Abrasive Waterjet Cutting of Alumina Ceramics-An Experimental Study

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Abstract

Abrasive waterjet cutting (AWJC) is superior to many other cutting techniques in processing variety of materials, particularly difficult-to-cut materials. This paper presents an investigation on depth of cut which is an important cutting performance measure in abrasive waterjet cutting of alumina ceramics. Experiments were conducted in varying the traverse speed, abrasive flow rate, standoff distance and water pressure for cutting alumina ceramics using AWJC process. In order to correctly select the process parameters, an empirical model for the prediction of depth of cut in AWJC process of alumina ceramics is developed using regression analysis. Verification of the model for using it as a practical guideline has been found to agree with the experiments.

Key words: *Abrasive waterjet, Alumina Ceramics, Depth of cut, Regression analysis, Predictive model*

1. Introduction

The use of advanced ceramics for a variety of high performance application in various industries has ushered the need for high precision material removal processes for processing ceramics. This is on account of their merits of hardness, corrosion resistance, electromagnetic response and biocompatibility. Abrasive waterjet cutting (AWJC) is the recently developed processes.Among different cutting techniques it is one of the most important techniques used in wide variety of industrial application. It gives a clean cut without any heat affected zone and hence has no thermal effects, does not cause chatter, imposes minimum stress on the work piece and high machining versatility and flexibility (1). 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 alumina ceramics (2, 3). The intensity and efficiency of the machining process depend on several AWJC process parameters (4, 5). Among which water pressure, abrasive flow rate, jet traverse rate, standoff distance and diameter of focusing nozzle are of great importance but precisely controllable (6, 7). 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 (6-9). In this paper depth of cut is considered as the performance measure as in many industrial application it is the main constraint on the process applicability. In order to effectively control and optimize the AWJC process, predictive models for depth of cut have been already developed (10-12). This paper assesses the influence of abrasive waterjet cutting process parameters on depth of cut of alumina ceramics. A new empirical model for the prediction of depth of cut in AWJC process of alumina ceramics is developed using regression analysis. The model is then experimentally verified when cutting an alumina ceramics within the practical range of process variables.

2. 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. Figure1 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 AWJ. 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 AWJ 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.

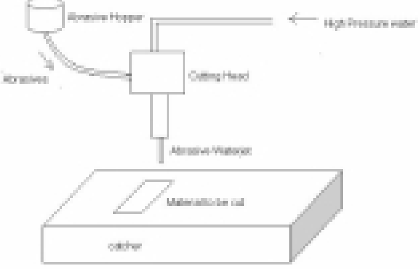

Fig. 1 - Schematic of an abrasive water jet cutting process

Eighty seven per cent alumina ceramic tiles were used as the specimens. The dimensions of these ceramic tiles were 150 x 100 x 25.4 mm. It has the following properties:

Material flow stress = 20,800 MPa.

Modulus of elasticity = 276,000 MPa

To achieve a complete 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 0.2 mm/s to 0.7 mm/s, standoff distance 1.75 mm to 5 mm and mass flow rate of abrasive particles from7.5 g/s to 15 g/s. More than 100 readings were taken with various combinations of process parameters.

3. Experimental results and discussion 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, nozzle traverse speed, nozzle standoff distance, and abrasive mass flow rate on the depth of cut are in the same fashion as reported in previous studies (13, 14).

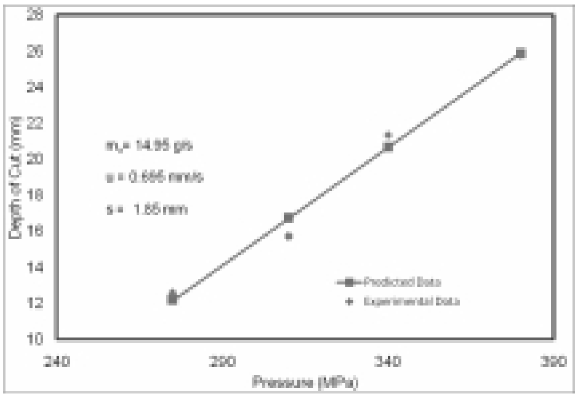

Fig. 2 - Effect of pressure on depth of cut

Fig. 2 shows the influence of water pressure on the depth of cut. 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.

Fig. 3 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 (15). Increase in abrasive mass flow rate increases the depth of cut.

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 (12).

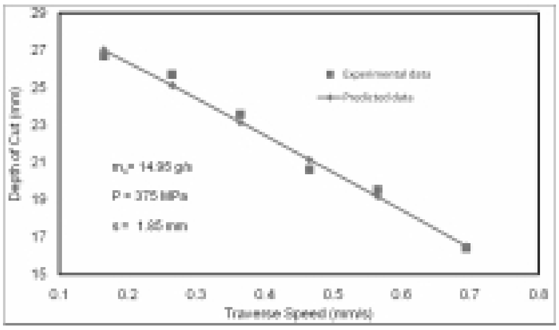

Fig. 3 - Effect of traverse speed on depth of cut

4. Predictive depth of cut model

Mathematical model for the depth of cut is empirically developed by using regression analysis technique on the experimental data. 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.

$$D_C = 2.339 \times 10^{8} \times \frac{P^{3.417} m_a^{0.466} d_p^{1.133} \rho_p^{0.445}}{\sigma_f^{3.128} u^{0.644} s^{0.065} \rho_w d_j}$$

where D_C, s, d_j and d_p are in mm, m_a is in g/s, u is in mm/s, $ñ_p$ and $ñ_w$ are in kg/m^3 and p and $ó_f$ are in MPa.

The above model is valid for the operating parameters in the following range for practical purposes and machine limitations:

270 MPa Â p Â 400 MPa

0.2 mm/s Â u Â 0.7 mm/s

1.75 mm Â s Â 5 mm

and

7.5 g/sÂ m_a Â 15 g/s

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

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

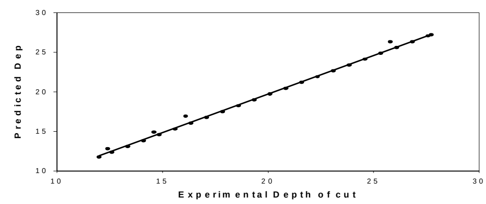

Fig. 4 - Comparision of experimental and predicted values of depth of cut

There is reasonable correlation between the experimental and predicted values for depth of cut as shown in fig. 4. 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.

5. Conclusion

An experimental study of the depth of cut in AWJC of alumina ceramics has been presented. The effects of pressure and traverse speed 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 alumina ceramics has been 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.

Nomenclature

D_c depth of cut (mm)

$$D_c = 2.339 \times 10^{8} \times \frac{m_a}{\rho_w d_j u} \times \left(\frac{p}{\sigma_f}\right)^{3.328} \times \left(\frac{s}{d_p}\right)^{0.469} \times \left(\frac{s m_a}{d_p^3 \rho_p u}\right)^{-0.534} \times \left(\frac{\rho_p u^2}{p}\right)^{-0.089}$$

m_a mass flow rate of abrasive particles (g/s)

ñ$_p$ density of particle (kg/m^3)

ñ$_w$ 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)

ó$_f$ flow stress of the material (MPa)

H_d dynamic hardness of material (MPa)

E modulus of elasticity of material (MPa)

s standoff distance (mm)

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