EXPERIMENTAL ANALYSIS OF IRREGULARITIES OF GRANITE SURFACES GENERATED BY ABRASIVE WATERJET

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Abstract- Abrasive waterjet cutting has been proven to be an effective technology for processing various engineering materials. Surface irregularity of machined parts is one of the major machining characteristics that play an important role in determining the quality of engineering components. This paper assesses the influence of process parameters on the irregularities of Granite surfaces generated by abrasive waterjet. Taguchi's design of experiments was carried out in order to collect surface roughness values. Experiments were conducted in varying water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance for cutting Granite using abrasive waterjet cutting process. The effects of these parameters on surface roughness have been studied based on the experimental results.

Keywords- Abrasive Waterjet, Garnet, Granite, Water Pressure, Mass Flow Rate, Traverse Speed, Standoff Distance

I. INTRODUCTION

Manufacturing industry is becoming ever more time conscious with regard to the global economy. The need for rapid prototyping and small production batches is increasing in modern industries. These trends have placed a premium on the use of new and advanced technologies for quickly processing raw materials into usable goods; with no time being required for tooling. Material cutting by abrasive waterjets was first commercialized in the late 1980's as a pioneering breakthrough in the area of unconventional processing technologies. The technology's main advantage is the absence of a heat-affected zone in the materials processed that makes it particularly suitable for processing various engineering materials where limiting heat flux into the workpiece is critical [1]. It gives less sensitive to material properties, does not cause chatter and imposes minimum stress on the work piece and high machining versatility and flexibility [2]. In this method, a stream of small abrasive particles is introduced in the waterjet in such a manner that waterjet's momentum is partly transferred to the abrasive particles. The main role of water is primarily to accelerate large quantities of abrasive particles to a high velocity and to produce a high coherent jet. This jet is then directed towards working area to perform cutting [3]. It is also a cost effective and environmentally friendly technique that can be adopted for processing number of engineering materials particularly difficult-to-cut materials such as ceramics [4], [5]. However, AWJC has some limitations and drawbacks. It may generate loud noise and a messy working environment. It may also create tapered edges on the kerf, especially when cutting at high traverse rates [6], [7].

As in the case of every machining process, the quality of AWJC process is significantly affected by the process tuning parameters [8], [9]. There are numerous associated parameters in this technique, among which water pressure, abrasive flow rate, jet traverse rate, standoff distance and diameter of focusing nozzle are of great importance but precisely controllable [10], [11]. The main process quality measures include attainable depth of cut, kerf width and surface finish. Number of techniques for improving kerf quality and depth of cut has been proposed [10]-[13]. In order to effectively control and optimize the AWJC process, predictive models for depth of cut have been developed for ceramics, aluminum, stainless steel, brass, copper, titanium etc. [14]-[16].

In this paper surface roughness is considered as the performance measure as in many industrial application it is the main constraint on the process applicability. More work is required to fully understand the influence of the important process parameters on surface roughness of Granite. Therefore experimental and theoretical studies have been undertaken in this project to investigate the effects of water pressure, nozzle traverse speed, abrasive mass flow rates, standoff distance on surface roughness of Granite.

II. EXPERIMENTAL WORK

A. Material

The material selected in this study is Granite. Granite is an igneous rock with at least 20% quartz by volume. Granite being the hardest stone and because of its architecturally beauty, it is highly used as a building stone. It takes a highly polished finish, which endures it even in inclement environments. Granite is available in a broad spectrum of colors ranging from nearly pure white to nearly pure black. The infusion of various minerals in varying compositions during the formation of granite provides differing patterns as well as colors. Granite is used as a building stone, architectural aggregate, decorative landscape stone, decorative rip rap stone in track & trail pathways and as a source of economically valuable minerals. Granite tiles were

used as the specimens. The dimensions of these granite tiles were 150 x 100 x 30 mm. It has the following properties: Density = 2.68 g/cm3; Modulus of elasticity = 54,000 MPa.

B. Equipment

The equipment used for machining the samples was Water Jet Sweden cutter which was equipped with KMT ultrahigh pressure pump with the designed pressure of 4000 bar. The machine is equipped with a gravity feed type of abrasive hopper, an abrasive feeder system, a pneumatically controlled valve and a work piece table with dimension of 3000 mm x 1500 mm. Sapphire orifice was used to transform the high-pressure water into a collimated jet, with a carbide nozzle to form an abrasive waterjet. The schematic of an abrasive waterjet cutting process is shown in fig.1.

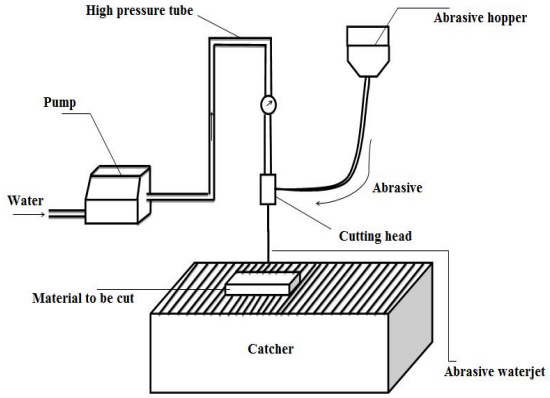


Fig.1. Schematic of abrasive waterjet cutting process

Throughout the experiments, the nozzle was frequently checked and replaced with a new one whenever the nozzle was worn out significantly. The abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The debris of material and the slurry were collected into a catcher tank. The sectional view of abrasive waterjet cutting head is shown in fig. 2.

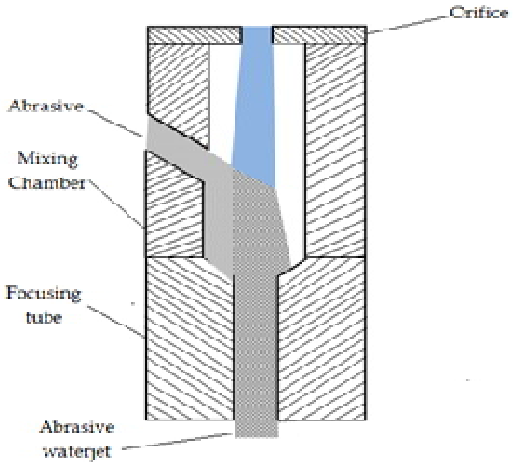


Fig. 2. Sectional view of abrasive waterjet cutting head

The specifications of abrasive waterjet cutting equipment used for the experiments are shown in table 1.

Table 1. Specifications of abrasive waterjet cutter

Machine Model	Classica-50 HP (KMT)
Energy consumption (kWh)	37
Abrasive consumption (g/min)	100-900
Nozzle diameter (mm)	1.05
Nozzle length (mm)	76.5
Water consumption (lt/min)	3.6

C. Design of Experiments (DOE)

Design of experiments (DOE) is a powerful tool that can be used in a variety of experimental situations. DOE techniques enable designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. To achieve a thorough cut it was required that the combinations of the process variables give the jet enough energy to penetrate through the specimens. In the present study four process parameters were selected as control factors. The parameters and levels were selected based on the literature review of some studies that had been documented on AWJC on graphite/epoxy laminates [17], metallic coated sheet steels [18] and fiber-reinforced plastics [19]. The process parameters and their ranges are as follows: water pressure 200 MPa to 350 MPa, nozzle traverse speed from 1.6 mm/s to 4.2 mm/s, standoff distance 1.8 mm to 5 mm and mass flow rate of abrasive particles from 2.5 g/s to 5.5 g/s. Table 2 shows the levels of parameters used in experiment.

Table 2. Levels of parameters used in experiment

Parameters	Unit	Level 1	Level 2	Level 3
Water pressure (p)	MPa	200	275	350
Traverse speed (u)	mm/s	1.6	2.9	4.2
Mass flow rate ($m_{a)}$	g/s	2.5	4	5.5
Standoff distance (s)	mm	1.8	3.4	5

Taguchi's experimental design was used to construct the design of experiments (DOE). Four process parameters, each varied at three levels, an L9 (34) orthogonal arrays table with 9 rows as shown in table 3 was selected for the experimentation. This

experimental design yielded 9 test runs. In order to produce sufficient "as measured" data for statistical analysis and graphic representation, additional tests were added to the experimental design.

Table 3. Experimental design using L_9 orthogonal arrays

Experiment No.	Level of Water pressure	Level of Traverse speed	Level of Mass flow rate	Level of Standoff distance
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

D. Data Collection

For each experiment, the machining parameters were set to the pre-defined levels according to the orthogonal array. All machining procedures were done using a single pass cutting. The abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The abrasive flow rates were calibrated by measuring the time spent for a certain weight of abrasives to be completely consumed in the hopper. The supply pressure was manually controlled using a pressure gauge. The standoff distance is controlled through the controller in the operator control stand. The traverse speed and supply of abrasives were automatically controlled by the abrasive waterjet system programmed by NC code.

The surface finish parameter employed to indicate the surface quality in this experiment was the arithmetic mean roughness (Ra). Workpiece surface roughness Ra was measured by a surface roughness equipment model "SURFPAK SV-514". Surface roughness was measured at the centre of the cut for each specimen. Each measurement of Ra was taken three times and their arithmetic mean was calculated as to minimize the error.

III. RESULTS AND DISCUSSION

Surface roughness is one of the most important criteria, which help us determine how rough a workpiece material is machined. In all the investigations it was found that the machined surface is smoother near the jet entrance and gradually becomes rougher towards the jet exit. This is due to the fact that as the particles moves down they loose their kinetic energy and their cutting ability deteriorates. By analyzing the experimental data, it has been found that the optimum selection of the four basic parameters, i.e., water pressure, abrasive mass flow rate, nozzle traverse speed and nozzle standoff distance are very important on controlling the surface roughness. The effect of each of these parameters is studied while keeping the other parameters considered in this study as constant. The following discussion uses the experimental data at the centre of the cut for each specimen and the surface roughness is assessed based on the centre-line average Ra. The effects of process parameters on surface roughness during cutting of Granite are shown in figures 3, 4, 5 and 6. Figure 3 shows the effect of water pressure on surface roughness. In this experimental study, mass flow rate, traverse speed and standoff distance were kept at 15 g/s, 0.5 mm/s and 1.8 mm respectively. The surface roughness gradually decreases when the water pressure from increases 270 MPa to 395 MPa. Figure 4 shows the trend in change in surface roughness with increase in mass flow rate. During the cutting process the water pressure was 395 MPa, traverse speed was 0.5 mm/s and standoff distance was 1.8 mm. As the mass flow rate is increased from 8 g/s to 15 g/s, the surface roughness is decreased. Figure 5 shows the relationship between traverse speed and surface roughness. The other three process parameters namely, mass flow rate, water pressure and standoff distance were kept constant at 15 g/s, 395 MPa and 1.8 mm respectively. The general trend of the curve shows that increase in traverse speed from 4.2 mm/s to 20 mm/s results in increase in surface roughness. Figure 6 shows the relationship between standoff distance ranging from 1.8 mm to 5 mm and surface roughness. During the cutting process mass flow rate, water pressure and traverse speed were 15 g/s, 395 MPa and 0.5 mm/s respectively. An increase in surface roughness is seen when the standoff distance is increased.

A.Effect of Water Pressure on Surface Roughness

The influence of water pressure on the surface roughness is shown in fig. 3. Jet pressure plays an important role in surface finish. As the jet pressure increases, surface becomes smoother. With increase in jet pressure, brittle abrasives break down into smaller ones. As a result of reduction of size of the abrasives the surface becomes smoother. Again, due to increase in jet pressure, the kinetic energy of the particles increases which results in smoother machined surface.

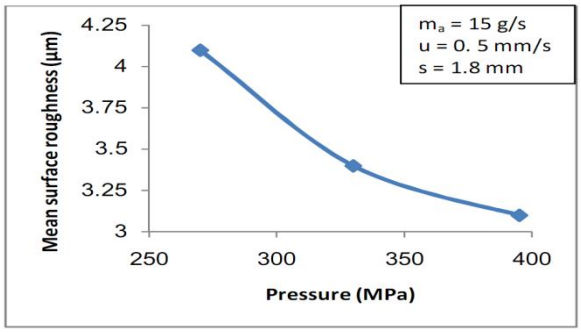


Fig. 3. Water pressure versus surface roughness

B. Effect of Mass Flow Rate on Surface Roughness

It needs a large number of impacts per unit area under a certain pressure to overcome the bonding strength of any material. With the increase in abrasive flow rate, surface roughness decreases. This is because of more number of impacts and cutting edges available per unit area with a higher abrasive flow rate. Abrasive flow rate determines the number of impacting abrasive particles as well as total kinetic energy available. Therefore, higher abrasive flow rate, higher should be the cutting ability of the jet. But for higher abrasive flow rate, abrasives collide among themselves and loose their kinetic energy. It is evident that the surface is smoother near the jet entrance and gradually the surface roughness increases towards the jet exit. The effect of abrasive mass flow rate on surface roughness is shown in fig. 4.

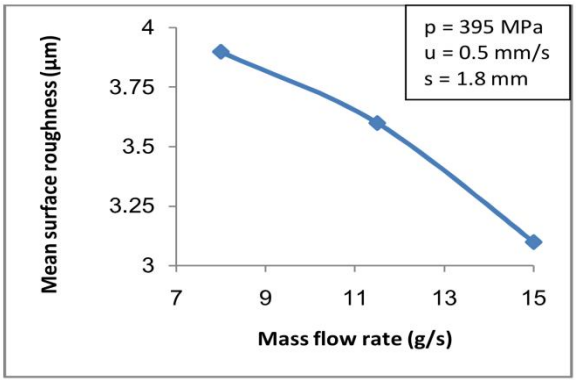


Fig. 4. Abrasive mass flow rate versus surface roughness

C. Design of Experiments (DOE)

Traverse speed didn't show a prominent influence on surface roughness. For decreasing of the machining costs every user try to choose the feed rate of the cutting head as high as possible, but increasing the traverse speed always causes increasing of inaccuracy and surface roughness. But with increase in work feed rate the surface roughness increased. This is due to the fact that as the work moves faster, less number of particles are available that pass through a unit area. Therefore, less number of impacts and cutting edges are available per unit area, which results a rougher surface. The relationship between the traverse speed and the surface roughness is shown in fig. 5.

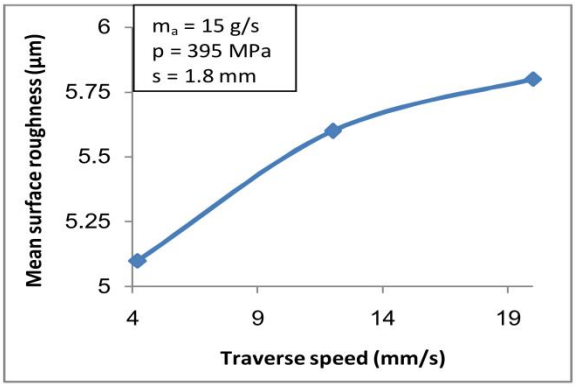


Fig. 5. Traverse speed versus surface roughness

D. Data Collection

Surface roughness increase with increase in standoff distance as shown in fig. 6. Generally, higher standoff distance allows the jet to expand before impingement which may increase vulnerability to external drag from the surrounding environment. Therefore, increase in the standoff distance results an increased jet diameter as cutting is initiated and in turn, reduces the kinetic energy of the jet at impingement. So surface roughness increase with increase in standoff distance. It is desirable to have a lower standoff distance which may produce a smoother surface due to increased kinetic energy. The machined surface is smoother near the top of the surface and becomes rougher at greater depths from the top surface.

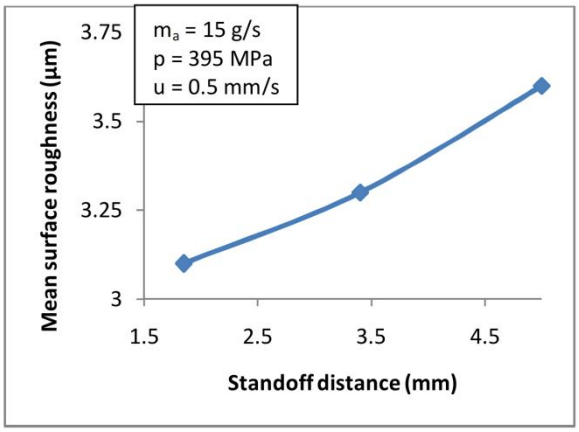


Fig. 6. Standoff distance versus surface roughness

CONCLUSIONS

Experimental investigations have been carried for the surface roughness in abrasive waterjet cutting of Granite. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on surface irregularities have been investigated. As a result of this study, it is observed that these operational parameters have direct effect on surface roughness. It has been found that water pressure has the most effect on the surface roughness. An increase in water pressure is associated with a decrease in surface roughness. These findings indicate that the use of high water pressure is preferred to obtain good surface finish. Surface roughness constantly decreases as mass flow rate increases. It is recommended to use more mass flow rate to decrease surface roughness. Among the process parameters considered in this study water pressure and abrasive mass flow rate have the similar effect on surface roughness. As nozzle traverse speed increase, surface roughness increases. This means that low traverse speed should be used to have more surface smoothness but is at the cost of sacrificing productivity. This experimental study has resulted surface smoothness increase as standoff distance decreases. Therefore to achieve an overall cutting performance, low standoff distance should be selected. Finally it is recommended that a combination of high

water pressure, more abrasive mass flow rate, low traverse speed and short standoff distance be used to produce more surface smoothness.

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