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Investigation of Drilling Time V/S Depth of Cut & Kerf Using Abrasive Jet Machining

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Abstract: *Abrasive jet machining (AJM) is a processing non-traditional machine which operates materials without producing shock and heat. AJM is applied for many purposes like drilling, cutting, cleaning, and etching operation. The particles of the materials get accelerate in gas stream and are made to focus on machine. It makes small fracture if particle focuses on the surface and the gas stream includes abrasive particles and fractured particles away. The process parameters are used like variables which effect metal removal. They are carrier gas, abrasive, velocity of abrasive, work material, and nozzle tip distance (NTD).In abrasive jet machining, a focused stream of abrasive particles, carried by high pressure air or gas is made to impinge on the work surface through a nozzle and the work material is made to impinge on the work surface through a nozzle and work material is removed by erosion by high velocity abrasive particles. The effect of the depth of material and the material characteristics on drilling time were investigated and discussed. Through this work, it was observed that machinability index of the materials drilled plays an important role in AJM process. The work investigates that there is nonlinear relation in drilling time v/s drilling depth and material of low machinability takes more time to drill because of as depth increases air pressure losses its cutting ability. It is also Investigate the effect of kerf and SOD on drilling time.*
***Index Terms**: Abrasive Jet Machining, Drilling, Abrasive, Depth of Cut, SOD.*

I. Introduction

An abrasive jet is one of the most recently developed non-traditional manufacturing processes. Abrasive jets have been used first time in 1980's for the cutting of glass materials. Here We are going to first study, how abrasive jet machining or what is the mechanism of material removal. What we have here? Here we have a nozzle. In this nozzle, there is an opening or a inner diameter which is typically around 1 to 5 millimetre. Through this nozzle a mixture of gas and abrasive particles are fed. They are fed at a velocity of 150 to 300 meter per second (12). These abrasive particles when they are issued from this particular nozzle they would interact with my work piece. Typically for abrasive jet machining brittle work piece brittle materials are machined more efficiently (10). So if you are using abrasive jet machining as a machining process you should rather try to machine glasses or other brittle materials rather than low carbon steel. Once these abrasive particle, interact with the work piece, they have some amount of kinetic energy.

As they interact with the work piece that kinetic energy is converted in to mechanical work. They would intend the surface. They would create a small crater and the kinetic energy would be absorbed with the work done. For producing this particular crater and in this way with multiple impact gradually we will be getting a machining. So this is a pure mechanical domain process where the mechanical energy of a high speed abrasive high speed abrasive is used for machining the material and the machining occurs because of the brittle fracture of the work piece. Now, let us come to the general description of abrasive jet machining equipment what we require?

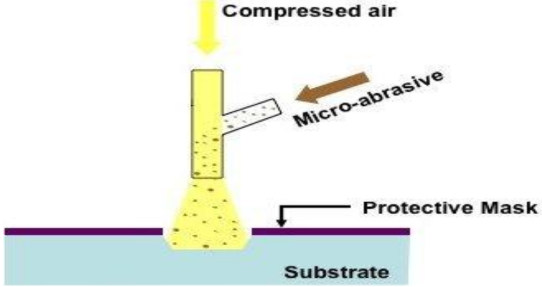

Figure 1: The Flow of Air and Abrasives towards work

Typically the mass flow rate of abrasive particles is around 2 to 20 grams per minute. So they are also consumption rate of abrasive is rather less. Now, as we have discussed we require a gas to propel those abrasive particles. So other than this abrasive particles this carrier gas would also play an important role. Generally air can be used or else carbon dioxide or nitrogen can be used. If we are using carbon dioxide or nitrogen, then you do not require this compressor. Instead of that, you will issue the gas from a gas cylinder. So instead of the compressor you will issue it from the gas cylinder that is also possible. So as a carrier gas typically air carbon dioxide and nitrogen is used. Typical density of the air is something around this. Velocity of the gas is around 500 to 700 meter per second. Pressure is around 10 Bar flow rate is around three to five to thirty lpm. One of the most important parameter is the pressure of this gas carrier gas because depending on the pressure, we will be getting a particular velocity and that will decide to what extent abrasive particles would be or the abrasive jet would be abrasive particles should be accelerated(3).

So once abrasive and the carrier gas they have mixed together, we will get the abrasive jet. The drop in velocity Causes because of the abrasive particles are mixing with the carrier gas. The carrier gas would lose momentum and will gradually transfer it momentum to the abrasive jet. So that the abrasives can be accelerated and in the process your velocity with drop down than there is mixing ratio. What is mixing ratio? How much abrasive you are pumping in to the system as compared to the mass flow rate of the gas. If you are pumping too much abrasive, they would not be accelerated properly. So mixing ratio is once again a very important parameter then stand-off distance. How far is your nozzle from the jet from the work piece. At what angle the jet is interacting with the work piece? If there is no technical or geometrical requirement typically impingement angle is around 90 degree but it can also be as less as 60 degree, then comes the nozzle material because this nozzle material has to be such it is handling abrasive particles which are moving through the nozzle at 300 meter per second. Typically tungsten carbide nozzles are used or even wear resistance sapphire nozzles are used. The inner nozzles are characterized by their internal diameter and the internal diameter of the nozzle would be 0.2 to 0.8 millimetre. Why they have to be wear resistance? If they are not wear resistance, then you will not get good life from the nozzle quite often under industrial situation the life expected around hundred hours or ten hours. If you are getting ten minutes by using steel nozzles, then all the time you would be changing your nozzle there would be no production. So appreciable life of the nozzle is very important for which we require a wear resistance nozzle material.

The life of a nozzle must be partly defined by its application. Exacting operations, such as cutting, required that nozzles be changed more often than when is in etching or cleaning. As nozzles wear, the jet stream tends to diffuse faster resulting in material damage outside the intended line of cut. This is known as stray cutting or overspreads. Rectangular nozzles create less overspread when compared with round ones.

The various abrasives used in Abrasive Jet Machine are selected in application. Aluminium oxide, one of the most commonly used materials, is used to clean, cut and deburr. Silicon carbide, a harder abrasive, is effective for the same applications as aluminium oxide is usually applied only when the work piece material is very hard. Silicon carbide is also known as carborundum, is a compound of silicon and carbon with chemical formula SiC. It occurs in nature as the extremely rare mineral moissanite. Silicon carbide powder has been mass-produced since 1893 for use as an abrasive. Polishing surfaces to a Matt finish or penning surfaces is accomplished with glass beads and can therefore be used for heavier cleaning and penning operations. abrasive particle size is important, abrasive are available in many sizes ranging from 10u to 50u. The similar sizes are most useful for polishing and cleaning (6,7,9), while the larger sizes are best for cutting and penning.

Abrasives are not reused because “chips” from the work piece material clog nozzle and also the cutting action of used particles is degraded. Under impact situations plastic deformation in brittle materials occurs only when small spherical particles impinging on the target surfaces above a certain velocity. Thus there exists a velocity surface above a certain velocity, which causes plastic deformation resulting in the formation of lateral cracks. As soon as the spherical particle touches the surface of a flat body contact stresses are setup.

Gas cylinders contains gas which is carried out by pipes, passing away from filter, which separates the dust particles and the pressure regulator is used to maintain the required gas pressure, then the gas collects in chamber where fine abrasive particles (50micron) are present. Here gas mixes with abrasive and a vibrator is connected to the chamber for better mixing which vibrates at 50c/s. Then this mixture is carried to the nozzle which concentrates the mixture at the work piece and erodes the material from the work piece.

Material removal rate of abrasive jet machining is quite high as compared to conventional machining. The material removal in Abrasive Jet Machining occurs due to brittle fracture (3). There is another consideration. Once a single abrasive particle interacts with the brittle material there would be a fracture and this fracture we be assume to be hemispherical and the diameter of the fracture would be the chordal length of the indentation. As the abrasive particle interacts with the work piece, it will create a small crater. That crater would be created because abrasive particles are highly kinetic energetic. So the kinetic energy of the abrasive particle would be absorbed as it creates that crater and the diameter of that particular crater or indentation would be equal to the chordal length. Another assumption is kinetic energy of the abrasive particles would be considered to be fully utilized. It is not partial; whatever is the kinetic energy we will assume that total kinetic energy is utilized in doing the work done. They would be assumed not to disintegrate and they would be spherical in shape and the particle size would be characterized by the mean diameter.

This is a process of removal of material by impact erosion through the action of concentrated high velocity stream of grit abrasives entrained in high velocity gas stream. AJM is different from shot or sand blasting, as in AJM, finer abrasive grits are used and parameters can be controlled more effectively providing better control over Product quality. In AJM, generally, the abrasive particles of around 50 microns grit size would impinge on the work material at velocity of 200 m/s from a nozzle of ID 0.5mm with a standoff distance of around 2mm. The kinetic energy of the abrasive particles would sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.

II. Experimental Work & Methodology

Experimental set up:

Experiments were conducted to confirm the validity of the proposed model as well as the models found in the literature. The experimental work was carried on a test rig which was designed and manufactured in the workshops of the Mechanical Engineering Department, ST MARTIN'S Engineering College, Secunderabad as in Fig (8). The abrasive grits of Silicon Carbide (Sic) was mixed with air stream ahead of the nozzle and the abrasive flow rate was kept constant throughout the machining process. The jet nozzle was made of Tungsten Carbide to carry high wear resistance and increase in Life of nozzle. Several nozzles were manufactured with different bore diameters of 2 mm, 3 mm and 4 mm. drilling of glass, Fibre and Ceramic sheets was conducted by setting the test rig on the parameters listed in Table 1.

Fig 2: Impingement of Abrasives through Nozzle

Table 1 Process Parameters of AJM

1	Type of abrasive
2	Carrier gas
3	Nozzle tip distance
4	Size of abrasive
5	Velocity of abrasive jet
6	Mixing ratio
7	Work material
8	Nozzle design
9	Shape of cut

III. Material

Glass, Ceramics and Fibre sheets are used as work piece materials because of their homogeneous properties (1, 2, 6, 9). The test specimens were cut into square and rectangular shape for machining on AJM unit having various thicknesses. In machine the initial weights of glass, fibre and ceramic specimens were measured with the help of digital balance. After machining the final weights were measured with the help of digital balance to calculate the material removal rate. First the abrasive that was **Sic** in powder form was fed in the hopper carefully. After that compressor connections were checked. The glass specimen was properly clamped on cross slide with the help of various clamps. As the Compressor was switched on, the hopper gate valve was opened so that abrasive grains were mixed with air jet coming from the compressor and focused on the specimen with help of nozzle.

Table 2: Characteristics Of Different Variables

Medium	Air , CO2 ,N2
Abrasive	SiC, Al2O3 (of size 20μ to 50μ)
Flow rate of abrasive	3 to 20 gram/min
Velocity	150 to 300 m/min
Pressure	2 to 8 kg/cm2
Nozzle size	0.07 to 0.40 mm
Material of nozzle	WC, Sapphire
Nozzle life	12 to 300 hr
Standoff distance	0.25 to 15 mm (8mm generally)
Work material	Non Metals like glass, ceramics, and granites. Metals and alloys of hard materials like germanium, silicon etc
part application	Drilling, cutting, deburring ,cleaning

IV. Results & Discussions

Experiments are conducted on Glass Ceramic tile and Fibre sheets of Various thicknesses (2mm, 4mm, 6mm,8mm).Keeping Pressure, SOD ,Nozzle Diameter and Abrasive Flow Rate as Constant .The time for each drilling is noted . The experimental results are Expressed with the help of Table 3,Table 4 . The results of drilling time versus drilling depth are compared with the help of graphs as shown in Fig(3,4,5). And also the results of drilling time versus drilling width are compared with the help of graphs as shown in Fig(6,7,8).

The exercise of varying depth of drilling on time of drilling shows that the relation between drilling time and the depth of drill is not linear. The time to mill as the drilling depth increases are not proportional to the increase in depth. For a difficult to machine material (low machinability index), the non-linearity effect is more prominent and rate of increase in drilling time is higher. This could be due to the loss of energy of jet as depth increases. This is due to the two reasons. One, as the drilling depth increases stand of distance also increases which causes reduction in jet pressure due to increase in distance and divergence of the stream of jet which leads to increase in jet foot print as show in fig(3,4,5), And hence take more time to cut. Another reason can be that depth of drill increases while machining blind pocket, the restricted volume of closed pocket increases and this causes the loss of energy of the fresh abrasive particles going to strike the work piece due to their collision with used abrasive particles and chips or work removed while machining.

Table 3 :

Material	Depth of cut (mm)	Time for drilling (sec)
Glass	2	6.5
	4	9.3
	6	11.6
	8	13.2
Ceramic tile	4	10.8
	8	11.3
	10	13.1
	12	14.0
Fibre sheet	2	5.8
	4	6.6
	6	8.7
	8	11.4

The Width of Cut (Kerf) of the Material that is machined by Abrasive Jet Machining is the difference between Top Surface diameter and the Bottom Surface diameter of the tapered portion that was drilled (4) .The Experiments are conducted to find out the width of cut at various Air Pressures .The time of Machining is also taken in to consideration for each width of cut (kerf).For these Experiments the air pressure, Abrasive flow rate and diameter of the nozzle are kept constant.

Table 4 :

Material		Width of cut(kerf) (mm)			Time for drilling (sec)
	Sod (mm)	Tkw(mm)	Bkw(mm)	Actual width	
Glass	8	9	6	3	5.3
	10	7	4.2	2.8	6.5
	12	6.1	3.8	2.3	9.0
	14	4.5	3	1.5	12.4
Ceramic tile	8	7	5	2	15
	10	6	4.2	1.8	18
	12	4.5	2.9	1.6	23
	14	4	3.3	0.7	28
Fibre sheet	8	8.2	4.8	3.4	5.1
	10	6.3	3.7	2.6	6.3
	12	4.9	2.8	2.1	7.6
	14	3.8	2.2	1.6	9.4

TSD : Top surface Diameter ,BSD : bottom surface Diameter

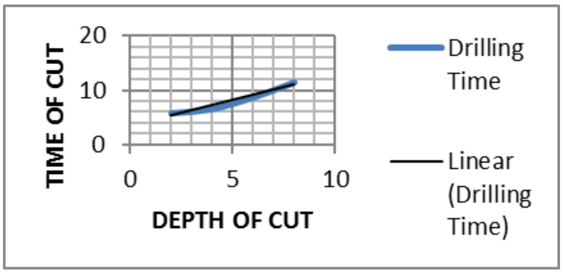

Figure 3: Drilling Time v/s Depth of cut in AJM for Glass

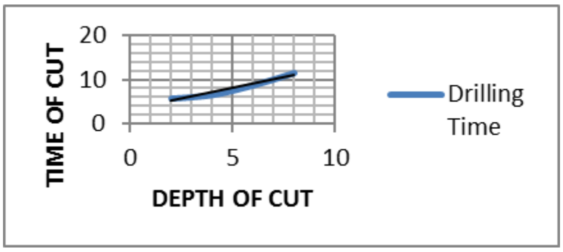

Figure 4: Drilling Time v/s Depth of cut in AJM for Ceramic Tile

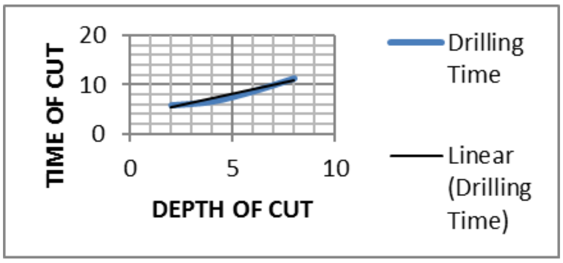

Figure 5: Drilling Time v/s Depth of cut in AJM for Fibre Sheet

The exercise of varying width of cut (kerf) on time of drilling shows that the relation between drilling time and the width of drill is not linear (6). The time to mill as the drilling width increases are not proportional to the increase in kerf. From fig(6,7,8) it is observed that by decrease in width will tends to increase in time but the relation between time and width of cut is not linear. The width of cut can be reduced by keeping proper stand of distance between nozzle and work surface. It is also observed that by increase in SOD the time for cutting will be increased.

As the distance between the face of nozzle and the working surface of the work increases, the diameter of hole also increases because higher the nozzle tip distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment.

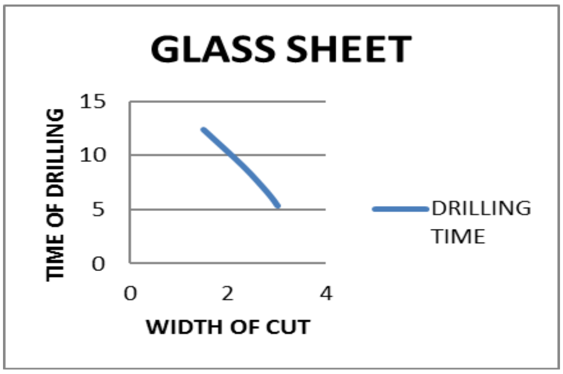

Figure 6: Drilling Time v/s width of cut in AJM for Glass Sheet

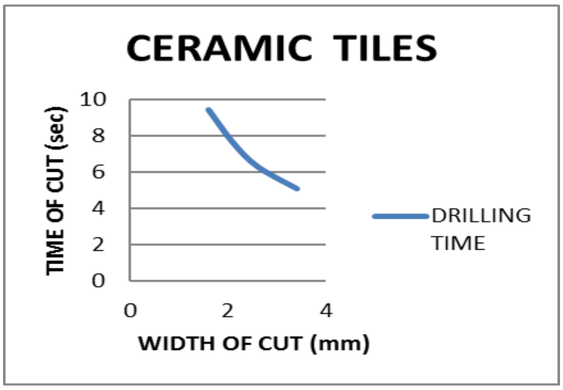

Figure 7: Drilling Time v/s width of cut in AJM for Ceramic Tile

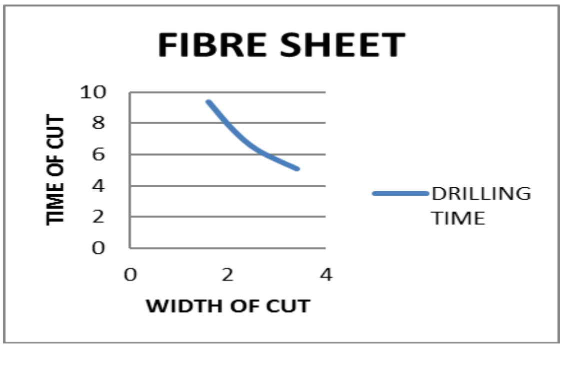

Figure 8: Abrasive Jet Machining Setup established at SMEC

Fig 9: Sic Abrasives of different Grit Sizes

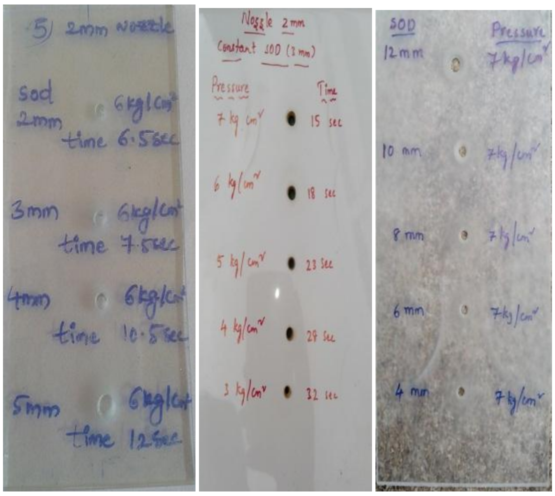

Fig 10 : Glass, Ceramic and Fibre Sheets drilled by AJM Process

V. Conclusion

This work is focused on exploring the effect of material thickness on drilling in drilling time using abrasive jet machining. For this Experimentation glass, ceramics, fibre sheets are considered due to their Brittleness where these are difficult to machine by conventional methods. At each of these locations for each of the work piece material holes are generated of thickness 2,4,6 and 8mm for glass and fibre sheets ,4,8,10,12mm Ceramic tiles. The influence of time on width of cut (kerf) is also discussed by keeping the variation in SOD's .As the Result of the Present work it is observed that drilling time is non-linearly related to material thickness and he machinability of the material significantly influences the time to drill a hole of specified size . It is also noticed that the width of cut decreases on decrease in SOD, The drilling time increases with the increment of Kerf. The work in future may be extended for more depths (less than 2 mm and more than 8 mm for glass and fibre ,less than 4mm and more than 12mm for ceramics) and with the help of larger drilling time vis-à-vis material thickness depth data, a mathematical model may be proposed to find out energy loss.

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