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Design and operation of abrasive jet machining of polydimethylsiloxane or silicone elastomer with abrasive particles of aluminum oxide

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Abstract

Abrasive jet machining (AJM) is a machining process that uses high-velocity gas to push abrasive particles and remove unwanted material from a workpiece. It is also known as abrasive micro-blasting or pencil blasting. The uses of this technology range from refining rough surfaces, such as deburring and rough finishing, to machining ceramics and other electronic devices. It can also be used for micro-machining procedures. AJM offers numerous benefits compared to alternative non-traditional cutting techniques, such as extensive machining adaptability and reduced substrate stress. This work explores a variety of studies carried out by researchers to assess the influence of AJM process parameters, such as the abrasive particle type, on the results of machining. Several studies were conducted to measure the impact of the abrasive jet machine.

Keywords: *Abrasive jet machining, Elastomer, Machinability*

1. Introduction

The sandblasting machine, pioneered by Benjamin Tilghman in 1870, initially aimed at removing paint and rust from material surfaces for subsequent practical applications. Thomas Pangborn's enhancements in 1904, incorporating compressed air with sand, expanded the technique's capabilities. Sandblasting setups typically consist of an air compressor, abrasive particles, and a blaster nozzle [1]. Primarily utilized for surface cleaning prior to decoration or use, or for etching textured designs, the method initially relied on sand [2]. However, due to the health risks posed by inhaling sand particles leading to conditions like silicosis, alternative abrasive materials became preferable.

In 1893, the introduction of the air processor facilitated industrial-scale sandblasting. By 1918, enclosures were devised to shield the process. By 1939, a variety of abrasive particles such as aluminum oxide, silicon carbide, quartz, glass particles, steel grit, walnut shells, and coconut shells found utility in sandblasting, depending on specific requirements. This variant of the technique became known as abrasive blasting.

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Initially employed in industrial settings for tasks like rust removal and metal finishing, sandblasting gradually transitioned to decorative applications. Micro abrasive blasting, or abrasive jet machining, emerged later for machining ceramic and brittle materials, utilizing small abrasive particles, fine nozzles, and high compressed air [3-5].

In a conducted experiment, an in-house fabricated Abrasive Jet Machine utilized atmospheric air as the carrier gas, aluminum oxide as the abrasive powder, and a stainless steel alloy nozzle, with glass as the workpiece material [6]. Material removal rate (MRR) and surface roughness (OC) were calculated numerically, with a focus on process parameters like pressure (P) and stand-off distance (SOD), crucially analyzed using the Taguchi method.

The machinability of a material in AJM hinges on factors like mixing ratio, nozzle diameter, stand-off distance, abrasive particle size, and pressure. In this analysis, pressure and SOD were identified as primary input parameters for optimization [7].

2. Experimental Procedure

Abrasive Jet Machining (AJM), also known as abrasive micro-blasting, stands as a nonconventional machining technique wherein a high-pressure air stream carries small abrasive particles through a nozzle to impinge upon the work surface for material removal. The erosive action of these abrasive particles striking the workpiece surface facilitates material removal. Due to its relatively low material removal capability, AJM finds its niche primarily in finishing processes. Particularly effective for hard and brittle materials, AJM shares similarities with sandblasting, albeit with finer abrasive powders and smaller nozzles being employed.

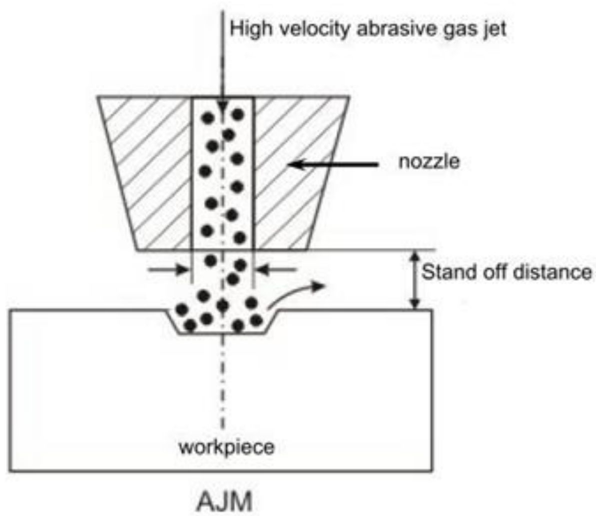

Fig. 1 Schematic diagram of AJM

2.1. Process description

In a schematic representation of AJM depicted in Fig. 1, the process involves compressing a carrier gas, such as dry air, CO_2, or N_2, at high pressure using an air compressor. Initially, the carrier gas passes through a pressure regulator to achieve the desired working pressure. Subsequently, it traverses through an FRL unit (filter lubricator and regulator) to eliminate dust particles, as well as to lubricate and regulate the gas flow.

The carrier gas then enters the mixing chamber, where abrasive particles from a container are introduced through an abrasive feeder, adjusted according to requirements, and mixed with the carrier gas with the assistance of an electric vibrator. These abrasive-laden carrier gas streams are conveyed from the mixing chamber to the workpiece via a hose pipeline and nozzle.

The entirety of the machining process is enclosed to ensure safety and eco-friendliness. A line diagram of the AJM setup is delineated in Fig. 2.

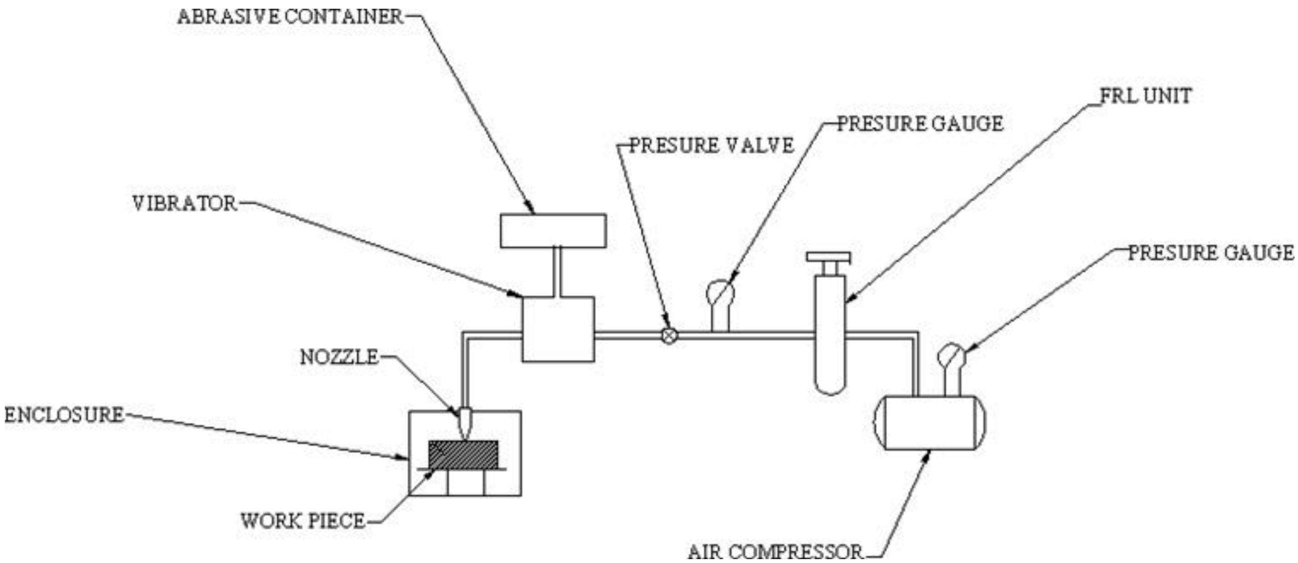

Fig. 2 Line diagram of AJM

The major components are:

- Air Compressor.
- FRL unit
- Pressure Gauge.
- Pressure Valve.
- Abrasive Container.
- Vibrator or Mixer.
- Nozzle.
- Enclosure.
- Work Piece.
- Abrasive Powder.

The process parameters and its standard value are in given in Table 1 that is required for experimental work.

Table 1. Process parameter and its standard values

1. Abrasive powder	Shape	Irregular or spherical
	Size	10-50µm
	Flow rate	5- 20 gm/min
	Material	AL_2O_3, SiC
2. Carrier gas	Composition	Air, CO_2, N_2
	Velocity	500-700 m/s
	Pressure	2-10 bar
	Flow rate	5-30 lpm
3. Abrasive	Velocity	100-300 m/s
	Mixing ratio	M_{abr}/M_{gas}
	Stand-off distance	0.5-5 mm
	Impingement angle	60^0-90^0
4. Nozzle	Material	Tungsten carbide, boron carbide, sapphire
	Diameter	0.2-0.8 mm
	Life	10-300 hr.

Machining Parameter

- Work piece
  - Material removal rate
  - Surface roughness
- Nozzle
  - Wear rate

2.2. Material removal rate

The material removal takes place from the work piece by the application high velocity abrasive jet particle. Due to the high kinetic energy of particle causes erosion of work piece. The material removal is depend upon the certain parameter such as abrasive flow rate, mixing ratio, gas pressure, stand-off distance etc. The MRR depends on different process parameter. The Fig. 3 shows that:

- Material removal rate (MRR) increases with increase of abrasive flow rate due to the more number of particles impingement in unit time. But after reaching an optimum value material removal rate decreases with further increase of abrasive flow rate because of mass flow rate of gas decreases with increase of abrasive flow rate.
- Similarly Material removal rate (MRR) increases with increase of mixing ratio (Mabr/Mgas). But after reaching an optimum value material removal rate decreases with further increase of mixing ratio.
- Material removal rate (MRR) continuously increases with increase in abrasive flow rate when mixing ratio is kept constant.
- Material removal rate (MRR) increases with the increase of gas pressure.
- At first Material removal (MRR) rate increases with increase in stand-off distance then it is remains constant for a period of time and after that decreases with increase in stand -off distance. This phenomena occurs due to penetration rate of abrasive material is optimum at certain level. After that, it will decrease.

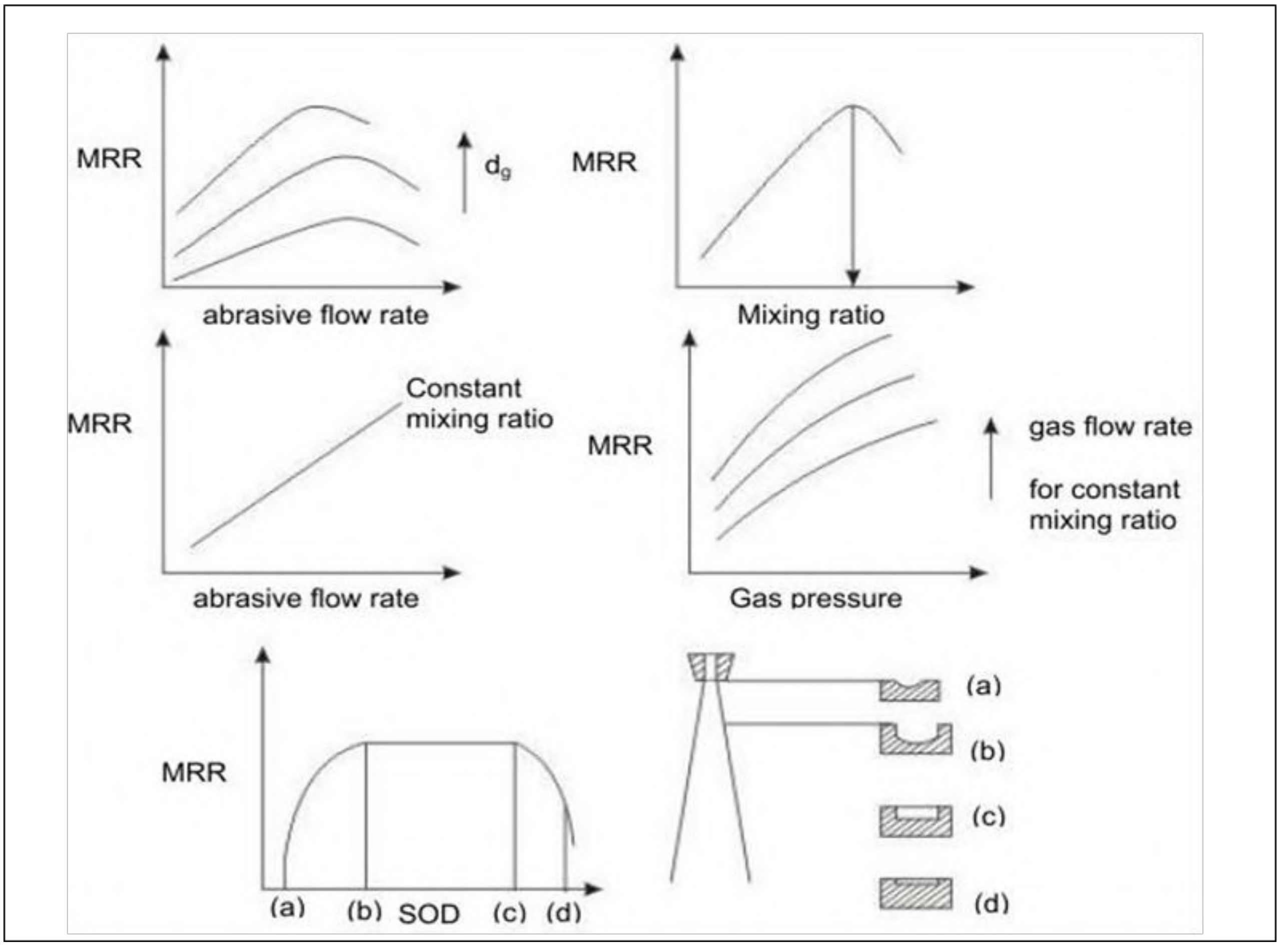

Fig. 3 Effect of process parameter on MRR

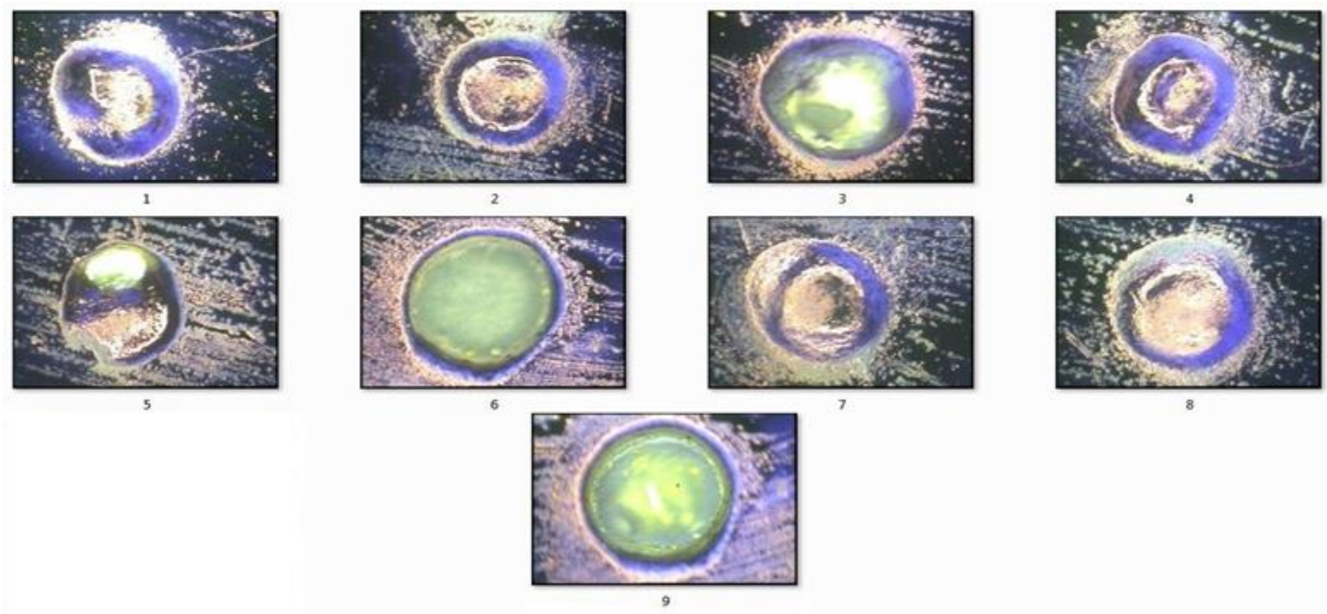

Fig. 4 Drilled cavity on work piece (run numbers are indicated)

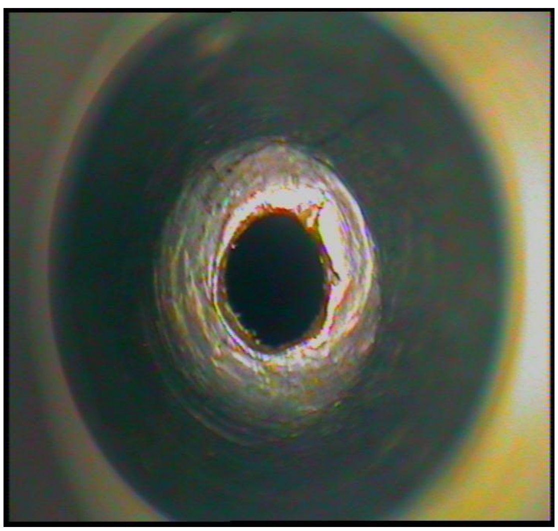

Fig. 5 View of nozzle dia before experiment

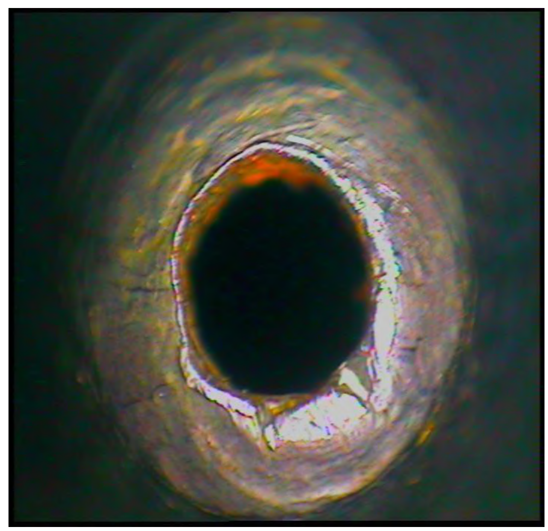

Fig. 6 View of nozzle dia. after experiment

2.3. Design of observation table

The design of observation table (Table 2) was generated by taking the weight of the workpiece (initial weight and final weight) and cavity dia of work piece.

Table 2. Design of observation table

Run no	SOD (mm)	P (bar)	Weight of work piece (gm)		Cavity dia (mm)
			Initial weight	Final weight	
1	0.6	2	65.678	65.675	2.265
2	0.6	4	65.675	65.665	2.364
3	0.7	6	65.665	65.648	2.875
4	0.8	2	65.729	65.723	2.290
5	0.8	4	65.723	65.709	2.613
6	0.9	6	65.709	65.684	3.015
7	1.0	2	65.764	65.759	2.320
8	1.0	4	65.759	65.748	2.413
9	1.0	6	65.748	65.729	2.915

2.4. Influences of MRR

The observed values of MRR are shown in Table 3 During the process of AJM, the influence of machining parameters like SOD and pressure has significant effect on MRR as shown in main effect plot for MRR in Fig. 3 The pressure (p) is directly proportional to MRR in the range of 2 to 6 bar.

Table 3. Observed value of MRR

Run no	SOD (mm)	P (bar)	MRR (mm^3/min)
1	0.6	2	1.667
2	0.6	4	3.751
3	0.7	6	7.083
4	0.8	2	2.500
5	0.8	4	5.833
6	0.9	6	10.417
7	1.0	2	2.083
8	1.0	4	4.583
9	1.0	6	7.917

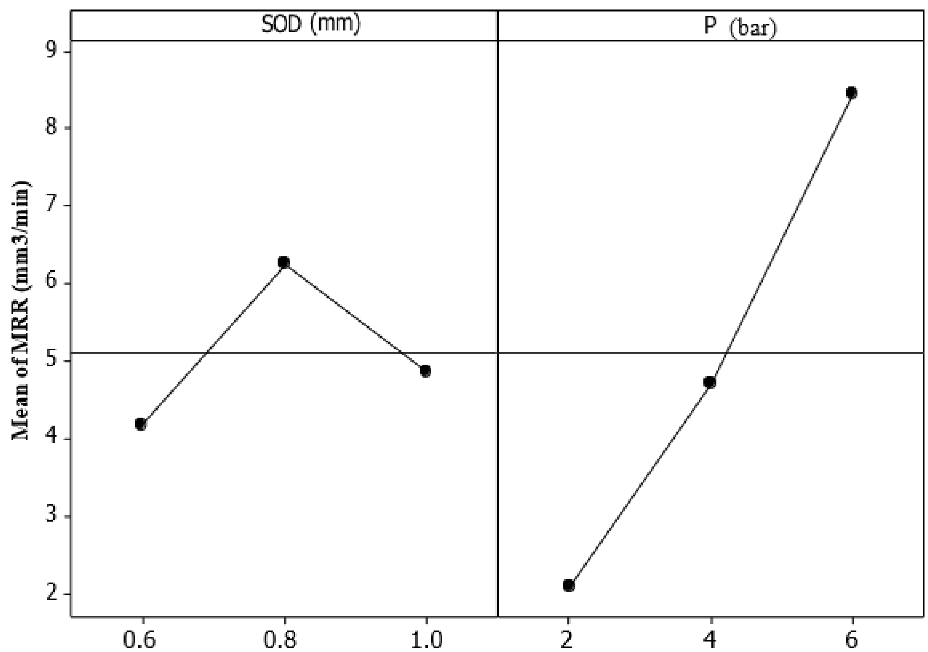

Fig. 7 Main effect plot for mean of MRR

This is expected because an increase pressure produces strong kinetic energy which produces the higher temperature, causing more material to erode from the work piece. The other factor SOD does not influence much as compared to pressure. It is clearly indicated from the above Fig. 7 at SOD 0.9mm the MRR was maximum. It decreases with increase in SOD and also decreases with decrease in SOD.

3. Conclusions

First of all component was made, and then fabrication was done in our production laboratory. The machine was fully automation by using controller. During the fabrication, different conventional machine tool was used. Care was taken easy and chief available of material in the market and also taking care of available space. Considering their efficiency sometimes procured quality product.

According to Taguchi method, experiments were conducted by using the machining set up. The process control parameters like SOD, Pressure were varied to conduct nine different experiments and the weights of the work piece were taken for calculation of MRR and dimensional measurements of the cavity of the work piece were taken for calculation of over cuts (OC).

The observed value of MRR and OC was analyzed by Taguchi design. From analysis it was concluded that the pressure and SOD both are significant for MRR and only pressure is significant for OC.

- A completed CAD model of AJM was prepared considering the optimum use of available material and space.
- Working chamber, nozzle holder arrangement, work holding device were made in our production laboratory
- The AJM is can be used for drilling and milling of glass plates or other brittle materials.
- By feeding different type of programming on controller, various complicated shapes are machined.
- Experimental work was done by considering SOD and Pressure are machining parameters to study MRR and OC.

- For MRR, both SOD and pressure are significant factor and for OC only pressure is significant.
- MRR is increases with increase in pressure. For increase in SOD firstly MRR increases then it is remain constant after that it is decreases.

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