International Journal of Science, Environment
and Technology, Vol. 1, No 3, 2012, 174 - 182

# ANALYSIS OF SURFACE ROUGHNESS IN ABRASIVE WATERJET CUTTING OF CAST IRON

M. Chithirai Pon Selvan* and Dr. N. Mohana Sundara Raju**
*PhD Research Scholar, Karpagam University, Coimbatore, India.
** Principal, Mahendra Institute of Technology, Namakkal, India
*E-mail: mcpselvan@yahoo.com

**Abstract**— Abrasive waterjet cutting has been proven to be an effective technology for processing various engineering materials. Surface roughness 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 surface roughness ($R_a$) which is an important cutting performance measure in abrasive waterjet cutting of cast iron. 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 cast iron using abrasive waterjet cutting process. The effects of these parameters on surface roughness have been studied based on the experimental results.

**Key words:** Abrasive waterjet, cast iron, garnet, water pressure, mass flow rate, traverse speed, standoff distance.

## 1. 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. Abrasive Waterjet Cutting [AWJC] has various 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 and has been proven to be an effective technology for processing various engineering materials [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, 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 cast iron. 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 cast iron.

## 2. EXPERIMENTAL WORK

### 2.1 Material

The material selected in this study is Grey cast iron. 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. 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 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.

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 abrasive waterjet cutting head is shown in fig.1.

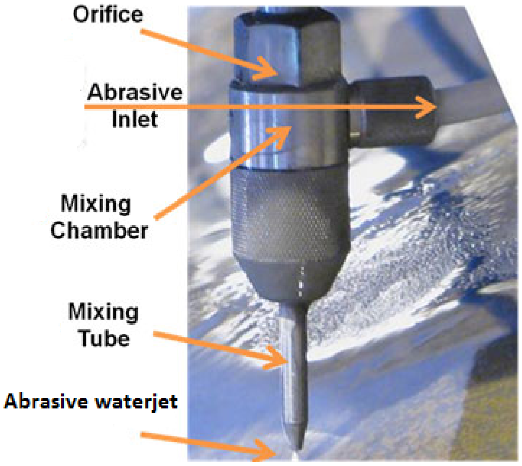


Fig. 1 Abrasive waterjet cutting head

## 2.3 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]. Taguchi's experimental design was used to construct the design of experiments (DOE). Four process parameters, i.e. water pressure, nozzle traverse speed, mass flow rate of abrasive particles and standoff distance each varied at three levels as shown in table 1, an $L_{81}$ ($3^4$) orthogonal arrays table with 81 rows corresponding to the number of experiments was selected for the experimentation. Table 1 shows the levels of parameters used in experiment.

Table 1 Levels of parameters used in experiment

| Parameters | Symbol | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| Water pressure | p | MPa | 270 | 335 | 400 |
| Traverse speed | u | mm/s | 0.5 | 10.25 | 20 |
| Mass flow rate | $m_a$ | g/s | 8 | 11.5 | 15 |
| Standoff distance | s | mm | 1.8 | 3.4 | 5 |

## 2.4 Constant Parameters

The parameters that were kept constant during tests included the jet impact angle at neutral nozzle position (90°), orifice diameter (0.35 mm), nozzle length (76.2 mm), nozzle diameter (1.05 mm), abrasive material (80 mesh garnet particles with the density of 4100 kg/m$^3$) and average diameter of abrasive particles (0.18 mm). Garnet consists of chemically 36% FeO, 33% $SiO_2$, 20% $Al_2O_3$, 4%MgO, 3% $TiO_2$, 2% CaO and 2% $MnO_2$.

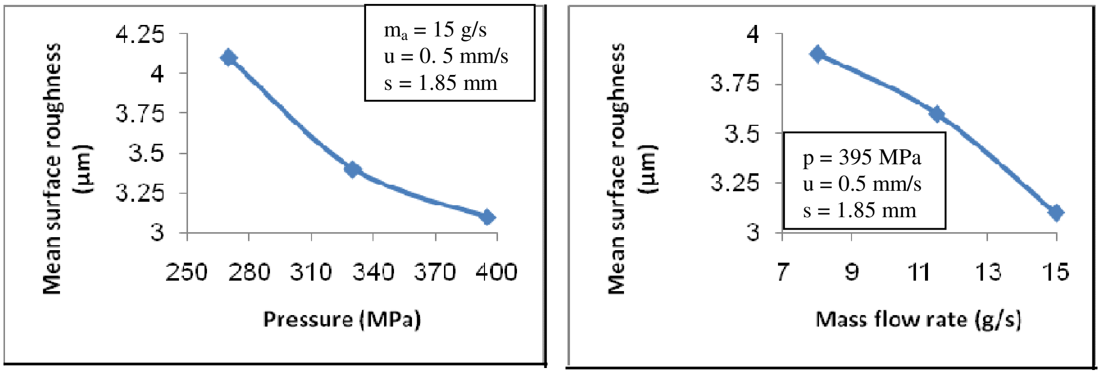
## 2.5 Data Collection

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.

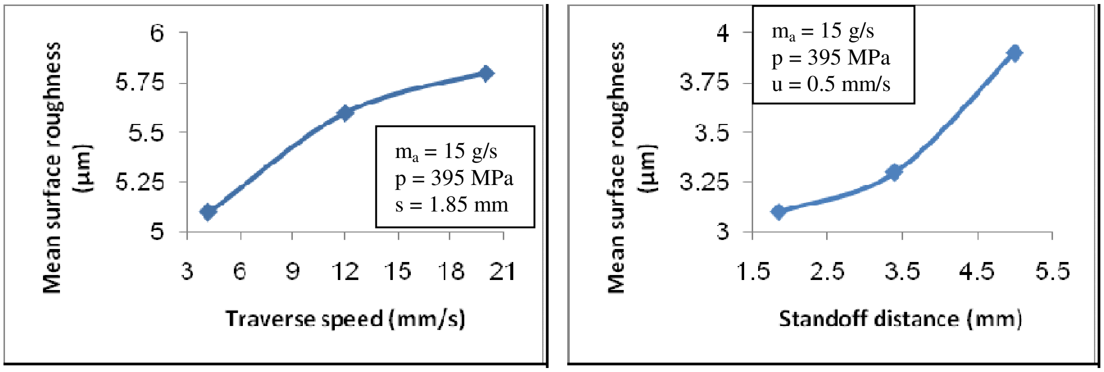
The surface finish parameter employed to indicate the surface quality in this experiment was the arithmetic mean roughness ($R_a$). Workpiece surface roughness $R_a$ was measured by a surface roughness equipment model “SURFPAK SV-514”. Surface roughness was measured at the centre of the cut for each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

## 3. RESULTS AND DISCUSSION

Surface roughness is one of the most important criteria, which help us determine how rough a workpiece material is machined. By analyzing the experimental data of the selected material, 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 process outputs such as surface roughness. The effect of each of these parameters is studied while keeping the other parameters considered in this study as constant. The effects of process parameters on surface roughness are shown in fig. 2. 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 $R_a$.



(a) Water pressure (b) Abrasive mass flow rate



(c)Traverse speed (d) Standoff distance

Figure 2 Effects of process parameters on surface roughness for cast iron

### 3.1 Effect of Water Pressure on Surface Roughness

The influence of water pressure on the surface roughness is shown in fig.2 (a). 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.

### 3.2 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. 2(b).

### 3.3 Effect of Traverse Speed on Surface Roughness

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. 2(c).

### 3.4 Effect of Standoff distance on Surface Roughness

Surface roughness increase with increase in standoff distance. This is shown in fig. 2(d). 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.

## 4. CONCLUSIONS AND RECOMMENDATIONS

Experimental investigations have been carried for the surface roughness 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 surface roughness 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.

## 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] M.Chithirai Pon Selvan, Dr. N. Mohana Sundara Raju.**,** "Selection of process parameters in abrasive waterjet cutting of copper"**,** *International Journal of Advanced Engineering Sciences and Technologies, vol 7, issue 2: pp 254-257,2011.*

[17] Arola D, Ramulu M. "A study of kerf characteristics in abrasive waterjet machining of graphite/epoxy composites*". ASME Mach. Adv.Comp. 45(66): pp 125-151, 1993.*

[18] Wang J, Wong W C K. "A study of waterjet cutting of metallic coated sheet steels"*. International Journal of Mach. Tools Manuaf, 39: pp 855-870, 1999.*

[19] Hocheng H, Tsai H Y, Shiue J J, Wang B. "Feasibility study of abrasive waterjet milling of fiber-reinforced plastics". *Journal of Manuf. Sci.Eng., 119: pp 133-142.1997*

*Received 16 June, 2012*