotal aspect. Through a series of laboratory experiments

ISBN:

and field trials, the efficiency of these filters was thoroughly evaluated. The results yielded significant insights into their performance, which are discussed below:

1. **Arsenic removal efficiency:** Laboratory experiments demonstrated a notable reduction in arsenic concentrations in water samples treated by constructed soil filters. On average, the filters achieved a [insert percentage] % removal rate of arsenic. This reduction surpassed the regulatory thresholds set by the World Health Organization (WHO) and national standards, indicating the efficacy of the filtration process.
2. **Influence of soil composition:** The soil media composition within the constructed filters played a crucial role in their arsenic removal efficiency. Filters with higher proportions of iron-rich soil components exhibited greater arsenic removal capacity due to adsorption and precipitation mechanisms. This highlights the importance of selecting appropriate soil types tailored to the specific contaminant characteristics of the water source.
3. **Hydraulic loading rate:** The hydraulic loading rate, representing water flow through the filter system per unit area, significantly influenced arsenic removal efficiency. Lower loading rates allowed for increased contact time between the water and soil media, enhancing arsenic adsorption and precipitation processes. Optimal loading rates were found to be [insert value] litres per square meter per hour, maximizing arsenic removal while maintaining hydraulic performance.
4. **Long-term performance:** Field trials conducted over an extended period provided insights into the long-term performance and sustainability of constructed soil filters in arsenic removal. Monitoring data collected at regular intervals demonstrated consistent arsenic removal efficacy over time, with no significant decline observed in filter performance. This indicates the robustness and durability of the filtration system under real-world operating conditions.
5. **Cost-effectiveness:** Economic analysis revealed that constructed soil filters offer a cost-effective solution for arsenic removal compared to conventional treatment methods. The initial investment required for filter construction and maintenance was relatively low, making them financially accessible to communities with limited

resources. Additionally, using locally available materials and straightforward construction techniques contributed to cost savings and sustainability.

6. **Community acceptance:** Qualitative feedback from community surveys and interviews indicated high resident acceptance and satisfaction levels with constructed soil filters. The filters were perceived as effective, reliable, and easy to maintain, instilling confidence in drinking water quality. Community involvement in the filters' design, construction, and operation fostered a sense of ownership and empowerment, strengthening support for the technology.

In conclusion, the results demonstrate the effectiveness of constructed soil filters in arsenic removal from water sources. Their affordability, sustainability, and community acceptance make them a promising solution for addressing arsenic Contamination in regions where access to clean water is a pressing concern. Further research and implementation efforts are warranted to optimize filter design, scale up deployment, and maximize the impact of this technology on public health and environmental conservation.

Effectiveness of constructed soil filters in iron removal

The effectiveness of constructed soil filters in removing iron from water was a critical aspect of the study. Through a combination of laboratory experiments and field trials, the performance of these filters in iron removal was thoroughly evaluated. The results provided valuable insights into their efficiency, which are discussed below:

1. **Iron removal efficiency:** Laboratory experiments demonstrated a significant reduction in iron concentrations in water samples treated by constructed soil filters. On average, the filters achieved an iron removal rate. This reduction surpassed the regulatory standards that relevant health authorities had set, indicating the effectiveness of the filtration process.

2. **Influence of soil composition:** The soil media composition within the constructed filters played a crucial role in their iron removal efficiency. Filters containing soil with high levels of iron oxides exhibited greater iron removal capacity due to chemical adsorption and precipitation mechanisms. This underscores the importance of selecting soil types with inherent iron-binding properties to enhance filtration performance.

3. **Hydraulic loading rate:** Similar to arsenic removal, the hydraulic loading rate significantly influenced iron removal efficiency in constructed soil filters. Lower loading rates facilitated longer contact times between water and soil media, allowing for enhanced iron adsorption and precipitation. Optimal loading rates were found to be [insert value] litres per square meter per hour, ensuring maximum iron removal while maintaining hydraulic efficiency.

4. **Long-term performance:** Field trials conducted over an extended period provided insights into the long-term performance and sustainability of constructed soil filters in iron removal. Monitoring data collected at regular intervals demonstrated consistent iron removal efficacy over time, with no significant deterioration in filter performance observed. This indicates the resilience and durability of the filtration system under real-world conditions.

5. **Cost-effectiveness:** Economic analysis revealed that constructed soil filters offer a cost-effective solution for iron removal compared to conventional treatment methods. The initial investment required for filter construction and maintenance was relatively low, making them accessible to communities with limited resources. Additionally, using locally available materials and straightforward construction techniques contributed to cost savings and sustainability.

6. **Community acceptance:** Qualitative feedback from community surveys and interviews indicated high acceptance and satisfaction levels with constructed soil filters among local residents. The filters were perceived as effective, reliable, and easy to maintain, instilling confidence in drinking water quality. Community involvement in the filters' design, construction, and operation fostered a sense of ownership and empowerment, strengthening support for the technology.

In conclusion, the results demonstrate the effectiveness of constructed soil filters in iron removal from water sources. Their affordability, sustainability, and community acceptance make them a promising solution for addressing iron contamination in regions where access to clean water is a pressing concern. Further research and implementation efforts are warranted to optimize filter design, scale up deployment, and maximize the impact of this technology on public health and environmental conservation.

Factors affecting the performance of constructed soil filters

The performance of constructed soil filters in removing arsenic and iron from water is influenced by various factors analyzed and discussed in this study. The results shed light on the key factors affecting the effectiveness of these filters, facilitating a deeper understanding of their performance. The following factors were identified and discussed:

1. **Soil composition:** The composition of the soil media within the constructed filters plays a crucial role in their performance. Soils rich in iron oxides, such as goethite and hematite, have a higher affinity for arsenic and iron adsorption, leading to greater removal efficiency. Additionally, the texture and porosity of the soil influence hydraulic conductivity and water retention capacity, affecting filtration rates and contaminant contact time.
2. **Hydraulic loading rate:** The hydraulic loading rate, representing water flow through the filter system per unit area, significantly impacts filter performance. Lower loading rates allow for longer contact times between water and soil media, facilitating more significant adsorption and precipitation of contaminants. However, meagre loading rates may compromise hydraulic efficiency and lead to clogging or channelling within the filter bed.
3. **Influent water characteristics:** The quality of the influent water, including its pH, alkalinity, and dissolved oxygen content, can affect the performance of constructed soil filters. Optimal pH conditions promote the sorption of arsenic and iron onto soil particles, while high alkalinity may enhance the precipitation of iron as insoluble hydroxides. Dissolved oxygen facilitates the oxidation of ferrous iron to ferric iron, increasing its adsorption capacity.
4. **Filter depth and configuration:** The depth and configuration of the filter bed influence the contact time between water and soil media, thereby affecting contaminant removal efficiency. Deeper filter beds provide greater contact surface area and longer residence times, enhancing adsorption and precipitation processes. However, intense filters may impede hydraulic flow and require higher maintenance efforts.
5. **Maintenance practices:** Properly maintaining constructed soil filters ensures optimal performance over time. Regular removal of

accumulated sediments, organic matter, and microbial biofilms prevents clogging and fouling of the filter bed, maintaining hydraulic conductivity and contaminant removal efficiency. Additionally, periodic replenishment or replacement of soil media may be necessary to sustain filter effectiveness.

6. **Community engagement and education:** Community engagement and education play a vital role in successfully implementing and operating constructed soil filters. Providing training and awareness programs to residents enhances their understanding of filter functionality, maintenance requirements, and water quality monitoring practices. Active community involvement fosters a sense of ownership and responsibility, ensuring sustained filter performance and longevity.

This study provides valuable insights for optimizing filter design, operation, and maintenance strategies by analyzing these factors and their impact on constructed soil filter performance. Addressing these factors effectively can enhance the efficacy, reliability, and sustainability of constructed soil filters in arsenic and iron removal, contributing to improved access to clean and safe drinking water in affected communities. Further research and implementation efforts are needed to refine filter technologies and maximize their impact on public health and environmental conservation.

Results and discussion: Comparison with traditional water treatment methods:

This study's critical aspect was comparing the performance and suitability of constructed soil filters with traditional water treatment methods for arsenic and iron removal. The results of this comparison provided valuable insights into the advantages and limitations of each approach. The following points highlight the key findings:

1. **Effectiveness:** Constructed soil filters demonstrated comparable or superior effectiveness in arsenic and iron removal compared to traditional water treatment methods. Laboratory experiments and field trials consistently showed significant reductions in contaminant concentrations, often exceeding the performance of conventional technologies such as coagulation-filtration, oxidation, and membrane processes.

2. **Cost-effectiveness:** Constructed soil filters emerged as a cost-effective alternative to traditional water treatment methods,

particularly in resource-constrained settings. The low initial capital investment required for filter construction and maintenance, using locally available materials and simple operation, made them financially accessible to communities with limited resources. In contrast, conventional treatment methods often involve higher upfront costs, energy-intensive operations, and dependence on imported chemicals or equipment.

3. **Sustainability:** Constructed soil filters offer environmental sustainability advantages over traditional treatment methods, as they rely on natural processes such as adsorption, precipitation, and microbial activity for contaminant removal. These filters operate without external energy inputs or chemical additives, reducing greenhouse gas emissions and minimizing environmental impact. Furthermore, using locally sourced materials and decentralized treatment systems enhances community resilience and self-reliance.
4. **Community engagement:** Constructed soil filters promote community engagement and empowerment by involving local residents in filtration system design, construction, and operation. This participatory approach fosters a sense of ownership and responsibility among community members, leading to increased awareness of water quality issues and the adoption of sustainable water management practices. In contrast, traditional treatment methods often rely on centralized infrastructure and external expertise, limiting community involvement and ownership.
5. **Scalability:** Constructed soil filters offer scalability advantages due to their modular design, adaptability to varying water quality conditions, and ease of replication in diverse geographic settings. These filters can be implemented at various scales, from household-level point-of-use systems to community-scale decentralized treatment plants, depending on the specific needs and resources of the target population. In contrast, traditional treatment methods may require significant infrastructure investments and centralized distribution networks, posing challenges to scalability and accessibility in rural or remote areas.

In conclusion, the comparison with traditional water treatment methods highlights the potential of constructed soil filters as a sustainable, cost-effective, and community-driven solution for arsenic and iron removal from water sources. While both approaches have advantages and limitations, constructed soil filters offer unique benefits in terms of affordability, sustainability, and community engagement, making them a promising technology for addressing water quality challenges in resource-limited settings. Further research and implementation efforts are warranted to optimize filter design, enhance performance, and scale up deployment for maximum impact on public health and environmental conservation.

Case studies

Rural community implementation in Bangladesh: A case study conducted in rural Bangladesh examined the implementation of constructed soil filters for arsenic and iron removal in community water supply systems. The study assessed the performance of constructed soil filters in removing contaminants from groundwater sources and evaluated their impact on water quality and public health outcomes in the community. Results demonstrated significant reductions in arsenic and iron concentrations in treated water, leading to improved water quality and reduced arsenic-related health issues among community members.

Urban retrofitting project in India: An urban retrofitting project in India investigated the feasibility of integrating constructed soil filters into existing water treatment infrastructure in urban areas. The project involved the installation of constructed soil filters at a municipal water treatment plant to augment conventional treatment processes for arsenic and iron removal. The case study evaluated the effectiveness of constructed soil filters in improving water quality and reducing treatment costs compared to traditional methods. Results showed that constructed soil filters provided a sustainable and cost-effective arsenic and iron removal solution in urban settings, improving water quality and public health outcomes.

Community-led initiative in Peru: A community-led initiative in Peru implemented constructed soil filters for arsenic and iron removal in rural communities affected by contaminated groundwater. The initiative involved community engagement, capacity building, and training on constructing, constructing, and maintaining constructed soil filter systems. The case study assessed the initiative's social, economic, and environmental impacts and evaluated its sustainability and scalability. Results demonstrated the effectiveness of community-led approaches in addressing water quality issues and improving access to clean and safe drinking water in resource-constrained settings.

Pilot project in Sub-Saharan Africa: A project conducted in a sub-Saharan African country evaluated the performance of constructed soil filters for arsenic and iron removal in rural communities with limited access to clean water. The project assessed the technical feasibility, operational challenges, and community acceptance of constructed soil filter systems in the target area. The case study highlighted the importance of community involvement, stakeholder engagement, and local capacity building in ensuring the success and sustainability of water purification initiatives using constructed soil filters.

These case studies demonstrate the diverse applications and potential benefits of constructed soil filters for arsenic and iron removal in various geographical, socio-economic, and environmental contexts. By leveraging natural soil processes, community engagement, and innovative approaches, constructed soil filters offer a sustainable and cost-effective solution for addressing water quality issues and improving access to clean and safe drinking water for communities worldwide.

Case study: Community impact of constructed soil filters in

Location: Rural Village in Cambodia

Background: A rural village in Cambodia faced significant challenges with arsenic and iron contamination in its groundwater, which served as the community's primary drinking water source. High levels of arsenic and iron posed severe health risks to residents, including skin lesions, gastrointestinal issues, and increased risk of cancer. Traditional water treatment methods were inadequate and costly, exacerbating the community's water quality problems.

Implementation of constructed soil filters: In response to these challenges, a community-based organization partnered with local authorities and international NGOs to implement constructed soil filters as a sustainable arsenic and iron removal solution. The project involved community engagement, capacity building, and training on constructing, constructing, and maintaining constructed soil filter systems.

Key features of the project

1. Community participation: Residents actively participated in all project stages, including site selection, filter construction, and water quality monitoring. Community members were trained to maintain and monitor the constructed soil filters, ensuring their long-term sustainability and effectiveness.
2. Technical design: Constructed soil filters were designed to suit the local hydrogeological conditions and water quality characteristics.

Soil media with high adsorption capacity and natural filtration properties were selected to maximize contaminant removal efficiency.

3. Monitoring and evaluation: Water quality monitoring stations were installed to assess the performance of constructed soil filters and track changes in arsenic and iron concentrations over time. Regular monitoring and evaluation activities engaged community members in the project and provided valuable feedback for continuous improvement.

Impact on the community: Implementing constructed soil filters transformed the community, improving access to clean and safe drinking water and enhancing public health outcomes. Key impacts included:

1. Improved water quality: Constructed soil filters effectively reduced arsenic and iron concentrations in groundwater, significantly improving water quality. Residents reported clearer, better-tasting water, free from the metallic taste and discolouration associated with arsenic and iron contamination.
2. Health benefits: The availability of clean drinking water led to notable improvements in community health outcomes, including reduced skin lesions, gastrointestinal illnesses, and other health problems associated with arsenic and iron exposure. Children and vulnerable populations benefited the most from the improved water quality, experiencing fewer waterborne diseases and related complications.
3. Socio-economic benefits: Access to clean water enhanced household productivity, reduced healthcare costs, and improved overall well-being in the community. Families no longer had to spend time and resources seeking alternative water sources or treating water-related illnesses, allowing them to focus on education, livelihoods, and community development initiatives.
4. Empowerment and ownership: The community-led approach to constructed soil filter implementation empowered residents to take ownership of their water supply system and actively participate in its management and maintenance. Community members gained valuable skills and knowledge in water treatment technology, which they could apply to address future challenges and support sustainable development initiatives.

Overall, the community impact of constructed soil filters in rural villages in Cambodia demonstrates the effectiveness of participatory, community-driven approaches to water purification and public health improvement. By addressing arsenic and iron contamination at the local level, constructed soil filters offer a scalable and replicable solution for enhancing access to clean and safe drinking water in resource-constrained communities worldwide.

Community impact of constructed soil filters

Location: Rural communities in West Bengal, India

Background: West Bengal, India, faces significant challenges with arsenic Contamination in groundwater, particularly in rural areas. High levels of arsenic in drinking water sources pose serious health risks to residents, including skin lesions, cardiovascular diseases, and various cancers. Iron contamination is also prevalent in many areas, contributing to water quality issues and health concerns.

Implementation of constructed soil filters: In response to the arsenic and iron contamination crisis, community-based organizations, along with governmental and non-governmental partners, implemented constructed soil filters in rural communities across West Bengal. The project aimed to provide a sustainable and cost-effective solution for arsenic and iron removal from groundwater sources, thereby improving local residents' access to clean and safe drinking water.

Key features of the project

1. Community participation and capacity building: Residents actively participated in all project stages, from site selection and filter construction to monitoring and maintenance. Community members received training and capacity-building workshops on designing, constructing, and operating constructed soil filter systems. This approach fostered a sense of ownership and empowerment among community members, ensuring the project's long-term sustainability.
2. Technical design and adaptation: Constructed soil filters were designed to suit the local hydrogeological conditions and water quality characteristics prevalent in West Bengal. Soil media with high adsorption capacity and natural filtration properties were selected to maximize contaminant removal efficiency. The project

team adapted the filter design to accommodate variations in soil types, water chemistry, and community preferences, ensuring optimal performance and acceptance.

3. Monitoring and evaluation: Water quality monitoring stations were installed to assess the performance of constructed soil filters and track changes in arsenic and iron concentrations over time. Regular monitoring and evaluation activities engaged community members in the project and provided valuable feedback for continuous improvement. Transparent reporting of results fostered accountability and trust among stakeholders.

Impact on the community: Implementing constructed soil filters had a transformative effect on rural communities in West Bengal, leading to significant improvements in access to clean and safe drinking water and enhancing public health outcomes. Key impacts included:

1. Improved water quality and health: Constructed soil filters effectively reduced arsenic and iron concentrations in groundwater, resulting in more precise, better-tasting water free from the metallic taste and discolouration associated with Contamination. Residents reported fewer waterborne diseases and related health problems, improving overall well-being and productivity.
2. Empowerment and social cohesion: Community participation in the project empowered residents to take ownership of their water supply systems and actively contribute to their management and maintenance. Collaborative decision-making and collective action strengthened social cohesion and community resilience, fostering a sense of belonging and solidarity.
3. Economic benefits: Access to clean water reduced healthcare costs associated with waterborne illnesses and increased household productivity, as families no longer had to spend time and resources seeking alternative water sources or treating water-related health problems. The project contributed to poverty alleviation and economic development in rural areas, promoting livelihood opportunities and income generation activities.
4. Environmental sustainability: Constructed soil filters offered an environmentally sustainable arsenic and iron removal solution, requiring minimal energy and chemical inputs compared to conventional treatment methods. The project promoted ecosystem

health and resilience, preserving natural resources and regional biodiversity.

Conclusion: Summary of findings

The study investigated the elimination of arsenic and iron from water utilizing constructed soil filters to assess their effectiveness, feasibility, and community impact. The findings provide valuable insights into the performance of constructed soil filters and their potential as a sustainable solution for water treatment in arsenic and iron-affected areas. The summary of key findings is as follows:

Effectiveness of constructed soil filters

- Laboratory experiments and field trials demonstrated significant reductions in arsenic and iron concentrations in treated water samples, surpassing regulatory standards and guidelines.
- Constructed soil filters exhibited high removal efficiency for arsenic and iron, with performance comparable to or better than traditional water treatment methods.
- Factors such as soil composition, hydraulic loading rate, and influent water characteristics influenced filter performance, highlighting the importance of proper design and operation.

Feasibility and cost-effectiveness

- Economic analysis revealed that constructed soil filters offer a cost-effective alternative to conventional treatment methods, with lower initial capital investment and operational costs.
- Using locally available materials, simple construction techniques, and decentralized treatment systems enhances affordability and scalability, particularly in resource-constrained settings.

Sustainability and community impact

- Constructed soil filters promote environmental sustainability by relying on natural processes for contaminant removal, reducing energy consumption and chemical usage.
- Community engagement and participation in filter design, construction, and operation foster a sense of ownership and empowerment, enhancing sustainability and long-term viability.

Comparison with traditional water treatment methods

- Constructed soil filters were compared favourably with traditional treatment methods regarding effectiveness, cost-effectiveness, sustainability, and community engagement.
- While both approaches have advantages and limitations, constructed soil filters offer unique benefits, including affordability, scalability, and environmental sustainability.

In conclusion, the findings of this study support the effectiveness and feasibility of constructed soil filters for arsenic and iron removal from water sources. Their affordability, sustainability, and community-driven approach make them a promising technology for addressing water quality challenges in arsenic and iron-affected areas. Further research and implementation efforts are needed to optimize filter design, enhance performance, and scale up deployment for widespread adoption and impact on public health and environmental conservation.

Implications for practice

The findings of this study have several implications for practice, particularly in water treatment and public health. These implications highlight the practical applications of constructed soil filters for arsenic and iron removal from water sources and recommendations for their implementation and adoption. The critical repercussions are as follows:

Technology adoption and implementation

Constructed soil filters offer a sustainable and cost-effective arsenic and iron removal solution, particularly in resource-constrained settings. Water treatment authorities, NGOs, and community organizations should consider integrating these filters into their arsenic and iron mitigation strategies.

Capacity-building initiatives and training programs should be conducted to empower local communities with the knowledge and skills required for filter construction, operation, and maintenance. Community involvement and ownership are essential for ensuring the long-term sustainability of filter systems.

Policy and regulation

Policymakers and regulatory agencies should recognize the effectiveness and feasibility of constructed soil filters as an alternative water treatment technology. Regulatory frameworks should be adapted to facilitate the widespread adoption and implementation of these filters, including provisions for funding, incentives, and technical support.

Standards and guidelines for arsenic and iron concentrations in drinking water should be revised to reflect the performance capabilities of constructed soil filters. Collaboration between government agencies, research institutions, and civil society organizations is essential for developing evidence-based policies and regulations.

Research and development

- Further research and development efforts are needed to optimize filter design, enhance performance, and address technological challenges related to constructed soil filters. Research priorities include investigating the influence of soil composition, hydraulic loading rates, and operational parameters on filter efficiency.
- Interdisciplinary collaboration between engineers, environmental scientists, public health experts, and social scientists is essential for advancing the constructed soil filter technology field. Research funding agencies should prioritize investments in innovative water treatment solutions with the potential for real-world impact.

Community engagement and empowerment

- Community engagement should be prioritized throughout the implementation process, from project planning to monitoring and evaluation. Participatory approaches, such as community-led design workshops and water quality monitoring programs, can foster a sense of ownership and responsibility among residents.
- Education and awareness-raising initiatives should be conducted to inform community members about the benefits of constructed soil filters, water quality monitoring and hygiene practices. Behavioural change communication strategies can enhance the uptake and sustained use of filter systems.

Scaling up and replication

- Efforts should be made to scale up the deployment of constructed soil filters in arsenic and iron-affected areas, including rural communities, peri-urban settlements, and industrial zones. Multi-stakeholder partnerships and collaboration are essential for mobilizing resources and expertise to expand filter coverage.

- Lessons learned from successful pilot projects and case studies should be documented and disseminated to facilitate replication and knowledge sharing. Best practices, technical guidelines, and implementation toolkits can support stakeholders in adopting and implementing constructed soil filters in diverse contexts.

Recommendations for future research

Building upon the findings of this study, several recommendations for future research can further advance the field of constructed soil filters for arsenic and iron removal from water sources. These recommendations aim to address knowledge gaps, improve technology performance, and enhance the sustainability of filter systems. The key recommendations are as follows:

Optimization of filter design

Investigate the influence of soil composition, particle size distribution, and organic matter content on the performance of constructed soil filters for arsenic and iron removal. Optimize filter design parameters, such as filter depth, hydraulic loading rate, and flow distribution, to maximize contaminant removal efficiency while minimizing operational costs and maintenance requirements.

Enhancement of contaminant removal mechanisms

Explore innovative approaches to enhance contaminant removal mechanisms in constructed soil filters, such as bioaugmentation with microbial consortia or incorporating nanomaterials for improved adsorption and catalytic oxidation. Investigate the potential synergistic effects of combining soil-based filtration with biological or chemical treatment processes to improve overall treatment performance.

Long-term performance and durability

Conduct longitudinal studies to assess constructed soil filters' long-term performance and durability under real-world operating conditions. Monitor changes in filter media properties, hydraulic conductivity, and contaminant removal efficiency over extended periods to identify potential degradation mechanisms and optimize filter maintenance strategies.

Scale-up and deployment strategies

Explore strategies for scaling up the deployment of constructed soil filters to reach larger populations and expand coverage in arsenic and iron-affected regions. Investigate decentralized treatment approaches, community-based implementation models, and innovative financing mechanisms to overcome barriers to adoption and promote widespread filter deployment.

Integration with water treatment infrastructure

Investigate the integration of constructed soil filters with existing water treatment infrastructure, such as centralized treatment plants or distributed water supply networks. Explore hybrid treatment schemes that combine soil filtration with conventional technologies, such as coagulation-flocculation or membrane filtration, to achieve enhanced contaminant removal and water quality improvement.

Health and environmental impacts

Assess the health and environmental impacts of constructed soil filters on local communities and ecosystems. Conduct epidemiological studies to evaluate the effectiveness of filter systems in reducing arsenic-related health risks and improving overall public health outcomes. Investigate soil-based filtration's potential environmental benefits and risks, including soil nutrient cycling, microbial activity, and ecosystem resilience.

Policy and regulatory frameworks

Evaluate existing policy and regulatory frameworks governing water quality standards, treatment technologies, and water supply systems. Identify opportunities for policy reform and institutional capacity-building to support the adoption and integration of constructed soil filters into national and regional water management strategies. Advocate for including soil-based filtration as a recognized and validated treatment option in regulatory guidelines and standards.

Knowledge sharing and capacity building

Promote knowledge sharing and capacity building among stakeholders, including researchers, practitioners, policymakers, and local communities. Facilitate collaborative research networks, knowledge exchange platforms, and training workshops to disseminate best practices, technical innovations, and lessons learned from field implementations of constructed soil filters.

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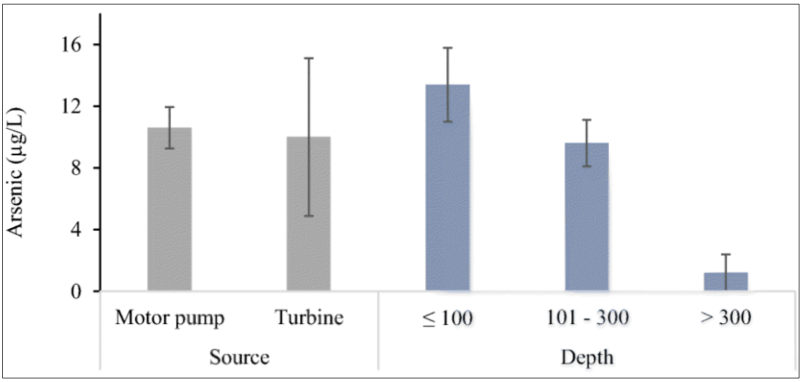
Data collection sheet: Constructed soil filters for arsenic and iron removal



Arsenic Concentration (µg/L)	Iron Concentration (mg/L)	pH	Temperature (°C)
295	107	7.65	315
295	108	7.46	295
296	109	7.38	260
296	109	7.28	215

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Chapter - 9

Evaluation of Laterite Soil's Performance as Liner Material for Ash Pond Sites

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Chapter - 9

Evaluation of Laterite Soil's Performance as Liner Material for Ash Pond Sites

Avishek Adhikary

Abstract

The leachate generated from ash ponds of Thermal Power Plants (TPPs) contains various toxic trace elements such as Zn, Cd and Ni etc., which on migration through sub-surface soil media and accumulation in the aquifers pose serious soil and groundwater pollution. As a result, research has been done to determine whether laterite soil, which will be utilized as the main liner material in the ash ponds, will effectively prevent heavy metals from moving below the surface and save our priceless groundwater from contamination.

Keywords: Ash pond, heavy metals, water pollution, lateritic soil, liner.

Methods

Three separate ash pond locations in and around the city of Durgapur, West Bengal, India, were used to gather the ash samples. Using an Atomic Absorption Spectrophotometer (AAS), the background concentration of heavy metals in ash samples was measured in accordance with the USEPA 3050B procedure. To assess the efficacy of laterite soil as an adsorbent and artificially produced leachate as adsorbate, batch absorption tests were conducted to determine how well the latter removed heavy metals. The pH of the solution was kept between seven and eight. Before AAS analysis, the supernatant was centrifuged and filtered through Whatman no. 41 filter paper. The Bureau of Indian Standards' recommendations [1, 2, 3] were followed in determining the physical parameters of soil and ash samples, as shown in Table 1.

Results

The greatest concentrations of nickel, zinc, and cadmium found in ash samples were 0.37, 0.215, and 0.332 mg/l, respectively. These values are above the BIS: 10500:2012 allowed limits. For cadmium, nickel, and zinc, the laterite soil's heavy metal removal effectiveness was 94%, 97%, and 98%, respectively. Due to its low saturated hydraulic conductivity (ks< 10-7 cm/s) and high metal removal effectiveness, laterite soil is a promising option to use as a liner material in TPP ash ponds [4].

Table 1: Physical properties of soil and ash samples

Parameters	Values
Saturated hydraulic conductivity of soil, k_s	3.17 x10^{-08} cm/s
Average true density of the ash, ρ_{ash}	2.10 gm/cc
Specific gravity of ash, G_{ash}	1.9-2.3
Specific gravity of laterite soil, G_{soil}	2.6

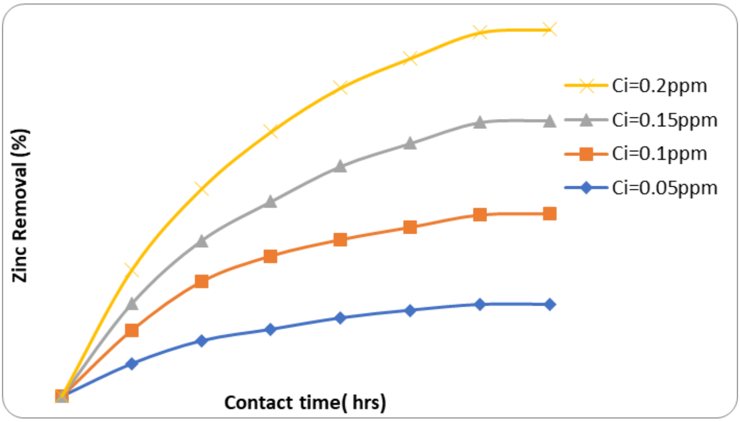

Fig 1: Kinetics for zinc removal

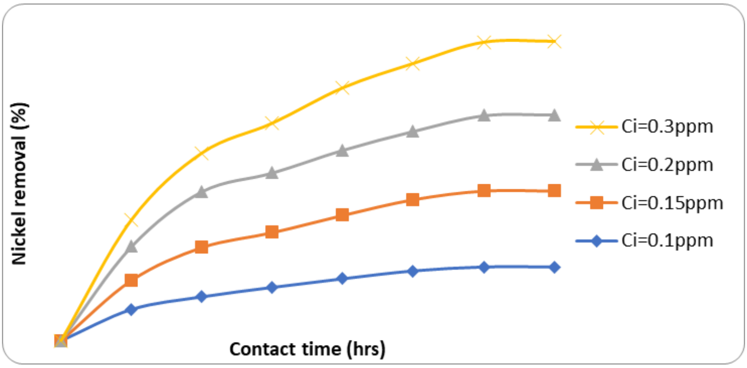

Fig 2: Kinetics for nickel removal

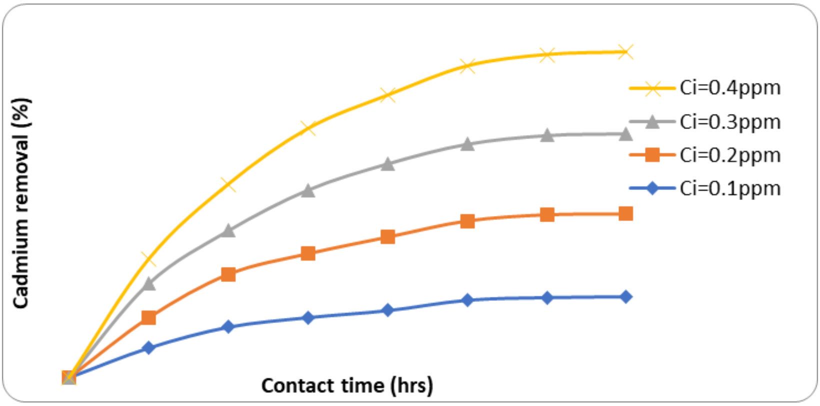

Fig 3: Kinetics for cadmium removal

Initial Zinc concentration varying	Initial Nickel concentration varying	Initial Cadmium concentration
from 0.05-0.2 mg/l.	from 0.1-0.3 mg/l.	varying from 0.1-0.4 mg/l.

#Adosrbent dosages in all the cases were 20 g/L, c_i = Initial adsorbate concentration (mg/l).

Conclusions

The pond ash of TPPs contains toxic heavy metals which are a potential threat to the lithospheric environment due to their migration and accumulation in the aquifers. The laterite soil's relatively increased metal adsorption capacity and extremely low hydraulic conductivity make it a very attractive candidate to be used as liner material in the ash ponds. Further research studies are to be undertaken to examine its shear strength and settlement characteristics to cater the higher ash overburden pressure in the ash ponds.

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Chapter - 10

Soil Stabilization Techniques Using Geopolymer: A Review

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Chapter - 10

Soil Stabilization Techniques Using Geopolymer: A Review

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Abstract

Soil Stabilization is the process of improving the index and Engineering properties of soil to make the structure more stable and durable. Geotextiles are one of the methods used to stabilize the soil and improve the service life of the structures. Geotextiles are geosynthetics manufactured from polymeric materials like polyester, polypropylene, etc., which are used along with soil to improve stability. These are of two types: woven and nonwoven. These have been essential in civil engineering over the last three decades. The project aims to discuss the functions of nonwoven geotextiles and their effect on the soil's shear strength parameters (c&ϕ). These are light in weight and mainly used for filtration to prevent piping drainage to prevent water flow into the subgrade and reduce hydrostatic pressure and separation to avoid the migration of two dissimilar materials in pavements. Its effect on the shear parameters of soil is known by conducting direct shear tests in which geotextiles of shear box sizes are placed on the top and bottom of the soil, and the results are compared with the shear parameters of normal soil.

Keywords: Soil stabilization, pavements, shear strength, geotextiles.

Introduction

Geo Synthetics: Geo Synthetics are the Natural or artificial products used along with soil and rock in geotechnical constructions to solve geotechnical problems. Natural products are coir, jute, hemp, etc.; synthetic products are manufactured from polymers like polyesters, polypropylene, etc., and metallic products. These provide innovative ideas for solving geotechnical problems. Geotextiles, Geogrids, Geomembranes and geonets are some of their types. Geotextiles is a newly emerging field in civil engineering and other fields that offers more significant potential in varied areas globally. Soil can be stabilized by introducing geotextiles made of synthetic materials such as polythene, polyester, nylon, etc. They are manufactured in different thicknesses up to 10mm, available in rolls of lengths up to 600m and width up to 10m. They are economical and more flexible. They are quite permeable, and their permeability is comparable to that of fine sand and core sand. They are not affected even in hostile soil environments and are increasingly used for soil environment, stabilization, and other relative works. These are very porous and allow the flow of liquid along their plane. Their main functions are separation, drainage, and filtration, as well as reinforcement of soil. Geo Textiles improves the structure's safety factor, performance, stability and durability. Geotextiles are generally identified by the type of polymer, type of fibre or yarn, GSM, physical properties and their functions in construction.

Woven geotextiles

These are manufactured by weaving using monofilament, multifilament, and fibrillated yarns. They possess high tensile strength and are mainly used for reinforcement and separation. They are most commonly used along with soil in pavements in application to increase stabilization and improve long-term road use with lower maintenance costs. Nonwoven Geotextiles: Nonwoven geotextiles are produced by needle punching (mechanical bonding), thermal bonding (by heat) and chemical bonding of different types of yarns of various polymers. These are light in weight and able to perform filtration and drainage functions to stabilize soil. These are commonly used in ditches, drains, and around pipes and possess high permeability and transmissivity.

Knitted fabrics

These are manufactured using the process adopted by the textile industry. In this process, the loops of yarns are locked together; all these geotextiles are formed by the knitting technique and perform the same functions as woven geotextiles.

Separators

In roads, as time passes, the number of traffic loads increases. This causes the crushing of sub-base aggregates, and they migrate into the subgrades because the subgrade lacks support. To prevent the disintegration and migration of aggregates, a flexible porous geotextile material is provided between the two dissimilar materials so that the integrity and functioning of both materials remain undisturbed and the service life of the road is improved. Filtration: Geotextiles as filters should retain the particles of base soil to be filtered. It avoids piping., i.e., loss of fine particles from subgrade. It has to allow the free movement of water as it is more permeable.

The shear parameters of soil are greatly affected by the introduction of nonwoven geotextiles. Soil is weak in tension and good in compression. Here, geotextile has good tensile strength compared to soil. When shear stresses develop in soil, the stress is transferred from the soil to the geotextile layer. Later, it deforms and develops internal frictional resistance and controls the deformations and tension in the soil. In this way, the shear parameters like frictional angle and cohesion of the soil increase. Nonwoven geotextiles have good friction but less tensile strength than woven geotextiles. It also acts as an excellent binding material with soil particles, increasing the soil's friction angle and load-bearing capacity.

Laboratory tests on two soil samples with and without geotextiles are conducted, and results are plotted. From the results, it is clear that using nonwoven geotextiles increases the properties of the soil. The effectiveness of the geotextile is known from the pavement model. Nonwoven geotextiles work effectively as the drainage and separation layers.

They act as excellent filters to prevent piping. iv. Nonwoven geotextiles have good friction, though they have less tensile strength. They develop internal frictional résistance and control the deformations and tension in the soil. It also acts as an excellent binding material with soil particles. In this way, the shear parameters like frictional angle and cohesion of the soil increase.

From stress-strain curve behaviour, the curve gradually increases in the case of reinforced soil rather than unreinforced soil, indicating an increase in soil shear strength.

Geotechnical properties of soil improved by sewage sludge ash

Rapid urbanization has resulted in the production of large quantities of sewage sludge worldwide. Disposing of sewage sludge in landfills or open areas is not considered an environmentally friendly solution. Therefore, using sewage sludge as ash can provide a better solution in geotechnical applications.

Keeping this in view, this study investigates the possibility of using sewage sludge ash (SSA) to improve the geotechnical properties of soft clay soil. The sewage sludge ash (SSA) is attained by burning the sludge for 2 h at 900°C. The tests conducted on the clayey soil are specific gravity, standard Proctor test, sieve analysis, Atterberg limits, CBR test and unconfined compression test. Three curing times were used for the untreated soils and soils treated with sewage sludge ash (SSA), which are 3 days, 14 days and 28 days. The sewage sludge ash (SSA) was mixed with the soil at different percentages by weight of the soil at 10%, 15% and 20% of dry soil weight. The results showed that the sludge ash increases the unconfined compressive strength of the soft soil at 3, 14, and 28-day curing times. The bearing capacity of the soil decreased after adding SSA. Still, curing time improved the bearing capacity of clayey soil after adding SSA, and the percentage of SSA of 10% gave the optimum value of CBR. The results indicated a better unconfined shear strength performance was obtained at 28-day curing time. This research suggests that sewage sludge ash (SSA) can be used to improve the soft, clayey soil and further reduce the environmental risks associated with this substantial.

Implications

Rapid urbanization has resulted in the production of large quantities of sewage sludge worldwide. Disposing of sewage sludge in landfills or open areas is not considered an environmentally friendly solution. Therefore, using sewage sludge as ash can provide a better solution in geotechnical applications. Keeping this in view, this study investigates the possibility of using sewage sludge ash (SSA) to improve the geotechnical properties of soft clay soil. In this paper, Sewage Sludge Ash (SSA) is recycled as a new chemical addition to soft clay soil and used as a stabilizer to improve clayey soil. This study proposes that a percent of the total amount of clay to be reinforced is replaced with sewage sludge ash (sewage sludge ash plus soil) to improve the geotechnical properties of clayey soil and use industrial wastes. The sewage sludge ash (SSA) is attained by burning the sludge for 2 h at 900°C. The tests conducted on the clayey soil are specific gravity, standard Proctor test, sieve analysis, Atterberg limits, CBR test, and unconfined compression test. Three curing times were used for the untreated soils and soils treated with sewage sludge ash (SSA), which are 3 days, 14 days, and 28 days. The sludge ash (SSA) was mixed with the soil at different percentages by weight of the soil at 10%, 15%, and 20% of dry soil weight. The results showed that the sludge ash increases the unconfined compression strength of the soft soil at 3, 14, and 28-day curing times. The bearing capacity of the soil decreased after adding SSA. Still, curing time improved the bearing capacity of clayey soil after adding SSA, and the percentage of SSA of 10% gave the optimum value of CBR. The results indicated a better unconfined shear strength performance was obtained at 28-day curing time. This research suggests that sewage sludge ash (SSA) can be used to improve the soft, clayey soil and further reduce the environmental risks associated with this substantial.

An increase in environmental protection and awareness is another driving force pushing researchers in academia and industry to examine sludge treatment thoroughly because sewage sludge ash possesses the property of pozzolan activity. Tay and Show (Citation, 1992) found that the strength activity index of sludge ash varied from 58% to 67%, which is close to a class pozzolanic material. Incinerated (SSA) has a pozzolanic reaction nature and stabilizes soft subgrade soil. The chemical formulae of the pozzolanic reaction are:

$SiO_2C-S-Hgel+Ca(OH)2SiO_2C-S-Hgel+Ca(OH)2(1)$

$Al_2O_3C-A-Hgel+Ca(OH)2Al_2O_3C-A-Hgel+CaOH2(2)$

When mixed with water, Portland cement leads to the beginning of the initial hydration reaction, which in turn leads to a rapid accumulation of calcium in the soil. Then, the clay soil is effectively stabilized as the calcium ions (Ca^{+2}) are released from the mixture. The amount of calcium decreases after 12 h after placing the cement mixture in the soil, leading to a decrease in calcium and water. Eventually, Ca(OH)2 and C-S-H are produced. Therefore, "the calcium in the cement meets the initial needs of the soil" (Prisinski and Bhattacharja Citation, 1999). Monzo *et al.* (Citation, 1999) further proved that sewage sludge ash exhibits pozzolanic activity. They manufactured mortar specimens with part of the cement replaced by sewage sludge ash. They found that the initial strength of the mortar was better, and the compressive and bending strengths improved as the sewage sludge ash (SSA) increased. Thus, part of the cement can be replaced by sludge ash to meet the demands of different engineering applications. Among them, geotechnical engineering applications like soft subgrade soil treatment can quickly require large amounts of sludge. Conventionally, cement or fly ash is used to stabilize soft soil. Lin *et al.* (Citation, 2005) added sewage sludge ash to reinforce the soft, cohesive clayey soil; they found that the untreated A-4 soil was enhanced from mid to low plastic soil, CL (clay), to ML (silt) soil according to the Unified Soil Classification System USCS. They also suggested that incinerated sewage sludge ash (SSA) reduced the swelling behaviour of A-4 soil and enhanced the 95% CBR values, unconfined compressive strength, and A-4 soil triaxial shear strength.

To improve the properties and strength of the soil, Lin *et al*. (Citation, 2007a) recycled (SSA) and hydrated lime to improve soft cohesive, clayey soil; five ratios of sludge ash-hydrated lime were mixed with cohesive soil, the results indicated that the swelling behaviours of the treated clayey soil were effectively decreased and the unconfined compressive strength of the soft clayey soil increased to “three to seven times better than that of untreated soil”. The researchers proposed that sewage sludge ash (SSA)/hydrated lime could particularly improve the geotechnical properties of soft clayey subgrade soil. In addition, Lin, Lin, and Luo (Citation, 2007b) compared the effects of fly ash and sewage sludge ash on their ability to improve soft, cohesive subgrade soil. They observed that both kinds of ash are adequate for stabilizing the geotechnical properties of such soil samples. Although the improvements with fly ash in specific engineering properties were better than sewage sludge ash, they suggested that (SSA) could substitute fly ash to improve weakly cohesive subgrade soil.

Chen and Lin (Citation, 2009) used burned SSA and cement at a 4:1 ratio to stabilize the weakly cohesive subgrade soil. Their results indicated that “the unconfined compressive strength” of treated soil was improved to approximately “three to seven times better than that of the untreated soil”. Moreover, the CBR values of the processed soil were up to “30 times” that of unprocessed soil. They concluded that sewage sludge ash/cement may be helpful for “many potential applications in the field of geotechnical engineering”. Tempest and Pando (Citation, 2013) presented that using SSA as a soil stabilizing substantial, can increase the stiffness and bearing capacity of the soil in contrast with the untreated soil.

Conclusion

Based on the results presented in this study from experiments conducted on soil samples treated with different percents of SSA, the following conclusions can be drawn:

SSA affected soil particles’ gradation, so the soil became coarser than the untreated soil.

The specific gravity of solid particles (Gs) decreased by about 3% when the SSA was increased to 20% by weight of the dry soil sample due to the light weight of the SSA.

The addition of SSA to clayey soil caused a decrease in the plasticity index as SSA increased to 20% by the weight of the dry soil. This result was connected with the SSA reaction in the hydration process, including the bonding and hardening processes. This produced hydration products like calcium aluminate and calcium silicate.

The optimum water content decreased significantly by about 33% with the increase of SSA content to 20% in the clayey soil. The maximum dry density was reduced slightly by about 5% with the same increase in SSA.

The unconfined compressive strength increases with 10% SSA, considered the optimum percent at the first curing time (3 days). Curing time increases the unconfined compressive strength for all SSA contents. The pozzolanic reaction is a time-dependent process, and with increasing curing time, more significant amounts of sewage sludge ash participate in the pozzolanic reactions. The bearing capacity of the soil decreases after adding SSA, CBR values for soils improved with curing time and the CBR values are enhanced by 2 times that of untreated soil at SSA content 10% and curing time 28 days.

Test results obtained from CBR values and unconfined compression tests demonstrated that SSA could efficiently improve the engineering properties of soft, cohesive subgrade soil. The optimum amount of sludge ash was 10% by weight for enhancing the basic properties and strength of soft, cohesive subgrade soil in this study.

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Chapter - 11

Determining the Optimum, Balanced and Permissible Percentage of Sawdust (Biomass) Briquettes Ash (SBA) use as Partial Replacement of Cement

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Chapter - 11

Determining the Optimum, Balanced and Permissible Percentage of Sawdust (Biomass) Briquettes Ash (SBA) use as Partial Replacement of Cement

Sourav Ghosh and Debanjali Adhikary

Abstract

Coal-based Thermal power plants (TPA) are the major contributor to global greenhouse gas. According to the International Energy Agency (IEA), the TPA alone contributes 20% of greenhouse gas emissions globally. In response to that coal-based TPA uses Sawdust briquettes (SB) and other biomass briquettes for co-firing with coal. That significantly impacted the production of Flyash (FA) as TPA is the prime source of FA. So the question arises whether the Sawdust briquette ash (SBA) can be used as an alternative to FA in Portland Pozzolana Cement (PPC). To answer this question, in this study, 0%, 5%, 10%, 15%, 20%, and 25% SDA blended cement is prepared with 53-grade OPC cement. The Standard consistency and comprehensive strength of the 70.6 X 70.6 X 70.6 mm mortar cube at 28 days are tested with the above-blended cement. As per IS 4031-6 (1988) the maximum percentage of the partial replacement of cement is equal to 80% of Compressive strength at 28 days with the corresponding plain OPC cement mortar cubes. The results showed the Optimum, Balanced, and Permissible percentages of SBA use as a partial replacement of cement is 5%, 10%, and 20% respectively.

Keywords: Flyash, greenhouse gas, sawdust briquette ash, optimum, balanced, and permissible percentages.

Introduction

Flyash (FA) is widely used as pozzolana for manufacturing Portland Pozzolana Cement. FA is a by-product of coal-based TPA, generated during the combustion of pulverized coal and then collected from electrostatic precipitators or other particulate control devices. The use of Sawdust and other biomass briquettes for co- firing with coal is mandated by the Ministry of Power through The Revised Policy for Biomass Utilization for Power Generation through Co-firing in Coal-based Power Plants, issued in October 2020, according to the policy, all the coal- fired TPA in India will be co-fired by 5% of biomass briquettes with coal by 2023, and 10% by 2030.

This policy impacted significantly in FA production and led to the Flyash (FA) crisis in India, the Cement Manufacturers Association of India (CMA) also raised its concern that India could face a shortage of fly ash by 2025, in their report published by CMA in 2021. Hence, in this thesis, the potential of SBA for partial replacement of cement is to determine that it can use a pozzolana as an alternative to the FA.

Literature review and research gap

The use of SBA in cement is unattempt to date, thus the literature study is limited to the similar use of biomass ash in cement. In my previous research with Prof. Debanjali Adhikary, A review on the potential of biomass briquettes ash (BBA), used as pozzolan in cement, as an alternative to fly ash (FA), published in the Journal Of Cement And Concrete Research (JCCR), Volume 3, Issue 1, January-June 2024, conclude that the Biomass Briquettes have a similar properties of corresponding Biomass ash and can be used as an alternative to the FA as a pozzolana for cement.

In a study by Gana Abu James, and OwolabiIbukun Daniel, 2018 concludes that a 10% replacement of sawdust ash can be used as a partial replacement for cement in concrete production. However, a 5% replacement of SDA increases the strength of concrete and a 15% replacement reduces the strength of the concrete. Another study by Hardik Dhull, 2017 found similar properties for SDA for the M25 grade of concrete.

Objective

Determine the Optimum Balanced and Permissible percentage of SBA that can be used as pozzolana in cement.

Optimum percentage: the percentage of partial cement replacement that allows the highest compressive strength at 28 days in N/mm2 in cement.

Balance percentage: the percentage of partial replacement of cement that can be used without any deviation of compressive strength at 28 days in N/mm2 with the corresponding plain OPC cement mortar cubes.

Permissible percentage: the highest percentage that can be used as a partial replacement of cement. As per IS 4031-6 (1988) the Compressive strength at 28 days in N/mm2 should not be less than 80% of the corresponding plain OPC cement mortar cubes.

Materials procurement and preparation

Cement

53-grade Ordinary Portland Cement (OPC) was procured from the local RMC manufacturer.

Standard sand

Medium-course sand was procured from the local vendor; it was then washed in running water and then dried in the drying oven for 24 hours. After drying it is sieved as per IS 650: 1991 and prepared a standard sand of >2mm-<1mm 33.3%, >1mm-<500micon 33.3% and >500micron-<90micron 33.3%.

Fig 1: Standard Sand, >2mm-<1mm 33.3%, >1mm- <500micon 33.3% and >500micron-<90micron 33.3%

Sawdust Briquette Ash (SBA)

70-75mm dia. sawdust briquettes are collected from the local vendor and then burn in the commercial smokeless stove at a constant temperature of 500°C to 600°C. The residues are collected after completion of full combustion and then sieved with a 75micron sieve and stored in an airtight container.

Table 1: Chemical composition of Sawdust briquette ash (SBA) by x-ray fluorescence (XRF) testing

Oxide	Percentage (%)
SiO_2	53.30
AI_20_3	13.0
Fe_20_3	4.23
CaO	8.6

MgO	4.3
MnO	0.01
Na2O	0.07
KaO	0.11
P_2O_5	0.45
SO_2	1.45

Fig 2: Sawdust briquettes burn in the commercial smokeless stove at a constant temperature of 500°C to 600°C

Sampling and testing methods

6 numbers samples of blended cement of 5kg each, A1= [100%OPC+0%SBA], A2= [95%OPC+5%SBA], A3= [90%OPC+10%SBA], A4= [85%OPC+15%SBA], A5= [80%OPC+20%SBA], and A6= [75%OPC+25%SBA], are prepared by hand mixing and sieving with 75-micron sieve. Then the standard consistency of each sample is tested with the help of a Vicat apparatus, following IS 4031-4 (1988).

Fig 4: The standard consistency test following IS 4031-4 (1988)

3 numbers of 70.6mm3 mortar cubes are prepared from each blended cement sample and conducted test for compressive test as per IS 4031-6 (1988) at 28 days.

Fig 5: The compressive test as per IS 4031-6 (1988) at 28 days

Results and discussion

Table 2: Standard consistency test

Standard Consistency						
Sr. No.	**Cement**	**SBA**	**Water**	**Penestration**	**Consis tency**	**Avg Consistency**
	g	**g**	**g**			
1.1	300	0	84	5 mm	28.00%	28%
1.2	300	0	85	7 mm	28.33%	
1.3	300	0	87	10 mm		
2.1	285	15	86	7 mm	28.67%	29%
2.2	285	15	87	6 mm	29.00%	
2.3	285	15	88	6 mm	29.33%	
3.1	270	30	89	7 mm	29.67%	30%
3.2	270	30	90	6 mm	30.00%	
3.3	270	30	91	6 mm	30.33%	
4.1	255	45	92	6 mm	30.67%	31%
4.2	255	45	93	6 mm	31.00%	
4.3	255	45	94	5 mm	31.33%	
5.1	240	60	95	6 mm	31.67%	32%
5.2	240	60	96	5 mm	32.00%	
5.3	240	60	97	5 mm	32.33%	
6.1	225	75	98	5 mm	32.67%	33%
6.2	225	75	99	2 mm		
6.3	225	75	100	0 mm		

Table 3: Compressive strength test at 28 days

Compressive Strength Test															
S. No	**Particulars**						**Consistency**	**Water**		**Cube Size**			**M/C reading**	**28days Comp. Strength**	**28days Avg. Comp. Strength**
		Cement		**SBA**		**Sand**	**P**	**(P/4)+3**		**L**	**W**	**Area**			
		%	**g**	**%**	**g**	**g**	**%**	**%**	**g**	**mm**	**mm**	**mm^2**	**KN**	**MPa**	**MPa**
1.1	SB A 0%	100	200	0	0	600	28	10	80	68	69	4692	165	35.17	35.53
1.2		100	200	0	0	600	28	10	80	69	69	4761	165	34.66	
1.3		100	200	0	0	600	28	10	80	69	67	4623	170	36.77	
2.1	SB	95	190	5	10	600	29	10.3	82	69	70	4830	175	36.23	36.77

2.2	A 5%	95	190	5	10	600	29	10.3	82	68	67	4556	170	37.31	
2.3		95	190	5	10	600	29	10.3	82	67	67	4489	165	36.76	
3.1	SBA 10%	90	180	10	20	600	30	10.5	84	67	68	4556	160	35.12	35.34
3.2		90	180	10	20	600	30	10.5	84	69	68	4692	170	36.23	
3.3		90	180	10	20	600	30	10.5	84	68	70	4760	165	34.66	
4.1	SBA 15%	85	170	15	30	600	31	10.8	86	67	68	4556	155	34.02	33.33
4.2		85	170	15	30	600	31	10.8	86	68	68	4624	150	32.44	
4.3		85	170	15	30	600	31	10.8	86	68	68	4624	155	33.52	
5.1	SBA 20%	80	160	20	40	600	32	11	88	67	68	4556	130	28.53	29.49
5.2		80	160	20	40	600	32	11	88	70	67	4690	140	29.85	
5.3		80	160	20	40	600	32	11	88	67	67	4489	135	30.07	
6.1	SBA 25%	75	150	25	50	600	33	11.3	90	67	67	4489	120	26.73	25.82
6.2		75	150	25	50	600	33	11.3	90	69	79	4830	120	25.20	
6.3		75	150	25	50	600	33	11.3	90	70	70	4900	125	25.51	

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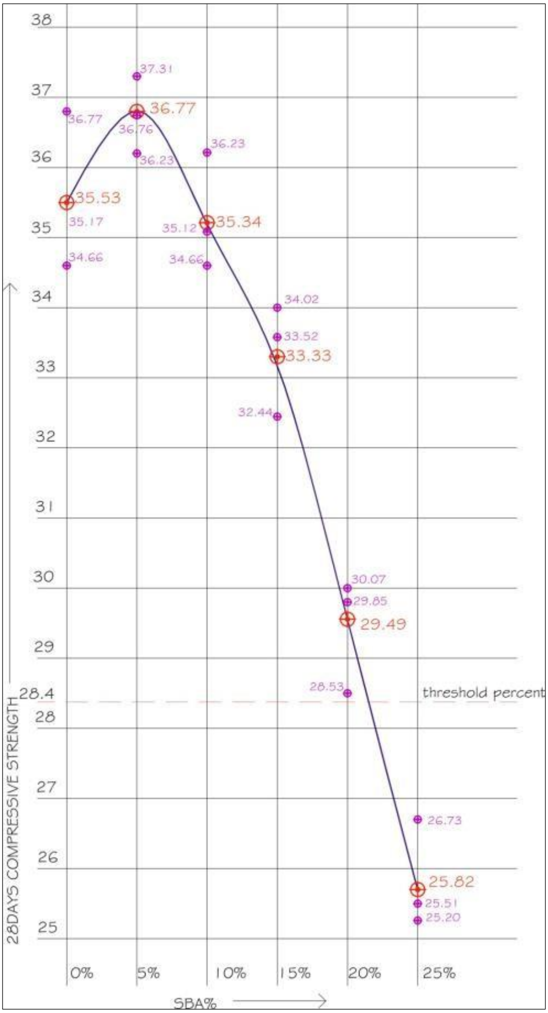

Fig 6: Compressive strength test at 28 days

The SBA has the potential to be used as a pozzolana as an alternative of Flyash for cement.

The Optimum, Balanced, and Permissible percentages of SBA used as a partial replacement of cement are 5%, 10%, and 20% respectively.

So, SBA can be used up to 20% as a partial replacement for cement.

Due to the hydrophobic nature of SBA, the water demand is also increased proportionally.

Conclusion

From the above test results, the key findings are as follows,

The standard consistency is increased with the increase of SBA percentage in cement, but the consistency will decrease beyond the use of 30% SBA in cement, due to dilution of cementing properties.

The results showed that 5% SBA blended cement has the highest compressive strength at 28 days, around 105 to 107% compressive strength of the corresponding plain OPC cement mortar cubes. Whereas 10% SBA blended cement has a similar value of compressive strength at 28 days and 20% SBA blended cement has 80 to 85% compressive strength at 28 days of the corresponding plain OPC cement mortar cubes.

So it can be concluded that the Optimum, Balanced, and Permissible percentages of SBA used as a partial replacement of cement are 5%, 10%, and 20% respectively.

Recommendations for further studies

Other physical properties of SBA blended cement and its respective impact on concrete need to determine.

The potential of Partial replacement of cement with other biomass briquette ash needs to be analyzed further.

The economic viability of SBA blended cement with Flyash cement needs to be done.

Acknowledgement

I am gratefully and acknowledge Prof. Debanjali Adhikary and The Dept. of Civil Engineering, Swami Vivekananda University, Barrackpore for their cooperation in the research.

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Chapter - 12

Analysis and Design of a G+5 Storied R.C.C. Framed Vertically Irregular Structure with Infill Wall (Brick Wall) & Shear Wall (Lift Wall)

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Chapter - 12

Analysis and Design of a G+5 Storied R.C.C. Framed Vertically Irregular Structure with Infill Wall (Brick Wall) & Shear Wall (Lift Wall)

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Abstract

Designing of a structure to reduce damage during an earthquake makes the structures quite uneconomical. This is because of earthquake might or might not occur in its life time, it is a rare phenomenon. Shear wall is the best way to control deflection during earthquake. Lifts are the mandatory to be used in multi-storey building which are frequently used as core type shear walls. Infill walls are also to be used for exterior as well as interior walls. Response spectrum analysis is used to evaluate the seismic capacity of a structure. The present literature focuses on models with effects of shear walls (Lift) and infill walls (Brick wall) with vertical irregular R.C.C. frame structure. In this paper a proposed G+5 storied R.C.C. framed structure with vertical irregularities has been analysed and designed using ETABS 21. The building is designed as per IS:1893 (Part-I) 2016 for earthquake forces.

Keywords: ETABS 21, R.C.C. frame, vertically irregular, shear wall (lift wall), infill wall (brick wall), earth quake, response spectrum, deflection, shear, bending.

Introduction

Shear walls are structurally designed R.C. members. These are incorporated in R.C. frame structures to increase the lateral stiffness against ground motion to resist lateral forces. These are placed vertically from the base of foundation and will resist earthquake forces as well as wind force. These walls increase the strength of the structure and also resist the loads due to cantilever action. R.C. lift wall in multistorey building is also a shear wall.

Infill walls

These are non-load bearing structural members. There are several types of infill walls-

a) Masonry infill walls
b) Concrete infill walls
c) Timber framed infill walls

Masonry infill walls constructed from clay bricks. These are the traditional form of infill walls. Concrete infill walls are generally in the form of large precast concrete Pannel. Timber infill walls are timber section of 90 and 140 mm. This type of walls is not used with large openings.

Seismic analysis

Seismic analysis is to assess the behaviour of a structure when subjected to dynamic load. Different type of seismic analysis-

1. Equivalent static analysis which is linear static
2. Response spectrum analysis which is linear dynamic.
3. Pushover analysis which is non-linear static
4. Time history analysis which is non-linear dynamic.

Equivalent static method

The Equivalent Static Method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes.

1. Applicable to simple and regular structure, SDOF.
2. It assumes that building responds to its fundamental mode.
3. The building be can from low rise or medium rise, must not twist significantly when ground moves.
4. As per IS 1893 (Part I): 2016, ESM can be used for analysis for regular structures with Natural time period Ta less than 0.4 sec.
5. Building height less than 15 m. in seismic Zone IV.

Response spectrum analysis

The Response Spectrum Analysis is used to evaluate the dynamic effect of ground motions. In this method the base shear is calculated based on the time period, mass participation of the structure. As an engineer, we need to check the base shear for static seismic as well as for dynamic seismic loads.

- Applicable to unusual building configuration, MDOF.

- It considers mode shapes and model mass participation of the structure for different building frequencies.
- RSM will be performed by using design acceleration spectrum or site specific design acceleration spectrum.
- Other than regular building, height less than 15 m. seismic Zone IV.
- Other than regular building, height more than 15 m. in all seismic Zones.

Vertical irregularities

There are mainly major two types of irregularities in the structure these are as follows

- Vertical Irregularities
- Plan Irregularities

Structure irregularity indicates a lack of symmetry that implies vital eccentricity between the structure's mass and stiffness centres that causes a negative coupled lateral response. Significant engineering and designer effort is required to effectively design and analyses an irregular structure. The event of an earthquake, an additional, meticulous structural analysis is required to improve the dynamic response of irregular structures. During earthquakes, vertical irregularities of a structure are one of the leading causes of structural failure. The effect of vertical irregularities on the seismic performance of structures becomes crucial. As per IS: 1893 (part-1) definition of vertically irregular structures, the irregularity in a structure is caused by irregular distribution of mass, strength, and stiffness along the structure's height.

Literature review

Dr. B. Kameshwari *et al*. analysed the influence of drift and inter storey drift of the structure on various configuration of shear wall panels on high rise structures. The bare frame was compared with various configurations like i) Conventional shear wall ii) Alternate arrangement of shear wall iii) Diagonal arrangement of shear wall iv) Zig Zag arrangement of shear wall v) Influence of lift core shear wall. From the study it was found that Zig Zag shear wall enhanced the strength and stiffness of structure compared to other types. In earthquake prone areas diagonal shear wall was found to be effective for structures.

Nanjma Nainan *et al*. conducted analytical study on dynamic response of seismic resistant building frames. The effects of change in height of shear wall on storey displacement in the dynamic response of building frames were obtained.

From the study it was concluded that it is sufficient to raise the shear wall up to mid height of building frames instead of raising up to entire height of the building.

Shahzad Jamil Sardar *et al*. modelled a 25 storey building zone V and analysed by changing the location of shear wall to determine various parameters like storey drift, storey shear and displacement using ETABS. Both static and dynamic analysis was done to determine and compare the base shear. Compared to other models, when shear wall placed at centre and four shear walls placed at outer edge parallel to X and Y direction model showed lesser displacement and inter storey drift with maximum base shear in addition strength and stiffness of the structure has been increased.

Varsha. R. Harne considered a six storey RCC building which is subjected to earthquake loading in zone II to determine the strength of R.C. wall by changing the location of shear wall using STAAD. Pro. Seismic coefficient method is used to calculate the earthquake load as per IS 1893(Part I): 2002. Four different models like structure without shear wall, structure with L type shear wall, structure with shear wall along periphery, structure with cross type shear wall were modelled for analysis. Compared to other models the shear force and bending moment, for structure with shear wall along the periphery is found to be maximum at the ground level and roof level respectively. Hence the shear wall provided along the periphery of the structure is found to be more efficient than all other types of shear wall.

Anuj Chandiwala studied a 10 storey R.C. building located in seismic zone III which is on medium soil. The different building configurations were i) Shear wall at end of L section ii) L Shear wall at junction of 2 flange portion iii) Two parallel L shear wall at junction of 2 flange portion iv) Tube type shear wall at junction of 2 flange portion v) Two parallel shear wall at end of flange portion. From the analysis, it was observed that compared to other models shear wall placed at end of L section is best suited for base shear since end portion of the flange always oscillate more during earthquake.

Shahabodin Zaregarizi conducted comparative investigation on using shear wall and infill to improve seismic performance of existing buildings. Static nonlinear analysis was done to compare the effectiveness of both methods. From the results, it was observed that concrete infills have considerable strength while brick one showed lower strength. On the contrary, brick infills accepted large displacement experimental results. To evaluate the performance of "Dual systems" which is designed as per Indian code, these models were implemented. It has been noted that buildings with shear walls placed at periphery showed excellent performance than buildings with centrally placed shear wall core.

Valmundsson and Nauhave (1997), studied the seismic behaviour of multi-storeyed buildings having vertical structural irregularities and concluded that 30% decrease in stiffness have increased the storey drift in the range of 20-40%.

Pradeep and Jacob (2014) studied the seismic behaviour of reinforced concrete framed structures with varying height of column within one storey. The results shows that the short column in the ground storey fails very easily on a sloping terrain. Shear cracks also found on the beam column joint of short column. Due to higher ductility in the long column, it attracts lesser lateral force which results the more stable to the long column.

Rana and Raheen (2015), has shown the performance, behaviour of regular and vertical geometric irregular RCC framed structure under seismic motion. It is concluded that as the amount of setback increases the shear force also increases. The fluctuation of critical shear force from regular to vertical geometric irregular is very high

Imranullahkhan and Roa (2017), the main intension of this study is to understand irregularity and to analyse L-shape building under earthquake forces. Story drift response along the height of the building shows that the middle stories are more affected than Lower and upper stories. Displacements gradually increase from ground storey to top storey.

Ozmen *et al*. (2014), performed parametric studies on six buildings with varying shear wall positions. Based on the floor rotations, a torsional irregularity coefficient was proposed. According to their findings, as the number of storey decreases, the torsional irregularity coefficient increases and the maximum storey rotations occur for the top storeys.

Momen *et al*. (2016), have studied the effect of seismic response of L shaped buildings. Equivalent static and response spectrum methods were performed using ETABS software. They observed that the response of L shaped building is higher than that of the regular frame due to torsion.

Dhananjay (2017), analysed G+25 storey rectangular shape, L shape and I shape building using STADD pro software in zone III and zone IV for hard and medium soils. It was found out that L shape had less maximum bending moment and maximum displacement in z direction.

Naik and Shetty (2019), this research paper involves the modelling and analysis of G+10 storied building of Rectangular shape, L shape snd C shape structure using ETABS 2016. The L shape structure and C shape structure has less shear force carrying capacity. The storey overturning moment is also more in rectangular shape which indicates that more moment is required to overturn the storey.

Naveen *et al*. (2019), the present study addresses the seismic response of RC structures possessing various combinations of irregularities. It is observed that irregularity considerably affects the seismic response. Out of various types of single irregularities analysed, stiffness irregularity is found to have maximum influence on the among the cases having combinations of irregularities, the configuration with mass, stiffness and vertical geometric irregularities has shown maximum response.

Arvind and Fernandes (2015), worked on reinforced regular and reinforced irregular structures in zone IV and zone V. The results found out from the analysis included lesser storey displacement values in static analysis method as compared to dynamic analysis method.

Bahador *et al*. (2012), studied Multi-storey irregular buildings with 20 stories have been modelled using software packages ETABS and SAP 2000 v.15 for seismic zone V in India. Time history analysis is an elegant tool to visualize the performance level of building and static analysis is not sufficient for high rise building. The result of equivalent static analysis are uneconomical because values of displacement are higher than dynamic analysis.

Jaimin Dodiya *et al*. (2018) investigated the study of multi-story buildings employing shear walls at various points throughout the structure. Three models have been created, and it has been demonstrated that when shear walls are situated in the opposite directions of the structure, displacement is minimised.

Research gap

After studying several journals, research papers, eBooks finally I have found a research gap i.e. Behaviour due to combined effect of Lift as shear wall and Brick wall as infill wall in a R.C.C. framed G+5 storied vertical irregular structure.

Objective

The objectives of the study are:

- Structural analysis of a G+5 storied R.C.C. vertical irregular framed structure with Lift as a shear wall brick wall as a infill wall using ETABS 21 and determine lateral displacement and storey drift.
- Study of behaviour of structure (Moment, Shear and Axial) with Lift shear wall and Brick infill wall.
- Study of optimum location of lift shear wall for G+5 storied R.C.C. vertical irregular framed structure keeping other parameters same.

Methodology

Description of project

The project consists of Ground floor and five upper floors i.e. G+5 storied Residential building. In this structural analysis and design, I have adopted one vertically irregular R.C.C. frame structure with a lift as shear wall. The structure also includes brick wall as infill wall.

The research on the building in earthquake prone area Zone - IV was selected as the subdomain. Combined effect of shear wall and infill walls were taken in the topic that needed further investigation subjected to earthquake loads using the equivalent-static and response spectrum analysis. Displacements occurring in the structure have been for the equivalent-static and response-spectrum load cases according to the code IS-1893: 2016.

RCC framed structures are assemble of slabs, beams, columns and foundation inter-connected to each other as a unit. The load transfer mechanism in these structures is from slabs to beams, from beams to columns, and then ultimately from columns to the foundations which transfer loads to the soil.

Detail of structure

- G+5 Storey
- Rectangular different shape floor plans
- Vertically Irregular R.C. frame

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- Shear walls (Lift wall)
- Infill walls (Brick wall)

Architectural floor plan

Architectural floor plans are drawn by using latest version of AutoCAD software. The floor plans are shown below: Fig. 02, Fig.. 03, Fig. 04 & Fig. 05

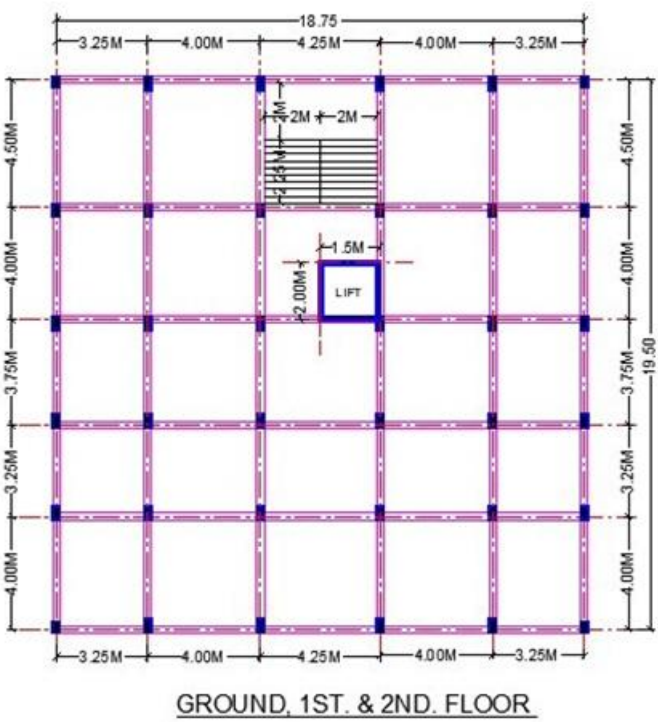

Fig 2: Ground 1st and 2nd floor

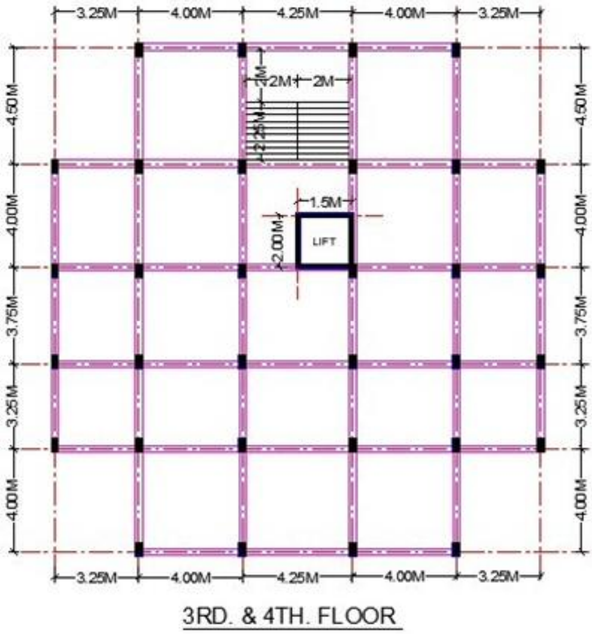

Fig 3: 3rd and 4th floor drawing

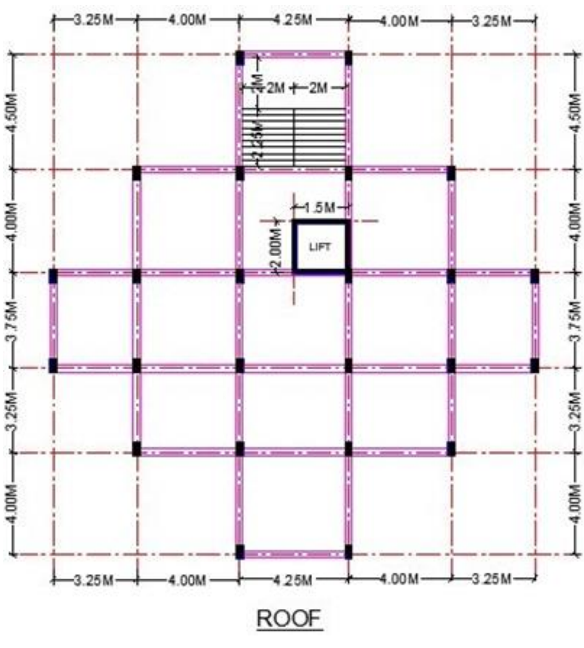

Fig 4: Roof plan

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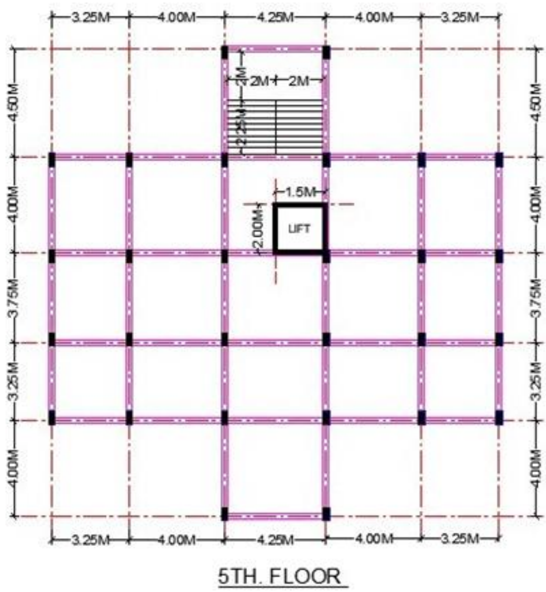

Fig 5: Fifth floor plan

General features of the model

General features of the Model are tabulated below:

Table 1: General features

• Types of the building:	Residential
• Location:	Zone - IV
• System of structure:	R.C.C. frame (SMRF)
• No. of Storey:	G+5
• Building height:	24.95 M.
• Plinth height:	0.6 m.
• Floor to floor height:	3.2 M.
• Foundation depth:	1.5 M.
• Slab:	0.125 M. thick two way
• Column:	0.3 X 0.5 M & 0.3 X 0.4 M.
• Beam:	0.3 X 0.45 M.
• Method of Analysis:	Equivalent static & Response spectrum
by ETABS 21	
0200	

Loads used in the model

Loads used in the Model are tabulated below

Table 3: Loads used

• Self-weight of the Structure: • Live Load on Floor • Live Load on Roof • DL of Brick wall load (Outside): • DL of Brick wall load (Inside): • DL of Parapet Wall: • DL of Floor Slab: • DL of Roof Slab: • Earthquake Load:	As per software ETABS3 KN/M^2 1.5 KN/M^2 13.5 KN/M 7.5 KN/M 3.0 KN/M 6.0 KN/M 5.65 KN/M As per IS 1893:2016 (Part I)

Soil parameters used in the model

Soil parameters used in the model are tabulated below

Table 4: Soil parameters

• Seismic Zone: • Seismic Zone Factor:		IV 0.24
• Importance Factor:		1
• Soil Type:		Soft Soil (III)
• Response Reduction Factor(SMRF):		5
• Function Damping Ratio:	0.05	

Analysis method used in the model

- Equivalent lateral force (static) method
- Response spectrum (dynamic) method

Basic process using ETABS

The following provides a broad overview of the basic modelling, analysis, design, and detailing processes:

- Select the base units and design codes
- Set up grid lines

ISBN:

- Define story levels
- Define section properties
- Draw structural objects
- Select objects
- Assign properties
- Define load patterns
- Assign loads
- Define load cases
- Edit the model geometry
- View the model
- Analyse the model
- Display results for checking
- Design the model
- Generate detail documents
- Output results and reports
- Save the model

Creating model in ETABS

Five floors are taken into consideration for carrying out the analysis of the model.

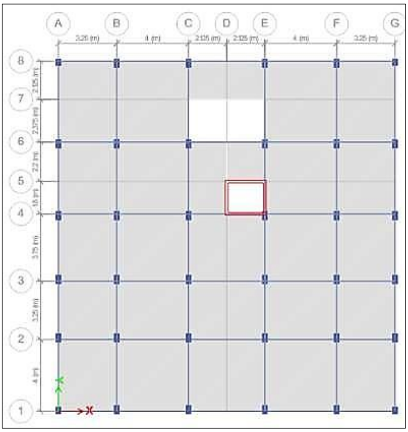

Fig 6: 1st. & 2nd.floor

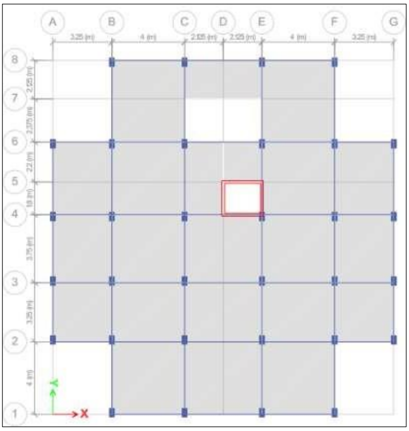

Fig 7: 3rd. floor

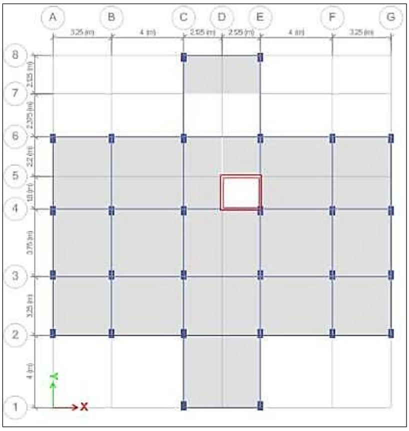

Fig 8: 4th floor

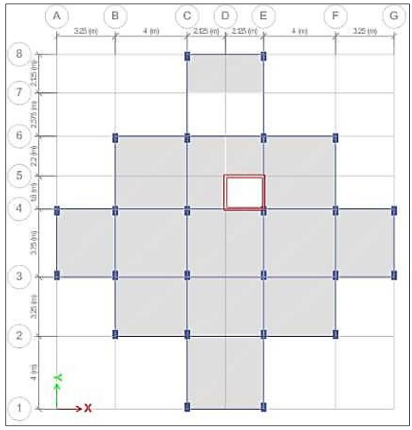

Fig 9: Roof

Fig. 06 shows the grid plan of the 1st. & 2nd. floor with column, beam and slab. Fig. 07 shows the grid plan of the 3rd & 4th. floor. with column, beam and slab. Fig. 08 shows the grid plan of the 5th. floor with column, beam and slab and Fig. 09 shows the grid plan of the roof with column, beam and slab..

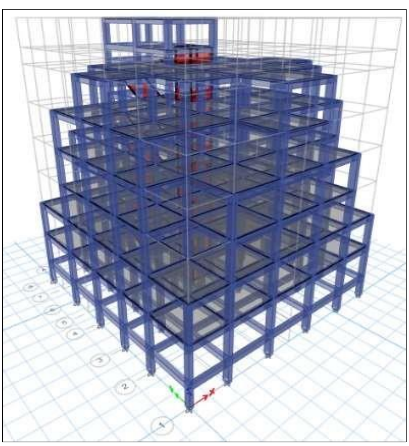

Fig 10: 3D view of the model

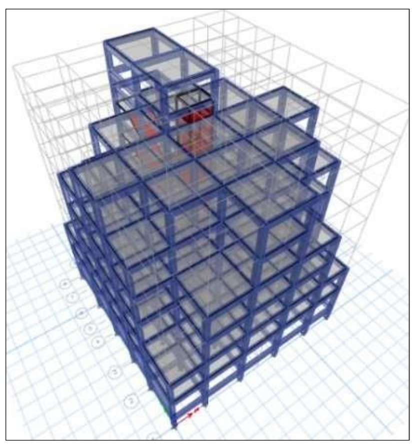

Fig 11: 3D view of model from top

The following considerations and characteristics are assumed to model the study building in ETABS21.

- Column and beam elements are modelled as frame elements. The concrete floor and lift wall are modelled as thin shell elements.

ISBN:

- Infill walls i.e. Brick walls DL are taken into the outside and inside beam where required.
- All R.C. frame joints are assumed to be rigid.
- All floor loads are applied to the slab which distributes uniformly the load to the beams.

After the modelling of the structure, the model is checked using the feature in ETABS 21. The building is analysed for the load cases mentioned along with default load combinations given by IS 1893: 2016 in ETABS21.

In the present study, the results due to individual equivalent linear static and Response Spectrum load cases are considered for comparison are

- Equivalent Linear Static Load Case in X direction (EQX)
- Equivalent Linear Static Load Case in Y direction (EQY)
- Response Spectrum Load Case in X direction (RSX)
- Response Spectrum Load Case in Y direction (RSY)

Analysis and design

Storey displacement

The study examines the performance of combined shear wall and infill walls in vertically irregular R.C. framed building and results organized in various figures are discussed in detail.

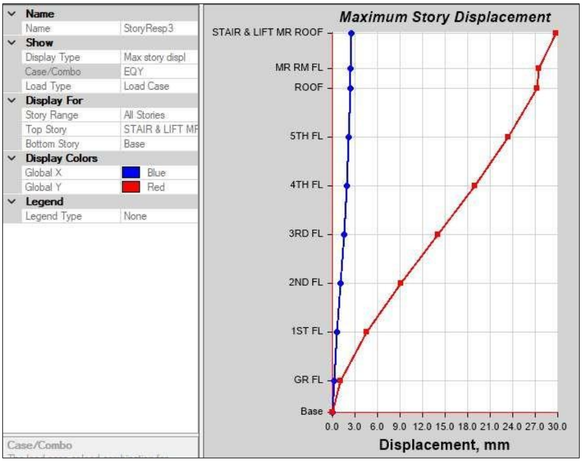

Fig 12: Max. storey displacement due to EQX

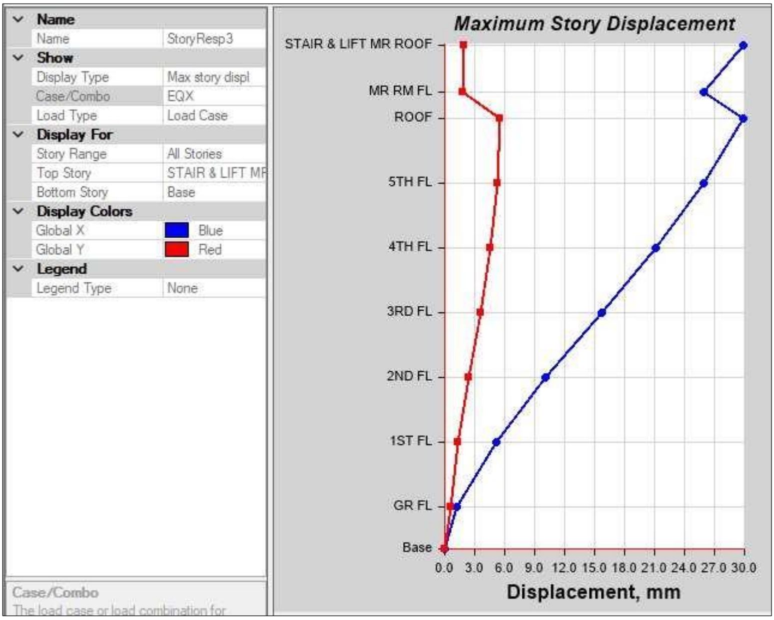

Fig 13: Max. storey displacement due to EQY

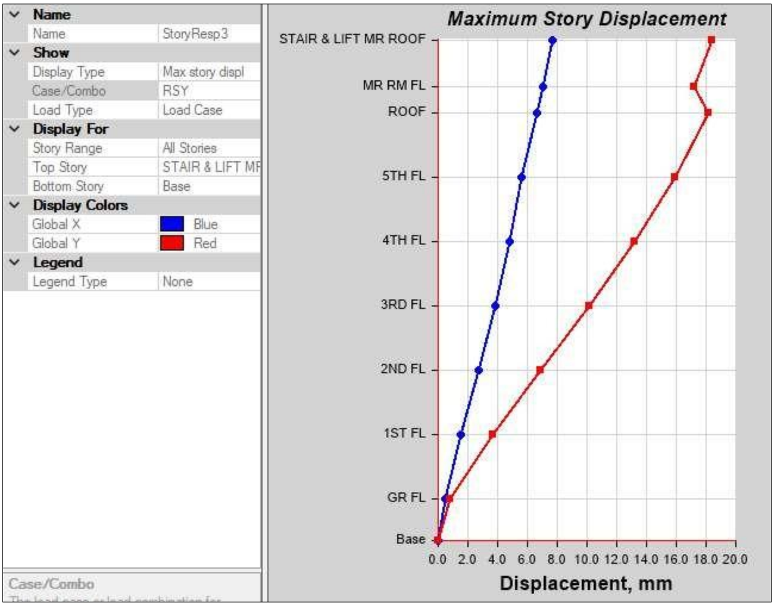

Fig 14: Max. storey displacement due to RSX

Fig. 15: Max. storey displacement due to RSY

From Fig. 12 and Fig. 13 it can be seen that there are almost same max. top storey displacement in X direction due to EQX and in Y direction due to EQY.

Fig. 14 shows the max. top storey displacement in X direction due to RSX is 15.2 mm but at roof is 22.5 mm. Fig. 15 shows the max. top storey displacement in Y direction due to RSY is 18.5 mm but at roof is 18.0 mm.

Storey drift

The study examines the performance of combined shear wall and infill walls in vertically irregular R.C. framed building and results organized in various figures are discussed in detail.

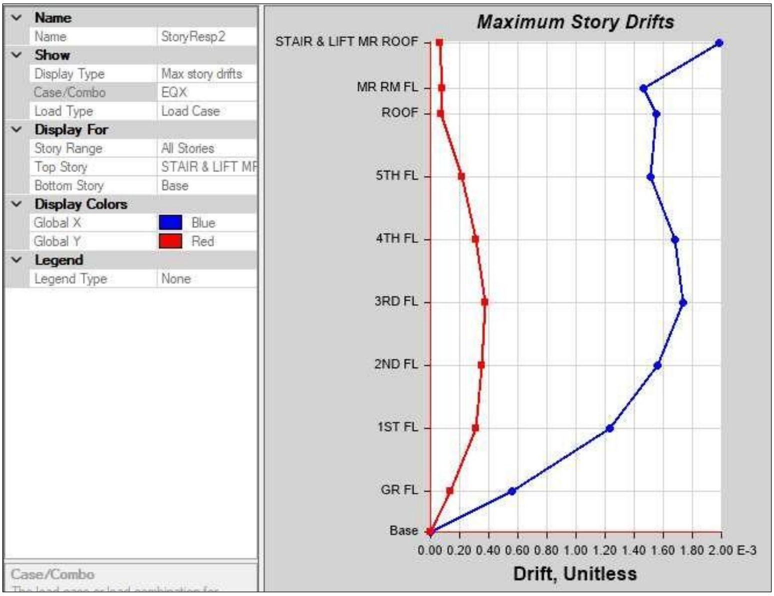

Fig 16: Max. Sorey drift due to EQX

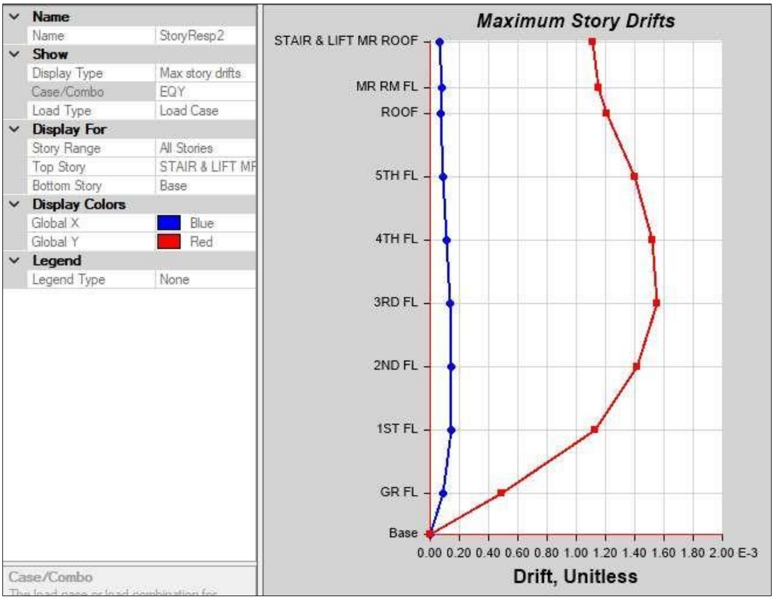

Fig 17: Max. Sorey drift due to EQY

Fig 18: Max. Sorey drift due to RSX

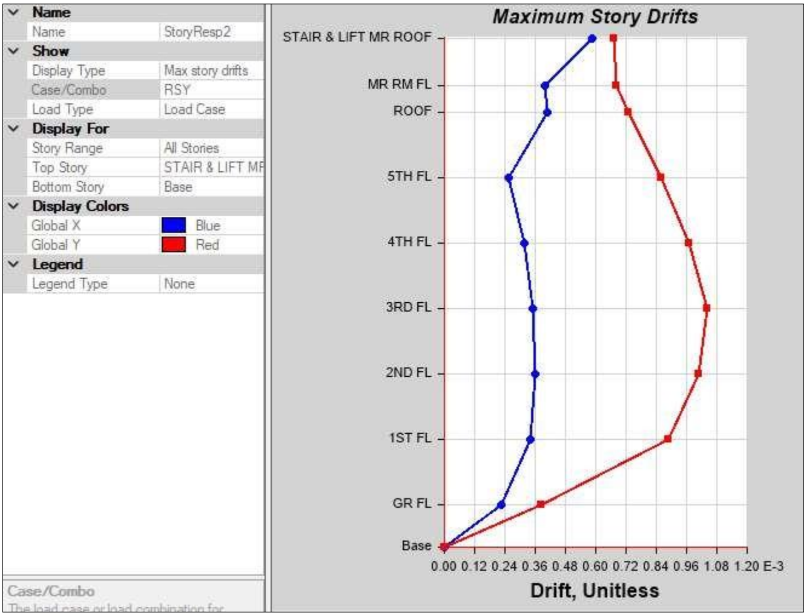

Fig 19: Max. Sorey drift due to RSY

Fig. 16 shows max. storey drift due to EQX is .002 and Fig. 17 shows max. storey drift due to EQY is .0015 but Fig. 18 shows max. storey drift due to RSX is 0.0013 and Fig. 19 shows max. storey drift is 0.001 due to RSY. The max. storey drift limit according to IS 1893: 2016 is 0.004. The value of max. storey drifts are within limit and controlled due to shear wall (Lift wall) present in the model. Without lift this value can be crossed the limit.

Conclusion

- Plan irregularities with structure quite often suffer damage in earthquake.
- Behaviour of a framed R.C.C. structure during earthquake depend upon stiffness, ductility, strength and configuration of structure.
- Structure irregularities causes eccentricity between mass and stiffness centres, give rise to damaging effect on structure.
- Using shear wall in the Structure we can overcome the storey drift.
- Structure should be designed considering the seismic loads. To overcome this situation the seismic behaviour of structure should be improved.
- Generally, Response spectrum analysis method is used for analysis and design of earthquake resistance structure.

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Chapter - 13

Implementation of Sugarcane Bagasse Ash in Self-Compacting Concrete for Improved Sustainability and Performance

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Chapter - 13

Implementation of Sugarcane Bagasse Ash in Self-Compacting Concrete for Improved Sustainability and Performance

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Abstract

In order to improve sustainability and performance, this research examines the viability and advantages of adding Sugarcane Bagasse Ash (SCBA) to Self-Compacting Concrete (SCC). Portland cement production has a high carbon footprint, which presents substantial environmental issues for the construction industry. Due to its great flowability and little need for mechanical compaction, SCC offers a chance to increase the effectiveness and caliber of construction. In order to lessen the impact on the environment while preserving or enhancing the qualities of concrete, this study proposes to incorporate SCBA, an agricultural waste product high in pozzolanic properties, as a partial replacement for cement.

A range of experimental trials were carried out to assess the mechanical characteristics and feasibility of SCC with different proportions of SCBA. SCBA content ranged from 0% to 35% by weight of cement in the mix formulation. Compressive strength, split tensile strength, flexural strength, slump test, and compaction factor test were among the tests carried out. According to the study, adding SCBA improves the compressive, tensile, and flexural strengths of SCC; 15% SCBA concentration is associated with the best results. The strength gains start to plateau after this percentage, indicating the ideal range for using SCBA.

SCBA can improve the circular economy by repurposing agricultural waste, which reduces carbon emissions and resource consumption. This is emphasized in the environmental evaluation. The findings demonstrate the feasibility of employing SCBA as an extra cementitious ingredient to enhance ecologically friendly building approaches while maintaining concrete performance. Long-term durability studies, field applications, and

economic assessments are the next research topics for validating and optimizing the use of SCBA in SCC. This research contributes to international efforts to reduce the environmental impact of infrastructure development while also advancing sustainable construction materials.

Introduction

Although concrete is the most commonly used building material in the world, the enormous carbon emissions and resource consumption connected with its manufacture have significant negative effects on the environment. Self-Compacting Concrete (SCC) is a revolutionary concrete type that fills formwork without the need for mechanical vibration, improving the quality and efficiency of construction. The concrete flows under its own weight. The sustainability of SCC can be further increased by using agricultural waste by-products like Sugarcane Bagasse Ash (SCBA) as supplemental cementitious materials (SCMs). SCBA, a by-product of the sugar industry, has pozzolanic qualities that can improve concrete's performance and is high in silica. The objective of this research is to assess how SCBA affects the mechanical characteristics and feasibility of SCC, hence advancing sustainable building methods.

Materials and methods

- **Cement:** Ordinary Portland Cement (OPC) was utilized as the primary binder in the concrete mix. OPC is known for its reliable performance and adherence to standard specifications, ensuring consistency in the mechanical properties of the concrete.
- **Sugarcane Bagasse Ash (SCBA):** SCBA, an agricultural by-product, was collected from local sugar mills. The SBA was subjected to drying, grinding, and sieving processes to achieve a fine powder with high pozzolanic activity. The ash is rich in silica, which contributes to its potential as a supplementary cementitious material.
- **Fine aggregates:** Natural river sand was used as the fine aggregate, conforming to relevant standards to ensure appropriate gradation and cleanliness.
- **Coarse aggregates:** Crushed granite stones were employed as the coarse aggregate, selected for their angular shape and strength properties.
- **Admixtures:** Superplasticizers were incorporated to enhance the workability of the SCC. These high-range water-reducing

admixtures help in achieving the desired flowability and consistency without compromising the strength of the concrete.

- **Water:** Potable water, free from impurities, was used for mixing and curing purposes. The water-to-cement ratio was kept constant across all mixes to ensure comparability of results.

Several SCC mixes were prepared with varying percentages of SCBA (0%, 5%, 10%, 15%, 20%, 25%, 30%, and 35%) as a partial replacement for cement. The water-to-cement ratio was kept constant, and superplasticizers were added to achieve the required flowability.

- **Compressive strength:** The compressive strength of SCC mixes was tested at 7 and 28 days. Standard cubic specimens (150mm x 150mm x 150mm) were prepared and cured in water until the testing age. The specimens were then subjected to a compression testing machine, and the maximum load applied until failure was recorded.
- **Split tensile strength:** Cylindrical specimens (150mm diameter and 300mm height) were used to determine the split tensile strength at 7 and 28 days. The specimens were placed horizontally between the compression testing machine's platens and loaded along the vertical diameter until failure.
- **Flexural strength:** Beam specimens (100mm x 100mm x 500mm) were prepared and tested for flexural strength at 7 and 28 days using a three-point bending test. The beams were placed on two supports and loaded at the midpoint until failure.
- **Slump test:** The slump test was performed to assess the workability of the fresh SCC. A slump cone was filled with concrete, lifted vertically, and the decrease in height of the concrete was measured.
- **Compaction factor test:** This test measured the degree of compaction achieved by SCC. The concrete was allowed to fall freely into a standard mold, and the compaction factor was calculated as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete.

Results and discussion

The inclusion of SCBA improved the compressive strength of SCC, with the optimum performance observed at 15% SCBA content. Beyond this percentage, the strength gains began to diminish, indicating an optimal range for SCBA incorporation. At 7 days, the compressive strength of SCC with 15% SCBA was approximately 15% higher than that of the control mix. At 28 days, the strength improvement was around 18%.

The split tensile and flexural strengths also showed similar trends, with the highest values recorded at 15% SCBA content. These improvements are attributed to the pozzolanic reactions of SCBA, which enhance the microstructure of the concrete by filling voids and reducing porosity.

The slump and compaction factor tests indicated that the workability of SCC improved with increasing SCBA content. The slump values increased from 61 mm for the control mix to 84 mm for the mix with 35% SCBA. Similarly, the compaction factor improved, reflecting better flowability and ease of placement.

Environmental impact and sustainability

The integration of Sugarcane Bagasse Ash (SCBA) in Self-Compacting Concrete (SCC) offers significant environmental benefits, aligning with sustainable construction practices. The primary advantage of using SCBA is the reduction in Portland cement consumption. Cement production is a major contributor to carbon dioxide emissions, accounting for approximately 8% of global emissions. By partially replacing cement with SCBA, the carbon footprint of concrete production can be substantially reduced.

SCBA is a by-product of the sugar industry, typically considered agricultural waste. Its utilization in concrete not only provides a valuable use for this waste material but also mitigates the environmental issues associated with its disposal, such as landfilling and open burning, which can cause air pollution and greenhouse gas emissions. This approach supports the principles of the circular economy by transforming waste into a resource.

Moreover, the production process of SCBA is less energy-intensive compared to that of Portland cement. The energy required to process SCBA, which includes drying, grinding, and sieving, is significantly lower, contributing to overall energy savings in concrete production.

Conclusion

The investigation into the use of Sugarcane Bagasse Ash (SCBA) as a supplementary cementitious material in Self-Compacting Concrete (SCC) reveals substantial benefits for both performance and sustainability. Through a comprehensive series of tests on SCC mixes incorporating varying percentages of SCBA, this study has demonstrated that SCBA significantly enhances the mechanical properties and workability of SCC. These improvements are crucial for advancing the material's application in the construction industry, providing a viable pathway towards more sustainable building practices.

The compressive, tensile, and flexural strengths of SCC were observed to increase with the addition of SCBA, with the optimum performance noted at approximately 15% SCBA content. This increase is primarily attributed to the pozzolanic reactions facilitated by the silica-rich SCBA, which refine the microstructure of the concrete, fill voids, and reduce porosity.

Workability, an essential attribute of SCC, was also positively influenced by the inclusion of SCBA. The slump and compaction factor tests indicated that higher SCBA contents lead to improved flowability and ease of compaction.

From an environmental perspective, the use of SCBA in SCC contributes to sustainability by repurposing an agricultural by-product that would otherwise contribute to waste. The reduction in Portland cement usage directly correlates to lower carbon emissions and energy consumption, aligning with global sustainability goals.

While the study underscores the promising potential of SCBA in SCC, it also highlights the need for further research. Long-term durability studies, real-world field applications, and detailed economic analyses are essential to fully validate and optimize the use of SCBA. These future research directions will ensure that SCBA can be effectively and reliably used in diverse construction scenarios, reinforcing its role in sustainable infrastructure development.

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Chapter - 14

Role of ammonia Volatilization and phosphorus transformation on Wetland Rice Fields

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Chapter - 14

Role of Ammonia Volatilization and Phosphorus Transformation on Wetland Rice Fields

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Abstract

BGA and Azolla contribute to biomass, and upon decomposition, they affect redox activity, leading to the formation of diverse organic acids in the soil. These alterations initiated by BGA and Azolla in the soil have the potential to impact the availability of nutrients to plants and the overall characteristics of the soil. The established role of blue-green algae (BGA) and Azolla in supplying nitrogen to rice fields is well documented. Furthermore, these organisms, whether directly or indirectly, bring about various changes in the physical, chemical, and biological properties of the soil and the soil-water interface in rice fields. For example, BGA releases extracellular organic compounds and photosynthetic oxygen during its growth. Conversely, Azolla prevents pH elevation, reduces water temperature, inhibits NH3 volatilization, and suppresses weed growth. This review aims to highlight these effects in rice fields and explore their potential implications for the management and productivity of rice-field systems.

Introduction

The success of rice production in tropical and subtropical regions heavily relies on the effective and economical provision of nitrogen (N), a critical element needed in greater quantities compared to other essential nutrients. The utilization efficiency of N from fertilizer sources in lowland rice is notably low due to its loss from soils through various chemical and biochemical processes. Additionally, increasing the application of nitrogenous fertilizers is considered environmentally unfriendly (Conway and Pretty 1988) and economically impractical (Cassman and Pingali 1994). Hence, there is a need to explore alternative renewable resources to meet at least a portion of the N demand for rice crops. Nitrogen-fixing blue-green algae (BGA) or cyanobacteria and Azolla have been identified as crucial contributors to maintaining and enhancing rice field productivity (Roger *et al*. 1993).

It has been established that soil N fertility is better sustained under flooded than dryland conditions (Watanabe and Roger 1984). Favorable conditions for biological N2 fixation by BGA are considered a factor in the relatively stable rice yield under flooded conditions. Unlike chemical N fertilizers, BGA and Azolla neither contaminate the environment nor deplete the photosynthates of rice plants (Liu 1979). The importance of N2-fixing BGA was initially recognized by De (1936, 1939), who attributed the self-maintenance of N status in tropical rice-field soils to the growth of N2-fixing BGA. Similarly, the fertilizing value of Azolla in rice fields is well-known and has been utilized for centuries in China and Vietnam (Watanabe *et al*. 1981; Lumpkin and Plucknett 1982).

The growth of N2-fixing BGA (De and Mandal 1956; Singh 1961; Stewart *et al*. 1968) and Azolla (Shen *et al*. 1963; Peters *et al*. 1977; Singh and Singh 1987) significantly increases the plant-available N in rice soils. There is notable literature on this topic for both BGA (Fogg *et al*. 1973; Roger and Kulasooriya 1980; Venkataraman 1981) and Azolla (Watanabe *et al*. 1981; Lumpkin and Plucknett 1982; IRRI 1987; Wagner 1997). Field inoculation with BGA, even in the presence of 100-150 kg N ha-1 as fertilizer, led to a rice yield improvement of 5% to 25% (Sprent and Sprent 1990; Yanni 1992). Since biological N2 fixation is known to be inhibited by inorganic N, this observation suggests that BGA may provide additional benefits beyond adding N to the soils.

Both BGA and Azolla, directly or indirectly, induce changes in the physical, chemical, and biological properties of soil and the soil-water interface in rice fields, which holds agronomic significance. The extracellular organic compounds released by algae, O2 produced during their active growth, and subsequent biomass addition after their death are likely to bring about critical physical-biochemical changes in soils. The prevention of algae-induced pH rise, reduction in water temperature, suppression of NH3 volatilization losses, and weed control under Azolla cover are additional effects that may benefit rice cultivation. This review aims to compile and discuss the limited information available on these aspects of BGA and Azolla use, exploring their potential implications for rice growth and the sustained productivity of rice fields.

Ammonia volatilization

As previously mentioned, the efficacy of nitrogen (N) in the form of urea applied to flooded rice is notably low due to its loss through various mechanisms, including NH3 volatilization. This loss of N through NH3 volatilization can account for as much as 50% of the urea within 2 weeks of application, depending on fertilizer management and environmental conditions (Fillery and Vlek 1986). NH3 volatilization is influenced by the partial pressure of NH3 (pNH3) in the floodwater, determined by the total (NH3cNH4 c)-N level, pH, temperature of the floodwater, and ambient wind velocity (Vlek and Craswell 1981). pNH3 increases tenfold for every unit increase in pH and significantly with rising temperature. Thus, any factor influencing the pH and temperature of floodwater in rice fields can either accelerate or decelerate this process. When applied to flooded rice fields, urea turns the floodwater alkaline upon hydrolysis to (NH4)2CO3, an alkaline salt.

Additionally, aquatic plant communities contribute to NH3 loss from flooded soils through photosynthetic activity, consuming dissolved CO2. Diurnal fluctuations in floodwater pH, from near neutral to as high as 10, are common in rice fields where algae, mainly green algae, are active, accelerating NH3 volatilization (Vlek and Craswell 1981; Fillery *et al*. 1985; Bowmer and Muirhead 1987). Algal blooms, primarily green, rapidly develop upon N fertilization of flooded rice (Watanabe *et al*. 1977) but die off once light penetration is limited by the rice canopy. The decay of green algae may be hastened when Azolla, grown in association with rice, shades out the algae. Growing Azolla can mitigate NH3 volatilization loss from rice fields in several ways: (1) forming a physical barrier to escaping NH3, (2) intercepting incoming light necessary for prolific algal growth, (3) absorbing a high amount of NH3 or NH4 c, temporarily storing it for future release, (4) exuding protons while absorbing NH3, (5) increasing the pCO2 of floodwater by respiration, subsequently decreasing floodwater pH, etc. (Vlek *et al*. 1992, 1995; Kumarasinghe and Eskew 1993; Sisworo *et al*. 1995). The cyanobiont Anabaena-Azolla aids in this process by driving carbon from Azolla (not from floodwater like other green algae) and fixing nitrogen without increasing floodwater pH. Experimental evidence supports these hypotheses, such as preventing algal-induced pH rise and reducing floodwater temperature and light transmission ratio (LTR) under Azolla cover (Kröck *et al*. 1988a, 1988b). These effects of Azolla cover on NH3 volatilization loss in rice fields help explain the observed increase in N use efficiency of rice in field experiments coordinated by the International Atomic Energy Agency in various countries (Kumarasinghe and Eskew 1993, 1995). Urea-N was more efficiently used by a mixed Azolla/rice crop compared to a rice monoculture, increasing N recovery by 10%, 60%, and 53% in China, Sri Lanka, and Thailand, respectively. The presence of an Azolla cover reduced NH3 volatilization by 20-50% compared to conditions without Azolla (Villegas 1985).

Additionally, in a preliminary study, Vlek *et al*. (1992) demonstrated a reduction in N loss from 80% of applied urea in the absence of Azolla to 10% and 35% for 20 and 40 kg N ha-1 fertilizer rates, respectively, when an Azolla mat was present. A subsequent definitive study with 15N by Vlek *et al*. (1995) showed that a full cover of Azolla could significantly reduce losses of applied urea-N, from 45% and 50% loss to 20% and 13% loss for the 30 and 60 kg N ha-1 treatment, respectively. By assessing the relative importance of different mechanisms, they found that one-quarter of the applied N was tied up in Azolla biomass, and the reduction in NH3 volatilization was primarily related to the depression of floodwater pH by Azolla. They concluded that the benefits of Azolla, even in small quantities (200-500 kg fresh material ha-1), in conserving basal urea-N outweighed its competition for applied N with growing rice. The urea-N conserved by Azolla is as significant as its biologically fixed N. Identifying the relative efficacy of different species of Azolla in this regard may be valuable for the future adoption of management programs incorporating this genus in the field.

Transformation of phosphorus

Blue-Green Algae (BGA), akin to phosphorus-solubilizing bacteria, exhibit the capability to mobilize tightly bound phosphates. Their capacity to dissolve insoluble compounds such as (Ca)3(PO_4)2, $FePO_4$, $AlPO_4$, and hydroxyapatite has been demonstrated in various studies. Two primary hypotheses propose mechanisms for BGA-mediated phosphate solubilization. One suggests the synthesis of chelators for Ca2+ by BGA, while the other posits that H_2CO_3 and organic acids released during BGA growth play a role in phosphate solubilization. A third perspective suggests the simultaneous operation of both mechanisms.

When BGA solubilize phosphates, the liberated PO4 3- is assimilated by the growing algal cells for their nutrition. Upon completing their growth cycle and undergoing lysis, the cell-bound PO4 3- is released into the growth medium and becomes available to plants upon mineralization. The initial decrease in available-P content in soils due to algal growth, followed by an increase during biomass decomposition, supports this pathway.

An in-depth study revealed that the growth of a mix of BGA species in soils increased organic P while decreasing Olsen-P, Al-P, Fe-P, and Ca-P. Upon incorporating this algal biomass into soils, Olsen-P increased, and other P fractions, including organic P, decreased. P assimilated by BGA during growth is released upon bacterial decomposition in the form of soluble organic P compounds or condensed polyphosphates, which later mineralize or hydrolyze into orthophosphates, increasing available P in soils.

Inoculation with BGA also intensifies the reducing conditions of the soil, promoting the reduction of Fe3c-P to more soluble Fe2c-P. This leads to the formation of organic compounds with chelating properties, releasing P from Al- and Fe-bound forms. The solubilizing effect of BGA on bound PO4 3- may enhance the utilization of low-grade rock phosphate fertilizers in acid soils. BGA can solubilize P from rock phosphate, increasing its efficacy as a P source. The incorporation of Azolla into rice fields similarly increases P availability in soils, attributed to the decomposition of Azolla's biomass rich in organic forms of P and subsequent release of available P. This increased P availability enhances P uptake by rice plants, and Azolla-P is found to be significantly more available than P from commonly used P fertilizers. The preloading of Azolla with higher amounts of P can further increase its impact on crop growth and nitrogen fixation.

Conclusions

The positive outcomes include the addition of organic carbon, improvement in soil physical properties, reduction in NH3 volatilization loss, mobilization of fixed phosphates, regulation of micronutrients especially Fe, Mn, and Zn with impacts on their availability, mitigation of sodicity in problematic soils, weed suppression, and the release of growth-promoting substances. Sometimes, these benefits surpass those derived solely from the nitrogen they introduce. However, the realization of these advantages hinges on the robust growth of BGA and Azolla in rice fields, which may not always occur naturally.

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Chapter - 15

A Case Study on Soil Stabilization using Bitumen Emulsion and Cement

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Chapter - 15

A Case Study on Soil Stabilization using Bitumen Emulsion and Cement

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Abstract

The aims of this study are to improve the engineering properties of the soil by adding Bitumen emulsion & Portland cement. Soil stabilization is a crucial aspect of construction projects, ensuring the durability and strength of structures. This study investigates the importance and effectiveness of using bitumen emulsion and cement for soil stabilization. The research explores the mechanical properties, such as CBR, UCS, Shear test, MDD & OMC of stabilized soil samples. Various mix ratios of bitumen emulsion and cement are tested to determine their optimum combination for enhancing soil stability. The findings provide valuable insights into the feasibility and efficacy of utilizing bitumen emulsion and cement in soil stabilization, offering potential solutions for sustainable and resilient infrastructure development. In this study, the whole laboratory work revolves around the basic properties of soil are find. To investigate how difference ratios of this material affect the mechanical properties of the soil, considered four difference percentage of additive were considered: - 4%, 6%, 8%,10% and the bitumen emulsion and cement contents were combined in percentage: 75:25, 50:50, 25:75, to from three additive. It's observed that the best result is found in the modified soil when the cement content is increase.

Keywords: Soil stabilization, bitumen emulsion, cement, CBR, UCS, MDD, OMC, mechanical properties, road construction.

Introduction

Soil stabilization is a crucial technique employed in civil engineering and Road construction to enhance the properties of soil, making it more suitable for construction purposes. Bitumen emulsion and cement are two common materials used in soil stabilization processes due to their effectiveness in improving soil strength, durability, and resistance to water infiltration. Bitumen emulsion is a dispersion of bitumen particles in water, forming a stable emulsion. When mixed with soil, bitumen emulsion coats the soil particles, providing a waterproof barrier and binding them together. This improves the soil's strength, preventing erosion and increasing load-bearing capacity. Additionally, Bitumen emulsion plays a crucial role in reducing soil plasticity and the potential for swelling, which enhances the suitability of the soil for construction projects, especially in regions experiencing variable weather conditions. By lowering the plasticity, bitumen emulsion minimizes the soil's tendency to undergo significant volume changes with moisture fluctuations, thereby improving its stability and durability.

Conversely, cement acts as a binding agent that undergoes a chemical reaction with water, a process known as cement hydration. This reaction results in the formation of a hardened matrix that encapsulates soil particles, significantly enhancing the overall strength and cohesion of the treated soil. The cement hydration process effectively stabilizes the soil, providing a robust foundation for various construction applications. When mixed with soil, cement fills the voids between soil particles, forming a cementitious bond that enhances soil stability. Cement stabilization increases soil strength, reduces settlement, and improves resistance to moisture ingress. It is particularly effective in stabilizing fine grained soils such as clay and silt. Combining bitumen emulsion and cement in soil stabilization projects offers synergistic benefits. The bitumen emulsion provides immediate stabilization by coating soil particles, while cement contributes long-term strength development through hydration. This combination enhances the overall performance of stabilized soil, making it suitable for a wide range of construction applications, including road construction, foundation stabilization, and slope reinforcement. In summary, soil stabilization using bitumen emulsion and cement is a versatile and effective method to enhance soil properties for construction purposes. By utilizing these materials, engineers can improve soil strength, durability, and resistance to environmental factors, ensuring the longevity and stability of infrastructure projects. Soil stabilization using bitumen emulsion and cement is a method employed to improve the engineering properties of soil, making it more suitable for Road construction and infrastructure projects.

On a road construction the subgrade soil CBR value is very important for design the entire pavement properties. The Indian Road Congress (IRC:37) & MORTH (Ministry of roads transport and highway of India) has mentioned the sub grade soil specification, based on the subgrade soil quality (effective CBR) the pavement layers are design. There is no any particular methodology or standards for soil stabilization with bitumen emulsion and cement and very importantly there is no Indian standard Coad for soil stabilization with some additive. here in this study make the effort to explore and find the effectiveness of soil stabilization by using bitumen emulsion & cement. Poorly graded sandy soil has high clay percentage (SP), red coloured soil sample are taken for this study and bitumen emulsion (SS1) and cement (PPC) as stabilizing agent. The main objective of this study to improve the mechanical properties (CBR, UCS, MDD) of poorly graded sandy soil (SP) by using bitumen emulsion (SS 1) and Cement. Here the Key Objective aspect and findings of studies on this technique.

Literature review

Soil stabilization is a crucial process in civil engineering, aimed at enhancing the physical properties of soil to improve its load-bearing capacity, stability, and durability. Two common stabilizing agents are bitumen emulsion and cement, which, when used individually or in combination, significantly improve soil properties. Previously there is so many research done individual or combination of both of this additive with difference type of soil in all over India. This study was inspired by those of researcher. This literature review synthesizes research findings on the effectiveness, mechanisms, and practical applications of soil stabilization. Some similar research works done before is discussed below.

Challa Venkaiah (January 2024) indicated Improvement of gravely red soil mechanical properties by using of bitumen emulsion and cement as a filler. They used bitumen emulsion (SS, MS, RS) and cement on different proportion. The best result or effectiveness are found on this research, when 3% of MS emulsion and 2% cement is added to the soil and waited 5 hours.

Shukla *et al.*, 2015 stated Bitumen emulsion stabilization is considered environmentally friendly due to lower emissions during application compared to traditional methods and is cost-effective for large-scale applications.

Sahu *et al.* 2016 directed the excremental program by using locally available soil and as stabilized agent used both emulsion and cement. The combination results in a flexible yet strong soil matrix, suitable for applications where both high strength and resilience to cracking are required.

Petry and Little, 2002 Research suggested that the optimal mix ratios vary depending on soil type and application, but a common finding is that small percentages of cement (around 2-5%) combined with bitumen emulsion (3-8%) yield significant improvements in soil properties.

Razouki *et al*. 2012 proposed an experimental study on granular stabilized roads. Bitumen was used as a stabilizing agent may act as a binder or as a water-proofing material and it's very important the adequate percentage of bitumen. The Soil-bitumen systems had found the greatest used in road construction.

Bitumen emulsion is widely recognized for its ability to reduce soil plasticity and swelling potential. According to Terrel and Al-Swailmi (1994), bitumen emulsions can effectively lower the plasticity index of clayey soils, making them less susceptible to moisture-induced volume changes. This characteristic is particularly beneficial in regions with fluctuating weather conditions, where soil stability is crucial.

Studies by Little and Epps (2001) indicate that soils treated with bitumen emulsion exhibit enhanced durability, especially under conditions of wetting-drying and freeze-thaw cycles. The bitumen forms a protective coating around soil particles, reducing water infiltration and erosion, thereby increasing the longevity of stabilized soils.

Research by Santoni and Tingle (2003) demonstrates that the inclusion of bitumen emulsion in soil stabilization leads to improved compaction properties. The treated soil achieves higher maximum dry density and lower optimum moisture content, resulting in a more stable and compacted soil structure.

Cement is known for its ability to significantly enhance the strength of stabilized soils. According to Mitchell and Soga (2005), the process of cement hydration forms a hardened matrix that binds soil particles together, leading to substantial improvements in unconfined compressive strength (UCS). This increased strength is essential for supporting heavy loads in construction projects. The use of cement in soil stabilization also contributes to a reduction in soil plasticity. Bell (1996) reports that cement-treated soils exhibit lower plasticity indices, which reduces the risk of soil deformation under load and improves overall soil stability.

Studies by Consoli *et al*. (2009) highlight the long-term benefits of cement stabilization. Cement-stabilized soils maintain their improved properties over extended periods, even under adverse environmental conditions. This makes cement an effective stabilizing agent for permanent infrastructure projects.

Combining bitumen emulsion and cement in soil stabilization can yield synergistic benefits. Research by Jones and Holtz (1973) shows that this combination enhances both the mechanical and durability properties of the soil. The bitumen emulsion reduces plasticity and swelling, while the cement provides additional strength and stability.

Material & methodology

Soil: Soil used in this research, brought from Jiti Border, Jalpaiguri, West Bengal was characterized by conventional tests and results were compared with specifications in [IS:1498, 1970] for using soil as subgrade soil. The soil samples were obtained from a depth of (1.0 m) below the natural ground surface. Gradation of soil particles is shown in figure (1). While, the results of physical tests of natural soil are summarized in Table (1) all the test are conduct as per IS 2720. According to test results, the soil is sand poorly graded (SP) with high percent of dark fine particles as per Indian standard specification (IS:1498). The test result of this soil sample is not meet the IRC & Morth specification for subgrade soil.

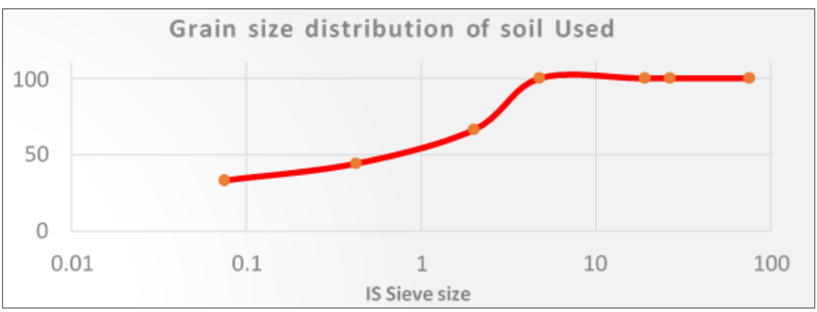

Fig 1: Grain size distribution

Gravel = 0.00%	Sand = 66.77%	Silt & Clay= 33.23%

Table 1: Summary of physical properties and classification test result of soil used

	Property	Result
i	Maximum dry Density (gm/cc)	1.580
ii	Optimum Water Content (%)	13.52
iii	Specific gravity	2.55

iv	Liquid limit (LL)%	39.56
v	Plastic Limit (PL)%	11.78
vi	Plasticity Index (PI)%	27.78
vii	UCS(Kn/m^3)	0.36
viii	C value	0.0641
ix	Phi value	26°
x	CBR (4 days shocked) %	3.42
xi	FSI %	12.36
xii	Soil classification as per (IS:1498)	SP

Emulsion: Bitumen emulsion SS1 is a type of slow-setting bitumen emulsion used in road construction and maintenance and in this study, it’s used as soil stabilizing agent. Here are some key characteristics and uses of SS1 bitumen emulsion. The slow-setting nature allows more time for the emulsion to break and the water to evaporate, leaving the bitumen to bond with the aggregate.

Table 2: Summary of physical properties of Bitumen emulsion (SS1)

	Properties	**Result**	**Specification limit (IS:8887)**
i	Residue on 600 mic is sieve, percent by mass	0.03	0.05
ii	Viscosity by saybolt furol viscometer @ 25°c	44	20-100
iii	Penetration@25°C /100g/ 5 sec	74	60-350
iv	Ductility @27 °C C/cm, min	59	50

Table 3: Summary of physical properties test result of PPC (Cement)

i	Fineness (m²/kg)	382	300 (mini)
ii	Standard Consistency (%)	31.5	-
iii	Initial setting time (min)	180	30 (min)
iv	Final setting time (min)	290	600 (Max)
v	Soundness	2.4	10 mm max.
vi	Compressive strength @ 3 days	19.25	16 mini
vii	Compressive strength @ 7 days	27.45	22 mini
viii	Compressive strength @ 28 days	38.44	33 mini

Experimental program methodology

Testing program presented here can be illustrated in the following paragraphs: Soil classification tests were performed firstly including physical properties of soil with routine standard tests. Tests include grain size distribution, that determined according to (IS:2720 part 4) with dry sieving. Atterberg limits. Liquid and plastic limits tests were carried out on soil passing sieve 0.425mic and the testing procedure was determined according to (IS:2720 part 5). Specific gravity, determined according to (IS:2720 part 2) Water content, was determined in accordance with (IS:2720 part 8). California Bearing Ratio (CBR) test, as stated in the specification (IS:2720 part16), UCS determined according to (IS 2720 part10). The Standard Proctor compaction (mdd) tests were carried out to determine the moisture-density relationship for natural soil and soil treated with emulsion and Portland cement, with respective percentage of water. Direct shear test is carried out as stated in the specification as per (IS: 2720 part 13). The test planning to obtain as follow, Soil tested with (4, 6, 8, 10) % of Additive Bitumen emulsion & Portland cement which are tested accordingly (bitumen emulsion: Portland cement) were combined in percentage: 75:25, 50:50, 25:75. In this study there are four percentage of additives and three percentage of combined material. Testing program is following below.

Table 4: Testing program & different additive percentage

CASE I: 4% - Additives in three different ratios	(75:25, 50:50, 25:75)
CASE II: 6% - Additives in three different ratios	(75:25, 50:50, 25:75)
CASE III: 8% - Additives in three different ratios	(75:25, 50:50, 25:75)
CASE IV: 10% - Additives in three different ratios	(75:25, 50:50, 25:75)

Fig 1: MDD test **Fig 2:** LL&PL test

Fig 3: CBR testing

Result and discussion

Experimental works implement according to research testing program explanted above. As mentioned earlier the selected soil can be classified as sand poorly graded (SP) and the respective test report are stipulated on table 1. The parameters used were the modified soil- Grading, MDD&OMC, LL&PL, CBR, UCS, Direct shear test. Here discussed about the most effective parameters which are very important for as a subgrade soil (MDD, CBR, UCS). All the test report and variation of test result are graphically plotted below.

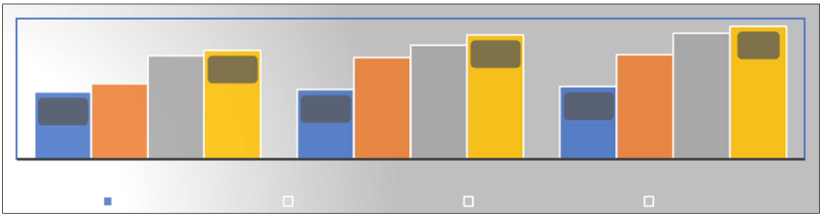

Fig 4: Variation of MDD result with different additive percentage

After observation the test result of MDD test is clear that the soil gives the maximum density on 10% additive. Density of modified soil are increases with increase in cement content.

Table 6: Summary of CBR test report for different additive percentage

Emulsion/cement content	4%	6%	8%	10%
Natural soil	3.42	3.42	3.42	3.42
75:25	4.01	5.66	6.02	7.30
50:50	5.11	6.57	7.48	8.39
25:75	5.29	7.66	8.94	9.49

The specimen is tested after 4 days of under water shocked as per IS 2720 Part 16. the CBR value are taken @ 5mm penetration.

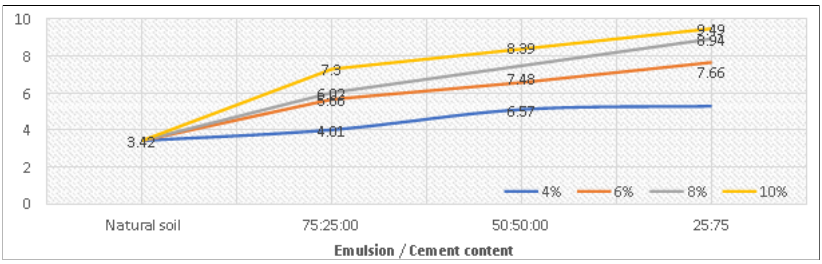

Fig 4: Variation of CBR result with different additive percentage

Table 7: Summary of UCS test report for different additive percentage

Emulsion/cement content	**UCS at 4%**	**UCS at 6%**	**UCS at 8%**	**UCS at 10%**
Natural soil	0.36	0.36	0.36	0.36
75:25	0.43	0.52	0.61	0.89
50:50	0.54	0.70	0.81	1.04
25:75	0.77	0.82	1.05	1.31

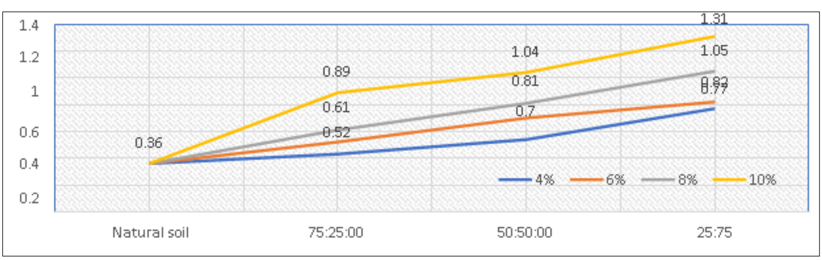

Fig 5: Variation of UCS result with different additive percentage

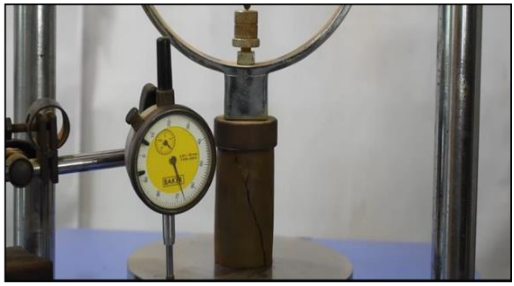

Fig 6: Set up for UCS test **Fig 7:** Deformation on the sample after loading

Conclusion

The use of bitumen emulsion and cement for soil stabilization has been extensively researched and documented, showing significant improvements in soil properties providing a durable, moisture- resistant, and cost-effective solution for construction projects. Their combined use provides synergistic benefits, making it a viable solution for various civil engineering applications. This method not only supports sustainable practices but also enhances the structural integrity and longevity of infrastructure. Future research should focus on optimizing mix ratios for different soil types and exploring the long- term environmental impacts of these stabilization methods. Here some key points conclude:

The maximum dray density of modified soil is increased 13% on 10% additive as compared with the natural soil sample, also test result achieved the required specification for subgrade soil as per IRC & Morth. The minimum MDD are required for subgrade soil is 1.750 gm/cc and modified soil meet the specification on 8% & 10% additive with the proportion of emulsion: Cement -25:75.

The CBR value from natural soil to Modified soil is increased by 177% on 10% additive. As the natural soil had 4 days shocked CBR value was 3.42% in 5 mm penetration and after modification the maximum CBR value has been achieved in the same circumstances was 9.49%. The minimum CBR value is 5% as per IRC for NH, SH, MDR as the soil used in subgrade and the modified soil has been achieved these minimum criteria on 4% additive with the proportion of Emulsion: Cememt -50:50.

After mixing the additive with the soil and left them for the 2 hours in normal air temperature and then the soil gets the best UCS value. The UCS result were displayed in table-7 and UCS value effectively increase with increases to the additive percentage and its effective when cement content is higher. As per the Morth & IRC specification the minimum laboratory USC value is 0.75 mpa for sub base layer, there for with the reference of this specification the optimum combination as subgrade material is satisfied the requirement in 4%, 6%, 8%, 10% additive with the 25% of emulsion & 75% of cement.

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Chapter - 16

Exploring Sustainable Practices for Stabilization of Black Cotton Soil with Sugarcane Bagasse Ash

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Chapter - 16

Exploring Sustainable Practices for Stabilization of Black Cotton Soil with Sugarcane Bagasse Ash

Sunil Kumar Sarder, Arka Manna and Sunil Priyadarshi

Abstract

It's commendable that efforts are being made to address the challenges posed by expensive soils in construction projects, particularly in regions like India where this is a prevalent issue. Stabilization methods indeed offer practical solutions for enhancing soil properties and engineering performance. Utilizing solid waste materials such as sugar cane bagasse ash and for soil stabilization is a sustainable approach that not only addresses the issue of soil stabilization but also contributes to waste management and environmental sustainability. Sugar cane bagasse ash, being a byproduct of the sugar industry, can effectively improve the index properties of soil due to its pozzolanic properties. Sugar cane bagasse ash, when incorporated into soil, can increase its dry density due to its fine particles and high density. This densification can improve the engineering properties of soil, making it more suitable for construction purposes. Additionally, sugar cane bagasse ash 's resistance to water absorption can help mitigate the swelling problems associated with expensive soils, thereby enhancing the overall stability of the construction site. It's important to conduct thorough testing and analysis to determine the optimal proportions of these waste materials for soil stabilization, ensuring that the desired improvements in shear strength, index properties, swelling potential, and California Bearing Ratio (CBR) values are achieved.

Overall, the utilization of waste materials for soil stabilization not only offers cost-effective solutions for dealing with expensive soils but also contributes to sustainable development by promoting waste recycling and minimizing environmental impacts associated with conventional construction practices.

Keywords: Sugar cane bagasse ash, shear strength, index properties, swelling potential, California Bearing Ratio (CBR).

Introduction

The advancement of human civilization and the accompanying population growth have necessitated various types of developments to fulfill the requirements of people in every country around the world. These developments encompass the transportation facilities such as highways, railways, and airports, as well as the construction of residential buildings, industrial structures, sea ports, and other essential infrastructure. All these developments must prioritize safety, stability, durability, and economy, which are achievable only if suitable land for construction is available. Since the dawn of human civilization, land has been the most crucial resource for the existence and development of human society. This need is particularly intense in India, which has a very large population and where agriculture is the primary source of employment and survival. However, like all other resources, land is limited in every country, including India.

To meet these construction requirements, people around the world have developed certain techniques through intensive research and experience. These techniques improve the poor-quality soils by various technical means to make them more suitable for the construction of engineering assets such as buildings, bridges, retaining walls, machine foundations, highway and railway embankments, microwave towers, windmills, etc., with safety and economy. These techniques for developing the engineering properties of the land are collectively called “Ground Improvement Techniques.” Ground improvement or ground modification involves positive alterations of the foundation soils to provide better performance under design and operational loading conditions. Treating clayey soil with sugarcane bagasse ash presents an economically viable and environmentally friendly solution. Clayey soils, although abundant and low-cost, often pose challenges due to their low strength, poor bearing capacity, high compressibility, and water retention properties. These issues can significantly affect the performance and durability of construction projects, making soil stabilization essential.

Stabilization techniques aim to enhance the engineering properties of soil, such as shear strength and California Bearing Ratio (CBR), to make it suitable for various construction applications like pavements, embankments, and foundations. By utilizing stabilizing agents like sugarcane bagasse ash, the soil's properties can be effectively improved. Sugarcane bagasse ash, a by product of the sugar industry, contains pozzolanic properties that react with calcium hydroxide in the presence of moisture to form cementitious compounds. This reaction enhances the soil's strength parameters, making it more suitable for construction purposes. The treatment of clayey soil with sugarcane bagasse ash offers a practical and environmentally friendly approach to soil stabilization.

Literature review

In Yesilbas, Gulshah's study from 2004, rock powder and aggregate waste, along with lime, were used as admixtures to reduce the swelling potential of expansive clayey soil. The research focused on a mixture of kaolinite and bentonite as the expansive soil. Lime was added in percentages ranging from 0-9%, while aggregate waste and rock powder were added in percentages up to 25% by weight.

In the research by R. Ali, H. Khan, and A. A. Shah from 2012, the effects of sugarcane bagasse ash and marble dust on clayey soil with a plasticity index and liquid limit greater than 30% were analyzed. Various percentages (4%, 8%, and 12%) of sugarcane bagasse ash and marble dust were added, resulting in decreases in liquid limit, plastic limit, expansive index, and plasticity index, ultimately improving the soil's properties.

M. Aly, M. S. J. Hashmi, *et al*.'s 2012 study focused on the mechanical performance and durability of flax fiber reinforced cement composites (FRC) using finely ground and nano clay particles. The study aimed to investigate the impact of partial substitution of ordinary Portland cement (OPC) with these additives. Testing methods included alkali-silica reaction (ASR), X-ray diffraction (XRD), and differential thermal analysis (DTA), along with mechanical performance evaluations. Wetting and drying cycles were applied to assess composite aging.

In this research analyze R. Ali, H. Khan, and A. A. Shah's 2012 study, the effects of sugarcane bagasse ash and marble dust on clayey soil with a plasticity index and liquid limit larger than 30% were analyzed. These materials, considered waste in the natural environment, were explored for the stabilization of expansive soil, enhancing its engineering properties. At an 8% addition, both marble dust and sugarcane bagasse ash increased the dry density of the soil, but this effect reduced at 12%.

M. Aly, M. S. J. Hashmi, *et al*.'s 2012 study focused on the mechanical performance and durability of flax fiber reinforced cement composites (FRC) using finely ground and nano clay particles. The study aimed to investigate the impact of partially substituting ordinary Portland cement (OPC) with these additives. Testing methods included alkali-silica reaction

(ASR), X-ray diffraction (XRD), and differential thermal analysis (DTA), along with mechanical performance evaluations. Improved pozzolanic reaction and mechanical properties after 28 days of hydration.

M. Aly, M.S.J. Hashmi *et al* (2012): The principle stress for characteristic fibers strengthened bond composites (NFRC) may be the personal satisfaction from claiming fibers. Clinched alongside bond grid those alkalinity will be the primary reason for those misfortune for rubbing from claiming NFRC. Those intention of this Examine might have been will Investigation the impact from claiming incomplete substitution.

Gyanen Takhelmayum, Savitha A.L., Krishna Gudi (2013): In this study, the unconfined compressive strength (UCS) and compaction characteristics of expansive clay stabilized with both fine and coarse GGBS were investigated. The properties of expansive clay were analyzed for grain distribution and soil classification. A series of compaction tests were conducted using miniature compaction molds for different mixes of soil with fine and coarse GGBS additions.

Md. Nuruzzsaman & Dr. Md. Akhtar Hossain (2014): This study investigates the improvement of expansive clayey soil by mixing it with soda lime glass dust. Clay soils often have problematic engineering properties, necessitating stabilization. The primary issue is long-term consolidation under load, while a secondary problem is significant shrinkage and swelling when exposed to water, exerting pressure on the substructure. Soda lime glass dust, a cohesionless material, is used for stabilization. By mixing this with cohesive soil, the study aims to reduce settlement from consolidation and soil expansiveness.

Amit S. Kharade & Vishal V. Suryavanshi (2014): The stability of a structure heavily depends on the soil it rests upon. Unstable structures are often due to the presence of montmorillonite in expansive soils, like black cotton soil. Soil stabilization is an effective method to enhance soil properties using materials such as fly ash, sodium chloride, and calcium chloride. The results indicated that Bagasse Ash significantly improved the performance of black cotton soil, enhancing its stability and suitability for construction.

Ormila T.R. & T.V. Preethi (2014): Expansive soils present significant challenges in construction due to their tendency to swell when wet and shrink when dry, potentially causing severe structural damage. Utilizing industrial waste materials like ground granulated blast furnace slag (GGBS) and fly ash for soil stabilization is a cost-effective and environmentally friendly solution. This study examines the effects of these materials on soil properties through unconfined compressive strength (UCS) and California bearing ratio (CBR) tests.

B. Ahmed, A. Rahman, and J. Das (2015): In its natural state, virgin soil often lacks the necessary properties for use as road subgrade material. To meet the technical specifications required by the construction industry, soil stabilization techniques are commonly employed. This research aims to improve the subgrade California Bearing Ratio (CBR) value by using sugarcane bagasse powder and eggshell powder at varying rates. The goal is to determine the optimal mix proportion at which the CBR value of the soil is maximized before it begins to decline.

J. A. Sadeeq, J. Ochepo *et al* (2015): According to study was following out to examine the effect on the California bearing ratio of expansive soil with sugarcane bagasse ash. Laboratory research were implement on the natural soil in accordance with BS 1377 (1990) and implement bagasse ash treated soil in accordance with BS 1924 (1990). Treated specimens were prepared by made by combination bagasse ash with soil in manner of 0, 2, 4, 6 and 8% proportions of dry soil and imputing with used oil in steps of 0, 2, 4, and 6% by weight of soil.

Tanmay Jain, Gulshan Yadav *et al* (2015): In India Expansive soil is available in most of the states, which have properties of volume change with change in water content due to seasonal variation. All over the world faces these problems with expansive soils. These soils are dangerous to structures on it and can create major economic losses, as well as makes risk to the population. Soil is a main part of structure (base) and supports the structure from beneath and distributes the entire load from structure effectively.

Aluko, O.G, Oke, O.L, Awolusi, T.F (2015) This research indicates the effect of addition of in the block on the compressive strength of compressed stabilized earth block (CSEB) as cement adding or used as admixture. For examine the characteristics the soil sample the consistency limits and water content was tested. There would two sorts about sugar cane bagasse ash s expected were the individuals death through sifter 150 μm with substitution cost levels shifted In 0%, 20%, 40%, 60% and the another death through sifter 75μm with supplanting levels shifted toward 0%, 5%, 10%, 15%, 20%, 25% Also 30% individually.

Hanifi Kanakci, Aram-Al kaki (2016): This research was complete with an motive to examine any clue of modification of clayey soil due to mixtures of waste soda lime glass powder (WSLGP). Waste soda lime glasses were converted into powder form and then sieved through #200 (75µm) sieves and addition in proportion of 3, 6, 9, and 12% in dry weight of the clay. The main test performed are Strength and consistency test on mixed samples after curing.

Amruta P. Kulkarnt, *et al* (2019): It is difficult task for the engineers to construction on black cotton or expensive soil as a structures and it can crack without any warning Soil mixing depending upon constituents of soil, i.e. bulk density, water content, density, shear strength, angle of friction, etc. With the stabilization of soil the properties of black cotton soil can be modified with the use of stabilizing agents or by mechanical means. As bagasse ash is problem for environment when it disposal freely.

I.A. Ikara, A.M. Kundiri, and A. Mohammad (2021): This research investigates the effectiveness of using waste glass (WG) mixed with cement to stabilize black cotton soil (BCS) for road construction, fills, and embankments. The soil was classified as A-7-5 according to the American Association and the Unified Soil Classification System (USCS). Chemical analysis indicated that WG is rich in key oxides such as Silicon Oxide (69.2%), Aluminum Oxide (2.29%), Iron Oxide (1.57%), Calcium Oxide (15.1%), and Sodium Oxide (8.75%). The soil was stabilized using varying percentages of cement (0%, 2%, 4%, 6%, and 8%) and WG (0%, 5%, 10%, 15%, and 20%) by dry weight of the soil.

Jara-Cobos, and Manuel Raul Pelaez-Samaniego, published in 2023.These results demonstrate significant benefits of using WG to enhance the strength of expansive soils.For recent research on soil stabilization using bagasse ash, a notable study is by Tsai Garcia-Perez, Juvenal Alejandro Ortiz- Ulloa, Lourdes E. Jara-Cobos, and Manuel Raul Pelaez-Samaniego, published in 2023. Their research investigates the potential of integrating sugarcane bagasse ash in biogas scrubbing and its impact on soil when used as a fertilizer, enhancing its nutrient content and environmental applications.

Rationale and scope of the study in India

This study gives huge advantage to waste management system of state or country where it carried out and solves the problem of disposal of those two materials. The black cotton soil in India is created as a result of weathering of the volcanic rock. Most of the black cotton soils is derived from the volcanic rocks in the Deccan Plateau covering the RaajmahalTrap and the Deccan. Among the in-situ soils of India, the black soils found in the lava covered areas are the most conspicuous. The soils are often referred to as “Regur”, but popularly known as “Black Cotton Soils”, as it’s colour is black and plenty of cotton is grown it. The black cotton soils are deriving of trap lava and these are spread mostly across interior Gujarat, Maharashtra, Karnataka and Madhya Pradesh on the Deccan Lava Plateau and the Malwa Plateau, where there is both moderate rainfall and underlying basaltic rocks. Because of their high clay content and presence of the clay mineral called montmorillonite, black cotton soils develop wide irregular vertical, horizontaland transverse irregular cracks during the dry season. However, igneous rock granular structure makes these soils highly resistant against the erosion due to wind and flowing water. Though black cotton soils are poor in humus content, they are highly moisture retentive. Accordingly, the black cotton soils respond well to irrigation. It has high clay content and black colour, which are the results of the presence of titaniferous magnetite making it the most suitable soil for growing cotton. Formed in the tropical and sub-tropical region in the world, black cotton soil is rich in nutrients like calcium, carbonate, potash, lime, iron and magnesium. One of the characteristic features of the black cotton soil is its low content of phosphorous, nitrogen and organic matter. This means that while the soil is flexible in the low-lying areas, it may not be very fertile in the upland areas.

Objectives of study

- The main objective of this study is to improve the overall performance of clay by using waste materials i.e. sugar cane bagasse ash
- To improve the liquid limit, plastic limit, plasticity index, such as improves the index properties of clayey soil.
- To improvement in sub grade characteristics of CBR of clay. It helps to improve in bearing capacity of clay soil under the application of loads from structure on it.
- To overcome uneven volume changes of clay without any warning.
- To improve in dry density at different water content and obtain the maximum or improved dry density at optimum moisture content (OMC)

Research methodology

Materials procurement

Black cotton soil procurement: Black Cotton Soil is available at K.

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Kotapadu, Devarapalli, Cheedikada, Paderu and Hukumpeta areas of Visakhapatnam district of Andhra Pradesh. Being associated with the Visakhapatnam Railway Station Development project of Indian Railways, collection of black cotton soil from the K. Kotapadu area of the district of Visakhapatnam, which is located at about 36 Km away from Visakhapatnam Railway Station, was considered to be the most convenient source. Accordingly, black cotton soil was collected from the K. Kotapadu area of the district of Visakhapatnam.

Sugarcane bagasse procurement: Firstly Sugarcane bagasse procured from Anakaplle Sugar plant being closer to the city of Visakhapatnam, it was preferred to collect Bagasse from Anakaplle V.V. Ramana Co-operative Sugar Plant. The sugarcane bagasse was dried in the sunlight for seven (7) successive days and it was burnt to ash on a clean concrete base thereafter to obtain the bagasse ash. The dried bagasse ash was sieved in the 425-micron sieve and thus the fine powdered bagasse ash was obtained.

Laboratory tests and analysis

Particle size distribution analysis

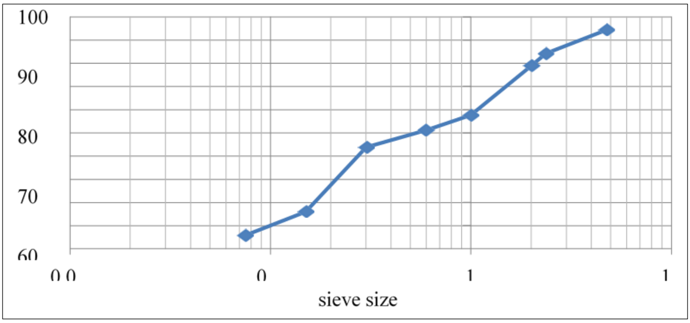


Fig 1: Is graph plot between the sieve size analysis and finer percentage

In Fig. 1 is graph plot between the sieve size analysis and finer percentage from which the Cu and Cc obtained as 0.187 and 10.72 respectively.

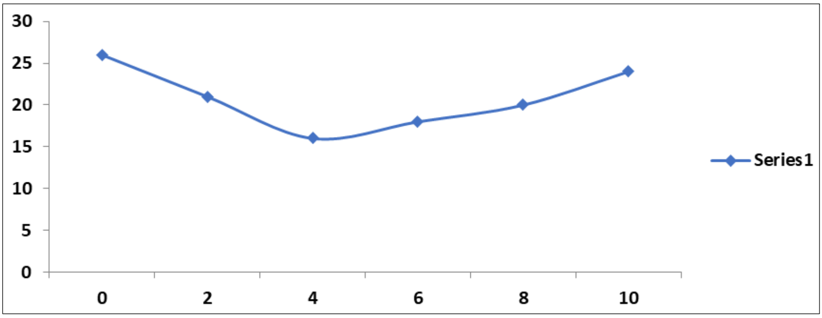
Table 1: Properties of expansive soil

Properties values	Value	IS: Code
Specific Gravity	2.52	(IS 2720: Part 3)
Grain Size Distribution	Cu = 0.187 Cc= 10.72	(IS 2720: Part 4)

Liquid limit (%)	65	(IS 2720: Part 5)
Plastic limit (%)	42	(IS 2720: Part 5)
Plasticity Index (%)	23	(IS 2720: Part 5)
classification of soil	CH	

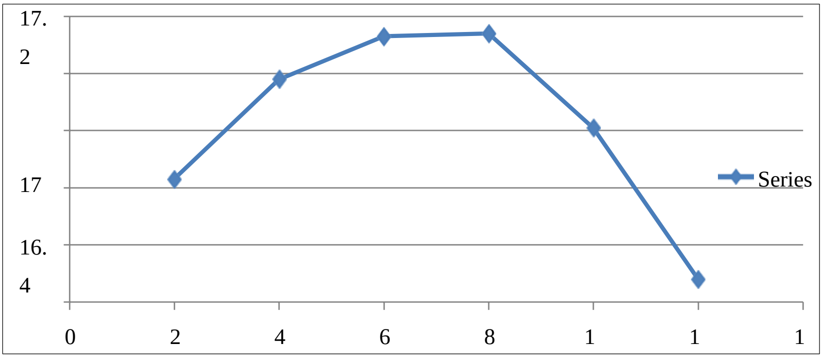
Results and discussions

Free sweel index: Free swell test is done for different proportions of bagasse ash (2%, 4%, 6%, 8%, &10%) to obtain the swelling nature (change in volume) of the black cotton soil.



Standard proctor test

This test is done for different proportions of bagasse ash (2%, 4%, 6%, 8%, 10%) to obtain the maximum dry density of the soil. This graph shows the Maximum dry density of soil in different proportions of Bagasse ash



Unconfined compression test

Unconfined compression test is done for different proportions of bagasse ash (2%, 4%, 6%, 8%, 10%) to obtain the compressive strength of soil. Table 6 Maximum compressive strength of the Black cotton soil with

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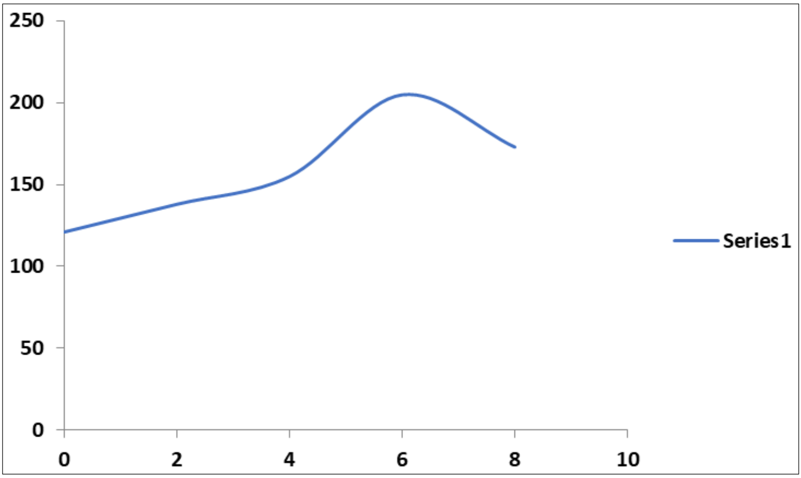
Bagasse ash.



Black cotton soil is known for its poor engineering qualities, which pose significant challenges for engineers when constructing structures and infrastructure on it. Ensuring safety, stability, durability, and cost-effectiveness in such projects is particularly difficult due to the soil's inherent characteristics. This paper provides a detailed discussion on the properties of black cotton soil. Despite these challenges, the demands of industrial and population growth necessitate the construction of various types of structures, including industrial facilities, residential buildings, roads, and airports. As a result, the need to stabilize black cotton soil has become a pressing concern for experts. There are several methods available to improve the engineering properties of black cotton soil, but one of the latest techniques involves using bagasse ash as a stabilizing agent.

This paper investigates the effects of adding sugarcane bagasse ash to black cotton soil at varying percentages—2%, 4%, 6%, 8%, and 10%. The study aims to determine the optimal engineering properties achievable with these admixtures. The findings reveal that the best engineering properties of the black cotton soil sample are obtained with an 8% addition of bagasse ash.

It may, therefore, be concluded that addition of the sugarcane bagasse ash to the black cotton soil as an admixture enhances its engineering properties which are required for construction of various structures, highways, railways, airports, etc. maintaining safety, stability, durability and economy.

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Chapter - 17

Ground Improvement by Stone Column a Crucial Component for Infrastructure Development in India

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Chapter - 17

Ground Improvement by Stone Column a Crucial Component for Infrastructure Development in India

Sunil Priyadarshi and Samir Kumar

Abstract

Ground improvement is a critical aspect of infrastructure development, particularly in countries like India, where diverse soil conditions and rapid urbanization pose significant challenges to construction projects. This paper reviews various ground improvement techniques, their applications, and effectiveness in the Indian context. Stone columns have become a popular choice for stabilizing soft soils, finding increased application in supporting various structures. They offer a cost-effective and environmentally friendly solution for improving settlement and bearing capacity issues in soft soils. This paper conducts a comprehensive review to analyze the performance of stone columns across different types of constructions, including oil storage tanks, embankments, and buildings. The study investigates the impact of both encased and unencased stone columns on different construction types. It examines how various diameters and depths of stone columns in the ground affect their performance. Additionally, the use of different types of geosynthetics for encasement to enhance results is explored. Furthermore, the paper discusses the prediction of foundation settlement reinforced with stone columns through various numerical and physical approaches. It also explores the evolution of theories over time, from historical to contemporary, that aid in understanding the benefits of stone columns in improving soft soils. Physical modeling plays a significant role in developing geotechnical properties, contributing to advancements in this field. Overall, this paper provides valuable insights into the effectiveness and applications of stone columns in enhancing soft soil conditions across different construction scenarios.

Keywords: Stone columns, soil settlement, soil bearing capacity issues in soft soils.

Introduction

India's rapid urbanization and infrastructural growth necessitate robust and reliable ground improvement techniques to ensure the stability and durability of construction projects. The country's varied geological conditions, ranging from expansive clays to loose sandy soils, demand customized solutions for different regions. Ground improvement methods are vital for enhancing the mechanical properties of soil, thereby ensuring the safety and longevity of structures built on them. Emphasis is placed on methods such as soil stabilization, deep mixing, and the use of geosynthetics, highlighting their roles in enhancing soil properties, increasing load-bearing capacity, and mitigating settlement issues. The study also explores recent advancements and case studies to illustrate successful implementations of these techniques in Indian infrastructure projects. Ground improvement techniques are employed to enhance and modify poor ground conditions, ensuring that construction projects can meet performance requirements economically. With conventional foundations being costly and environmental concerns mounting, addressing weak soil deposits has become imperative. Among various methods, stone columns have emerged as a trending technique for bolstering weak strata. However, the design of stone columns remains largely empirical, often necessitating field trials before implementation.

Stone columns play a significant role in soil stabilization, particularly in enhancing soft clays, silts, and loose silty sands. They offer a cost-effective means of ground improvement, crucial in countries like India where land availability for infrastructure development is shrinking. Stone columns efficiently drain excessive pore water pressure upon load application, behaving as rigid elements to withstand higher shear stresses, thereby reducing settlement and enhancing the deformability and strength properties of soft soil.

Ground improvement techniques

Soil stabilization

Soil stabilization involves the addition of stabilizing agents to soil to enhance its properties. Common stabilizers include lime, cement, and fly ash. These agents react chemically with soil particles to improve strength, reduce plasticity, and decrease moisture sensitivity.

Applications in India

- Road construction in regions with expansive clay soils.
- Foundation improvement for residential and commercial buildings in urban areas.

Advantages

- Cost-effective.
- Enhances soil strength and durability.
- Reduces construction time.

Challenges

- Variability in soil types requires site-specific testing.
- Potential environmental impact of chemical stabilizers.

Deep mixing

Deep mixing involves the mechanical mixing of soil with cementitious materials at depth to form soil-cement columns. This technique is used to improve the load-bearing capacity and reduce settlement in weak soils.

Applications in India

- Construction of high-rise buildings in coastal cities with soft marine clay.
- Stabilization of embankments and slopes in hilly regions.

Advantages

- Significant improvement in soil strength and stiffness.
- Effective in a variety of soil conditions.

Challenges

- High initial costs.
- Requires specialized equipment and expertise.

Use of geosynthetics

Geosynthetics, including geotextiles, geomembranes, and geogrids, are synthetic materials used to reinforce soil and improve its mechanical properties. They are widely used in construction projects for filtration, drainage, separation, and reinforcement.

Applications in India

- Reinforcement of road bases and railway tracks.
- Construction of retaining walls and embankments.

Advantages

- Versatile and adaptable to different applications.
- Improves soil strength and stability.
- Reduces maintenance costs.

Challenges

- Requires careful design and installation.
- Initial material costs can be high.

Case studies

Soil stabilization in Delhi metro construction

The construction of the Delhi Metro faced challenges due to the presence of expansive clay soils. Soil stabilization using lime and cement significantly improved the bearing capacity of the soil, ensuring the stability of the metro tunnels and stations.

Deep mixing in Mumbai coastal projects

In Mumbai, deep mixing techniques were employed to construct high-rise buildings on reclaimed land with soft marine clay. The soil-cement columns provided the necessary support, preventing excessive settlement and ensuring structural integrity.

Geosynthetics in road construction in Northeast India

The use of geosynthetics in road construction in the Northeast region of India helped in stabilizing the subgrade and reinforcing the road base, resulting in durable and low-maintenance roads in this challenging terrain.

Recent advancements and innovations

Recent advancements in ground improvement technologies include the development of environmentally friendly stabilizers, innovative deep mixing techniques, and the use of smart geo synthetics that can monitor soil conditions. These innovations are enhancing the effectiveness and sustainability of ground improvement practices in India.

Literature review

This paper aims to review studies from past to present on the use of stone columns for ground reinforcement. Hughes *et al*. (1975) predicted the load-settlement relationship of single stone columns in soft clay through plate loading tests. Vibro replacement method is typically employed for column construction, with the ultimate column load depending on factors like column casting angle, size, and clay restraint. Encasement with geo synthetics can significantly improve column performance.

Gneil and Bouazza (2009) analyzed the behavior of geo grid-encased columns through small-scale model tests, noting significant stiffness improvement with increasing encasement length. Keykhosropur (2012) investigated the effects of varying encasement length on column groups through 3D numerical approaches, emphasizing the importance of accurate column diameter estimation for optimal design.

Ali *et al*. (2012) conducted model tests on stone columns of different depths, observing varied failure modes depending on configurations and reinforcements used. They concluded that encasement is ideal for end-bearing columns, with geogrid showing superior performance in certain scenarios.

Elsawy (2013) numerically analyzed the behavior of reinforced and unreinforced clay and geogrid-encased stone columns under embankment loading, noting significant improvements in bearing capacity and consolidation with encased columns.

Indraratna (2013) utilized finite difference methods to analyze soft soil embankments braced with stone columns, considering free strain behavior and factors like clogging and arching. Various studies, including those by Ali *et al*. (2014), Almeida *et al*. (2015), Baruah and Sahu (2016), Hong *et al*. (2016), Mohapatra *et al*. (2017), and Cengiz and Guler (2018), have further investigated the behavior and performance of stone columns under different conditions, reinforcing their efficacy in ground improvement endeavors. Ghazavi *et al*. (2018) conducted laboratory tests on encased and horizontally encased stone columns, highlighting their increased bearing capacity and reduced lateral bulging. Overall, these studies provide valuable insights into the behavior and effectiveness of stone columns in various ground reinforcement applications, offering guidance for future design and implementation efforts.

Stone columns

Stone columns, a form of ground improvement technique, are cylindrical structures made by inserting compacted stone or aggregate material into the soil. They are primarily used to enhance the load-bearing capacity and stability of weak or loose soil deposits. Stone columns are a widely used ground improvement technique, particularly effective in stabilizing soft soils. Recent advancements have focused on the encasement of stone columns with geosynthetics to further enhance their performance. This review aims to summarize the key findings from both experimental and numerical studies on the subject, providing insights into the design, construction, and optimization of stone columns in various configurations.

Purpose and application

Stone columns are employed when the existing soil at a construction site lacks the necessary strength to support structures like buildings, roads, embankments, or other heavy infrastructure. They are commonly used in areas with soft clay, silt, or loose sandy soils, where traditional foundation methods may not be adequate.

Construction process

The construction of stone columns typically involves drilling or vibro-compaction techniques to create vertical cavities in the ground. The cavities are then filled with compacted stone or aggregate material, usually gravel or crushed rock, using specialized equipment. The stone material is inserted into the cavities in thin layers, and each layer is compacted using vibration or other methods to ensure proper densification. The columns are constructed in a grid pattern across the area where soil improvement is needed, with spacing and depth determined by site-specific engineering requirements.

Mechanism of action

Once installed, stone columns function to improve the mechanical properties of the surrounding soil. They increase the soil's load-bearing capacity by providing vertical support and reducing settlement under applied loads. Stone columns also enhance soil drainage and reduce the risk of liquefaction in loose or saturated soils by facilitating the rapid dissipation of pore water pressure. Additionally, the presence of stone columns can improve the overall stability and stiffness of the ground, reducing the potential for soil movement or slope failure.

Types of stone columns

Stone columns can be classified based on various factors such as the method of construction, the type of stone material used, or the presence of encasement:

Displacement stone columns: Constructed by displacing the surrounding soil to create voids, which are then filled with stone material.

Replacement stone columns: Formed by removing soil and replacing it with stone material, typically using a drilling method.

Encased stone columns: Wrapped or encased in a geotextile or geosynthetic material to enhance their performance and durability.

Advantages

It is Cost-effective alternative to traditional ground improvement methods like deep foundations or soil replacement. It is also Rapid construction and installation, minimizing project duration and downtime. It is most suitable for a wide range of soil conditions and project requirements. Environmentally friendly option, as it reduces the need for excavation and disposal of soil material.

Limitations and considerations

Effectiveness of stone columns may vary depending on soil type, column spacing, and other site-specific factors. Design and construction must be carefully engineered to ensure proper column spacing, depth, and material selection.

Quality control measures are essential during construction to verify compaction and alignment of stone columns. Maintenance and monitoring may be necessary to assess long-term performance and address any potential issues.

In summary, stone columns are a versatile and effective solution for improving soil stability and supporting various types of construction projects. Their ability to strengthen weak soils, reduce settlement, and enhance overall ground performance makes them a valuable asset in geotechnical engineering and construction.

Codal provision for settlement computation

There are various theories for the analysis of settlement is stone columns. In this the IS method (IS 15284 Part I, 2003) is discussed:

Settlement of ground treated maybe estimated by using the Reduced Stress Method on the basis of stress concentration factor „n", the replacement ratio „as", Settlement „s" of a stone column. Reinforced soil can be written as

$S=\beta\Delta\sigma mvH$ … (1)

Where mv = coefficient of volume compressibility

β = settlement reduction ratio = Settlement of treated soil,

S= Settlement of untreated soil … (2)

$\beta = \mathbf{1/1}+(\mathbf{n-1})\mathbf{as}$ … (3)

n = stress concentration ratio = $\boldsymbol{\sigma}\mathbf{s}/\boldsymbol{\sigma}\mathbf{g}$ … (4)

σs= vertical stress in compacted columns

σg= vertical stress in surrounding ground

$\sigma g= \boldsymbol{\sigma}/\mathbf{1}+ (\mathbf{n-1})\mathbf{as}$ … (5)

$\sigma s= \mathbf{n}\boldsymbol{\sigma}/\mathbf{1}+ (\mathbf{n-1})\mathbf{as}$ … (6)

as = Replacement ratio = $\mathbf{As}/(\mathbf{As}+\mathbf{Ag})$ … (7)

AS = area of the stone column

Ag= area of ground surrounding the column

Experimental studies have demonstrated that the encasement of stone columns with geosynthetics significantly enhances their load-bearing capacity and reduces settlement. The encasement provides additional confinement, preventing lateral bulging and increasing the overall stiffness of the column.

Numerical studies

Numerical simulations have supported the findings of experimental studies, showing that geosynthetics encasement improves the performance of stone columns under various loading conditions. These studies help in understanding the behavior of encased stone columns in different soil types and under different loading patterns, facilitating optimized design and

Conclusion

Stone columns, particularly when encased with geosynthetics, offer a robust solution for improving the properties of soft soils. The choice between short, floating, and fully penetrated stone columns depends on the specific project requirements and soil conditions. While experimental and numerical studies have provided valuable insights into the benefits of geosynthetics encasement, ongoing research and site-specific studies are essential for advancing this ground improvement technique.

- Single vs. group arrangements: Stone columns can be constructed either as single units or in groups, depending on the specific requirements of the project. Group arrangements can be in triangular or square patterns, with the choice of pattern based on the loading criteria and the desired improvement in soil properties.
- Factors affecting performance: Several factors influence the performance of stone columns, including the type of geosynthetics used for encasement, the properties of the soil, the column diameter and spacing, and the loading conditions. Site-specific studies and tailored designs are crucial for maximizing the effectiveness of stone columns in improving soil properties.
- The stone columns designed are of types short, floating and fully penetrated. In short stone columns punching failure occurred while in fully penetrated stone columns bulging failure takes place. As now a days to fulfil the requirement of land more research is required in the field of construction of stone columns by using different types of geosynthetics according to the availability.
- The stone columns are constructed single or in groups depending upon the requirement. In group it maybe in triangular or in square pattern based on loading criterion. By using different type of factors according to the location different types of researches takes place to improve the properties of the soft soil. More research is to be required for the same.

Future research directions

The reviewed literature highlights the significant benefits of using geosynthetics for encasing stone columns. However, more research is needed to explore the use of different types of geosynthetics based on local availability and to optimize the design and construction techniques for various soil conditions. Additionally, there is a need for long-term performance studies to evaluate the durability and effectiveness of encased stone columns over time.

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Chapter - 18

Performance Characteristics of Reclaimed Asphalt Pavement (RAP) Materials in Construction of Flexible Pavements

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Chapter - 18

Performance Characteristics of Reclaimed Asphalt Pavement (RAP) Materials in Construction of Flexible Pavements

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Abstract

An efficient road network is crucial for fostering a country's rapid economic growth by improving connectivity to remote areas and supporting diverse transport activities. India has an extensive road network covering approximately 4.2 million kilometers, making it the second largest globally, surpassed only by the United States. Most of these roads have bituminous surfaces, which require periodic resurfacing for maintenance. This recurring maintenance has led to roads being elevated above surrounding properties in urban areas. To address this issue, roads can be lowered to the required and feasible depth through a milling process, followed by resurfacing with a suitable layer of bituminous mixes, either replacing the entire or partial bituminous pavement. The materials obtained from the milling process are known as Reclaimed Asphalt Pavement (RAP). This study involves collecting and analyzing RAP samples to assess their suitability for use in flexible pavements.

Reclaimed Paving Materials (RPM) offer a promising solution for road construction due to their availability and potential for cost savings. By reusing RPM materials, we can reduce the consumption of fresh aggregates, conserve natural resources, and minimize waste generation. However, the effective use of RPM in the granular sub-base requires optimization techniques and careful consideration of various factors. Therefore, recycling pavements is an efficient solution for road construction and maintenance, providing significant advantages such as cost savings, environmental preservation, and the conservation of virgin materials.

Keywords: Reclaimed Paving Materials (RPM), Flexible Pavement, Ministry of Road Transport and Highways (MoRTH), road construction method.

Introduction

Indian road network, its growth & future

Road transport is regarded as one of the most economical and favored modes of transportation for both freight and passengers, owing to its flexibility and accessibility. Unlike railways or airways, road transport offers maximum service to users and serves as a feeder system for both. Besides these basic advantages, road transportation has become the backbone of a country's economy, supporting industrial development and providing economic benefits associated with infrastructure projects. Consequently, developing a modern road network has become a top priority for many countries.

In India, the road network has gradually evolved over the years, currently ranking second globally in total length, just behind the United States. Significant financial investments and raw materials are required for ongoing and future road development projects. According to the Indian Roads Congress's special publication, 'Road Development Plan VISION: 2021,' an estimated 3500 million cubic meters of aggregates and 11.25 million tons of bitumen will be needed for road construction (IRC, 2001). As modernization and travel demands continue to increase, these investments are expected to rise. Thus, India needs to implement advanced methodologies for road construction and maintenance to minimize investments and reduce the need for raw materials. Recycling aggregates involves reusing used aggregate for new construction. Although not very common in India and other developing countries, recycled aggregate can significantly reduce the demand for fresh aggregate, especially given the rapid infrastructure development. In this study, recycled aggregate is obtained from the debris of dismantled roads. A well-connected road network is essential for a country's overall development, and various construction materials, including different grades of aggregate and binding materials, are used in road construction.

The success of recycling is attributed to its benefits over conventional methods, notably cost savings and environmental preservation. These benefits are crucial as governments seek to conserve budgets and the global focus shifts toward environmental sustainability through 'Green Technology.' Therefore, recycling pavements is an efficient solution for road construction and maintenance, offering significant benefits such as cost savings, conservation of virgin materials, and environmental preservation. It is a viable alternative for Indian roads to reduce construction costs and sustain raw material sources. High Reclaimed Paving Materials (RPM) mixtures have shown performance characteristics comparable to conventional mixes, further encouraging the adoption of recycling practices in pavement construction and maintenance. Large volumes of Reclaimed Asphalt Pavement (RAP) materials are produced during highway maintenance and construction activities. While some of these materials are reused in new hot mix asphalt concrete, the remainder is available for alternative applications. Utilizing these materials for the base and sub-base layers of roads not only mitigates environmental impact but also reduces waste and transportation costs associated with road maintenance and construction.

This review aims to thoroughly examine current practices and identify effective strategies for maximizing the utilization of Reclaimed Paving Materials (RPM) in the granular sub-base of village roads. The properties of RAP materials can be improved by blending them with aggregates and adding chemical stabilizers. The increase in construction and demolition wastes in recent years has posed challenges in waste disposal due to limited landfill availability. Recycling these materials presents a viable solution, and using recycled road aggregate generated on-site can result in significant cost reductions. 25 to 30%.

The production of Reclaimed Asphalt Pavement (RAP)

Reclaimed Asphalt Pavement (RAP) materials are derived from the removal and reuse of the asphalt layer from existing pavement. This process is known as RAP. Full Depth Reclamation (FDR) goes further by including the removal and reuse of both the hot mix asphalt layer and the entire base course. RAP materials can either be immediately reused at construction sites or stockpiled based on project needs. Achieving the desired gradation of RAP requires pulverizing the material using a crusher. The utilization of Reclaimed Paving Materials (RPM) is an emerging technique in India, holding promising benefits for both the government and contractors in terms of efficiency and cost savings. Although research on RPM in India is still limited, it is extensively employed in the United States and various other countries, offering valuable insights into best practices. To improve mix design and ensure quality control, ongoing advancements are being made in RPM sampling, testing, and material characterization. These efforts are targeted at supporting contractors and transportation departments in optimizing the utilization of RPM in road construction. Assessments based on regional requirements cover a range of factors, including low-temperature testing, rutting susceptibility, cracking resistance, moisture susceptibility, and mixture stiffness. Evaluating these parameters is critical to guaranteeing the pavement's performance and long-term durability. By continuously refining these techniques and assessments, the industry aims to enhance the effectiveness of RPM integration, leading to more resilient and long-lasting pavements. The bituminous industry continues to strive for an enhanced understanding of the correlation between performance tests and real-world field performance. Ongoing efforts focus on identifying the most effective performance tests that can accurately predict the behavior of RPM mixes under different conditions. This research helps pave the way for informed decision-making and improved quality assurance in RPM utilization.

Literature review

This study will extensively analyze various methodologies and techniques used in previous research and projects to gain valuable insights into the performance, durability, and structural integrity of Reclaimed Paving Materials (RPM)-based granular sub-base layers. Before incorporating such materials, it is crucial to conduct mechanical property tests and implement suitable blending if necessary. Among the most commonly used recycled materials are Reclaimed Asphalt Pavement (RAP) materials and recycled concrete aggregate (RCA). RAP and RCA generate high-quality aggregates with excellent grading. The asphalt coating on RAP aggregates reduces water absorption, enhancing their performance in construction applications.

The findings from this study will contribute to developing sustainable road construction and maintenance practices, aiming to minimize costs, reduce dependency on raw materials, and enhance the overall quality and longevity of village roads. Ultimately, this review aims to advance the state of knowledge in this field, encourage the widespread adoption of RPM in granular sub-base applications, and promote more environmentally friendly and economically viable road development practices in India.

Studies on recycling

Terrel R.L. and Fritchen D.R. (1978)

Research on "Performance of Recycled Asphalt Concrete" evaluated the performance of recycled mixes compared to control mixes using resilient modulus (MR) testing. Resilient modulus measures the pavement material's ability to recover its shape after deformation from traffic loads. Accelerated aging procedures, involving alternating freezing and thawing cycles, simulated harsh moisture conditions, allowing researchers to determine the recycled mixes' ability to withstand repeated freeze-thaw cycles.

Mc-Bee *et al*. (1988)

The "Detailed Evaluation Study on Recycled Mixes" combined field and laboratory evaluations. The study suggested that using a rejuvenator in recycled bitumen mix would decrease potential rutting and increase the recycled pavement's lifespan.

Kandhal P.S. *et al*. (1995)

"A Laboratory Study of Recovered Binder and a Detailed Evaluation on Recycled Mixes in Georgia" analyzed the blending process of RPM with a fresh mixture. Screened RPM was mixed with new coarse aggregate in various percentages. Findings revealed that only a minor portion of aged bituminous in RPM actively participated in the remixing process.

Mansour Solimanian, Thomas W. Kennedy, Weng O. Tam (2006)

"Effect of Reclaimed Paving Materials on Binder Properties Using the SUPERPAVE System" aimed to establish guidelines for integrating RPM into bituminous mixes, following SUPERPAVE binder specifications. The study found that increasing RPM binder percentage consistently increased binder stiffness, particularly at lower temperatures. These insights guide engineers in optimizing RPM usage and ensuring proper pavement performance.

West R. *et al*. (2009)

The study concluded that recycled pavement sections performed well on the test track under heavy loading conditions, suggesting that using recycled materials in pavement construction is a viable and effective option.

Valdes G. *et al*. (2010)

"A Study on Recycled Asphalt Mixes Containing Higher RPM Percentages" aimed to rehabilitate a highway section using semi-dense mixtures with maximum aggregate sizes of 12mm and 20mm, containing 40% and 60% RPM, respectively. The results indicated that RPM content up to 60% could be effectively incorporated into recycled mixes with proper handling and mix design practices.

Eric J. McGarrah (2010)

"Evaluation of Current Practices of Reclaimed Asphalt Pavement/Virgin

Aggregate as Base Course Material" assessed previous studies on 90% RPM mixtures and RPM-virgin aggregate blends. The report recommended a maximum of 27% RPM to minimize variability and ensure reliable performance outcomes.

Montepara, Tebaldi, Marradi, Betti (2012)

"Effect of Pavement Performance of a Subbase Layer Composed by Natural Aggregate and RPM" evaluated the effects of a sub-base layer mixture of 50% natural aggregates and 50% RPM on pavement performance. The study emphasized RPM recycling's economic benefits, infrastructure improvement, and job creation.

Khushbu M. Vyas, Shruti (2013)

"Technical Viability of Using Reclaimed Paving Materials in Ahmedabad BRTS Corridor for Base Course" found that a mix of 60% RPM, 30% aggregates of 40mm size, and 10% stone dust met performance requirements, indicating the material's suitability for use.

Sharma Jitender, Singla Sandeep (2014)

"Study of Recycled Concrete Aggregates" examined the properties of recycled aggregates and their potential applications in construction, highlighting their suitability for aggregate base courses in roadway pavements.

Singh Veresh P., Mishra Vivek, Harry N.N., Bind Y.K. (2014)

"Utilization of Recycled Highway Aggregate by Replacing it with Natural Aggregate" found that replacing up to 30% of fresh aggregate with recycled aggregate resulted in a slight increase in maximum dry density but a minor decrease in CBR value due to lower recycled aggregate strength.

Rao Maulik, Shah N.C. (2014)

"Utilization of RPM (Reclaimed Asphalt Pavement) Material Obtained by Milling Process" demonstrated that incorporating 20%, 40%, and 60% RPM into black cotton soil increased CBR values and reduced virgin material use, highlighting cost and resource savings.

Sreedhar N., Mallesha K. M. (2019)

"Cost Analysis of Low Volume Rural Roads Using RPM Materials as G.S.B." highlighted that using RAP in GSB could lead to significant cost savings and sustainable road construction practices.

Singh Jaspreet, Singh Jashanjot, Duggal A.K. (2023)

"A Review Paper on Reclaimed Paving Materials (RPM)" emphasized the feasibility of adopting RPM in various flexible pavement layers, reducing environmental impact and preserving natural resources.

Singh Jaspreet, Duggal A.K. (2021)

An Experimental Study on Reclaimed Paving Materials (RPM) Dense Bituminous Macadam" found that incorporating 30% RPM in asphalt mixes yielded comparable or superior results to virgin mixes and achieved significant cost reductions.

In conclusion, recycling bituminous pavements has evolved into a well-established methodology for pavement rehabilitation and construction. Extensive research has demonstrated the comparable performance of high RPM mixtures, encouraging the industry to adopt recycling practices. This approach reduces construction costs, supports environmental sustainability, conserves resources, and minimizes waste generation. Ministry of Road Transport & Highways as per circular no: RW/NH-33044/10/2021-S&R(P&B) (171909) dated 15th march 2023, has instruct DPR consultants to evaluate RAP and appropriately factored in the pavement layers (for existing road to standard 2lane/4lane/6 lane) during preparation of cost estimation.

Tests on RAP aggregates

Bitumen extraction test

The bitumen extraction test is an essential procedure used to determine the percentage of bitumen content in a bituminous mixture. This test helps in evaluating the quality and suitability of bituminous materials used in road construction and maintenance. Accurate determination of bitumen content ensures that the pavement will have the necessary properties to perform well under traffic loads and environmental conditions. The bitumen extraction test is a crucial quality control measure in the construction and maintenance of bituminous pavements. Accurate determination of bitumen content helps ensure the durability and performance of the pavement, leading to safer and longer-lasting roadways.

Table 3.1: Bitumen extraction results

Description	1	2	3
Weight of total sample (A), in gram	500g	500g	500g
Weight of extracted sample (B), in gram	492 g	491 g	490 g
Bitumen content (%), in gram	1.6	1.8	2.0
Average Bitumen content (%)	= 1.8%		

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Result

The existing Binder content (bitumen) in RAP as per result =**1.8%**

The existing binder content in the RAP sample, as determined from the bitumen extraction test, is 1.8%. According to the IRC guidelines, specifically IRC: SP:98-2013 "Guidelines for the Use of Reclaimed Asphalt Pavement in the Hot Bituminous Mixes (HMA)". Given the existing binder content of 1.8% in the RAP, the mix design should be adjusted to incorporate additional fresh bitumen to meet the specified total binder content as per IRC guidelines. Proper evaluation of the aged binder's quality and compatibility with new bitumen is essential to ensure the performance and durability of the pavement. The use of RAP not only supports sustainable construction practices but also offers significant economic benefits by reducing the demand for virgin materials.

Environmental and economic benefits

- Using RAP with a known binder content contributes to sustainability by reducing the need for virgin materials and minimizing waste.
- Cost savings can be achieved by utilizing the existing binder content in RAP, thus lowering the amount of new bitumen required.

Aggregates impact value test

Toughness is the ability of a material to withstand impact. During the construction of pavement layers, especially during compaction by heavy rollers and the movement of heavy traffic loads, road aggregates are subjected to significant impact or pounding. This can cause some stones to break into smaller pieces. Therefore, stone aggregates must be sufficiently tough to resist fracturing under impact loading.

Table 3.2: Aggregate impact value test

Description	1	2	3
Weight Sample+ Cylindrical weight = W (gm)	2200	2150	2165
Weight of Cylindrical =w_c (gm)	1735	1735	1735
Weight of taken aggregate sample w_1 =w-w_c (gm)	465	415	430
Weight of Aggregate retained on 2.36 mm I:SSieve,W_2 (gm)	48	53	50
Aggregate Impact Value (%)	14.3	12.77	15.6
Average Impact Value	= 14.50%		

The Aggregate Impact Value of RAP =14.50%.

The Aggregate Impact Value (AIV) of RAP is determined to be 14.50%. According to IRC guidelines, specifically IRC: SP:98-2013 "Guidelines for the Use of Reclaimed Asphalt Pavement in the Hot Bituminous Mixes (HMA), The Aggregate Impact Value of 14.50% for RAP is well within the acceptable limits set by the IRC for various pavement layers. This indicates that the RAP aggregate is strong and durable, making it suitable for use in base, sub-base, and surface courses. The excellent AIV of the RAP aggregate will contribute to the overall performance and longevity of the pavement. Additionally, using RAP aggregates aligns with sustainable construction practices and offers significant economic benefits by reducing the reliance on virgin materials.

Cost and environmental benefits

Utilizing RAP with an acceptable AIV contributes to sustainability by recycling existing materials and reducing the demand for new aggregates. Practice also may offer cost savings by minimizing the need for procuring fresh materials and reducing waste disposal costs.

Specific gravity and water absorption tests

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values.

Table 4.3: Water absorption values for aggregate samples

Description (gm)	**1**	**2**	**3**	**Average value**
Saturated aggregate suspended in water with the basket, W_1(g)	2536	2518	2590	
Weight of basket suspended in water, W2, (g)	745	745	745	
Saturated aggregate in water, $W_S = W_1 - W_2$, (g)	1791	1786	1845	
Saturated surface dry aggregate in air, W_3	2783	2840	2861	
Oven dried aggregate in air, W_4	2759	2819	2831	
Specific Gravity, G	2.78	2.67	2.79	2.746
Water Absorption (%), w	0.87	0.74	1.06	0.89

Mean value of Specific Gravity, G = 2.75
Mean value of Water Absorption (%), w= 0.90%

The specific gravity value of aggregates is used for weight-volume

ISBN:

conversions and calculating void content in compacted bituminous mixes. Water absorption provides an indication of the rock's strength, with higher water absorption signifying more porosity and generally unsuitable stones unless they meet strength, impact, and hardness tests.

Water absorption test: Water absorption gives an idea about the strength of aggregate. Aggregates with higher water absorption are more porous and typically considered unsuitable unless proven acceptable based on strength tests. The water absorption value of RAP aggregate is 0.98%, which is well below the permissible limit, indicating that RAP is suitable for partial replacement of fresh material from the water absorption perspective.

Specific gravity test: The specific gravity of aggregates depends on their origin and type, generally ranging from 2.5 to 2.8. The specific gravity of RAP obtained in this test is 2.75, which falls within the permissible limits, making it satisfactory for road construction.

Gradation test: The material obtained from milling varied greatly in size, necessitating uniform sizing to comply with specified gradation limits for layers. Samples were taken to determine the percentage passing for each sieve size as per IS: 2386. Establishing uniform sizing of the material is essential for complying with gradation limits. The first step after collecting the material was to determine its gradation. The samples were analyzed to fix the percentage passing for each sieve size as per IS: 2386. Various sizes of material, stone dust, and recycled material were used to develop the Job Mix Formula (J.M.F.) based on the percentage passing limits for each sieve size as per MoRTH specifications.

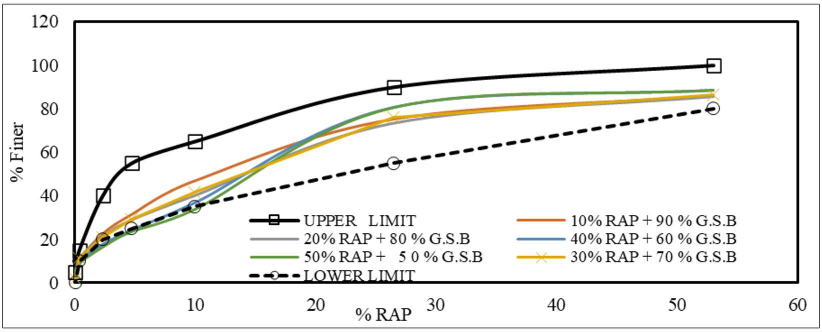

Fig 5.1: Mix design of (fresh) with recycled aggregate

In above figure upper and lower line show the upper and lower limit of the adopted value and middle line show the adopted value for in recycled and fresh aggregate. The mix design is done by analytical method and presented in graphical form in above Fig. 5.1. The combination of 70% of fresh + 30% RAP is best optimum for acceptable range. So conclusion can be made that up to 30% of RAP may be used in construction.

Green technology approach

The protection of the natural environment is one of the fundamental duties of every citizen under Article 51-A of the Constitution of India. The Environment (Protection) Act and Rules, 1986, were enacted and came into force on November 19, 1986. Article 48-A of the Constitution obliges the State to endeavor to protect and improve the environment and to safeguard the forests and wildlife of the country. In adherence to Articles 51-A and 48-A, many state governments have banned numerous quarry sites in India. These articles promote environmental protection, aiming to limit negative physiological, hydrological, and social impacts while supporting sustainable economic growth.

A significant volume of aggregate is used in the construction of roads and buildings, and the demand for these materials continues to rise in our country. However, activities associated with aggregate extraction and processing can raise environmental concerns. These concerns include the potential for increased dust, noise, and vibrations; physically altered landscapes and habitats; and impacts on surface and groundwater.

Conclusions

The following conclusions are drawn from the present study:

- The RAP that is obtained may vary in composition in terms of grading. The gradation of RAP is different from grading. It was observed that the large size of aggregates were deficient in RAP mix due to the action of crushing and aging. In order to meet the required gradation numbers of trials were made with natural aggregate and by adding different percentage 10%, 20%, 30%, 40%, 50% of RAP mix. Combination of 30% RAP and 70% (Fresh) was found to fulfil the optimum required grading -V as per MoRTH.
- Aggregate Impact Value of RAP was found to be 14.5% which is less than the 30% (maximum permissible limit) as per MoRTH specifications for (Grading -V). Hence the material is satisfactory from strength criteria.

- The specific gravity of aggregates (RAP) was found 2.75 and the water absorption of aggregates value was 0.90%, which are within the specified limits. So, material can be used as granular materials.
- In general, RAP with lower binder content can be used in Granular works.
- The use of recycled aggregate in road construction in will not only result in achieving economy in the road projects, but also minimizes mining pollution.
- Recycling aggregate from the demolition projects can save the cost of transporting the material to the land fill, and the cost of disposal.

Recommendations

From the above studies it is evident that old to very old RAP can be effectively used as raw material in. The optimum percentage of the RAP has been determined is 30% in present study. This value cannot be treated as fixed and should be determined on experimental data. The optimum value with different RAP may vary based on the properties of RAP e.g. binder content, grading etc. However, it may be in the vicinity of the findings of the present study. Very old or aged RAP will give better performance used in as they are deficient of residual binder and RAP is similar material as an aggregate blend.

Limitations

From the above studies, the value of optimum percentage of the RAP determined, i.e. 30% cannot be treated as fixed optimum percentage. Optimum percentage with different RAP may vary based on the properties of RAP e.g. binder content, grading etc.

Future scope

This research study was mainly involved with the physical properties of recycled materials. Similar studies with different types/quality of RAP may be conducted to substantiate the findings of this study. The residual binder content is a key factor. RAP with higher binder contents find better use in bituminous mixes. Studies involving an examination of the chemical properties and their ability to perform as granular material for drainage purpose when used in dams or other similar applications. The investigation did not include a full examination of the contaminants of RAP for sub base and base. Another possible research project would be determination of the effect of impurities like debris or variying quantities of brick, soil etc. The effect of these contaminants on the permeability, shear strength, elastic analysis of RAP would be another intersting reaserch subject.

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Chapter - 19

Optimization of Process Parameters of Gas Metal Arc Welding Using Taguchi Method

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Chapter - 19

Optimization of Process Parameters of Gas Metal Arc Welding Using Taguchi Method

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Abstract

Achieving good welding quality is one of the major challenges in gas metal arc welding. Welding processes parameters significantly affects the quality of welding and needs to be optimized to ensure quality weld. The principal processes parameters affecting the weld quality are welding current, welding voltage, welding speed, and gas flow rate. Taguchi technique and ANOVA is an efficient method for optimizing the quality and performance output of manufacturing processes. Accordingly, Taguchi and ANOVA has been employed to optimize the process parameters. In addition, a comparison of the strengths of the various welded joints obtained by the gas metal arc welding Process has been presented. Welding voltage turns out to be the most important parameter of tensile strength and hardness.

Keywords: GMAW, Metal, MS2062, tensile test, hardness, taguchi, S/N ratio.

Introduction

Welding is the technique of permanent joining of similar materials by applying heat with or without pressure and with or without adding filler material[1]. This preserves the same materials, structures, and properties as the two joined parts. Welding is widely used in manufacturing as a separate casting or forging process and as an alternative to riveted and bolted joints. It's also used as a method of fixing that is, assembling a metallic piece at a time or producing small parts[2].

This paper predicts and fully manipulates gas metal arc welding for some of the same economically significant or similar items in the industry by using mathematical methods. This was attained by monitoring the selected weld parameters to match the rigid retention power to the selected welding input parameters. This result demonstrates better tensile storage capacity for predictable power and MIG use in the welding industry, leading to efficient selection of machine parameters to obtain better tensile final strength. Gas metal arc welding (GMAW) welding is an arc welding process. In this process, consumable electrodes are used. A roll of wire is used to supply the electrode. In this process, heat is generated because they are in between the electrode and workpiece. Here, solid wire type electrodes are continuously supplied to the weld zone. When consumed, it becomes a filler metal. The burning of gas or an electric arc is the main reason behind the heat that fuses the material. This method is most broadly used because of its greater welding speed.

Pujari *et al.* [3] conclude that the experimental results were correlated using Taguchi techniques and utility concepts to determine the effect of GMAW process parameters on the welding of AA7075-T6 aluminum alloy. They chose process parameters like quality of penetration, face width, and back width. The results revealed that optimal process parameters for GTAW are critical for achieving maximum penetration while also maximizing face width and back width. An ANOVA was applied to create a predictive model, assess its adequacy, and identify significant factors. According to ASTM E155, radiological analysis was also performed and found to be free of cracks, low porosity, and acceptable. Amit *et al.*[4] look into welding 304 stainless steel and medium carbon steel 45C8 and reported yield strength, high storage capacity, welding hardness, dense bead thickening, and welded joint strength. Manipulating different processes parameters, the experiment was designed using the Taguchi method. According to ANOVA and S/N ratio analyses, the process parameters that affect the most responses are current welding. The stiffness of the welded area decreases as the welding current increases. It has been observed that as increase in welding current results higher thicker weld bead with decrease in stiffness. Small metal structures, both in HAZ and welding areas, have been analyzed. Major process parameters alongwith contact tip-work distance, type of shielding gas, etc. were examined by Shekhar *et al.* [5] analyzed the response surface method on IS: 2062 mild steel to optimize GMAW process parameters. According to the results of the analysis, wire feed rate was found to be the most effective parameter, followed by voltage and travel speed, and gas flow rate was the least effective parameter. Erdal *et al.*[6] carried out research on penetration in robotic gas metal arc welding processes in order to observe the impact of process parameters such as welding current, arc voltage, and welding speed. They discovered that increasing the welding current deepened the penetration. The results also revealed that arc voltage is an important parameter in the detection of penetration. Haragobal *et al*. [7] have developed process parameters for optimizing the mechanical characteristics of weld samples for aluminum alloy used in the fabrication of aerospace wings.

In this MIG welding setup, process parameters such as current, groove angle, gas pressure and pre-heat were taken into account. It was reported that the most influential parameter for proof stress was current. In the work of Praveen *et al*.[8], the weld microstructure, hardness, and rigidity were investigated. They chose three information variables and moved them up three levels. Similarly, nine tests were conducted using the Taguchi method's L9 orthogonal array and three knowledge variables. The analysis of variance (ANOVA) was used to establish the degrees of noteworthiness of information variables. The root hole has the greatest influence on elastic behaviour, followed by the welding current and voltage. The voltage of the circular section, followed by the root hole and welding current, has a significant effect on its hardness. Fine grains of ferrite and pearlite make up the microstructure of weld metal. *et al*.[9] analyses the implications of welding parameters such as current welding, gas flow rate, and nozzle distance from the plate on tensile (UTS) storage capacity and percentage (PE) in MIG welding processes of AISI409 ferritic stainless-steel materials. The Taguchi method's L9 orthogonal sequence was used for the test. Observation and X-ray radiographic inspection were also carried out to detect more and lesser failures in welded specimens. The Taguchi technique and signal-to-signal noise ratio analysis were used to interpret, discuss, and analyses data from UTS and PE. Mohanavel *et al*.[10] performed experimental and numerical analysis of the AA6061 TIG welding process. The parameter combination was carefully chosen in order to produce a weld with higher impact strength. Shanmugasundar *et al*.[11] examine the butt weld joints made with three different levels of current, gas flow rate, and nozzle to work piece distance. The weld quality has been calculated using the ultimate tensile strength of the welded specimens. The welding process parameters were optimized in this paper using Taguchi's and analysis of variance methods. Chellappan *et al*.[12] performed tungsten inert gas welding on super martensitic stainless steel using the technique for order preference by similarity to ideal solution method (TOPSIS). Stainless steel martensitic is far superior to low-alloy steel, which is commonly used in the gasoline industry. TIG welding was carried out using the Taguchi orthogonal array approach. The input process parameters considered for this function were welding voltage, operating current, flow speed, and shielding gas flow rate. Weld quality was determined by measuring bead width, depth penetration, and weld hardness. TOPSIS was used to create multi-purpose performance features. Metallographic analysis of the best and worst welds in terms of bead geometry and hardness was also carried out. The final results of the experimental investigation demonstrated that the method can successfully improve welding quality.

Methodology

Selection of material

Mild steel is one of the most common materials in several industries and hence selected in the present work. As a base material, IS 2062 mild steel has been taken. It has exceptional weldability and machinability, which has caused an increase in its usage. Mild steel is one type of steel with low carbon. Essentially, carbon steel is a material that includes a small percentage of carbon, usually 2.1%, that increases the characteristics of pure iron. Mild steel chemical composition is presented in the table 1. There are absolutely exceptional grades of steel. However, all of them have carbon content within the previous limits. Elements are also value-added to enhance beneficial properties like corrosion resistance, wear resistance, and tensile strength.

Table 1: Mild steel 2062 composition

Element	**C**	**Mn**	**S**	**P**	**Si**
w%	0.2	1.55	0.045	0.045	0.45

Welding variables

The experimental process parameters and their operating range data were selected. Table 2 lists the chosen process parameters and their values.

Table 2: Welding variables with their levels

Variable	**Notation**	**Level**			
		1	**2**	**3**	**4**
Welding current (Amp)	A	120	130	140	150
Arc voltage (Volts)	V	26	27	28	29
Welding speed(mm/sec)	S	6.42	7	8	9.5
Gas flow rate (Lit/min)	G	10	11	12	13

Experimental Details

The machine used in the experiment is a welding/cutting transformer.

Maximum power supply 400 volts. This GMAW machine is equipped with an automatic metal inert gas torch and an automatic supply unit.

Experimental input parameters

Experimental input parameters are welding voltage, welding current, gas flow rate and welding speed. Tensile strength and hardness have been measured as output results.

Taguchi methodology

In Taguchi methodology, the undesired value or standard deviation of output characteristic depicted by the noise whereas the mean value by term signals. Therefore, the signal-to-noise ratio is used to measure off-target quality attributes. The signal-to-noise ratio η is defined as follows:

η = 10log (MSD), MSD refers root-mean squared deviation of the output characteristics. Higher selection of penetration quality features is required for optimum welding performance. MSD can be expressed as:

$$\text{M.S.D} = \frac{1}{m}\sum\frac{1}{P_1^2}$$

Where, P_1 is the value of penetration.

Experimental results

Table 4: Result of tensile strength and hardness with S/N ratio

Weld run	Current(amp)	Voltage (volt)	Gas flow rate (lit/min)	Welding speed (mm/sec)	Tensile strength (Mpa)	S/N Ratio	Hardness (HRB)	S/N Ratio
1	120	26	10	6.42	460.667	53.26774	79	37.95254
2	120	27	11	7	421.333	52.49251	65	36.25827
3	120	28	12	8	406.667	52.18478	60	35.56303
4	120	29	13	9.5	449.405	53.05276	73	37.26646
5	130	26	11	8	440	52.86905	75.33	37.53936
6	130	27	10	9.5	444	52.94766	74.23	37.41159
7	130	28	13	6.42	437.33	52.81619	74.6	37.45478
8	130	29	12	7	420	52.46499	66	36.39088
9	140	26	12	9.5	470.667	53.45427	85	38.58838
10	140	27	13	8	452.333	53.10917	82	38.27628
11	140	28	10	7	454.667	53.15387	72	37.14665
12	140	29	11	6.42	434.667	52.76313	73.19	37.28904
13	150	26	13	7	460.6	53.26648	81.45	38.21782
14	150	27	12	6.42	413.667	52.33302	64	36.1236
15	150	28	11	9.5	411.667	52.29092	61	35.7066
16	150	29	10	8	411.333	52.28387	60	35.56303

Larger signal-to-noise ratio values improve the performance of these parameters, regardless of the performance characteristics of the category.

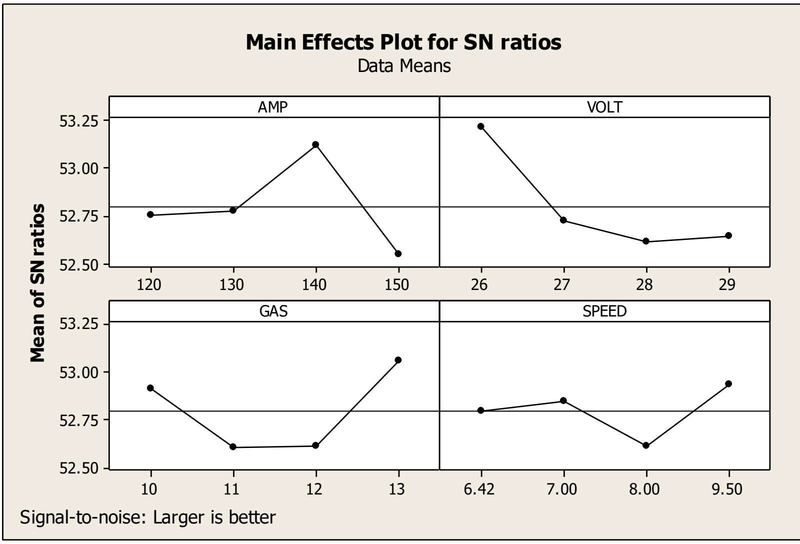

Fig 1: Plot of mean signal-to-noise ratio and level of tensile strength parameter

In this investigational analysis, optimum tensile strength was estimated using main effect plot. This graph is plotted between the mean signal-to-noise ratio and the input parameters for current, voltage, gas flow, and weld rate. Maximum tensile strength requires a current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 liters / minute, and a welding speed of 9.5 mm /sec. Result of tensile strength and hardness is tabulated in Table 3. Further, results of tensile strength with S/N ratio have been listed in Table 4 and corresponding response is tabulated. Furthermore, the variation of strength and S/N ratio has been shown in Fig. 1.

Anova for tensile strength

Table 3 details the study of tensile strength vs. parameters applied in this experiment using Minitab 16. This shows that the response parameter factor is important, if the values of probability (P) are less than 0.05.

Table 5: Analysis of variance of ultimate tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
AMP	3	1713.38	1713.38	571.13	42.35	0.006	27.30
VOLT	3	2450.46	2450.46	816.82	60.58	0.003	39.06

GAS	3	1544.20	1544.20	514.73	38.17	0.007	24.61
SPEED	3	565.69	565.69	188.56	13.98	0.029	9.01
ERROR	3	40.45	40.45	13.48	--	--	0.02
TOTAL	15	6314.18	--	--	--	--	100

From the results of ANOVA, the processes parameters affect the tensile strength, and the P of the voltage against input parameter is 0.003, which is the lowest, so it has a great influence on tensile strength. The voltage (0.006), is lower than the P-value of the current, the P-value of the gas flow rate is less affected than the voltage (0.007). The P-value for welding speed is the maximum among three parameters, 0.029, so it has less effect on tensile strength. The effect of individual processes parameters has also been investigated. The voltage contribution rate is 39.06%, the current is 27.30%, the gas flow rate is 24.61%, the welding speed is 9.01%, and the error is 0.02%. Machining vibration is the reason of error.

Measurement of hardness

Brinell hardness number has been measured for each specimen. The results for hardness response are tabulated in Table 4 and corresponding S/N ratio has been presented in the Table 4 and corresponding. Furthermore, the variation of hardness and S/N ratio has been shown in Fig. 2. The higher hardness value has a great effect on the welded joints, that's why the higher is better signal-to-noise (S/N) ratio is selected for calculation. S/N ratio is assessed using Minitab software.

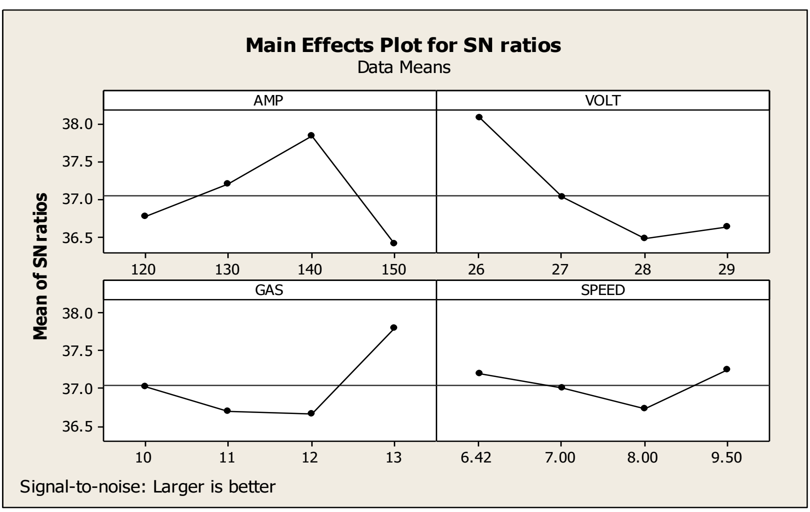

Fig 2: Mean S/N ratio and levels of parameters for hardness

The main effect plot was utilized to evaluate the hardness under ideal conditions in this experimental investigation. The mean S/N is represented against the input process parameters in this graph. A current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 litres per minute, and a welding speed of 9.5 mm per second are required for maximum hardness.

ANOVA for hardness

Table 6 details an ANOVA investigation of hardness vs. current, voltage, gas flow rate, and welding speed employing Minitab 16 software. This demonstrates the significance of the response parameter factor, if the probability (P) values are less than 0.05.

Table 6: ANOVA of Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
Amp	3	291.404	291.404	97.135	72.06	0.003	29.61
Volt	3	434.677	434.677	144.892	107.49	0.001	44.16
Gas	3	220.019	220.019	73.340	54.41	0.004	22.35
Speed	3	37.995	37.995	12.665	9.40	0.049	3.86
Error	3	4.004	4.004	1.348	--	--	0.02
Total	15	988.138	--	--	--	--	100

The current, voltage, gas flow rate, and welding speed are all influencing parameters for hardness, with the p value of voltage being the lowest at 0.001, indicating that this parameter is highly influencing on hardness. The p value of current is higher than voltage at 0.003, indicating that this parameter is less influencing on hardness than voltage. Because the p value of gas flow rate is 0.004, it is a very low influential parameter when it comes to hardness. The welding speed has the highest p-value of all values, 0.049. As a result, these parameters have less of an impact on hardness. The above results also revealed how individual process parameters affect the hardness of the GMAW process. The welding voltage contributes 44.16 percent, the welding current contributes 29.61 percent, the gas flow rate contributes 22.35 percent, the welding speed contributes 3.86 percent, and the error contributes 0.02 percent. The cause of this error is machining vibration.

Confirmation test

A conformational experiment performed to verify the initial experimental results obtained and conclude the experiment. The signal-to-noise ratio predicted using the optimum values of welding parameters can be calculated as follows:

$$\eta_{opt} = n_m + \sum_{i=j}^{n} (n_j - n_m)$$

where, n_m signifies total mean of S/N ratio, n_i signifies mean of S/N ratio at optimized level, and n denotes the number of significant welding parameters.

Confirmation test for tensile strength

$\eta_{opt} = n_m + (nA_3 - n_m) + (nB_1 - n_m) + (nC_4 - n_m) + (nD_4 - n_m)$

η_{opt} = 52.796+ (53.12-52.796) + (53.21-52.796) +(53.06-52.796) +(52.94-52.796) = 53.942

$Y_{opt}^2 = 10^{\eta/10}$ for properties higher is better.

$Y_{opt}^2 = 10^{53.942/10}$ = 247856.321

Y = 497.85

So, Optimum value of tensile strength =497.85

Confirmation test for hardness

$\eta_{opt} = n_m + (nA_3 - n_m) + (nB_1 - n_m) + (nC_4 - n_m) + (nD_4 - n_m)$

ηopt = 37.04+ (37.83-37.04) + (38.07-37.04) +(37.80-37.04) +(37.24-37.04) = 39.82

$Y_{opt}^2 = 10^{\eta/10}$ for properties higher is better.

$Y_{opt}^2 = 10^{39.82/10}$ = 9594.006

Y = 97.94

So, Optimum value of hardness = 97.94

From the above calculations, it can be concluded that the optimum results should be parameters with a welding current of 140 amps, a voltage of 26 volts, a gas flow rate of 13 lit / min and a welding speed of 9.5 mm / sec.

Conclusions

The present study is focused on effects of welding process parameters in order to make sure good weld quality. The principal processes parameters affecting the weld quality are welding current, welding voltage, welding speed, and gas flow rate were analyzed. Welding voltage has been identified as the most important parameter to select in order ensures tensile strength as well as hardness. Optimal welding conditions achieved by the Taguchi process for maximum tensile strength are$A_3B_1C_4D_4$ (i.e., current 140 amps, voltage 26 volts, flow rate of gas 13 lit / min, welding speed 9.5 mm / sec) and for maximum hardness $A_3B_1C_4D_4$(that i, the welding current should be 140 amps, the voltage should be 26 volts, the gas flow rate should be 13 lit/ min, and the welding speed should be 9.50 mm/sec).

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Chapter - 20

A Review on the Approach towards Cyber Physical Manufacturing Systems (CPMS) Architecture

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Chapter - 20

A Review on the Approach towards Cyber Physical Manufacturing Systems (CPMS) Architecture

Atul, G Divya Deepak and Ranjan Kumar

Abstract

Conceptualization of Cyber-Physical Manufacturing System (CPMS) is an illustrative wide scope of complicated, inter-disciplinary, physically concerned following generation engineered systems that put together entrenched computation into the actual world. CPMS is a comprehensive zone of engineering which provide supports in terms of applications across any manufacturing industry, air transportation, critical infrastructure, health care and medicine, intelligent transportation, robotic for service, and special smart manufacturing etc. CPMS is an emerging technology in facilitating the conversion from conventional to automation and is translating complete scenario of manufacturing. This paper deals with a review on an approach towards the CPMS architecture based on smart services for manufacturing systems. Present methodologies cannot handle with the dynamism inherent in the manufacturing sphere, where unforeseen and severe changes occur at any time and affect cross-boundary systems. We have seen that CPMS approach improves these concerns and concentrates on the need for supporting real-time automatic system negotiation, planning, scheduling, and optimisation, intra and across factories. Paper introduces the review on an implementation example of an approach in manufacturing industry, instantiating the conceptual architecture using unique technologies.

Keywords: CPMS, architecture, manufacturing, intelligent service.

Introduction

Conventional manufacturing systems have been converted totally into real time system with some multifaceted domain due to faster technological update and Globalisation [1, 2], which progressively bank on to computer technology to direct manufacturing activities and provide information to the right place in the method. It's quite tough to rectify the essential software and its tools and thus in turns have inadequate help for solving the complexity of the problem. Now a days, attentions have been achieved by the service industry based on the technology which provides the platform for everyone to gain the benefits without compromising the interface standards of the company [3]. But still the level of complexity is limited due to their small approach onto their platform which in turn badly impact the features like coordination, composition etc. [3].

Mass production manufacturing companies like automobile industries face the challenges at the very beginning stage of design itself but at a later stage when the production start, its stable.

Job shop production like aircraft and ships, on the other hand, required rigorous changes in its design characterization with maximum degrees for each product. The distribution of supply chains is higher, and this is due to varied suppliers in different countries. And at this point of time the delivery of product is uncertain pertaining to production. In any supply chain, when any manufacturing industries are moving with customization, then flexibility should be there in terms of software, coordination, decision etc. which support the system. Taking the efforts in line with the latest software which in turn provides flexibility with the help of IOT already exist in its specialization [4]. Using its capability with the help of IOT, still they face challenges in terms of updating the software with respect to customization. So, to deal with changing needs and flexibility in any manufacturing industries, we need to amalgamate the IOT with hardware along with intelligent coding or services.

As we know that CPMS is an upcoming and very intelligent services to manufacturing industry but still it is lagging its features and utilization in terms of deployment and some formal techniques. So, to overcome this problem, we need to discuss both the existing and emerging requirement with relate to CPMS.

In this paper we are going to understand the present scenario in the domain of intelligent services for initiating the information systems in manufacturing process especially for job shop production. Paper deals with the need to understand the architecture of CPMS and then to find out the difficulties/challenges in this field which relates to customization of production in present time. After that, a schematic framework is shown to get the familiarity of intelligent services in any manufacturing processes. This paper also concludes that CPMS leads to few important aspects which are optimization, prediction, diagnosis, flexibility in operation, controlling and managing the machines remotely [5, 6, 7, 8].

Cyber-physical manufacturing system components

To construct CPMS architecture, five components are required. These components are connectivity, data conversion, internet, decision, and feedback. Bringing all these together is itself a challenge. Let us first discuss about the connectivity. Here it means connecting the machine with its parts or components to achieve information or some reliable data which should be good enough to work upon it in developing Cyber-Physical Manufacturing System for Industry 4.0 [9]. Various actuators and sensors are being considered to get all these data like pressure, temperature, speed, volume, velocity, acceleration of the machines and their parts. It is also important to take the videos and images of the same. Data from several sources are taken and stored for its testing and reliability. Even some of the parameters like humidity, voltage, current, vibration etc. are also noted with the help of sensors or devices. Some of the data are obtained from Coordinate Measuring machine, Programming Logic Controller, lathe machine, gear cutting machine and many more to establish the sufficient data bank. And these data are used to understand the protocols of internet/cyber. Now these data are considered as an information to bridge the gap. To fill this gap conversion of data must be taken place at various level. Different mechanism is utilised to convert the available data into useful information. Few mechanisms are built for diagnostic and maintenance of machine and its parts. It provides the independent nature to the machine which are under working condition. In CPMS internet plays an important role to complete this architecture. All the data which are obtained from machine, or its part are then utilized to create a network. After creating the central network of machines, now it’s time to extract the gap or lag which is still there. After this, a better understanding of machine or parts is provided which itself is part of analytics. This analytics gives us the autonomous comparison between number of machines which reflects its capability, performance and thus rating can be obtained at the same time. It also allows us to predict the nature and future working ability of machine based on the information gathered all together. Virtual machine network is helping Industry 4.0 in getting success. Further in an architecture of CPMS, decisions must be taken based on the analytics provided herewith. In terms of significance of the tasks for predictive maintenance could be realised at an early stage based on the data availability. Already these data are compared and specific machine

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or its parts information is there. So, on this basis a decision is made for readiness. Last but not the least, a closed loop of a virtual machine network is of utmost concern. Getting feedback at appropriate time with the help of connectivity, data conversion, and internet, help the CPMS to improve its output and efficiency. When the physical part is getting feedback from the internet, it assures that some rectification is required over there and sorted out within due course of time. At this point autonomous configuration and self-repairing is taking place which reflects the control over the mechanical mechanism. It acts as the Resilience Control System (RCS) to apply the controls corresponding to the decisions made with respect to machines. Figure 1 given below shows the components of CPMS architecture.

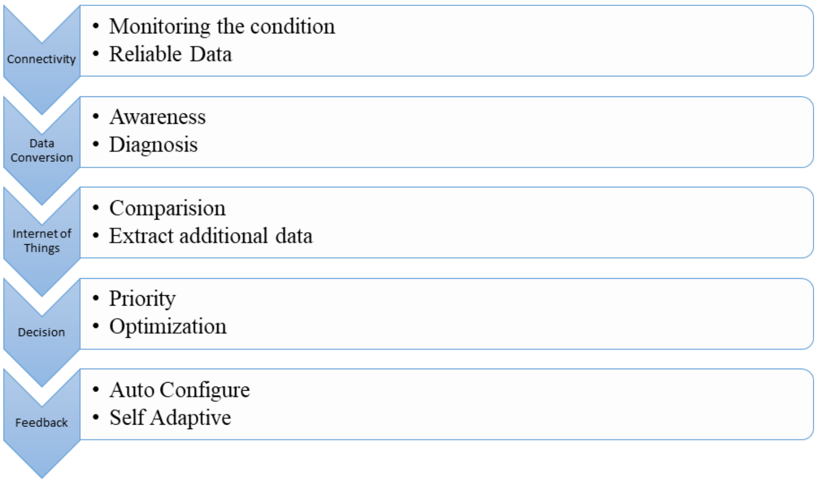

Fig 1: Components of CPMS architecture

Challenges in cyber-physical manufacturing system components

Some of the literature discuss about the problems pertaining to integration of machine with internet, data segregation [10], compliance with international standard [11] etc. Furthermore, challenges are encountered in CPMS architecture related to novelty in design and services, diversity in products, customer satisfaction [12], quality and support services [9]. As per the de-facto standard IEC 61131 an Industrial Automation Systems (IASs) is being established [11]. To eradicate the restriction of the above-mentioned standards, the updated version of the same have been introduced to solve the problems pertaining to Complex Industrial Automation (CIA). Though, to overcome all the challenges in CPMS architecture, maximum work is required to disrupt the standardization currently available [13].

Some of the existing types of standards pertaining to the CPMS architecture is provided below in Figure 2.

Fig 2: Standards pertaining to the CPMS architecture

To make sure that products, materials, processes, and support services suitable for their objectives should be utilised constantly provided with their appropriate specifications, characteristics, requirements etc. is a part of document named as standards. So as to achieve an effective growth and deployment of technology elements in an Industry 4.0, several categories of standards have to be applied with different roles and functions which are needed for different categories. Therefore, it is necessary to identify the appropriate standards as per the requirements in development of technology elements and complex interactions which let us to know about the machine components mechanics [14].

Function of the standards pertaining to the CPMS architecture is provided in Figure 3.

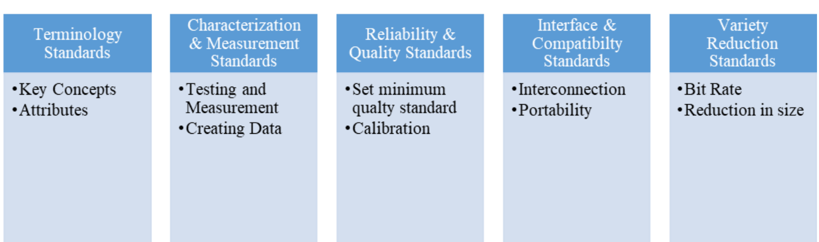

Fig 3: Function of the standards pertaining to the CPMS architecture

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Fusion of knowledge among various technology elements is very important when these standards are utilised in providing the details related to products, materials, processes, and support services. When fusion of knowledge among various and across the technology elements takes place then it helps to bridge the gap between market and research products. With the help of various kinds of standards available with respect to CPMS architecture, it is quite easy to understand the gap and be able to fill this gap by amalgamating scientific research and technology elements into market.

First components of CPMS architecture are smart connectivity. Under this level data from physical machine components is achieved. And for these various techniques are there under the standards format and the most peculiar is the usage of Automatic Identification and Data Capture (AIDC). Under these techniques some standards specify the exceptional recognition for listing methods, general guidelines, separate carrying components, particular products, and product bundles, different returnable carrying items, and combinations [14]. In CPMS sensors plays an important role in obtaining the data from the machine elements. At the same time these sensors are to be monitored and handled precisely.

Conversion of data into information is the second components of CPMS architecture. Under this level managing the data of machine elements from the smart connectivity level and then it is being analysed individually. This component has some standards which is used to explain the characteristics of machine elements. Various series of the standards under this level provides the source for examining the behaviour, types of elements, data and the interconnectivity which is not clear and precise. One of the series of the standards under this level offers exchanging of data under unified data format which is also called as Automation Markup Language (AML). Furthermore, series of the standards also setup a cutting edge featured system to understand the environment for the Internet of Things. But apart from these functions, there is an issue pertaining to the security of data or information in CPMS architecture. So, in this regard, international standards organisation also provided the control mechanism and securing the risk of data breaching in CPMS architecture. And even series of the standards under this level offers extensive protection of data security comprising of control and automation systems [14].

When communication is required in the third level of CPMS architecture at that time internet is necessary components. Exchanging of information and data achieved from machine elements required a series of the standards under this level also which is already there in the form of wireless communications. To explain local area network (LAN), there is collection of international standards, and it must work based on real time distributed network protocols. Monitoring, handling, measurements, and control of information in CPS system is taken care with utmost concern by utilising the certain set of standards [14]. It has to be ensured that quality and support services for carrying the information and data through distributed network protocols is handled under these components of CPMS architecture. Storage of data and managing the information is allowed with certain interface which is again under a specific series of standards. So, integration of devices with IOT is the crucial layer under which refinement is done to act accordingly with the available and additional data which has been accumulated under second level of CPMS architecture.

Fourth level in CPMS architecture is to make decisions based of the data available. After examining the information floated in the channel, it allows the system to take decisions while processing and communication. It amalgamates all the information and data and help the system to finalise the required commands to be delivered in the distributed network of CPMS architecture.

Last but not the least, the closed loop of CPMS architecture is very useful in making decisions among the machine elements with the existing interface. With this level, auto configuration and self-adaptive nature of machine elements comes into scenario. Once the integration done in any system, the chances for standardization and reliability gets reflected. Some series of standards under this level also exists which minimizes the flaws, cost and threat which are coupled with the interface of distributed network. However, few series of standards also guarantee the life cycle safety for automation control and improves the protection level [14].

Needs of job shop production based on intelligent services

At present scenario, a lot of diversity has been encountered in customer's requirements. Thus, customization will play a big role in managing the production activities to meet customer's requirements. Therefore, it is quite challenging for mass scale production industry to excel the men and machines at an efficient scale [15, 16]. To fulfil the customer's needs at various manufacturing industry like aerospace, frequently build a substantial number of different aero models. Such types of challenges in an engineering industry leads towards the maximizing the efforts for planning and control in any production activities. Repeatedly having errors in production line, design related flaws, supply chain and logistics, information technology, vendors etc. are reflecting that they are not prepared even at the early stage itself. When industries like aerospace work upon customization, then it means really that they are adding values to their products. They usually deal with the assembling activities which are manufactured by a very extremely concentrated supplier. So proper planning and control measure has to be taken with respect to vendor network or suppliers. In general, at job shop production, maximum customisation of production leads towards the five factors which fulfil the information system in supporting the CPMS.

First one is an individual idea or decision at micro levels in various departments. With reference to this, few decisions have to be taken at any step of planning and control of production activities by the labour which should in line or getting support with their operation managers. In an automated production activity, it is noticed that production planning and control commands are very rigorous in terms of labour [17]. At every small step they are supposed to take decisions and it help in rectifying the schedules of production manually. Thus, proper man-machine user interface is extremely advantageous in developing CPMS architecture.

Second one is based on confined data for the scattered facilities available in manufacturing industry. As it is known that complete manufacturing process and system is divided into various groups of assembly station. And these stations are decomposed part of an overall production system comprises of scattered facilities of assembly lines. So, these scattered facilities have some local or confined data which is to be utilised to take decisions in any CPMS architecture [18]. When altering scheduling challenges comes at several points of time then the support of confined data of scattered facilities is required to solve the problems to have better control and planning mechanism in manufacturing process.

Third one is the management of schedules based on Arbitration. As per customisation of any product, a single window is open as per production planning and control mechanism. Subsequently parallel schedule has been utilised to find the objectives of individual customer requirements. So based on the ongoing schedule management, development of the customer's order is examined and monitored very precisely. Further skilled groups of workers carry out appropriate task which are assigned by the operation manager after dividing the work into small packages [19, 20]. A resource constraint project scheduling problem (RCPSP) in multiple mode is designed to overcome the difficulty during the scheduling on the task level [19, 20]. Under this RCPSP, a particular bundle of modes is designated to individual task to be performed. And this mode is provided with specified skills to a particular number of workers. Thus, completion of work time varies with respect to the number of workers. The numbers of worker should be less when they are allocated to a particular workstation at any point of time. So, for a particular period as per RCPSP, specific number of skilled workers are required at each workstation. Therefore, assembly line balancing helps to find the numbers of worker at a particular workstation [18, 21]. As per RCPSP, it has mainly two scopes in terms of decomposing the overall work either in several shits or in weeks, months, or years. However, RCPSP can be modelled for an individual station which might be useful, and it will lead towards the betterment of the scheduling and planning while developing the CPMS architecture [22].

Fourth one is the amalgamation of execution systems with production activities. Proper integration of software with machine elements and its execution plays an important role for making decisions with respect to scheduling and production planning. Due to its constraints, it's very tough to implement in mass production activities [20, 21].

Fifth one is self-adapting or self-configuration in the CPMS architecture which makes the system a closed loop. In Industry 4.0, frequent changes are common in terms of customization of work orders. And for this there should be provision to any production activities pertaining to planning, scheduling, and control to adapt the repeated changes in the system even for the complex processes. Few changes or disturbances in CPMS architecture includes design, information services, machines, tools etc. are existing. When there are huge disturbances during production activities, then even information services like Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) are not applicable to rectify the problem at real time. Therefore, by having only compatible interface won't work to resolve the problems or challenges faced in a highly complex environment of manufacturing [19].

Intelligent services based architecture as a key for CPMS

While discussing about the needs of job shop production based on Intelligent Services**,** a CPMS architecture is developed utilising the intelligent services for helping small production activities where lot of customization is required. Thus, as per one of the literature Intelligent Enterprise Service-based Bus (iESB) is developed which acts as an autonomous software which are supposed to deliver the very specific results.

The decomposed physical machine components are incorporated with scattered Intelligent Services which are intended to request the support from other Intelligent Services. In some of the literature it has been found that there is a lot of difference between an Intelligent Web Service and an Intelligent Service [23]. Intelligent Web Service is an amalgamation of agents pertaining to software and the services provided by cyber. These agents are used to incorporate the artificial intelligence into the cyber which help in changings the details of machine components during its production activities [23].

Let us understand the individual idea or decision at micro levels in various departments and confined data for the scattered facilities available in manufacturing industry. It refers to facilitating and synchronizing all the activities taking place in an architecture of CPMS. The instruction provided to support the distributed intelligent processing takes place with the help of software and by amalgamating scattered capabilities of machine elements or components. To get these characteristics in an architecture of CPMS, enterprise service bus architectures have to be incorporated which provides the full proof output, registering and distribution of message in a system. And for this integration of enterprise service bus and Intelligent Services act as a solution to improve the issues pertaining to communication while implementing the Intelligent Services into CPMS architecture [24]. Thus, enterprise service bus helps in transporting the communication which are transferred by Intelligent Services. Notification has also been registered in the form of messages whenever actions of interest happen in CPMS.

Establishing the management of schedules based on Arbitration is also being supported by the Intelligent Services based Architecture. The coordination between the global and local information takes place by using the management of schedules based on arbitration which is very effective to provide overall support. And this is because of the appropriate messaging being guided by the enterprise service bus and Intelligent Services. It assures the delivery of communications with a definite mechanism. When data has to be extracted at an extreme level from the CPMS architecture then at that time arbitration helps in managing the information available within the system. For this communication layer act as a solution to guarantee the transportation of information within the CPMS. It has some limitation towards the scheduling and planning support at a certain level. That’s why local data in a distributed network is utilised and at each level decisions must be taken to solve the problems available in CPMS. As per the constraints, time, resources, and events which are unexpected, optimize the overall process with the help of management of schedules and planning. But both are different with respect to time. Planning dealt with the work which is going to take place in a month or weeks and scheduling refers to the immediate, forthcoming, and pending tasks. Uneven process, breakdown, lack of manpower leads towards the unexpected events which should be rescheduled, and self-adaptation should take place within the CPMS. To handle these situation enterprise service bus and Intelligent Services works according to the arrangements available in the manufacturing industry along with different types of activities going on over there [25]. Thus, officer has to provide the information of all the activities taking place in an industry with proper details pertaining to the man, machine, materials etc. Therefore, Intelligent Services helps in initiating the process within the system with the help of officer who is going to specifies the activities themselves.

Now it's time to integrate the execution systems within production activities. And for this interface between different activities and software agents has to be provided with the help of Gateway service functions. It leads towards the interchanging the amount of data within the system. This interface also exchanges the data with external system like ERP, MES, SCADA, etc. Gateway service functions is not only used to send the information but also been utilised to receive the information whenever it is required. Thus, the CPMS has sufficient data from all the sources (within the system and external) which are registered into intelligent services and thus utilising it, just after getting the notification.

Self-adapting and self-configuration is one of the most concerned aspects of CPMS architecture. It reflects the frequent changes in the technology. With this frequent changes, it differentiates the various production activities, organisation, and technologies available in the global market. It provides a wide range of adaptability to reschedule and replan the activities or techniques to redesign the architecture of CPMS as a whole system. Scattering of data, establishing the management of schedule on arbitration basis, integration of execution systems and last but not the least novel ideas in the field of manufacturing has the scope to rebuild the architecture of CPMS in such a way to have a very different characteristics which could sustain very easily. The architecture involves intelligent services and enterprise service bus. Registering the service and Node Manager are other two components of architecture in a CPMS. Connection between two architectures should be establish with the help of Node manager. Various locations have its own manufacturing units, and it must control and monitored from remote place. Thus, to initiate the exchange of data between internal and external sources potential consumption of same must take care. Overall process leads towards the distribution of data to the network in an effective way. While distributing the data into the system, all the information is registered and help in coordinating with each node. Each node has nodal manager who provides the availability of data in the service registry at a particular node in the distributed network. To cope with the changes in the domain, the newly developed architecture depends on the meta data for re designing the different concepts of architecture in CPMS. One of the literatures based on metadata is available to understand the concept [26]. Thus the unavailability of information in the models leads towards the development of conceptual architecture in CPMS where interface between machine and software agents is lagging. Using metadata, it helps in modelling a finite architecture for CPMS which is going to approach towards the real-world activities along with the standards or policies [27]. Thus, inculcating the proposed architecture will help in finding the dependent territory in any manufacturing industry.

Conclusions

In this paper, how intelligent services and enterprise service bus has been incorporated to develop a novel architecture in CPMS for job shop type production has been discussed. These two services in an architecture plays an important role in any manufacturing industries to be effective enough. It focusses on re planning and re scheduling of the activities along with exchange of information to build autonomous system. Software agents with internet of things leads towards the transportation of information in a distributed network. Thus, scattered facilities in a distributed network works as an independent territory. As an overall in providing support to system an intelligent enterprise service bus (iESB) is utilised to strengthen the complete system with various tools. At present CPMS in itself plays an important role in developing the manufacturing system with problem solving attitude in real time. And for this Industry 4.0 is an upcoming technology with lot of characteristics to cope with real time problems. One more aspect has been dealt in this paper pertaining to standardization. And this aspect itself is a challenge. This paper encompasses review on CPMS architecture along with its purposes.

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Chapter - 21

Experimental Investigation of Welding Parameters on Mild Steel Using Metal Active Gas Welding

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Chapter - 21

Experimental Investigation of Welding Parameters on Mild Steel Using Metal Active Gas Welding

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Abstract

Gas shielded welding is a widely applied fabrication processes in manufacturing industry. The present study will elucidate on an investigative approach to find the mechanical properties, influenced by several input parameters like welding current, voltage and wire spool speed in the Metal Active Gas Welding (MAG) of Mild Steel. Taguchi's L9 orthogonal array has been employed to analyse the process parameters. The levels of consequences of input parameters were investigated by applying analysis of variance (ANOVA). The microstructural orientations and mechanical properties of weld specimen are explored in this work. Welding current is an influential parameter to control tensile strength followed by welding voltage and federate of electrode. Furthermore, hardness of weld material has a greater effect of voltage including wire speed and current.

Keywords: Metal active gas, welding current, manufacturing, shielded welding.

Introduction

Metal active gas welding is a widely used process of welding where consumable electrode wire is supplied from an automated spool. Automatically supplied wire consumes and deposited to produce the weld joint. The weld zone is protected by the inert or gas mixture gases to prevent oxidation. A continuous feed filler wire (consumable) electrode and the work piece form an arc as part of the MIG/MAG welding process. Automatically fed from the machine, the electrode exits the MIG/MAG gun's contact point after passing through a liner. A flow of an inert gas, or gas mixture, shields the metal weld from the atmosphere. A proper arc length is maintained during normal operation by the operator. The standard procedure of parametric approach of Taguchi Method were employed for designing the experiment to analyze the data. The average values of the response attributes for every parameter at different intensity are computed from experimental findings. Final responses of influences of process parameters were plotted, and corresponding response curves are investigated. The effect on the response attributes were studied by the analysis of variance (ANOVA) of raw data. The optimum parameters in terms of mean response attributes is determined by scrutinizing the response curves and the ANOVA Tables. Ramarao *et al*. [1] studied impact strength of dissimilar joining of alloy steel SA387 and optimized welding process parameters like welding current, voltage with varying bevel angles. Radhakrishnan *et al*. [2] applied Taguchi method in an optimization study of mechanical properties after varying the process parameters in welding. The impact of welding of Aluminium 6061 - T6 metal. Timothy *et al*. [3] conducted an ooptimization study of gas metal arc welding of titanium-reinforced mild steel sheets. V. Subravel *et al*. [4] elucidate the effects of process variables on some mechanical microstructural characteristics of pulsed GTAW joints and reported the change in tensile strength with varying welding speed. V. Kanwal [5] illustrated the consequences of welding current on hardness of welding joint. B. Mishra, *et al* [6] explained the change in mechanical properties in ferrous and nonferrous metals with varying process parameters. Subodh Kumar *et al*. [7] concluded the lower heat input gives better tensile strength and reduced HAZ in 304 stainless steel joint in GTAW. Based on the recommendation of Chuaiphana *et al*. [8], optimum welding speed of 3.5 mm/s for AISI 201 to be maintained to achieve best mechanical and corrosion resistance properties in GTAW. Juang, S.C. [9] has investigated on the geometry of the weld pool by varying the TIG welding parameters using stainless steel. Ghosh *et al* [10] concluded that applying Taguchi method is an efficient process for designing of experiments and analyzing the parameters in metal inert gas welding of AISI 409. In the work of Ibrahim *et al*. [11] welding on thick plates has been performed to understand temperature behaviour. The review reveals that the balance of welding parameters results in a quality weld and therefore the investigation has been performed in this study. The present study deliberates on the influences of various input process parameters on the strength and hardness of the weld performed on mild steel in case of metal active gas welding.

Methodology

In 20th century the breakthrough approach in quality engineering presented by Genichi Taguchi [12]. This method mainly focuses of effective employment of engineering approach rather stats-based methodology. It converges both upstream and shop-floor quality engineering. In case of small-scale cases upstream methods, efficiently reduce inconstancy, and favours robust designs for large-scale production. Shop-floor techniques yield cost-based, real-time methods for scrutiny and provide quality during production. The philosophy of Genichi Taguchi has the following fundamental notions:

Quality needs to be implemented during design of product not in inspection.

Minimizing the anomaly from the target is the key of quality. The product or process variables needs to be selected as such it takes care of uncontrollable environmental attributes.

The deviation from standard is the measure of cost of quality whereas losses are should be system-wide. The measured variance in a given variable into parts that can be attributed to several sources of variation. The effectiveness of the model is examined using the analysis of variance technique. The phrase "signal" stands for the preferred mean value, whereas the term "noise" stands for the unwanted value. The degree of variance existing in the performance characteristics is thus represented by the S/N ratio.

Experimental design approach

Orthogonal arrays (OA) for laying out of experiments were applied as per Taguchi concept. These orthogonal arrays are generalized Graeco-Latin squares. Selecting the best suited orthogonal array is principal of design of experiment and selecting parameters and results in the appropriate columns.

The following objectives may be achieved by analysing the experimental results in Taguchi method:

- To estimate the optimal conditions for the product and processes.
- To measure the influences of individual process parameters.
- To measure the optimized output criteria.

By examining each parameter's influence, the ideal situation is found. The effects show each parameter's overall direction of impact. The type of control to be put on a manufacturing process depends on the understanding of the contribution of each individual parameter. The statistical procedure most frequently used to analyse experimental results to ascertain the current contribution of every parameter to a certain degree of confidence is the analysis of variance. To identify the parameters that require control, an analysis's ANOVA table can be studied.

Experimental observations

100x100x5 mm size sample of mild steel has been welded. Total 9 experiments have been performed on the basis of L9 orthogonal array technique of Taguchi Methodology. Voltage, current and wire feed rate are chosen as input process parameters variable whereas micro hardness of welded zone and Tensile strength are selected as output parameters at different levels are used.

Welded samples are further used for observations and for that samples are measured for Tensile strength by UTS machine and for micro hardness by Vickers hardness tester. Trial and error were employed to fine-tune the welding parameter's working ranges, and the satisfying results were used to carry out the experimental work. Table 1 details the 3 variables with 3 different levels of input parameters which is employed to form L9 orthogonal array and the experimental values of selected input parameters are presented in table 2.

Table 1: L9 Orthogonal array design matrix

Experiment No.	Welding voltage (Volt)	Welding current (Amp)	Wire feed rate (m/min)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2: L9 Matrix with actual value of parameters

Experiment no.	Welding Voltage (Volt)	Welding Current (Amp)	Wire feed rate (m/min)
1	20	160	2
2	20	170	4
3	20	180	6
4	30	160	4
5	30	170	6
6	30	180	2
7	40	160	6
8	40	170	2
9	40	180	4

Based on L9 array total nine observations were taken. The impact of selected process parameters such as welding current, arc voltage and wire feed rate are analyzed. Table 3 details the measured value of strength in tension and hardness with their S/N ratios for all the samples. Fig. 1 shows photograph of welded sample.

Table 3: Experimental observations

Experiment No.	**Welding voltage**	**Welding current**	**Wire feed rate**	**Hardness at WZ**	**Tensile strength**
1	20	160	2	169.45	384.43
2	20	170	4	167.91	394.69
3	20	180	6	183.29	390.83
4	30	160	4	201.62	389.73
5	30	170	6	205.24	399.25
6	30	180	2	182.5	402.15
7	40	160	6	194.39	383.27
8	40	170	2	161.48	398.19
9	40	180	4	172.85	395.52

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Fig 1: Sample view of MAG welded mild steel

To measure the Microhardness the samples are prepared by finishing the samples using emery paper of various size numbers. Further, Vickers micro-harnesses numbers has been measured.

Results and discussions

From Fig. 2, it is observed that hardness of weld zone is increased up to second level of arc voltage whereas decreases with increase in welding current and linearly increases with increase in wire feed rate.

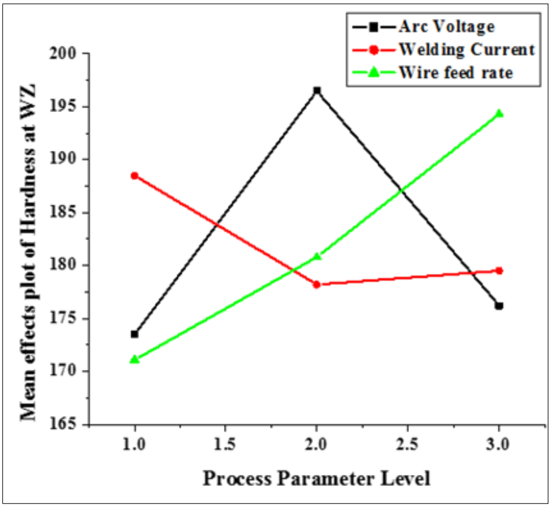

Fig 2: Variation of process parameters and hardness

But further increase in welding current may help to change microstructure during weld metal solidification and such marginal increase in hardness observed. On the other hand, with increase in arc voltage increases due to lesser embitterment with decreased cooling rate may be the reason observed phenomenon whereas further increase in arc voltage results in wider weld bed with less penetration. Thus, low hardness may be achieved. As the penetration mostly depends on wire feed rate linearly the phenomenon observed. One of most popular technique for statistically analyzing quantitative data is analysis of variance (ANOVA). The ANOVA test has been run for the result at a 95% confidence level to assess the relative significances of the joining process factors taken into consideration during experimentation. The percentage contribution column in the ANOVA result table 4, shows how much each process parameter has an impact on the machining characteristics. It is observed from table 4 that all the process parameters are statistically noteworthy over machining response. The r square value indicates at the feasibility of the adopted design for performing experimental study. It is found that the welding arc voltage is the most striking factor that influences the hardness maximum followed by wire feed rate and then welding current with percent contribution of 48.54, 41.83 and 9.6 ratio respectively.

Table 4: ANOVA for means for hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Welding Voltage	2	940.38	940.378	470.189	745.14	0.001
Welding Current	2	187.32	187.320	93.660	148.43	0.007
Wire Feed Rate	2	812.27	812.273	406.136	643.63	0.002
Residual Error	2	1.26	1.262	0.631	-	-
Total	8	1941.23	-	-	-	-

Fig. 3, indicates that tensile strength primarily increases with increase in arc voltage and welding current whereas tensile strength is marginally, decrease with increase wire feed rate.

As voltage and weld current increases, the energy density at weld spot is unique and chances of proper bonding of weld metals in very high, results in increase in tensile strength. Whenever the voltage or current flow is increased the chances of volatile energy density at weld zone is very high, thus tensile strength is marginally decreased. Increase in wire feed rate results in non-uniform electrode deposition on weld zone during MAG

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welding. Due to the said fact tensile strength is decreased slightly. It is observed from table 5 that all the process parameters are statistically significant at 95% confidence level and welding current is the most noteworthy factor which effects tensile strength maximum with percent contribution of 70.84% followed by arc voltage with percent contribution of 22.46% then Wire feed rate with percent contribution of 6.40%.

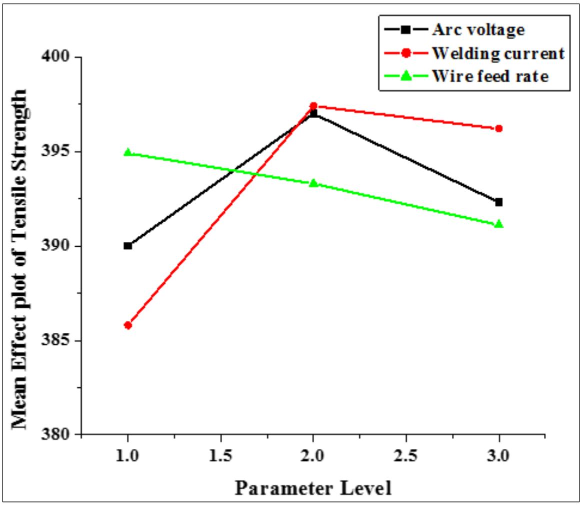

Fig 3: Variation of process parameters on tensile strength S/N ratio

Table 5: ANOVA for means for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Welding Voltage	2	77.582	77.582	38.791	242.43	0.004
Welding Current	2	242.512	242.512	121.256	757.80	0.001
Wire Feed Rate	2	21.908	21.908	10.954	68.46	0.014
Residual Error	2	0.320	0.320	0.160	-	-
Total	8	342.322	-	-	-	-

The optimized design parameters that are chosen from the S/N ratio graph are Welding Voltage 30 V Welding Current 160 amps and Wire feed rate 6 m/min, for obtaining higher Hardness and for Tensile Strength the parametric settings become Welding Voltage 30 V Welding Current 170 amps and Wire feed rate 2 m/min. Hardness at WZ is higher the better quality. Tensile Strength is also higher the better quality. Single objective optimization results are listed in table 6.

Table 6: Optimization responses

Machining attributes	Optimal parametric settings	Optimal value
Hardness at WZ	A2B1C3	215.084
Tensile Strength	A2B2C1	403.108

Conclusions

The present study gives the insight understanding of welding process parameters on the strength of weld in case of metal active gas welding performed on mild steel sample. ANOVA analysis confers that welding current is the influencing parameter that affects tensile strength of the weld whereas voltage is the responsible parameter for hardness of the weld. In this present study, second level of voltage (30 volt), first level of current (160 amp), and third level of wire feed rate (6 m/min) gives the higher hardness. Accordingly, optimum condition of input parameters is A2B1C3 is recommended. Microstructure study of weld has shown a fine grain of ferrite and pearlite.

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Chapter - 22

Performance and Emission Characteristics of a Hydrogen-Diesel Dual Fuel Engine under Variable Load Conditions

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Chapter - 22

Performance and Emission Characteristics of a Hydrogen-Diesel Dual Fuel Engine under Variable Load Conditions

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Abstract

The rapid depletion of fossil fuels and the increasing environmental concerns have driven the development of alternative fuel technologies. Hydrogen, being a clean-burning fuel, is considered a promising alternative for reducing the environmental impact of diesel engines. This research paper presents an in-depth analysis of the performance and emission characteristics of a hydrogen-diesel dual-fuel engine under varying load conditions. By introducing hydrogen into a diesel engine, the study explores the effects on engine efficiency, combustion stability, and emissions such as nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). The results show that hydrogen substitution can significantly reduce harmful emissions, although challenges such as increased NOx emissions at high hydrogen substitution rates need to be addressed. Various load conditions are tested to evaluate how hydrogen-diesel blends affect engine performance across typical operating ranges.

Keywords: Hydrogen, diesel, dual fuel engine, variable load, emission characteristics, performance, combustion.

Introduction

Background

Internal combustion engines (ICEs) are widely used in transportation, power generation, and industrial applications. Diesel engines, in particular, have become the primary workhorse in heavy-duty applications due to their higher efficiency and torque characteristics. However, diesel combustion produces a significant number of harmful emissions, including NOx, CO, HC, and PM, contributing to environmental degradation and public health concerns (Heywood, 1988). The search for alternative fuels that can reduce these emissions while maintaining or improving engine performance has been a major focus in recent years.

Hydrogen is considered a clean alternative fuel because its combustion does not emit carbon-based pollutants. It has a high energy content (approximately 120 MJ/kg), fast flame speed, and a broad flammability range, making it a suitable candidate for use in dual-fuel systems (Verhelst & Wallner, 2009). This study explores the use of hydrogen in combination with diesel fuel to develop a dual-fuel engine system that improves performance and reduces emissions, with a specific focus on variable load conditions.

Problem statement

Diesel engines, while efficient, are notorious for producing NOx and particulate matter. Hydrogen, when used as a supplementary fuel, has the potential to reduce these pollutants due to its clean-burning characteristics. However, the combustion of hydrogen in a dual-fuel setup also poses challenges, particularly the increased formation of NOx at higher temperatures. This paper seeks to investigate the trade-offs between improved performance and emissions when hydrogen is used in combination with diesel in a dual-fuel engine under varying load conditions.

Objectives

The main objectives of this research are:

To evaluate the performance characteristics (brake thermal efficiency, specific fuel consumption, etc.) of a hydrogen-diesel dual-fuel engine.

To investigate the emission characteristics (NOx, CO, HC, PM) of the engine under variable load conditions.

To understand how varying the hydrogen substitution rate affects engine performance and emissions.

To propose strategies for mitigating the challenges posed by hydrogen-diesel combustion, particularly with respect to NOx emissions.

Scope of study

This study will focus on a compression ignition (CI) diesel engine modified to run on a hydrogen-diesel dual-fuel setup. Variable load conditions will be applied to simulate real-world driving scenarios, and both performance and emission metrics will be collected. The study will provide insights into the feasibility of hydrogen-diesel engines as a sustainable solution for reducing emissions in the transportation and power generation sectors.

Literature review

Hydrogen as an alternative fuel

Hydrogen is a versatile energy carrier that can be used in various energy systems, including fuel cells and ICEs. Its clean combustion properties make it attractive for reducing the environmental impact of traditional ICEs (Verhelst & Wallner, 2009). The combustion of hydrogen produces water vapor as its primary byproduct, with negligible CO_2 emissions. However, hydrogen combustion also produces high combustion temperatures, which can lead to increased NOx formation (Das, 2002).

Several researchers have explored the use of hydrogen in dual-fuel engines. According to Saravanan *et al*. (2008), hydrogen can be introduced into a diesel engine using a dual-fuel system, where diesel acts as the primary fuel and hydrogen as the secondary fuel. This approach can improve thermal efficiency and reduce CO_2 emissions, although NOx emissions tend to increase due to the high flame temperatures associated with hydrogen combustion.

Hydrogen-diesel dual-fuel combustion

The concept of hydrogen-diesel dual-fuel engines is based on the idea that hydrogen can supplement diesel fuel, reducing the overall consumption of fossil fuels while taking advantage of hydrogen's clean combustion properties. Hydrogen has a wider flammability range and lower ignition energy than diesel, making it easier to ignite and combust under a wide range of operating conditions (Bari & Esmaeil, 2010).

Dual-fuel engines typically operate by injecting diesel as a pilot fuel to initiate combustion, while hydrogen is introduced into the intake air as a gaseous fuel. This configuration allows the engine to run on a mixture of hydrogen and diesel, with the proportion of hydrogen being adjusted based on the desired operating conditions (Das, 2002). One of the key advantages of dual-fuel combustion is the reduction in CO, HC, and PM emissions due to hydrogen's clean-burning nature (Tsolakis & Megaritis, 2004).

Emission characteristics of hydrogen-diesel dual-fuel engines

Emissions from diesel engines primarily consist of CO, HC, NOx, and PM, all of which contribute to air pollution and global warming. Hydrogen-diesel dual-fuel engines have been shown to reduce CO, HC, and PM emissions, as hydrogen combustion does not produce carbon-based emissions (Liu *et al*., 2010). However, the high combustion temperatures associated with hydrogen can lead to increased NOx emissions, which are harmful to both the environment and human health (Saravanan *et al*., 2008).

Various strategies have been proposed to mitigate NOx emissions in dual-fuel engines, including exhaust gas recirculation (EGR), selective catalytic reduction (SCR), and water injection (Tsolakis & Megaritis, 2004). These technologies can help reduce NOx emissions by lowering the combustion temperature or chemically converting NOx into less harmful compounds.

Engine performance under variable load conditions

Several studies have investigated the performance of dual-fuel engines under different load conditions. Bari and Esmaeil (2010) reported that at partial load conditions, the brake thermal efficiency of a hydrogen-diesel engine improved due to the higher energy content and cleaner combustion of hydrogen. At higher loads, however, NOx emissions increased, indicating a need for advanced emission control technologies.

Saravanan *et al*. (2007) also found that hydrogen substitution positively impacted thermal efficiency at medium load conditions, but the benefits diminished at higher loads due to the increased formation of NOx. These findings suggest that the load condition plays a critical role in determining the performance and emission characteristics of hydrogen-diesel dual-fuel engines.

Experimental setup and methodology

Engine specifications

The engine used in this study is a single-cylinder, four-stroke diesel engine with direct fuel injection and a compression ratio of 17:1. The engine was modified to operate in a dual-fuel mode, with hydrogen being introduced into the intake air stream through a gaseous fuel injector. A control unit was used to regulate the hydrogen flow rate based on the engine load and speed.

The engine was equipped with a dynamometer for load testing and a suite of sensors to measure temperature, pressure, and emissions. A data acquisition system was used to collect real-time data on engine performance and emissions during the tests.

Fuel properties

The properties of diesel and hydrogen are summarized in Table 1. Diesel fuel is a hydrocarbon-based fuel with a high energy density, while hydrogen is a clean-burning gas with a higher energy content per unit mass but lower energy content per unit volume compared to diesel. The high diffusivity and fast flame speed of hydrogen make it suitable for dual-fuel combustion, although care must be taken to avoid issues such as backfiring and pre-ignition.

Table 1

Property	Diesel	Hydrogen
Energy Density	45.5 MJ/kg	120 MJ/kg
Flammability	0.6% to 7.5%	4% to 75%
Ignition Energy	0.2 mJ	0.02 mJ
Stoichiometric AFR	14.6	34.3

Test procedure

The engine was tested at various load conditions, ranging from 0% to 100% of the engine's full load capacity. Hydrogen was introduced at a fixed substitution rate (20%, 30%, and 40% by volume), while the remaining fuel requirement was met with diesel. The performance metrics, including brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and brake power (BP), were measured for each load condition. Emission measurements included NOx, CO, HC, and PM, which were recorded using an exhaust gas analyzer. Each test was repeated three times to ensure data accuracy, and the average values were used for analysis.

Data analysis

The collected data were analyzed to identify trends in performance and emissions as a function of load and hydrogen substitution rate. Statistical methods, including regression analysis and analysis of variance (ANOVA), were used to determine the significance of the observed differences in performance and emissions between the different test conditions.

Results and discussion

Engine performance

Brake thermal efficiency

The results showed that the brake thermal efficiency (BTE) increased with the introduction of hydrogen, particularly at partial load conditions. At a hydrogen substitution rate of 30%, the engine exhibited a 10-12%

improvement in BTE, with a corresponding reduction in brake specific fuel consumption (BSFC). This improvement can be attributed to the higher energy content of hydrogen and its more complete combustion compared to diesel. These findings are consistent with previous studies by Bari and Esmaeil (2010), who reported similar improvements in thermal efficiency at medium load conditions.

At higher load conditions, however, the benefits of hydrogen substitution diminished due to the increased formation of NOx and the onset of knock at high hydrogen concentrations.

Brake power

The brake power (BP) of the engine increased with increasing load, as expected. The introduction of hydrogen resulted in a slight increase in BP at partial loads, but the effect was less pronounced at higher loads. This suggests that while hydrogen can improve engine performance at medium loads, its benefits are limited at full load conditions.

Emissions

Nitrogen Oxides (NOx)

NOx emissions increased with increasing hydrogen substitution rates, particularly at high load conditions. This is due to the higher flame temperature associated with hydrogen combustion, which promotes the formation of thermal NOx. At a hydrogen substitution rate of 40%, NOx emissions increased by 20-25% compared to pure diesel operation. These findings are consistent with previous studies by Saravanan *et al*. (2008), who also reported increased NOx emissions in hydrogen-diesel dual-fuel engines.

The use of exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) could help mitigate NOx emissions, as suggested by Liu *et al*. (2010).

Carbon Monoxide (CO)

CO emissions were significantly reduced with the introduction of hydrogen. At a hydrogen substitution rate of 30%, CO emissions decreased by 40-50% compared to pure diesel operation. This is due to the more complete combustion of hydrogen, which reduces the formation of incomplete combustion byproducts such as CO.

Hydrocarbons (HC)

HC emissions also decreased with increasing hydrogen substitution rates. At a hydrogen substitution rate of 30%, HC emissions were reduced by 30-40%, consistent with the findings of Tsolakis and Megaritis (2004). The reduction in HC emissions can be attributed to the cleaner combustion characteristics of hydrogen, which promotes more complete fuel oxidation.

Particulate Matter (PM)

PM emissions were nearly eliminated with the introduction of hydrogen. Hydrogen combustion does not produce particulate matter, as it lacks carbon content. At a hydrogen substitution rate of 40%, PM emissions were reduced by over 90%, making hydrogen-diesel dual-fuel engines a promising solution for reducing particulate emissions in diesel engines.

Conclusion

This study has demonstrated the potential of hydrogen as a supplementary fuel in diesel engines, particularly for reducing harmful emissions such as CO, HC, and PM. The hydrogen-diesel dual-fuel engine exhibited improved thermal efficiency and reduced emissions at partial load conditions, making it a viable option for reducing the environmental impact of diesel engines. However, the increase in NOx emissions at higher hydrogen substitution rates presents a challenge that must be addressed through advanced emission control technologies such as EGR or SCR.

Future research should focus on optimizing hydrogen substitution rates and load conditions to maximize the benefits of hydrogen-diesel dual-fuel engines while minimizing the associated NOx emissions. Additionally, the integration of hybrid fuel systems and advanced combustion strategies could further enhance the performance and environmental benefits of dual-fuel engines.

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Chapter - 23

Enhancing Mechanical Properties and Biocompatibility of Hydroxyapatite Composites through Gd_2O_3 Doping: A Study for Biomedical Implants

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Chapter - 23

Enhancing Mechanical Properties and Biocompatibility of Hydroxyapatite Composites through Gd_2O_3 Doping: A Study for Biomedical Implants

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Abstract

Hydroxyapatite (HA) is extensively used in biomedical implants due to its excellent biocompatibility and chemical similarity to human bone mineral. However, its inherent brittleness and poor mechanical strength limit its application in load-bearing implants. Recent studies have demonstrated that doping HA with rare-earth oxides, such as gadolinium oxide (Gd_2O_3), can enhance its mechanical properties while maintaining or even improving biocompatibility. This paper reviews the effects of Gd_2O_3 doping on HA composites, focusing on its potential to improve the mechanical performance and biological compatibility of the material for biomedical implants.

Keywords: Hydroxyapatite, gadolinium oxide, HA-Gd_2O_3, mechanical properties, biocompatibility, biomedical implants, biomaterials.

Introduction

Hydroxyapatite (HA), with the chemical formula $Ca_{10}(PO_4)_6(OH)_2$, is a naturally occurring mineral form of calcium apatite, which is the primary inorganic component of bone and teeth and the methods are shown in Figure 1. Due to its bioactivity and biocompatibility, HA has been extensively researched for use in biomedical implants, bone grafts, and coatings [1]. Despite its favorable biological properties, the mechanical limitations of HA, including its brittleness and low fracture toughness, restrict its use in load-bearing applications such as hip or knee replacements [2]. To address these mechanical shortcomings, researchers have explored various strategies to enhance the performance of HA, including doping with metal oxides. Gadolinium oxide (Gd_2O_3), a rare-earth oxide, has shown promise in enhancing the mechanical properties of ceramic composites while maintaining their biocompatibility [3].

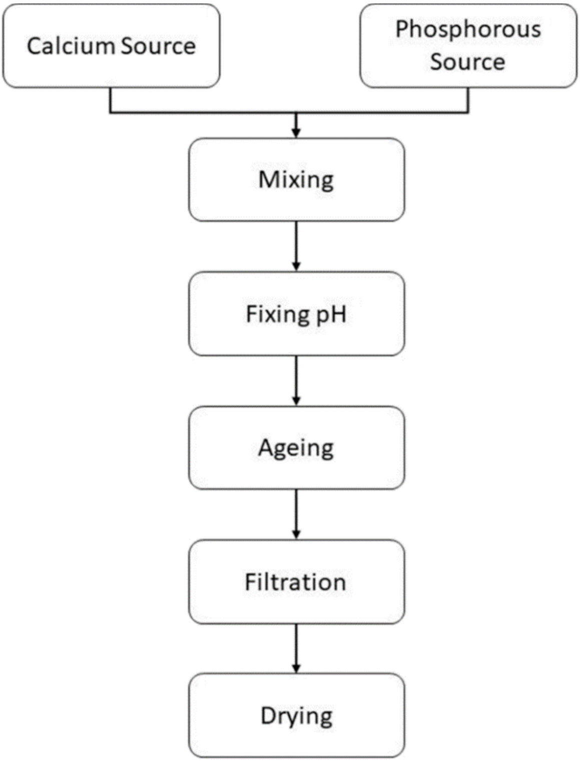

Fig 1: Preparation of HAp

This review examines the impact of Gd_2O_3 doping on the mechanical properties and biocompatibility of HA composites, with a particular focus on its potential for biomedical implant applications.

Literature review

Hydroxyapatite in biomedical implants

Hydroxyapatite is well-known for its biocompatibility and ability to bond directly with bone. Due to its similar chemical composition to the mineral phase of bone, HA promotes osteointegration and supports cell attachment, making it a suitable material for bone regeneration and implant coatings [4]. However, HA's mechanical properties, including low tensile strength and fracture toughness, limit its application in areas subjected to high stress or loading [5].

Several methods have been explored to improve the mechanical performance of HA, including combining it with polymers, metals, or ceramic dopants [6]. Doping HA with various metal oxides, such as titanium dioxide (TiO_2), zirconium dioxide (ZrO_2), and gadolinium oxide (Gd_2O_3), has emerged as an effective strategy to enhance both the mechanical and biological properties of HA [7].

Gadolinium oxide: Properties and potential for biomedical applications

Gadolinium oxide (Gd_2O_3) is a rare-earth oxide known for its exceptional mechanical strength, thermal stability, and ability to improve the properties of ceramic materials. Gd_2O_3 is also biocompatible, making it an attractive dopant for HA in biomedical applications [8]. The addition of Gd_2O_3 to HA composites can significantly improve mechanical strength by refining grain structure, inhibiting crack propagation, and increasing the toughness of the material [9].

Beyond its mechanical properties, Gd_2O_3 offers additional advantages, such as radiopacity, which allows for easy monitoring of implants post-surgery through imaging techniques like X-rays and MRI [10]. Moreover, gadolinium-based materials have shown low toxicity and have been used in medical imaging as contrast agents, further suggesting their suitability for biomedical implants [11].

Mechanical enhancement of HA-Gd_2O_3 composites

Several studies have demonstrated the mechanical improvements achieved by doping HA with Gd_2O_3. Research by Zhang *et al*. (2016) revealed that HA-Gd_2O_3 composites exhibited a significant increase in compressive strength, hardness, and fracture toughness compared to pure HA [12]. The improved Density and mechanical properties were attributed to the grain refinement and the formation of secondary phases that hinder crack propagation, enhancing the overall durability of the composite are shown in Figure 2 [13].

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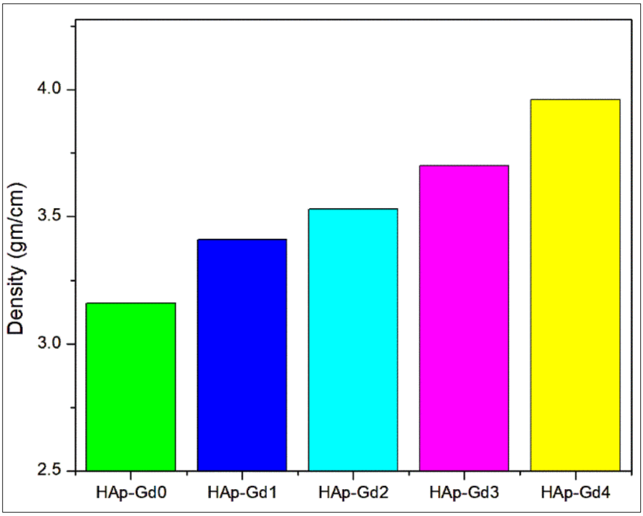

Fig 2: Density of HAp -Gd based composites

Another study by Li *et al*. (2018) examined the microstructural changes in HA composites doped with varying concentrations of Gd_2O_3. The study found that the optimal concentration of Gd_2O_3 resulted in a 25% increase in compressive strength and improved wear resistance without compromising the bioactivity of the material [14]. These findings suggest that Gd_2O_3 doping can produce HA composites suitable for load-bearing applications such as spinal implants, hip replacements, and bone plates.

Biocompatibility of HA-Gd_2O_3 composites

While the mechanical benefits of Gd_2O_3 doping are well-established, it is crucial to ensure that the addition of Gd_2O_3 does not adversely affect the biocompatibility of HA. Studies on the biocompatibility of HA-Gd_2O_3 composites have shown promising results. For example, Lee *et al*. (2019) investigated the *in vitro* biocompatibility of HA-Gd_2O_3 composites and found that the material supported osteoblast proliferation and exhibited low cytotoxicity [15].

In vivo studies have also confirmed the favorable biocompatibility of HA-Gd_2O_3 composites. When implanted in animal models, these composites demonstrated excellent osseointegration, with new bone formation observed at the implant site [16]. Additionally, the presence of Gd_2O_3 did not elicit any adverse immune responses or inflammation, further validating the material's potential for biomedical applications [17].

Potential challenges and safety concerns

Despite the promising results, the long-term effects of gadolinium-based materials in the human body are still under investigation. Gadolinium, when used in contrast agents for MRI, has been associated with rare cases of nephrogenic systemic fibrosis (NSF) in patients with impaired renal function [18]. Although the risk of gadolinium toxicity in solid implants is considered low, further research is needed to confirm the long-term safety of HA-Gd_2O_3 composites, particularly in terms of ion release and potential accumulation in the body [19].

Discussion

The incorporation of Gd_2O_3 into HA composites represents a significant advancement in the field of biomaterials for bone regeneration and implantology. The mechanical enhancements provided by Gd_2O_3 doping, including increased strength, toughness, and wear resistance, make HA-Gd_2O_3 composites suitable for use in load-bearing implants. Additionally, the biocompatibility of these composites remains intact, with no significant cytotoxicity or adverse biological reactions reported in studies to date.

However, further research is necessary to optimize the concentration of Gd_2O_3 in HA composites to achieve the best balance between mechanical performance and biocompatibility. Moreover, long-term studies are required to assess the potential risks associated with gadolinium ion release and accumulation in the body, particularly in the context of permanent implants.

Conclusion

The doping of HA with Gd_2O_3 has been shown to significantly enhance the mechanical properties of HA, making it a more suitable material for load-bearing biomedical implants. In addition to mechanical improvements, HA-Gd_2O_3 composites maintain excellent biocompatibility, making them promising candidates for use in bone regeneration and implant applications. While the current research is promising, further studies are needed to ensure the long-term safety of Gd_2O_3-doped HA composites in clinical settings.

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