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Fabrication of Abrasive Jet Machine to Study Effect of SIC Abrasive Particles on Various Materials

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ABSTRACT: Abrasive jet machining is process of removing material from work piece by the application of high speed stream of abrasive particles carried by pressurised air through nozzle. This machining process is ideal for cutting materials that cannot be cut by laser or thermal cut. Since no heat is induced while machining the surface, the workplace is protected from thermal shocks. Holes with minimum diameter and maximum depth can be drilled with accuracy by using abrasive jet machine. In this project we have fabricated abrasive jet machine and performed drilling operation on glass work piece and pterocarpusmarsupium wood work piece. The material removal rates were calculated by varying parameters such as abrasive flow rate, carrier gas pressureand stand-off distance for each work piece.

KEYWORDS: Material Removal Rate, carrier gas pressure, stand-off distance, abrasive flow rate.

I. INTRODUCTION

In conventional machining processes material is removed in the form of chips by applying forces on the work material with a wedge formed cutlery which is tougher than the work material under machining condition. These forces induce plastic deformation among the work piece resulting in shear deformation on the shear plane and chip formation. In abrasive jet machining process the high speed abrasive particles take away the fabric by micro cutting action in addition as brittle fracture of the work material.

Abrasives are very expensive but abrasive jet process demand low capital cost and operational cost because the investment on equipment is very low in comparison with other non-traditional machining processes giving tighter tolerances. As the carrier gas serves as a coolant, the cutting action is cool and hence better surface finish can be obtained. Now days it is widely used in manufacturing of electronic devices, LCD's, tribo-elements, MEMS, and semiconductors. There exists an increasing demand to develop micromachining technologies for these difficult-to-machine materials due to their properties of extreme hardness, brittleness, corrosion resistance and low melting temperatures. Abrasive jet machining (AJM) is a non-traditional machine process which operates without producing shocks and heat. In this machining process, the high - velocity stream of abrasives is generated by converting the pressure energy of carrier gas or air to its Kinetic energy and hence the high - velocity jet results. A nozzle directs abrasives in a controlled manner onto the work material. AJM is applied for many applications like cutting, cleaning, polishing, deburring, etching, drilling and finishing the operation. The nozzle is the most critical part in the abrasive air-jet equipment. The process is used chiefly to cut intricate shapes in hard and brittle materials which are sensitive to heat and have a tendency to chip easily. The process can be easily controlled by varying the parameters such as Velocity, Flow rate, Pressure, Standoff distance, Grit size, and nozzle angle.

II. RELATED WORK

D.V. Srikanth and M. Sreenivasa Rao [1] conducted experiments and analyzed the influence of process parameters on MRR and Kerfs width in abrasive jet machining of ceramic tile. The results of experiments was analyzed. It is observed that by increasing nozzle diameter the MRR increases, similarly decrease in stand-off distance will reduce the divergence of the hole produced.

V. C. Venkatesh [2] performed parametric studies on abrasive jet machining. He demonstrated the effect of feed rate, pressure, abrasive grit size, spray angle, nozzle tip to work distance and metal removal rate. He reported that wear is severe in exit nozzle, considerable in mixing chamber, and negligible in inlet nozzle.



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Y M Wan et al. [3] performed analysis using abrasive jet machining on soda lime glass and borosilicate glass. Mathematical approach was simulated. Results showed that there was reasonable agreement between experimental values and predicted values.

N. S. Pawara et al. [4] considered parameters like nozzle, abrasive particles and simulated cubic polynomial model to obtain material removal rate values experimentally. When material removal rate is within limits percentage of error is less. It was observed that material removal rate is directly proportional to pressure; whenever pressure will increase material removal rate will slightly increase. During the experiment at pressure 5 kg/sq. cm material removal rate is 0.0289 gram/sec. Thus results obtained using linear model for polynomial were found to be 95 % of predicted.

R Vijay Kumar [5] performed machining of glass with different parameters. He derived mathematical formulas with which when the stand-off distance is maintained at 20 mm, 30 mm then the variations of material removal rate could be noticed.

III. COMPONENTS

1 Air Compressor

This air compressor is a piston type air compressor, the rotation of the crankshaft and connection rod was converted into piston movement by up and downs to generate the compressed air in the cylinders, the compressed air was forced into the air tank via one way check valve and generated compressed air in the air tank. Lubricating oil is required for the movements of all parts within the pump heads, without adequate lubricating oil within the pump heads, the pump heads will be damaged.

Power		Cylinder	Exhaust	√olume	Pressure		Noise	Rated Voltage	Tank Capacity
KW	HP	ММ	LPM	CFM	Bar	PSI	dB	V	Liter
1.1	1.5	Ф42*1	135	4.8	8	116	≤90	240/50	25





Figure 1: Air Compressor



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2 Sand Blasting gun

Sand blasting gun is used for mixing abrasive with compressed air and directing mixture on work piece. Sand blasting gun has tungsten carbide nozzle with I.D. 2mm. Tungsten carbide is abrasive ceramic material having high temperature tolerance, stiffness, hardness and flexural strength. Sand blasting gun is provided with gravity feed detachable cup which can hold approximately 90 ml abrasive powder.



Figure 2: Sand Blasting Gun

3 Silicon Carbide Abrasive Powder

Silicon carbide powder is used in this project as abrasive powder having grit size 240 according to ANSI (American National Standards Institute) standard. Sandblasting media grit is measured by how much media passes through or is retained by a series of mesh sieve sizes. The grit size is based on the sieves used. 240 grit size is equivalent to 50 to 53.5 microns.



Figure 3: Silicon Carbide Abrasive Powder



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4 Pneumatic Connector

Pneumatic connectors were used to connect compressed airline to air compressor and sand blasting gun.



Figure 4: Pneumatic Connector

5 Enclosure

Abrasive particles are very fine grit size which remain suspended in the air for very long time. Inhalation of abrasive particles creates seriously respiratory problem on the lungs and makes disease called silicosis. Silicosis is an incurable condition with its potential to cause permanent physical disability. So enclosure was placed over workpiece and sand blasting gun while operating abrasive jet machine. Enclosure was made using 2 mm thick acrylic sheets. Acrylic is suitable for use as an impact resistant alternative to glass. Acrylic can withstand bombardment of abrasive particles since it has up to 17 times the impact resistance of ordinary glass. Acrylic has excellent optical clarity and transparency.



Figure 5: Enclosure



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6 Pneumatic Air Line Pipe

Pneumatic airline pipe made up of polyurethane material was used to carry compressed air from air compressor to sand blasting gun. Polyurethane is a very flexible elastomer which is synthetic polymer having elastic properties. Polyurethane material has abrasion resistance and impact resistance which helps to prevent tubing from being damaged and causing the inner contents to leak and flow outside of the tubing due to exterior damage. Polyurethane air tubing are used for flexible applications with a tight bend radius. This unique feature of polyurethane tubing assists for maximum kink resistance and minimum kink memory, making it an excellent choice for use in confined spaces. Polyurethane has a high compression load capacity. It may undergo a change in shape under a heavy load, but will return to its original shape once the load is removed. Polyurethane possesses high tear resistance along with high tensile properties. These properties of polyurethane air tubing make it suitable for the application of pneumatic airline pipe. Polyurethane pipe having outer diameter 10 mm and inside diameter 8 mm was selected for fabrication of abrasive jet machine.



Figure 6: Polyurethane Pipe

7 Frame

Table frame was fabricated by welding mild steel square bars.



Figure 7: Frame



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IV. EXPERIMENTATION

1 Experimental Set up

Air compressor was connected with sand blasting gun by using polyurethane pipe. Air compressor pressurised the carrier gas. Compressed carrier gas passes through polyurethane pipe. Compressed carrier gas is mixed with abrasive in sand blasting gun. Sand blasting gun was provided with gravity feed detachable cup through which abrasive material was supplied. The mixture of abrasive particles and compressed carrier gas is directed towards the workpiece by nozzle provided on sand blasting gun. As accelerated abrasive particles impact the surface, they cause small fracture, and the gas stream carries both the abrasive particles and the fractured particles away. The machining enclosure was used to contain abrasive and machined particles in safe and eco-friendly manner. The actual experimental set up is shown in figure no. 8.

Table 2: Experimental condition of performance parameters for abrasive jet machining

Sr. No.	Parameters	Values	
1	Abrasive Material	Silicon Carbide	
2	Abrasive Size	50 – 53.5 microns	
3	Nozzle Material	Tungsten Carbide	
4	Nozzle Diameter	2 mm	
5	Stand-off Distance	0.5 – 2 mm	
6	Carrier Gas	Air	
7	Pressure	5 – 8 bar	
0	Work piece	Glass, 3mm thick	
0	work piece	Pterocarpusmarsupium wood, 5 mm thick	



Figure 8(a): Experimental Set up of Abrasive Jet Machine



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Figure 8(b): Experimental Set up of Abrasive Jet Machine

2 Selection of nozzle material

Materials with high wear resistance will have great potential as abrasive air-jet nozzle materials. For this project we have selected tungsten carbide as nozzle material. Tungsten carbide is generally made with high percentage of either cobalt or nickel as a second, metallic phase. These ceramic metals, or "cermet's", have wide use as cutting tools and other metals-forming tools. Pure tungsten carbide can be made as an advanced technical ceramic using a high-temperature hot isostatic pressing process. This material has very high hardness and wear resistance, and is used for abrasive jet nozzles.

Table 3:	Tungsten	Carbide	Pro	perties
	6			

Sr. No.	Properties	Values
1	Density	13.0-15.3 gram/ <i>cm</i> ³
2	Hardness	1307-2105 kg/mm ²
3	Compressive Strength	3.10-5.86 MPa
4	Modulus of Elasticity	483-641 GPa
5	Thermal Conductivity	71-121 W/m-K
6	Coefficient of Linear Thermal Expansion	$5.9 \times 10^{-6} K^{-1}$
7	Specific Heat	945 J/kg K

3 Silicon Carbide abrasive material properties

Silicon carbide abrasive have stable chemical properties, high thermal conductivity, low thermal expansion coefficient, and good wear resistance. It has extreme hardness, good fatigue resistance and resistance to corrosion. The relatively high thermal conductivity and low coefficient of thermal expansion result in favourable thermal shock resistance when compared to other ceramic materials. Black silicon carbide abrasive contains about 98.5% of SiC, and its toughness is higher than that of green silicon carbide. It is mostly used to process materials with low tensile strength, such as glass, ceramics, stone, refractory materials, cast iron and non-ferrous metals.



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Table 4: Silicon Carbide Properties

Sr. No.	Properties	Values	
1	Density	3.16 gram/ <i>cm</i> ³	
2	Elastic Modulus	410 GPa	
3	Hardness	2800 Kg/mm ²	
4	Maximum Use Temperature(no load)	1650°C	
5	Thermal Conductivity	120 W/m K	
6	Coefficient of Thermal Expansion	4.0× 10 ^{−6} /°C	
7	Specific Heat	750 J/Kg K	

4 Selection of work piece material

For this project we have selected two work piece materials:

A. Glass

Glass work piece has thickness of 3 mm.

Table 5: Properties of Glass

Sr. No.	Properties	Values
1	Density	2500 Kg/m ³
2	Hardness (Brinell Hardness Number)	1550 HB
3	Compressive Strength	$1000 \times 10^6 N/m^2$
4	Young's Modulus	70 GPa
5	Coefficient of Linear Thermal Expansion	$9 \times 10^{-6} m/mK$

Conversion of Brinell hardness number into Newton per meter square for glass: Hardness of Glass = 1550 HB

 $= 1550 \text{ Kgf/mm}^{2}$ $= \frac{1550 \times 9.8}{(10^{-3})^{2}} \text{ N/m}^{2}$ Hardness of Glass = 1.519× 10¹⁰ N/m²



Figure 9: Glass work piece



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B. PterocarpusMarsupium Wood

PterocarpusMarsupium wood work piece has thickness of 5mm.

Table 6: PterocarpusMarsupium Wood Properties

Sr. No.	Properties	Values
1	Density	0.88 gram/ <i>cm</i> ³
2	Stiffness	133900 Kgf/cm ²
3	Bending Strength	1379 Kgf/cm ²
4	Compression Parallel to Fibre	683 Kgf/cm ²
5	Shear Strength Radial	116 Kgf/cm ²

5 Experimental Procedure

- 1. By keeping stand off distance constant at 2 mm and by varying pressure of carrier gas from 5 bar to 8 bar; change in material removal rate with respect to change in abrasive flow rate was studied for glass work piece and PterocarpusMarsupium wood work piece.
 - i. For both work pieces abrasive flow rate was calculated by using following formula:

Abrasive Flow Rate =
$$\frac{W}{t} Kg/s$$

Where, W = Mass of Abrasive, Kg

t = Time taken by abrasive jet machine to drill hole , seconds

ii. Material removal rate for glass work piece was calculated by using following formula:

$$MRR_B = \frac{1.04 \times m_a \times V^{\frac{3}{2}}}{\rho_a^{\frac{1}{4}} \times H^{\frac{3}{4}}}$$

Where, ma = Abrasive flow rate (Kg/s)

V =Velocity of abrasive particle (m/s) at point of impact

 ρg =Density of abrasive (Kg/m^3)

H = Hardness or flow strength of work material (N/m^2)

- iii. Velocity of abrasive particle at point of impact can be calculated by using following steps:
 - a) Volume flow rate of abrasive can be expressed as;

Volume flow rate of abrasive =
$$\left(\frac{mass \ flow \ rate \ of \ abrasive}{density \ of \ abrasive}\right)$$

Volume flow rate of abrasive = $\left(\frac{ma}{\rho g}\right) m^3/s$

b) Volume flow rate of carrier gas discharged from compressor can be calculated by using Boyle's Law;

Where,
$$P_1 = Initial Pressure$$

$$P_1 \times V_1 = P_2 \times V_2$$

$$V_1 = Initial Volume$$

 $P_2 = Final Pressure$
 $V_2 = Final Volume$

At 8 bar pressure, exhaust volume of air compressor is 135 LPM.

By considering, $P_1 = 8 \text{ bar}$ and $V_1 = 135 \text{ LPM}$, exhaust volume of carrier gas can be calculated at different pressures.

Volume flow rate of carrier gas =Exhaust volume of carrier gas (LPM)

Volume flow rate of carrier gas = $(LPM) \times \frac{1 \times 10^{-3}}{60} m^3/s$

c) Volume flow rate of carrier gas and abrasive mixture at exit of nozzle can be given as; Volume flow rate of mixture= $(Va + Vg)m^3/s$ Where, $V_a = Volume$ flow rate of abrasive, m^3/s



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 $V_a = Volume \ flow \ rate \ of \ carrier \ gas, m^3/s$

d) Jet velocity at exit of nozzle can be given as; Jet Velocity(V) = $\frac{(Va+Vg)}{\frac{\pi}{4} \times d^2}$

Where, $d = Nozzle \ diameter$

Velocity of abrasive particle at point of impact = Jet Velocity (V), m/s

iv. Material removal rate for PterocarpusMarsupium wood work piece can be calculated by using following formula:

Material removal rate = $\frac{Area \ of \ hole \ drilled \ \times thickness \ of \ work \ piece}{time \ taken \ by \ abrasive \ jet \ machine \ to \ drill \ hole} m^3/s$ Material removal rate = $\frac{\frac{\pi}{4} \times D^2 \times h}{t} m^3/s$

Where, D = Diameter of hole drilled, m

h = thickness of work piece, m

t = time taken by abrasive jet machine to drill hole, seconds

- 2. By keeping stand off distance constant at 2 mm and varying pressure of carrier gas from 5 bar to 8 bar; change in material removal rate with respect to change in pressure of carrier gas was studied for glass work piece and PterocarpusMarsupium wood work piece. Material removal rates for glass work piece and PterocarpusMarsupium wood work piece were calculated by using formulae mentioned in previous steps.
- 3. By keeping pressure of carrier gas constant at 8 bar and varying stand-off distance from 0.5 mm to 2 mm; change in material removal rate with respect to change in stand-off distance was studied for glass work piece and PterocarpusMarsupium wood work piece. Material removal rates for glass work piece and PterocarpusMarsupium wood work piece were calculated by using formulae mentioned in previous steps.

V. EXPERIMENTAL RESULTS

1 Effect of change in abrasive flow rate on variation in MRR for glass work piece Stand-off distance was kept constant at 2 mm.



Figure 10: Drilling operation on glass work piece at different abrasive flow rates



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Table 7: MRR at different abrasive flow rates for glass work piece

	-		-		
Sr. No.	Pressure (bar)	Mass of Abrasive (Kg)	Time (seconds)	Abrasive Flow Rate(Kg/s)	$\frac{MRR}{(m^3/s)}$
1	8	0.0316	38.097	8.2946× 10 ⁻⁴	5.097548×10^{-8}
2	7	0.0632	43.014	1.4692×10^{-3}	1.1032×10^{-7}
3	6	0.0948	65.084	1.4565×10^{-3}	1.37819×10^{-7}
4	5	0.1264	90.005	1.4043×10^{-3}	1.7466×10^{-7}



Figure 11: Effect of change in abrasive flow rate on variation in MRR for glass work piece

2 Effect of change in pressure of carrier gas on variation in MRR for glass work piece Stand-off distance was kept constant at 2 mm.



Figure 12: Drilling operation on glass work piece at different pressures



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Table 8: MRR at different pressures of carrier gas for glass work piece

Sr. No.	Pressure (bar)	Mass of Abrasive (Kg)	Time (seconds)	Abrasive Flow Rate (Kg/s)	$\frac{MRR}{(m^3/s)}$
1	8	0.0632	62.003	1.0193×10^{-3}	6.2645×10^{-8}
2	7	0.0632	71.020	8.8989×10^{-4}	6.6816× 10 ⁻⁸
3	6	0.0632	99.053	6.3804×10^{-4}	6.0365×10^{-8}
4	5	0.0632	119.003	5.31079× 10 ⁻⁴	6.6048×10^{-8}



Figure 13: Effect of change in carrier gas pressure on variation in MRR for glass work piece

3 Effect of change in stand-off distance on variation in MRR for glass work piece Carrier gas pressure was kept constant at 8 bar.



Figure 14: Drilling operation on glass work piece at different stand - off distances



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Table 9: MRR at different stand - off distances for glass work piece

Sr. No.	Stand-off Distance (m)	Mass of Abrasive (Kg)	Time (seconds)	Abrasive Flow Rate (Kg/s)	$\frac{MRR}{(m^3/s)}$
1	0.5×10^{-3}	0.0316	30.061	1.05119×10^{-3}	6.46055×10^{-8}
2	1×10 ⁻³	0.0316	33.036	9.5653×10^{-4}	5.87866×10^{-8}
3	1.5×10^{-3}	0.0316	41.086	7.69118×10^{-4}	4.72667×10^{-8}
4	2×10^{-3}	0.0316	47.017	6.7209×10^{-4}	4.13029×10 ⁻⁸



4 Effect of change in abrasive flow rate on variation in MRR for PterocarpusMarsupium wood work piece Stand-off distance was kept constant at 2 mm.



Figure 16: Drilling operation on PterocarpusMarsupium wood work piece at different abrasive flow rates



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Table 10: MRR at different abrasive flow rates for PterocarpusMarsupium wood work piece

Sr. No.	Pressure (bar)	Abrasive (Kg)	Time (seconds)	Abrasive Flow Rate (Kg/s)	Diameter of hole drilled (m)	MRR (m^3/s)
1	8	0.0316	52.095	6.0658×10^{-4}	2.050×10^{-3}	3.1679×10^{-10}
2	7	0.0632	72.023	8.7749×10^{-4}	2.081×10^{-3}	2.3612×10^{-10}
3	6	0.0948	96.017	9.8732×10^{-4}	3×10^{-3}	3.6809×10^{-10}
4	5	0.1264	137.021	9.2248×10^{-4}	2.063×10^{-3}	1.21975× 10 ⁻¹⁰



Figure 17: Effect of change in abrasive flow rate on variation in MRR for PterocarpusMarsupium wood work piece

5 Effect of change in carrier gas pressure on variation in MRR for PterocarpusMarsupium wood work piece Stand-off distance was kept constant at 2 mm.



Figure 18: Drilling operation on PterocarpusMarsupium wood work piece at different carrier gas pressures



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Table 11: MRR at different carrier gas pressures for PterocarpusMarsupium wood work piece

Sr. No.	Pressure (bar)	Diameter of hole drilled (m)	Time (seconds)	$\frac{MRR}{(m^3/s)}$
1	8	2.046×10^{-3}	50.052	3.2843×10^{-10}
2	7	2.067×10^{-3}	70.020	2.3961×10^{-10}
3	6	2.098×10^{-3}	80.093	2.1581×10^{-10}
4	5	2.049×10^{-3}	137.025	1.2032×10^{-10}





6 Effect of change in stand-off distance on variation in MRR for PterocarpusMarsupium wood work piece Carrier gas pressure was kept constant at 8 bar.



Figure 20: Drilling operation on PterocarpusMarsupium wood work piece at different stand-off distances



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Sr. No.	Stand-off distance (m)	Diameter of hole drilled (m)	Time (seconds)	$\frac{MRR}{(m^3/s)}$
1	0.5×10^{-3}	2.011×10^{-3}	28.091	5.65349×10^{-10}
2	1×10^{-3}	2.028×10^{-3}	31.085	5.1957×10^{-10}
3	1.5×10^{-3}	2.015×10^{-3}	39.076	4.08037×10^{-10}
4	2×10^{-3}	2.073×10^{-3}	45.025	3.7480×10^{-10}

Table 12: MRR at different stand-off distances for PterocarpusMarsupium wood work piece



Figure 21: Effect of change in stand-off distance on variation in MRR for PterocarpusMarsupium wood work piece

VI. CONCLUSION

- 1. Abrasive jet machine was fabricated and drilling operations were performed on glass work piece having 3 mm thickness and PterocarpusMarsupium wood work piece having 5 mm thickness; by varying process parameters such as carrier gas pressure, stand-off distance, abrasive flow rate. Experimental results were recorded carefully and material removal rates were calculated.
- 2. Graphs showing variations in material removal rate with respect to changes in process parameters values were plotted.
- 3. For glass work piece it was observed that material removal rate decreases with increase in stand-off distance.
- 4. For PterocarpusMarsupium wood work piece material removal rate was decreasing with increase in abrasive flow rate up to abrasive flow rate of 9.2248×10^{-4} Kg/s. Further increase in abrasive flow rate results in increase in material removal rate.
- 5. For PterocarpusMarsupium wood work piece material removal rate was found to be increasing with increase in carrier gas pressure.



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6. For PterocarpusMarsupium wood work piece material removal rate decreases with increase in stand-off distance.

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