INVESTIGATION OF DRILLING TIME V/S MATERIAL THICKNESS USING ABRASIVE WATERJET MACHINING

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ABSTRACT

Abrasive Water Jet Machining (AWJM) process is usually used to through cut materials which are difficult to cut by conventional machining processes. This process is also used for drilling on hard to soft materials. This paper primarily focuses on making hole of different depth on different materials. The present work controlling the traverse speed and observe the drilling time on various samples and on making drill holes on a set of materials with AWJM drilling process. The materials used in experimentation are AL 6061 alloy, AL 2024, Brass 353, Titanium (Ti6Al4V), AISI 304 (SS) and Tool Steel (M_2 Rc 20), due to their wide spread usage. 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 milled plays an important role in AWJM process. The work investigate the there is non linear relation in drilling time v/s drilling depth and material of low machinability takes more time to drill because of as depth increases water pressure losses its cutting ability.

KEYWORDS: *Abrasive Water Jet Machining, Drilling, Abrasive, Depth of Cut*

I. INTRODUCTION

An abrasive water jet is one of the most recently developed non-traditional manufacturing processes. Abrasive water jets have been used first time in 1983 for the cutting of glass materials. Material is removed by erosion processes and the jet fully penetrates the material being cut in a single pass. More recently, abrasive water jets have been employed for the machining of materials where the abrasive water jet does not penetrate the sample as is the case in abrasive water jet cutting. Such a technology may be employed to mill components in materials that are difficult to machine by conventional methods. Due to the differences in flow patterns, the erosion conditions are very different to those occurring in conventional cutting.

Ashraf I. Hassan et al. [1] reported that abrasive water jet (AWJ) cutting process has become increasingly important and proposed a model for on-line depth of cut which monitor the acoustic emission (AE) response to the variation in depth of cut as a replacement for the expensive and impractical vertical cutting force monitoring. The main objective of AE technique is to predict the actual depth of cut in AWJ cutting under normal cutting conditions. They found that the root mean square of the acoustic emission energy increasing linearly with an increase in the depth of cut and would be used for its on-line monitoring. They also found that the vertical cutting force in AWJ varies due to the variation in the cutting parameters such as pressure, nozzle diameter, standoff distance, and flow rate. H. Liu et al. [2] stated that Computational fluid dynamics (CFD) models for ultrahigh velocity water jets and abrasive water jets (AWJs) which are established using the Fluent6 flow solver. They simulated under steady state, turbulent, two-phase and three-phase flow conditions. The velocities of water and abrasive particles are obtained under different input and boundary conditions which provide an insight into the jet characteristics and a fundamental sympathetic of the kerf formation process in AWJ cutting. They concluded that velocity decay for different sizes of particles was similar, but less than that of the corresponding water velocity and that smaller diameter particles decelerate more rapidly than larger particles.

S. Paul et al. [3] reported that the material removal mechanism in the AWJ machining of ductile materials and reviewed the existing erosion models. They developed the concept of indiscriminate kerf shape for aluminium and steel and also analytical models for the total depth of cut, which take into account the variation in the width of cut along the depth. They concluded that the predictions of the present model correlate quite nicely with experimental observations. G. Fowler et al. [4] reported the difficulties in the use of traditional mechanical methods to mill of difficult-to-machine materials (particularly in thin section and has prompted examination of alternative processes for drilling to a controlled depth which is AWJ technology. They found that the surface waviness can be reduced as the traverse speed is increased and the surface roughness is not strongly dependent on traverse speed. Smaller sized grit also leads to a reduction in material removal rate but also to a decrease in both waviness and roughness. D. A. Axinite at al. [5] reported the model which firstly found the material specific erosion (etching) rate. They used geometrical modeling for predicting the jet footprint in controlled-depth AWJ cutting (drilling) and also generated shallow kerfs enabling the evaluation of the specific etching rate of the target workpiece material under the specified AWJ conditions.

G. Fowler at al. [6-7] found that abrasive water-jet (AWJ) technology is routinely used to cut materials which are difficult to cut by other methods. They developed technology for through-cutting of materials is mature and also being developed for controlled depth drilling (CDM) of materials since other processes such as chemi-drilling are under increased pressure due to legislative restrictions and costs associated with effluent disposal. They demonstrated that grit embedment could be minimized either by drilling with a high jet traverse speed at low impingement angles or by low speed drilling at jet impingement angles up to 45◦ in the backward direction only and observed the enslavement upon complex interactions of the various processing parameters. P. H. Shipway et al. [8] found abrasive water jets had been used for many years for the cutting of materials and examined the abrasive water jet drilling behavior of Ti6Al4V in terms of the surface properties of the milled component, such as roughness, waviness and level of grit embedment. They concluded that the properties of the surface following drilling depend strongly on the drilling parameters, such as jet-workpiece traverse speed, impingement angle, water jet pressure and abrasive size. Iain Finnie [9] stated that the kinetic energy of wear particles removed by the erosive action of a high-speed mixture of abrasive particles and water is estimated, based on a simple analysis and on impact-force measurements of the abrasive–water-jet before and during the material-removal process and concluded that the dynamics of the force signal are increased during cutting. L. Chen [10] compared with traditional mechanical cutting methods and most non-traditional machining technologies; abrasive water jet (AWJ) cutting technology is acquiring increasingly extensive applications for the shape cutting of difficult-to-machine materials such as ceramics while Hlavac [11] derived the functions that describes the curvature of the jet trajectory inside the kerf and established its dependence on the material properties, jet parameters and the traverse speed.

This work aims to achieve a hole of 10 mm diameter on different depths for each material. To hold the specimen on the machine a suitable fixture is designed. The drilling process is achieved through the varying traverse speed in the machine's proprietary software. By varying the values of material depth, holes of various depths may be created. In the given setup, the values of parameters like abrasive flow rate, pressure and stand-off distance are provided and the etch speed may be calculated automatically. Here, the each speed was varied by controlling the abrasive flow rate. The mass flow rate of abrasive particles may be changed by changing traverse speed during the experiments. The specimen is kept under water during experimentation. All the trials are conducted at an impingement angle of 90^0. Abrasive particles are mixed with pressurized water ahead of nozzle. The experiments are conducted at high traverse speed and large mass flow rate at low pressure of water. The pressure of the water is controlled by VFD by reducing the rpm of the motor of the pump.

The paper is organized as follows: Section 2 of the manuscript explains about the materials that are considered for milling. The experimental procedure carried out during this work is presented in Section 3. The results and discussions on the experiments performed are discussed in Section 4, while Section 5 presents the concluding remarks and scope for further work.

II. EXPERIMENTAL SETUP AND METHODOLOGY

The equipment required for abrasive water jet machining is quite straight forward. A head mechanism is needed to form the jet of water and a delivery and injection system must act to entrain the abrasive particles into the jet stream. Since the jet is a high-speed stream of water there must be a pump to increase the pressure of the water. Usually a table is necessary for placement of the material to be cut/ machined. ***Fig. 1*** gives a basic schematic of the equipment:

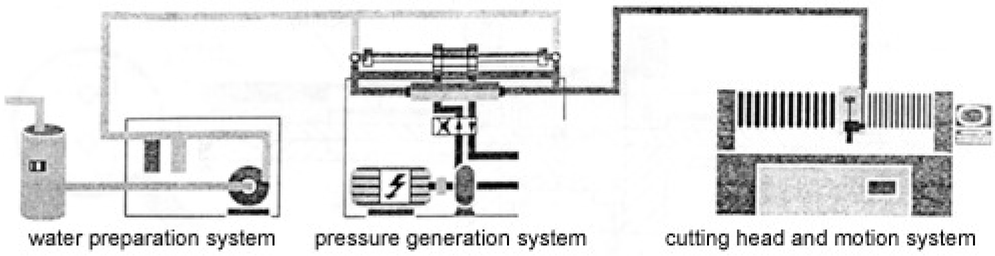


Figure 1. Basic Abrasive Water Jet Cutting Set-up

The abrasive water jet is focussed through the focussing tube before making an impact on the selected area on the material. In present work a blind pocket of size 100 mm x 50 mm area has been milled for varying depth 2,4,6,8 and 10 mm. The drilling time for every material for five different depths was obtained on six different set of materials having a range of machieability. To hold the specimen on the machine a suitable fixture is designed. The CDM process is achieved through the etch option of the machine's proprietary software. By varying the values of depth, holes of various depths may be created. In the given setup, the values of parameters like abrasive flow rate, pressure and stand-off distance are provided and the etch speed may be calculated according to depth of drilling. Here, the traverse speed was varied for different depths. The specimen is kept under water during experimentation. All the trials are conducted at an impingement angle of 90^0. Abrasive particles are mixed with pressurized water ahead of nozzle. The experiments are conducted at given traverse speed and keeping all other process parameters constant. The specifications of machines and properties of materials are given in Table 1 and Table 2.

Table 1. Machine specifications

Maximum traverse speed	4572 mm/min
Jet impingement angle	90^0
Orifice diameter	0.33 mm
Abrasive flow rate	0.226 kg/min
Mixing tube diameter	0.762 mm
Mixing tube length	101.6 mm
Maximum working pressure	45 kpsi

Table 2. Properties of materials

Material	Property			
	Quantity		Value	Unit
Al-2024	Mechanical	Young's modulus	70000	Mpa
		Shear modulus	27500	Mpa
		Tensile strength	240-280	Mpa
		Elongation	1-3	%
		Fatigue	80	Mpa
	Physical	Thermal expansion	23-23	e-6/k
		Melting Temperature	550-650	c
		Density	2750-2750	kg/m^3

Al-6061	Mechanical	Young's modulus	68900	Mpa
		Shear modulus	26000	Mpa
		Tensile strength	276	Mpa
		Elongation	12	%
		Fatigue	96.5	Mpa
	Physical	Thermal expansion	20.5	e-6/k
		Melting Temperature	582-652	c
		Density	2700	kg/m^3
Stainless steel	Mechanical	Young's modulus	193000	Mpa
		Shear modulus	62100-86000	Mpa
		Tensile strength	2.76-3000	Mpa
		Elongation	0-62	%
		Fatigue	85-1070	Mpa
	Physical	Thermal expansion	10-10	e-6/k
		Melting Temperature	1230-1530	c
		Density	7990	kg/m^3
Ti6Al4V	Mechanical	Young's modulus		Mpa
		Shear modulus		Mpa
		Tensile strength		Mpa
		Elongation		%
		Fatigue		Mpa
	Physical	Thermal expansion		e-6/k
		Melting Temperature		c
		Density		kg/m^3
Tool steel	Mechanical	Young's modulus		Mpa
		Shear modulus		Mpa
		Tensile strength		Mpa
		Elongation		%
		Fatigue		Mpa
	Physical	Thermal expansion		e-6/k
		Melting Temperature		c
		Density		kg/m^3

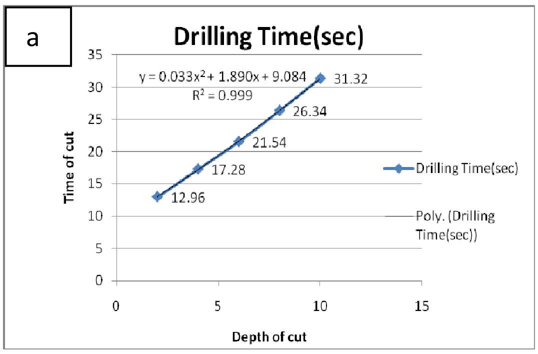
III. RESULTS

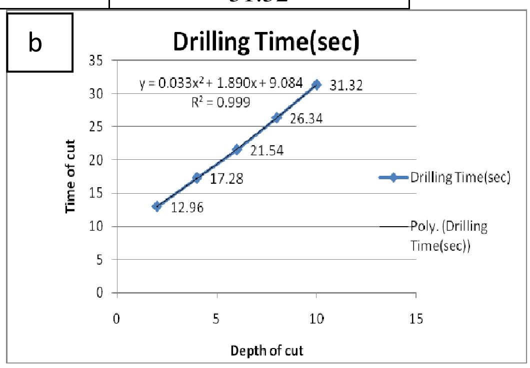
The experiments are carried out and test samples of varying thickness 2-2-10 mm thickness are made of different materials (AL 6061 alloy, AL 2024, Brass 353, Titanium, AISI 304 (SS) and Tool Steel). Each sample is milled at different five thickness i.e. 0.5, 1.0, 1.5, 2.0, 2.5 mm respectively at four different locations using AWJ, with different paths of motion and in the process time to mill each depth of cut for each material is recorded. All experiments are carried out by keeping pressure and abrasive flow rate constant. The standoff distance and traverse rate varies due to change in cutting conditions. The experimental results are shown with the help of Table 3. The results of drilling time versus depth of drilling are compared with the help of graphs as shown in Fig. 2. The equations of drilling time with drilling depth and the correlation coefficients achieved for different materials for varying depth of drilling are shown in Table 4. Surface roughness has been measured by profilometer for each depth. No significant variations have been observed in the surface roughness due to variations in SOD and traverse speed.

The exercise of varying drilling depth on drilling time shows that the relation between drilling time and the depth of mill is not linear. The time to mill as the drilling depth increases are not proportional to the increase in depth. Further, it has been observed that the machinability of the material also plays an important role in drilling time in CDM along with the drilling 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 shown in Fig. 2 (e) and Fig. 2 (f) and hence take more time to cut. Another reason can be that depth of mill 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. Drilling Time on different Depth on different Materials

Material	Depth (in mm)	Drilling time
Al-2024	2	11.82
	4	15.36
	6	18.9
	8	22.62
	10	26.64
Al-6061	2	11.94
	4	15.54
	6	19.2
	8	22.86
	10	26.94
S.S.	2	17.16
	4	24
	6	32.1
	8	41.94
	10	54
Ti	2	15.06
	4	20.7
	6	26.64
	8	33.36
	10	41.34
Tool Steel	2	18.78
	4	26.52
	6	36.54
	8	49.2
	10	64.32
Brass	2	12.96
	4	17.28
	6	21.54
	8	26.34
	10	31.32





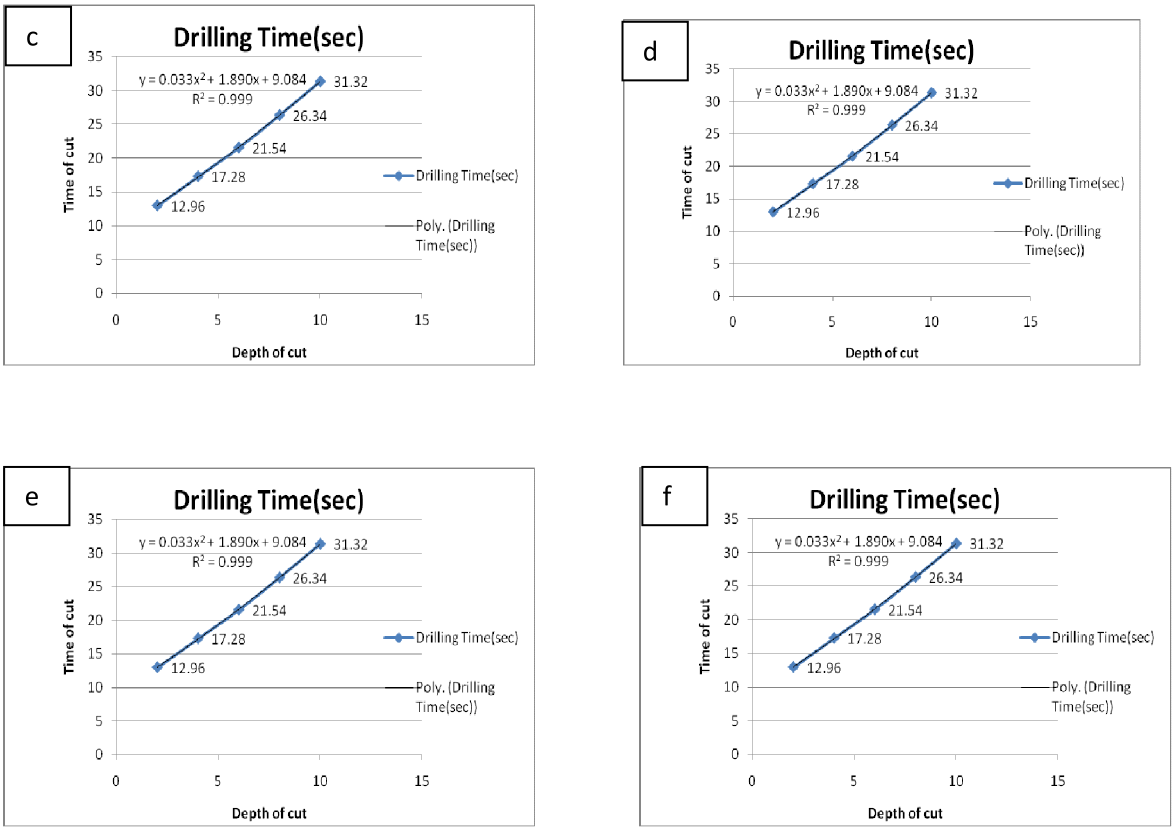


Figure 2: Drilling Time v/s Depth of cut in AWJM for different Materials (a) Al 2024 (b) Al 6061 (c) Stainless Steel (d) Titanium (e) Tool Steel (f) Brass

IV. CONCLUSION

The present work is focused on exploring the effect of material thickness on drilling in drilling time using abrasive water jet. For this a set of materials that includes range of machinability index are selected. At each of these locations for each of the work piece material holes are generated of thickness 2,4,6,8 and 10 mm.

- The result of experiments shows that drilling time is non-linearly related to material thickness and the machinability of the material significantly influences the time to drill a hole of specified size. For a material with lesser machinability index i.e. one that is difficult to machine, the non-linearity effect is more prominent and the increase in drilling time per unit change in material thickness is more. These results may be recognized to loss of energy and decrease in cutting efficiency due to increase in standoff distance, drop in pressure and infringement of the abrasive particles with chips in the restricted volume.
- The curves plotted help in establishing curve fitting equations for the given materials and given cutting conditions and with this the milling time for any depth of mill (for a blind pocket) can be found out.
- The work in future may be extended for more depths (less than 2 mm and more than 10 mm) 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.
- The experiments show that drilling time is non-linearly related to depth of material and the machinability of the material significantly influences the time to drill of specified size. For a material with lesser machinability index i.e. one that is difficult to machine, the non-linearity effect is more prominent and the increase in drilling time per unit change in depth of material is more.
- These results may be attributed to the loss of energy and decrease in cutting efficiency due to increase in stand-off distance, drop in pressure and infringement of the abrasive particles with chips in the restricted volume.

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