ASSESSMENT OF PROCESS PARAMETERS IN ABRASIVE WATERJET CUTTING OF STAINLESS STEEL

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ABSTRACT

Abrasive waterjet cutting is one of the non-traditional cutting processes capable of cutting wide range of hard-to-cut materials. This paper assesses the influence of process parameters on depth of cut which is an important cutting performance measure in abrasive waterjet cutting of stainless steel. The process variables considered here include traverse speed, abrasive flow rate, standoff distance and water pressure. Experiments were conducted in varying these parameters for cutting stainless steel using abrasive waterjet cutting process. In order to correctly select the process parameters, an empirical model for the prediction of depth of cut in abrasive waterjet cutting of stainless steel is developed using regression analysis. This developed model has been verified with the experimental results that reveal a high applicability of the model within the experimental range used.

KEYWORDS

Abrasive waterjet, Garnet, Stainless steel, Depth of cut and Empirical model.

1. INTRODUCTION

Stainless steel is the name given to a group of corrosion resistant and high temperature steels. Their remarkable resistance to corrosion is due to a chromium-rich oxide film which forms on the surface. Stainless steel is used where both the properties of steel and resistance to corrosion are required. It is a highly durable material used in many qualified applications.

Abrasive waterjet cutting [AWJC] is one of the most recently developed manufacturing technologies. It is superior to many other cutting techniques in processing variety of materials and has found extensive applications in industry [1]. 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 [2]. This technology is less sensitive to material properties as it does not cause chatter, has no thermal effects, impose minimal stresses on the work piece and has high machining versatility and flexibility [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].

In this paper depth of cut in abrasive waterjet cutting 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 depth of cut of stainless steel. No predictive depth of cut models has been developed for abrasive waterjet cutting of stainless steel. This paper assesses the influence of abrasive waterjet cutting process parameters on depth of cut of stainless steel. Experiments were conducted in varying traverse speed, abrasive flow rate, standoff distance and water pressure for cutting stainless steel using abrasive waterjet cutting process. Based on the experimental data, an empirical model for the prediction of depth of cut in AWJC process of stainless steel is developed using regression analysis. The model is then experimentally verified when cutting stainless steel within the practical range of process variables.

2. RELATED WORK

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 several process 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 surface finish 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, aluminium etc. [14-16].

3. EXPERIMENTAL SETUP AND PROCEDURE

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. Figure 1 shows the schematic of the abrasive waterjet cutting process. 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. A 0.35 mm diameter sapphire orifice was used to transform the high-pressure water into a collimated jet, with a carbide nozzle of 1.05 mm diameter to form an abrasive waterjet. Throughout the experiments, the nozzle was frequently checked and replaced with a new one whenever the nozzle was worn out significantly. The abrasives used were 80 mesh garnet particles with the average diameter of 0.18 mm and density of 4100 kg/m^3. The abrasives were delivered using compressed air from a hopper to the mixing chamber and were regulated using a metering disc. The abrasive waterjet pressure is manually controlled using the pressure gauge. The standoff distance is controlled through the controller in the operator control stand. The traverse speed was controlled automatically by the abrasive waterjet system programmed by NC code. The debris of material and the slurry were collected into a catcher tank.

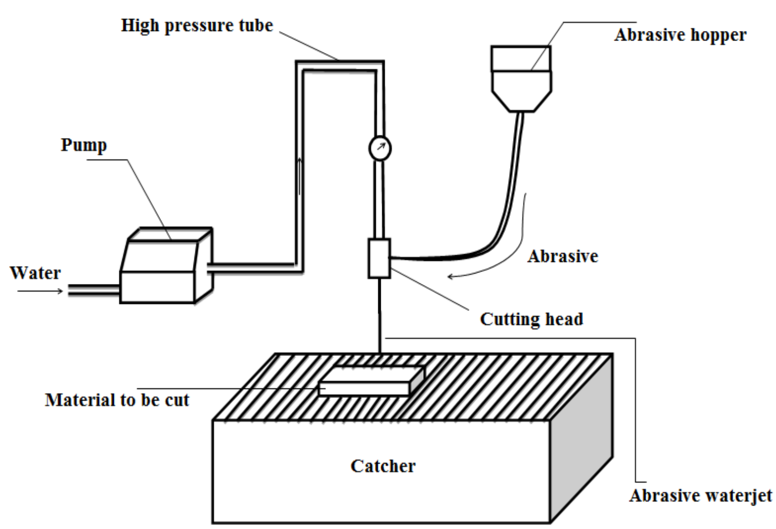

Figure 1. Schematic of an abrasive waterjet cutting process

Stainless steel - Grade 304 plates were used as the specimens. The dimensions of these stainless steel plates were 150 x 100 x 60 mm. It has the following properties:
Density = 8000 kg/m^3, Modulus of elasticity = 193,000 MPa.

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. The four variables in AWJC which was varied are as follows: water pressure 270 MPa to 400 MPa, nozzle traverse speed from 0.42 mm/s to 2.5 mm/s, standoff distance 1.75 mm to 5 mm and mass flow rate of abrasive particles from 8 g/s to 15 g/s. Readings were taken with various combinations of process parameters to gather the required data. Three different readings were taken at each sample and the average readings were calculated as to minimize the error.

4. EXPERIMENTAL RESULTS ON DEPTH OF CUT

By analysing the experimental data, it has been found that the effects of the four basic parameters, i.e., water pressure, abrasive mass flow rate, nozzle traverse speed and nozzle standoff distance on the depth of cut are in the same fashion as reported in previous studies for other materials [17-19]. The effect of each of these parameters is studied while keeping the other parameters considered in this study as constant.
The influence of water pressure on the depth of cut is shown in figure 2. Results indicate that, within the operating range selected, increase of water pressure results in increase of depth of cut while keeping mass flow rate, traverse speed and standoff distance as constant. When water pressure is increased, the jet kinetic energy increases that leads to more depth of cut.

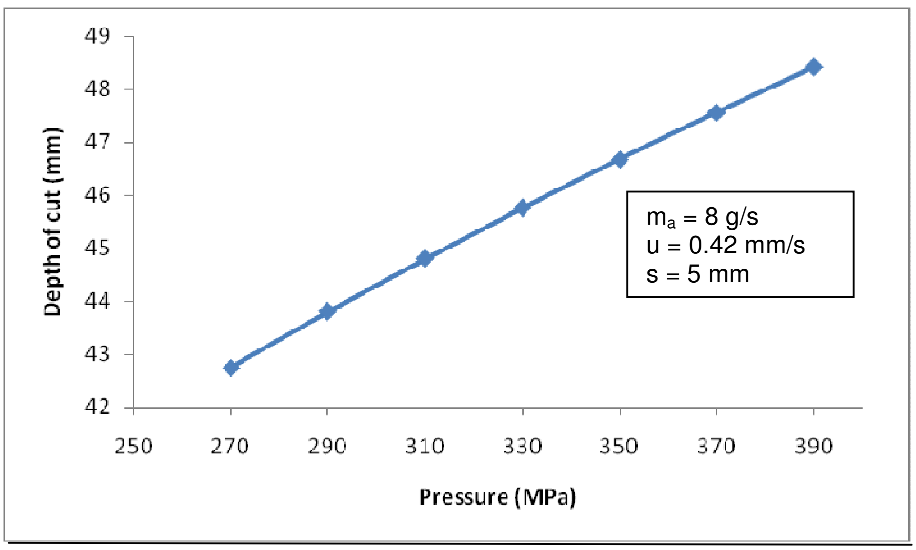

Figure 2. Effect of water pressure on depth of cut

Increase in abrasive mass flow rate also increases the depth of cut as shown in figure 3. This is found while keeping the pressure, traverse speed and standoff distance as constant. It is implicit that a critical energy transfer from the jet to the particles is needed to fracture the material. Therefore at higher mass flow rate more material is removed, which results more depth of cut.

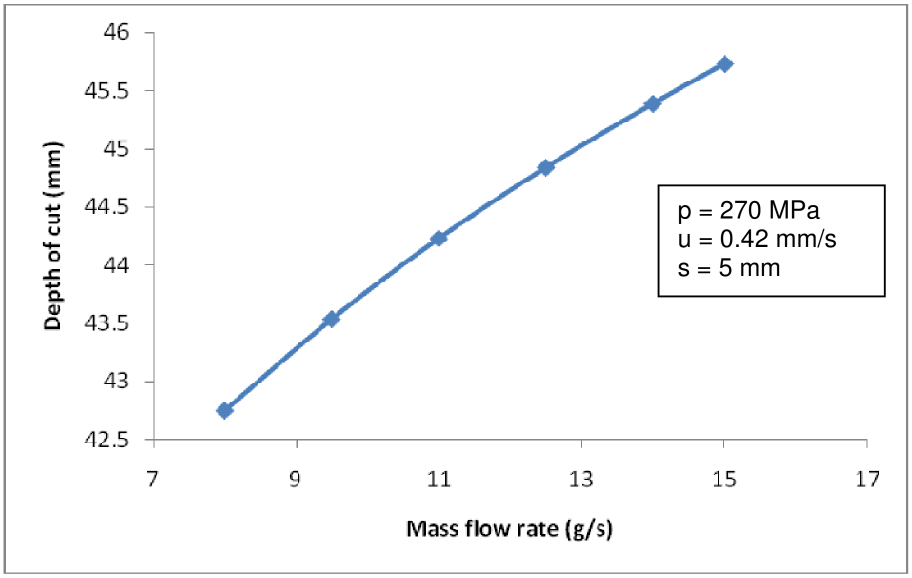

Figure 3. Effect of abrasive mass flow rate on depth of cut

Traverse speed is the advance rate of nozzle on horizontal plane per unit time during cutting operation. Figure 4 shows the relationship between the traverse speed and depth of cut. Results indicate that increase of traverse speed decreases the depth of cut within the operating range selected, by keeping the other parameters considered in this study as constant. The decrease in depth of cut is a direct result of the exposure time, because at higher traverse speed less time is available for cutting, leading to less overlapping of the jet on the target material.

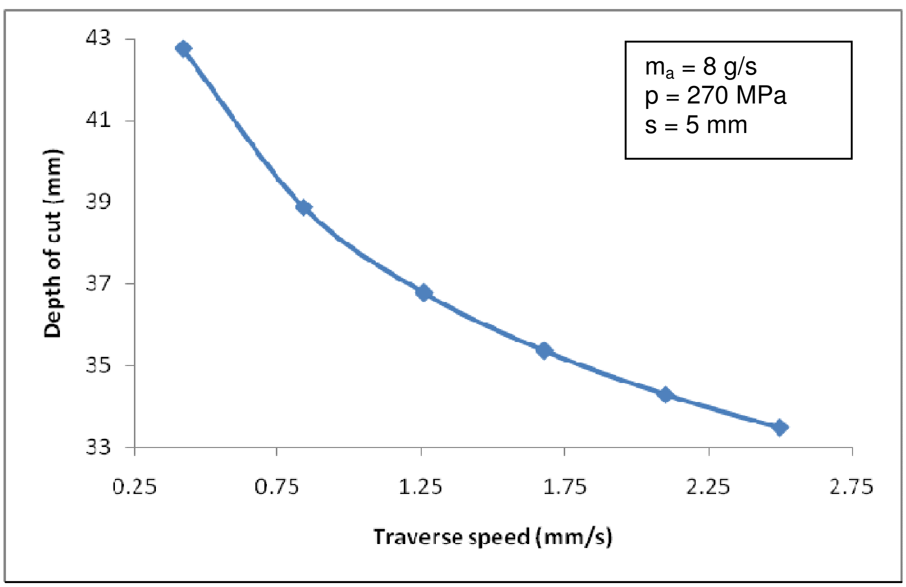

Figure 4. Effect of traverse speed on depth of cut

Standoff distance is the distance between the nozzle and the work piece during cutting operation. Increase in nozzle standoff distance decreases the depth of cut when the other parameters considered in this study as constant as shown in figure 5. However standoff distance on depth of cut is not much influential when compared to the traverse rate.

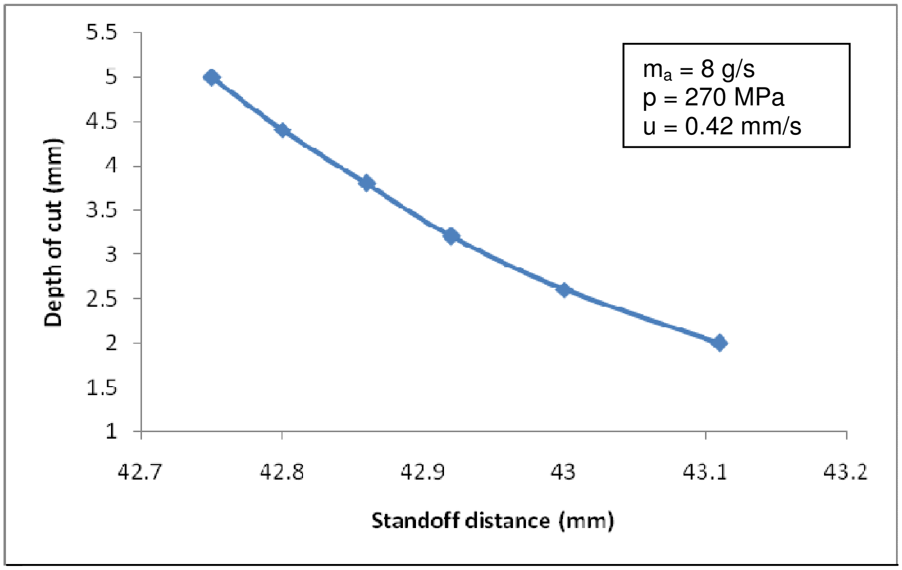

Figure 5. Effect of standoff distance on depth of cut

5. EMPIRICAL MODEL FOR DEPTH OF CUT

Based on the experimental data set, mathematical model for the depth of cut is empirically developed by using regression analysis technique as shown in Eq. (1). This model relate the depth of cut to four process variables, namely water pressure, nozzle traverse speed, nozzle standoff distance and abrasive mass flow rate.

$$D_c = 678 \times \frac{m_a}{\rho_w d_j u} \times \left(\frac{p}{E}\right)^{0.324} \times \left(\frac{s}{d_p}\right)^{0.884} \times \left(\frac{s\, m_a}{d_p^3 \rho_p u}\right)^{-0.893} \times \left(\frac{\rho_p u^2}{p}\right)^{-0.015}$$

----------- (1)

where D_C, d_j, d_p and s are in meters, m_a is in kg/s, u is in m/s, ρ_p and ρ_w are in kg/m^3 and p and E are in MPa.

The above model is valid for the operating parameters in the following range for practical purposes and machine limitations.
Water pressure: 270 MPa < p < 400 MPa, nozzle traverse speed: 0.42 mm/s < u < 2.5 mm/s, standoff distance: 1.75 mm < s < 5 mm and abrasive mass flow rate: 8 g/s < m_a < 15 g/s.

To facilitate the understanding of the effect of the process parameters, the above equation may be re-arranged as below:

$$D_c = 678 \times \frac{p^{0.339} m_a^{0.107} d_p^{1.795} \rho_p^{0.878}}{E^{0.324} u^{0.137} s^{0.009} \rho_w d_j}$$

------------ (2)

For the material under consideration, it can be given by

$$D_c = 13.14344 \times \frac{p^{0.339} m_a^{0.107} d_p^{1.795} \rho_p^{0.878}}{u^{0.137} s^{0.009} \rho_w d_j} \quad \text{--------- (3)}$$

It is shown that the model predictions are in good agreement with the experimental data with the average deviations of about 5%.

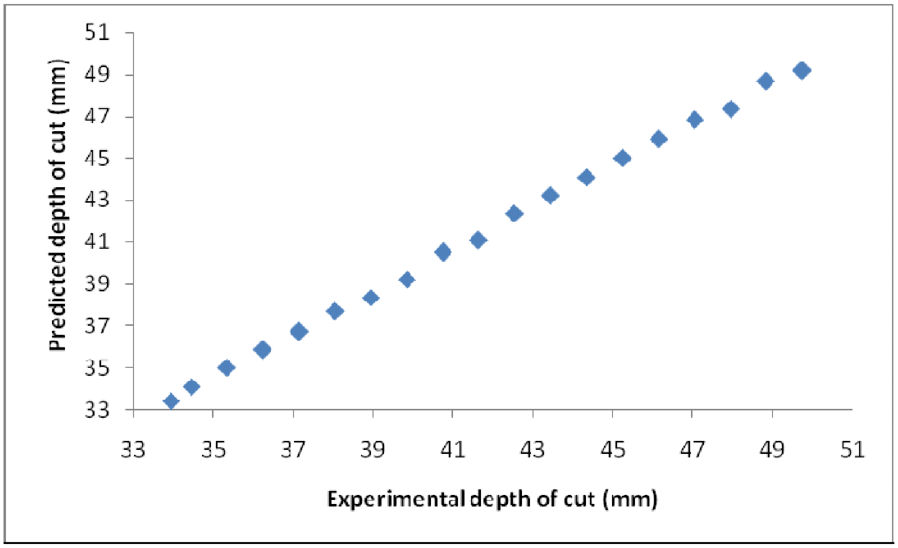

Figure 6. Comparision of experimental and predicted values of depth of cut

There is reasonable correlation between the experimental and predicted values for depth of cut as shown in figure 6. Thus, it may be stated that the developed model can give adequate predictions for the depth of cut for the conditions considered in this study.

6. CONCLUSION

Experimental investigations have been carried for the depth of cut in abrasive waterjet cutting of stainless steel. The effects of pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on depth of cut have been studied. From the experimental results an empirical model for the prediction of depth of cut in AWJC process of stainless steel has been developed using regression analysis. The developed model is finally assessed using the experimental data and found to be able to give adequate predictions within the experimental range considered in this study.

NOMENCLATURE

D_c depth of cut (mm)
m_a mass flow rate of abrasive particles (g/s)
ρ_p density of particle (kg/m^3)
ρ_w density of water (kg/m^3)
d_j diameter of jet (mm)
d_p average diameter of particle (mm)
u traverse speed of nozzle (mm/s)
p water pressure (MPa)
E modulus of elasticity of material (MPa)
s standoff distance (mm)

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