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Design of AJM, Analysis of Process Parameter and Their Effect on MRR

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***Abstract*— The present research work involves designing of a simple AJM machine. The AJM setup designed and fabricated is used for machining brittle materials of different thickness i.e. glass. The material removal rate is formulated by taking some parameters into assumption. The experiment shows different machining parameters are affecting the material removal rate (MRR). Some important parameters which are having directly impact on MRR such as grain size, nozzle tip distances (NTD/SOD) and pressure of carrier gas have investigated. it is found that increasing the grain size, NTD MRR also increases up to some point after that further increment decreases the MRR. Increasing the Pressure of gas increases the MRR. Finally the experimented result is compared with the theoretical value and observed suitable agreement between them. So the design is validated.**

Index Terms— MRR, Process parameter, grain size, SOD, pressure of carrier gas and AJM set up.

I. Introduction

Conventional machining sufficed the requirement of the industries over the decades. But new exotic work materials as well as innovative geometric design of products and components were putting lot of pressure on capabilities of conventional machining processes to manufacture the components with desired tolerances economically.

Machining intricate and complicated shapes of thin and fragile components and accurate and economical forming of very hard, high strength materials which are being extensively used in Airplane and nuclear industries have forced the scientist, engineers and technologists to search for new techniques of machining which can readily provide an effective solution to these problems.

This led to the development and establishment of Non Traditional Machining processes in the industry as efficient and economic alternatives to conventional ones. With development in the Non Traditional Machining processes currently there are often the first choice and not an alternative to conventional processes for certain technical requirements.

As a research and development for the last forty years several new methods of machining have emerged. Among the new methods we are going to deal with the Abrasive Jet Machining [Fig.1]. The conventional techniques like turning, drilling, milling etc., are well known and involves the use of mechanical power between the work piece and the tool whereas in this method need not be the case with unconventional on advanced machining techniques.

In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The jet of abrasive particles is carried by carrier gas or air.

The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet. The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material. AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more effectively providing better control over product quality. In AJM, generally, the abrasive particles of around 50 μm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a standoff distance of around 2 mm. The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.

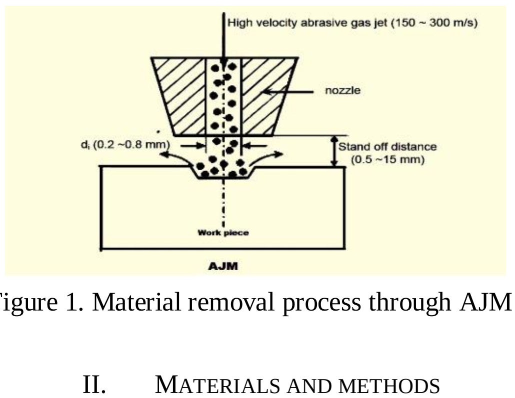

Figure 1. Material removal process through AJM

II. Materials and Methods

A. Materials

1. Gas Propulsion System

Supplies clean and dry air. Air, Nitrogen or carbon dioxide is used to propel the abrasive particles. Gas may be supplied either from a compressor or a cylinder. In case of a compressor, air filter cum drier should be used to avoid water or oil contamination of abrasive powder.

Gas should be non-toxic, cheap, and easily available. It should not excessively spread when discharged from nozzle into atmosphere. The propellant consumption is of order of 0.008 m^3/min at a nozzle pressure of 5 bar and abrasive flow rate varies from 2 to 4 gm/min for fine machining and 10 to 20 gm/min for cutting operation.

2. Abrassive Feeder

Required quantity of abrasive particles is supplied by abrasive feeder. The filleted propellant is fed into the mixing chamber where in abrasive particles are fed through a sieve. The sieve is made to vibrate at 50-60 Hz and mixing ratio is controlled by the amplitude of vibration of sieve. The particles are propelled by carrier gas to a mixing chamber. Air abrasive mixture moves further to nozzle. The nozzle imparts high velocity to mixture which is directed at work piece surface.

3. Machining Chamber

It is well closed so that concentration of abrasive particles around the working chamber does not reach to the harmful limits. Machining chamber is equipped with Vacuum dust collector. Special consideration should be given to dust collection system if the toxic materials (like beryllium) are being machined.

4. AJM Nozzel

AJM nozzle is usually made of tungsten carbide or sapphire (usually life – 300 hours for sapphire, 20 to 30 hours for WC) which has resistance to wear. The nozzle is made of either circular or rectangular cross section and head can be straight or at a right angle to the work piece. It is so designed that loss of pressure due to the bends, friction is minimized. With increase in wear of nozzle, the divergence of jet stream increases resulting in more stray cutting and inaccuracy.

5. Abrasive

Aluminum oxide (Al_2O_3) Silicon carbide (SiC), Glass beads, crushed glass and sodium bicarbonate are some of abrasives used in AJM. Selection of abrasives depends on MRR, type of work material and machining accuracy.

TABLE I: PROCESS PARAMETERS

Abrasive	Material - Al_2O_3 / SiC / glass beads Shape – irregular / spherical Size – 10 ~ 50 µm Mass flow rate – 2 ~ 20 gm/min
Carrier gas	Composition – Air, CO_2, N_2 Density – Air ~ 1.3 kg/m^3 Velocity – 500 ~ 700 m/s Pressure – 2 ~ 10 bar Flow rate – 5 ~ 30 lpm
Abrasive Jet	Velocity – 100 ~ 300 m/s Mixing ratio – mass flow ratio of abrasive to gas Stand-off distance – 0.5 ~ 5 mm Impingement Angle – 60^0 ~ 90^0
Nozzle	Material – WC / sapphire Diameter – (Internal) 0.2 ~ 0.8 mm Life – 10 ~ 300 hours

TABLE II: MACHINING CHARACTERISTICS

The important Machining characteristics are	The material removal rate (MRR) mm^3/min or gm/min
	The machining accuracy
	The life of the nozzle

B.Methodology

Determination of metal removal rate in AJM Process:

Material removal in AJM occurs due to brittle fracture of work piece as abrasive grains strike at high velocity.

Following assumptions are made during MRR calculation.

- Abrasives are spherical in shape and rigid. The particles are characterized by mean of diameter
- The kinetic energy of abrasives are fully utilized for removing materials
- Brittle materials are considered to fail due to brittle fracture and the fracture volume is considered to be hemispherical with diameter is equal to chord length of indentation
- For ductile material, removal volume is assumed to be equal to the indentation volume due to particular impact.

Abrasive particles are assumed to be spherical in shape having diameter (d_g)

From the geometry

$$AB^2 = AC^2+BC^2 \text{---------------------------------} (1)$$

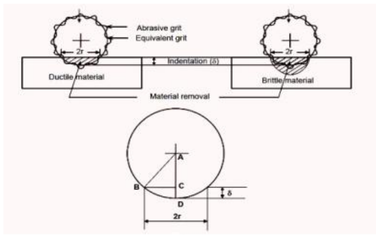

Figure-2. Mathematical modeling of a single abrasive grit

$$(\frac{d_g}{2})^2 = (\frac{d_g}{2} - \delta)^2 + r^2$$

$r^2 = -\delta^2 + d_g\delta$ [neglecting δ^2 term we can write]

$$r = \sqrt{d_g \delta}$$

Volume of the material removal in brittle material is the volume of the hemispherical impact crater is given by,

$$V_B = \frac{2}{3} * \pi * r^2$$

$$= \frac{2}{3} * \pi * (d_g \delta)^{3/2}$$

Kinetic energy of single abrasive particle is given by

$$KE_g = 0.5 * m * v^2$$

$$= 0.5 * (V_B \rho_g) * v^2$$

$$= 0.5 * \{ \frac{\pi}{6} * d_g{}^3 * \rho_g \} * v^2$$

$$KE_g = \frac{\pi}{12} * d_g{}^3 * \rho_g * v^2 \text{------------------------------} (2)$$

On impact the work material will subjected to a maximum force F, which will lead to an indentation δ. Hence, the work done during indentation,

$$W = \frac{1}{2} * F * \delta$$

Now considering, H be the flow strength of work material the impact force F can be calculated,

$$F = \text{Indentation area} * \text{hardness} = \pi r^2 * H$$

$$W = \frac{1}{2} * \pi r^2 \delta * H \text{------------------------------------} (3)$$

As kinetic energy of abrasive particle is equal to work done

$$W = K.E$$

$$\frac{1}{2} * \pi r^2 \delta H = \frac{\pi}{12} * d_g{}^3 * \rho_g * v^2$$

$$\delta = d_g{}^3 * \rho_g * v^2 / 6 * r^2 * H$$

$$\delta = \{\frac{d_g{}^2 * \rho_g * v^2}{6H}\}^{\frac{1}{2}}$$

$$\delta = d_g v * (\frac{\rho_g}{6H})^{1/2} \text{----------------------------------} (4)$$

So, material removal rate in AJM of brittle material can be expressed as,

MRR_B= [volume of material removal] * [no. of impact by abrasive grits/second]

$= V_B * N$

$= V_B * m_a$ / mass of grits

$$= \frac{\frac{2}{3} * \pi * (d_g * \delta)^{\frac{3}{2}} * m_a}{\frac{\pi}{6} * d_g{}^3 * \rho_g}$$

$$MRR_B = 4 * \frac{m_a}{\rho_g} * (\frac{\delta}{d_g})^{3/2}$$

$$\Rightarrow \quad MRR_B = \frac{m_a v^{3/2}}{\rho_g{}^{1/4} H^{3/4}} \text{---------------------------} (5)$$

III. EXPERIMENTATION

In this experiment different components of the AJM machine is designed and fabricated into suitable dimensions for proper functioning the list of the components their function with dimension is given below:

1. Air Compressor

It is most vital part of Abrasive Jet Machining that provides required air pressure to carry out abrasive that will strike the work piece for cutting purpose.

Capacity: 25 bar (max.), working pressure below 10 bar

Type: Reciprocating dual cylinder

2. Abrasive Storage Tank

As per its name it stores the abrasive particles (sand) through which compressed air passes and carries out the abrasives up to the nozzle. It has three openings, one from the compressor outlet another connected to nozzle by hose pipe and the third one (closed by a threaded cap) is for entry of abrasives into the tank. Material: Galvanized Iron

Dimension: Diameter-10.5 cm

Length-23 cm

The purpose of this stand is to hold the storage tank in a position with respect to the cutting chamber. It facilitates the storage tank to be kept either in horizontal or inclined (60 degrees) as per our requirement.

During cutting the inclined position of storage tank causes increment in mass flow rate of abrasive. To prevent the accumulation of abrasive at nozzle when the machine is not in operation the horizontal position is preferred.

3. Hose pipe

The compressed air from compressor to the storage tank and the mixture of compressed air and abrasive (sand) to the inlet of nozzle is carried through the hose pipe.

Diameter: Inlet-8mm, outlet-14mm

Length: 1 m

Capacity: 1700psi

Material: reinforced plastic

4. Nozzle

It converts the pressure energy contained by the compressed air into kinetic energy. It directs the mixture of air and abrasive that comes through hose pipe from storage tank towards the cutting zone.

Material:

Length: 8cm

Diameter: 2mm (inner diameter),

5. Cutting chamber

A well closed machining chamber is essential for abrasive jet machining so that the abrasive particles around the cutting zone do not harm the operator. The frame of cutting chamber is made of mild steel enclosed by 4 fiber glasses. The lower part is fixed with closed by a mild steel plate and upper part is provided with a mild steel cap having a hole through which a nozzle along with hose pipe from storage tank passes through it.

Dimension: 25*25*30 (length*breadth*height) cm^3

6. Work-piece Holder

The work piece is kept fixed with respect to the nozzle by the help of work piece holder. Nozzle tip distance can also be varied in work-piece holder. It is provided with three rows of aluminum channel on both wood pieces. The wood pieces are fixed with each other by means of steel plates.

IV. RESULT AND DISCUSSION

The calculation involved in finding the MRR by abrasive jet machining of glass using sand as abrasive is given by,

$$MRR = \frac{\textbf{Volume of Cut}}{\textbf{Time Taken}}$$

After machining, we get the hole in the workpiece as a tapered one. So, we take the profile of the hole as conical section, therefore MRR is,

$$= \frac{\textbf{Volume of cylinder}}{\textbf{time taken}}$$

$= \pi r^2 h$ / time (where time in seconds)

OBSERVATION- 1

Pressure=12 bar

r = 4mm

h = 4.5mm

Volume = 226.08mm^3

Time taken=10.57 sec

Material removal rate =21.38mm^3/sec

OBSERVATION- 2

Pressure= 10 bar

r = 4.5mm

h =5mm

Volume=317.925mm^3

Time taken=12.63sec

Material removal rate= 25.17mm³/sec
OBSERVATION- 3
Pressure=7 bar
r =6mm
h = 5mm
Volume = 565.2mm³
Time taken= 33.41sec
Material removal rate= 16.91mm³/sec
OBSERVATION- 4
Pressure= 6 bar
r = 5mm
h =5mm
Volume=392.69mm³
Time taken=42.6sec
Material removal rate= 9.218mm³/sec
Time taken= 33.41sec

RESULT-1
Graph showing variation of MRR with pressure and table showing variation of time taken to cut the glass (fixed thickness=5mm) at different pressure and at constant stand-off distance and grain size.

TABLE III- VARIATION OF MRR WITH PRESSURE

Standoff dist.	Grain size (microns)	Pressure (bar)	Time (sec)	MRR (mm3/sec)
2mm	250-355	12	10.57	21.38
2mm	250-355	10	12.63	25.91
2mm	250-355	7	33.41	16.91
2mm	250-355	6	42.92	9.218

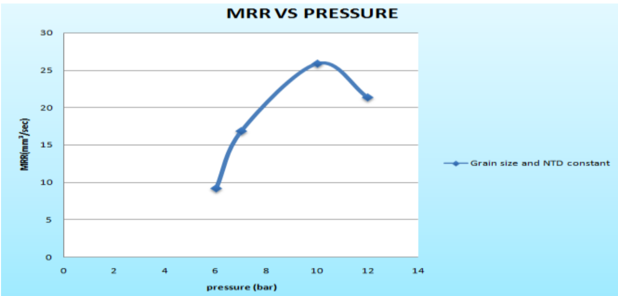

Figure 3. Variation of MRR with pressure

RESULT-2
Graph showing variation of MRR with nozzle tip distance and table showing variation of time taken and MRR to cut the glass (fixed thickness=3.5mm) at different nozzle distance and at constant pressure and grain size tip.

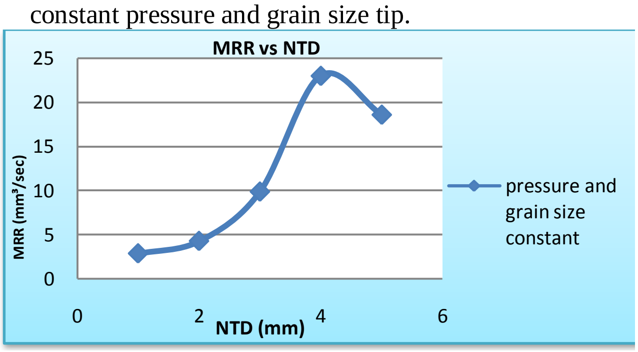

Figure 4. showing variation of MRR with nozzle tip distance

RESULT -3
Graph showing variation of MRR with grain size and table showing variation of time taken and MRR to cut the glass (fixed thickness=3.5mm) at different Grain size and at constant pressure and nozzle tip distance.

TABLE IV- VARIATION OF MRR WITH GRAIN SIZE

Pressure (bar)	NTD (mm)	Grain size (microns)	MRR (mm3/sec)
11	4	150-250	1.39
11	4	250-355	2.38
11	4	355-500	4.24
11	4	500-1000	9.27

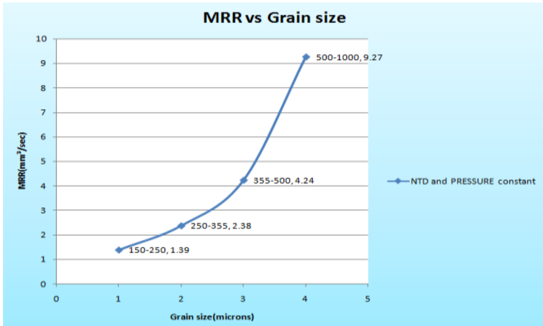

Figure 5. Variation of MRR with grain size

III. Conclusion

- This paper presents various results of experiments, which have been conducted by varying pressure, nozzle tip distance and grain size on different thickness of glass plates.
- The effect of their process parameters on the material removal rate (MRR), top surface diameter and bottom surface diameter of hole obtained were measured and plotted. It was observed that as nozzle tip distance increases, the diameter of hole increases as it is in the general observation in the abrasive jet machining process.
- Again with increase in nozzle tip distance, MRR first increases upto an optimum value and then decreases with further increase of NTD. As the pressure increases material removal rate (MRR) was also increased as available energy per grain increases with high pressure. It is also observed that surface finishing decreases with increase in grain size, but MRR increases as larger grains having greater momentum.

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