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# Effects of Process Parameters on Depth of Cut in Abrasive Waterjet Cutting of Cast Iron

M.Chithirai Pon Selvan, Dr.N.Mohana Sundara Raju, Dr.R.Rajavel

**Abstract**— Abrasive waterjet cutting has been proven to be an effective technology for processing various engineering materials. This paper investigated the effects of process parameters on depth of cut in abrasive waterjet cutting of cast iron. Four different process parameters were undertaken for this study; water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance. Experiments were conducted in varying these parameters for cutting cast iron using abrasive waterjet cutting process. The influence of these process parameters on depth of cut has been studied based on the experimental results.In order to correctly select the process parameters, an empirical model for the prediction of depth of cut in abrasive waterjet cutting of cast iron 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.

**Index Terms**— abrasive mass flow rate, abrasive waterjet, cast iron, empirical model, garnet, nozzle traverse speed, regression analysis, standoff distance, water pressure.

## 1 INTRODUCTION

ABRASIVE waterjet cutting [AWJC] is an emerging technology with distinct advantages over the other non-traditional cutting technologies, such as no thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces. [1]. It is superior to many other cutting techniques in processing variety of materials and has found extensive applications in industry [2]. In this method, water serves primarily as an accelerating medium while the abrasive particles take over the role of material removal. 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. Water accelerates 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. They are water pressure, waterjet diameter, nozzle traverse speed, number of passes, standoff distance, impact angle, nozzle diameter, nozzle length, abrasive mass flow rate, abrasive particle diameter, abrasive particle shape and abrasive particle hardness. Among these parameters 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, top kerf width, bottom kerf width, kerf taper, surface roughness, surface waviness and material removal rate. Number of techniques for improving kerf quality and surface finish has been proposed [10], [11], [12], [13].

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 for ceramics, aluminium, stainless steel etc. [14], [15], [16]. But no such models have been developed for cast iron. More work is required to fully understand the influence of the important process parameters on depth of cut of cast iron. This paper assesses the effects of abrasive waterjet cutting process parameters on depth of cut of cast iron. An empirical model for the prediction of depth of cut in AWJC process of cast iron is developed using regression analysis. The model is then experimentally verified when cutting cast iron within the practical range of process variables.

## 2 EXPERIMENTAL WORK

### 2.1 Material

The material selected in this study is Grey cast iron

- *M. Chithiri Pon Selvn is currently pursuing PhD in Mechnical Engineering from Karpagm University, India, PH-+914651274573. E-mail: selvan.mcp@gmail.com*
- *Dr. N. Mohana Sundara Raju is currently working as Principal in Mahandra Institute of Technology, India,*
- *Dr. R. Rajavel is currently working as Assistant Professor/Department of Mechanical Engineering in Manipal University, Dubai.*

(ASTM-A48). Cast irons may often be used in place of steel at considerable cost savings. The design and production advantages of cast iron include: low tooling and production cost, good machinability without burring, ability to cast into complex shapes excellent wear resistance and high hardness and high inherent damping capabilities.

Gray cast iron is the oldest and most common form of cast iron. It contains carbon in the form of flake graphite in a matrix which consists of ferrite, pearlite or a mixture of the two. The fluidity of liquid Gray iron and its expansion during solidification due to the formation of graphite has made this metal ideal for the economical production of shrinkage-free, intricate castings. The graphite flakes act as stress raisers which may prematurely cause localized plastic flow at low stresses, and initiate fracture in the matrix at higher stresses. As a result, Gray iron exhibits no elastic behavior but excellent damping characteristics, and fails in tension without significant plastic deformation. The presence of graphite flakes also gives Gray Iron excellent machinability and self-lubricating properties. Grey cast iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low and medium carbon steel.

Grey cast iron (ASTM-A48) bars of thickness 100 mm were used as the specimens. It has a chemical composition of 3.4% carbon, 1.8% silicon, 0.5% manganese and the remainder is iron. Its modulus of elasticity is 70,000 MPa.

### 2.2 Abrasive waterjet cutting set up

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. Fig. 1 shows the schematic of an abrasive injection nozzle.

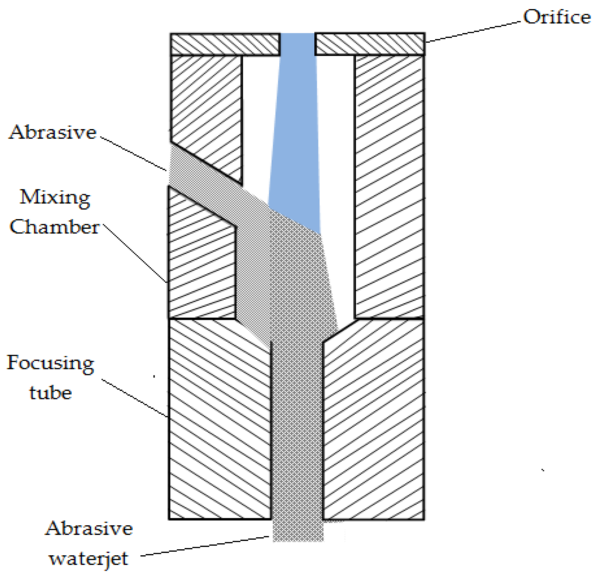


Fig.1 Abrasive injection nozzle

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.

### 2.3 Experimental procedures

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 0.5 mm/s to 20 mm/s, standoff distance 1.8 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.

## 3 Experimental Results and Discussion

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], [18], [19], [20]. The effects each of these parameters is studied while keeping the other parameters considered in this study as constant.

### 3.1 Effect of water pressure on depth of cut

The influence of water pressure on the depth of cut is shown in Fig. 2. Results indicate that, within the operating range selected, increase of water pressure results in increase of depth of cut when mass flow rate, traverse speed and standoff distance were kept constant. When water pressure is increased, the jet kinetic energy increases that leads to more depth of cut.

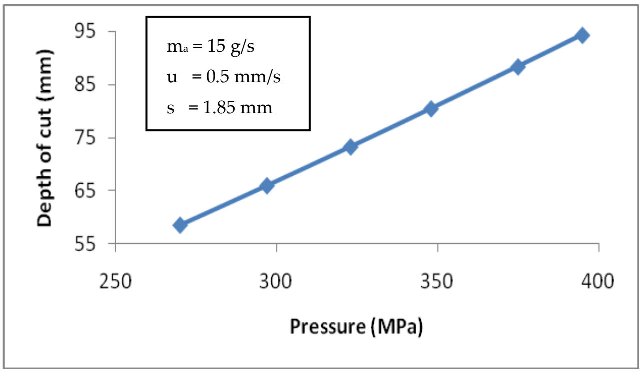


Fig.2 Water pressure versus depth of cut

### 3.2 Effect of mss flow rate on depth of cut

Increase in abrasive mass flow rate also increases the depth of cut as shown in Fig. 3. This is found while keeping the pressure, traverse speed and standoff distance as constant. The impact between the abrasive particle and the material determines the ability of the abrasive waterjet to cut the material. Since cutting is a cumulative process, the speed of the abrasive particle and the frequency of particle impacts are both important. The speed of the particle determines the impulsive loading on the material and the potential energy transfer from the particle to the material. The frequency of the impact determines the rate of energy transfer and hence, the rate of cut depth growth. The mass flow rate of the abrasive particles partially determines the frequency of the impacting particles and partially determines the speed at which they hit. In addition, with the greater mass flow rates, the kinetic energy of the water must be spread over more particles. Therefore, the depth of cut goes down with the increased mass flow rate.

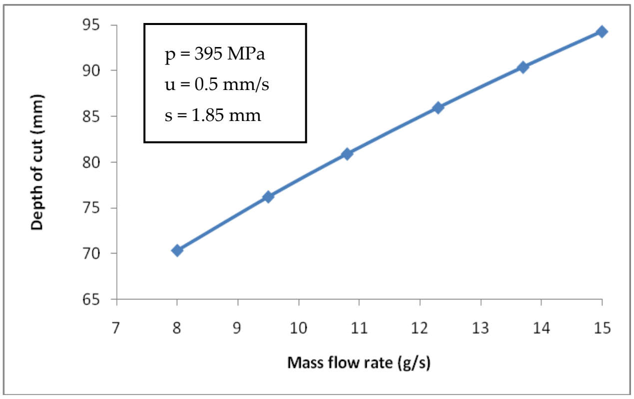


Fig.3 Abrasive mass flow rate versus depth of cut

### 3.3 Effect of traverse speed on depth of cut

Traverse speed is the advance rate of nozzle on horizontal plane per unit time during cutting operation. 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 longer the abrasive waterjet stays at a particular location, the deeper the cut will be because the stream of abrasive particles has more time to erode the material. This effect is due to two reasons. First the longer the dwell time the greater the number of impacting abrasive particles hit the material and the greater the micro damage, which starts the erosion process. Secondly, the water from the jet does have a tendency to get into the micro cracks and because of the resulting hydrodynamic pressure, the crack growth results. When the micro cracks grow and connect, the included material will break loose from the parent material and the depth of cut increases. For this reason, it seems reasonable to expect an inverse relationship between the traverse speed and the depth of cut as shown in Fig. 4.

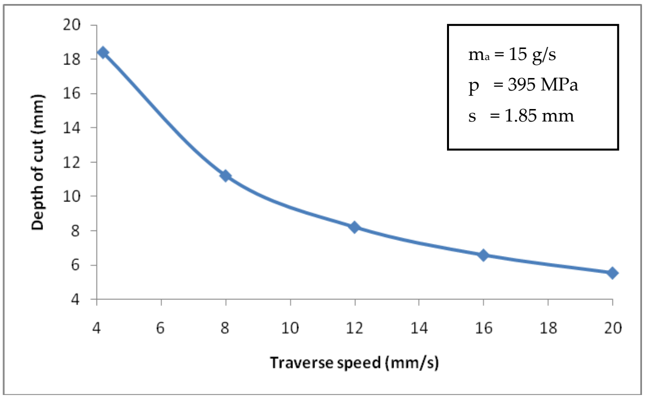


Fig.4 Nozzle traverse speed versus depth of cut

### 3.4 Effect of standoff distance on depth of cut

Standoff distance is the distance between the nozzle and the work piece during cutting operation If we keep other operational parameters constant, when standoff distance increases, depth of cut decreases. This is shown in Fig. 5. However standoff distance on depth of cut is not much influential when compared to the other parameters considered in this study.

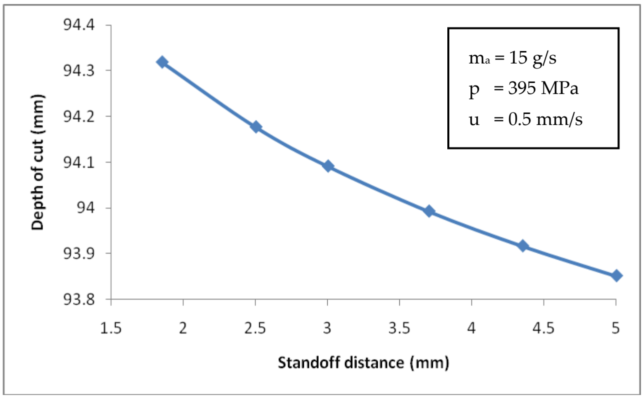


Fig.5 Standoff distance versus depth of cut

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## 4 Predictive Depth of Cut Model

To understand the effects of process parameters an empirical model is developed based on the experimental data set using regression analysis technique as shown in (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.

$$D_c = 104\frac{m_a}{\rho_w d_j u}\left(\frac{p}{E}\right)^{1.102}\left(\frac{s}{d_p}\right)^{0.529}\left(\frac{s m_a}{d_p^{\,3}\rho_p u}\right)^{-0.534}\left(\frac{\rho_p u^2}{p}\right)^{-0.151} \qquad (1)$$

where $D_c$, $d_j$, $d_p$ and s are in meters, $m_a$ is in kg/s, u is in m/s, $\rho_p$ and $\rho_w$ are in kg/m$^3$, 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: 0.5 mm/s < u < 20 mm/s, standoff distance: 1.8 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 rearranged as in (2)

$$D_c = 104 \times \frac{p^{1.253} m_a^{0.466} d_p^{1.073} \rho_p^{0.383}}{E^{1.102} u^{0.768} s^{0.005} \rho_w d_j} \qquad (2)$$

For the material under consideration, it can be given as in (3)

$$D_c = 4.7614 \times 10^{-4} \times \frac{p^{1.253} m_a^{0.466} d_p^{1.073} \rho_p^{0.383}}{u^{0.768} s^{0.005} \rho_w d_j} \qquad (3)$$

It has been shown that the above developed model (3) can adequately predict the depth of cut both qualitatively and quantitatively within the tested range of process parameters in this study, with an average percentage deviation of less than 3%.

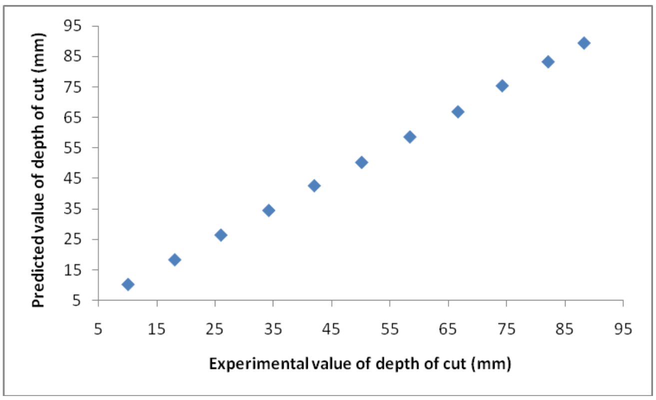


Fig.6 Comparision of experimental and predicted values depth of cut

There is a reasonable correlation between the experimenttal and predicted values for depth of cut as shown in Fig. 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.

## 5 Nomenclature

$D_c$ depth of cut (mm)
$m_a$ mass flow rate of abrasive particles (g/s)
$\rho_p$ density of particle (kg/m$^3$)
$\rho_w$ 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)

## 6 Conclusion

In the present study experimental investigations have been carried for the depth of cut in abrasive waterjet cutting of cast iron. The effects of different operational parameters such as: pressure, abrasive mass flow rate, traverse speed and nozzle standoff distance on depth of cut have been studied. As a result of this study, it is observed that these operational parameters have direct effect on depth of cut. Statistical regression analysis has been employed to develop empirical model relating these process parameters to the depth of cut. The developed model is finally assessed using the experimental data and found to be able to give adequate predictions of the depth of cut with less than 3% of average deviations.

## References

[1] Hascalik, A., Caydas, U., Gurun, H. "Effect of traverse speed on abrasive waterjet machining of Ti-6Al-4V alloy".Meter.Des.28: pp 1953-1957, 2007.
[2] Momber, A., Kovacevic, R. "Principles of Abrasive Waterjet Machining". Springer-Verlag, London, 1998.
[3] Hashish M. "A model for abrasive waterjet (AWJ) machining". Transactions of ASME Journal of Engineering Materials and Technology, vol. III: pp 154-162, 1989.
[4] Siores E., Wong W C K., Chen L., Wager J G. "Enhancing abrasive waterjet cutting of ceramics by head oscillation techniques". Ann CIRP, 45[1]: pp 215-218, 1996.
[5] Wang J. "Abrasive Waterjet Machining of Engineering Materials". Uetikon-Zuerich [Swizerland]: Trans Tech Publications, 2003.
[6] M.A. Azmir, A.K. Ahsan. "Investigation on glass/epoxy composite surfaces machined by abrasive waterjet machining". Journal of Materials Processing Technology, vol.198, pp 122-128, 2008.
[7] C. Ma, R.T. Deam. "A correlation for predicting the kerf profile from abrasive waterjet cutting". Experimental Thermal and Fluid Science, vol.30, pp 337-343, 2006.

[8] Kovacevic R. "Monitoring the depth of abrasive waterjet penetration". International Journal of Machine Tools & Manufacture, vol 32(5), pp 725-736, 1992.

[9] Hashish, M. "Optimization factors in abrasive waterjet machining". Transaction of ASME J. Eng. Ind. 113: pp 29-37, 1991.

[10] John Rozario Jegaraj J., Ramesh Babu N. "A soft computing approach for controlling the quality of cut with abrasive waterjet cutting system experiencing orifice and focusing tube wear", Journal of Materials Processing Technology, vol.185, no.1–3: pp 217–227, 2007.

[11] Shanmugam D. K., Wang J., Liu H. "Minimization of kerf tapers in abrasive waterjet machining of alumina ceramics using a compensation technique". International Journal of Machine Tools and Manufacture 48: pp 1527–1534, 2008.

[12] Shanmugam D. K., Masood S. H. "An investigation of kerf characteristics in abrasive waterjet cutting of layered composites". International Journal of Material Processing Technology 209: pp 3887–3893, 2009.

[13] E. Lemma, L. Chen, E. Siores, J. Wang. "Optimising the AWJ cutting process of ductile materials using nozzle oscillation technique". International Journal of Machine Tools and Manufacture 42: pp 781–789, 2002.

[14] Wang J. "Predictive depth of jet penetration models for abrasive waterjet cutting of alumina ceramics". International Journal of Mechanical Sciences 49: pp 306–316, 2007.

[15] Farhad Kolahan, Hamid Khajavi A. "A statistical approach for predicting and optimizing depth of cut in AWJ machining for 6063-T6 Al alloy". World Academy of Science, Engineering and Technology 59, 2009.

[16] Wang J. "A new model for the prediction depth of cut in abrasive waterjet contouring of alumina ceramics". Journal of material processing technology, 209: pp 2314-2320, 2009.

[17] M.Chithirai Pon Selvan, Dr. N. Mohana Sundara Raju. "An Experimental investigation on depth of cut in abrasive waterjet cutting of aluminium". International Journal of Engineering Science and Technology, 3: pp 2950-2954, 2011.

[18] Wang J, Kuriyagawa T, Huang C Z. "An experimental study to enhance the cutting performance in abrasive waterjet machining". Machining Science & Technology, 7: pp 191-207, 2003.

[19] Wang J, Xu S. "Enhancing the AWJ cutting performance by multi pass machining with controlled oscillation". Key Engineering Materials, 291-292: pp 453-458, 2005.

[20] Shanmugam D. K., Masood S. H. "An investigation on kerf characteristics in abrasive waterjet cutting of layered composites". Journal of materials processing technology, 209: pp 3887-3893. 2009.