

Investigation of Surface Roughness in Abrasive Water Jet Machining

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Abstract

Abrasive Waterjet Machining (AWM) is a machining process a high quality finish. Abrasive Waterjet Machining on various materials have been studied and it has been observed that various factors have an impact on the surface roughness of the machined surface. A study on the research done on these parameters and innovations to improve the surface roughness has been conducted. General parameters such as nozzle angle, transverse speed, particle impact velocity standoff distance and so on were considered for the experimentations done. The final conclusion of this study shows that the main parameters that affect the surface roughness are the standoff distance and the abrasive flow rate of the tool or nozzle.

Introduction

Abrasive Waterjet Machining is a cold cutting process in which the material is cut by using a high pressure jet of water or a solution of water and abrasive material. When only water is used, it is known as pure waterjet machining. The most common abrasive material used in Abrasive Waterjet Machining is garnet mesh of various quality (mostly 80 mesh but 50 and 120-mesh can be used).



Fig.1 Abrasive Waterjet Machining

It is practical to use it to cut any kind of material. In waterjet cutting, there is no heat generated. This is especially useful for cutting tool steel and other metals where excessive heat may change the properties of the material.

Surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. It describes the geometry and surface textures of the machined parts (Nalbant et al., 2007). There are several ways to describe surface roughness, such as roughness average (R_a), root-mean-square (rms) roughness (R_q) and maximum peak-to-valley roughness (R_y or R_{max}), etc. R_a is defined as the arithmetic value of the

profile from centre line along the sampling length. The average surface roughness R_a is measured within $L = 0.8\text{mm}$. [38]

2. Literature Review

Some of the main factors that affect the surface roughness of the machined surface are:

Particle Impact Velocity

The velocity of the particles has a direct relation with the surface roughness. As the velocity of the particles increase, the kinetic energy of the particles also increases. This results in more impact force on the workpiece and thus more material is removed. So it can be concluded from these observations that as with increase in surface roughness, there is increase in surface roughness.

Only the kinetic energy due to the normal component of the velocity, U_{vn} , was assumed to influence the surface roughness. [14] In most of the cases, velocity exponent, was determined experimentally by measuring the erosion rate at varying pressures, which were related to average particle velocities using the free jet model. [27]

Nozzle Angle

The effect of nozzle angle on the surface roughness of the machined surface has been measured through various angles (30° , 45° , 60° , 75° and 90°).

The effect of impact angle on the channel centerline roughness was measured using forward nozzle inclinations of $\alpha = 30, 45, 60, 75$ and 90 . The optical profilometer was scanned over a 10 mm length of each channel using a $1\text{ }\mu\text{m}$ sampling interval, with a 0.25 mm cut-off length (low-pass wavelength filter). The measurements were repeated over each separate the three 10 mm sections comprising the 30 mm long channel. [2] Highest roughness values (R_a) were observed when the nozzle angle was 45° . The erosion rate was also at its highest at this angle. [2]

Increasing both particle size and impact angle, it has been examined the abrasive waterjet milling behavior of Ti6Al4V in terms of the surface properties of the milled component, such as roughness, waviness and level of grit embedment. [29]

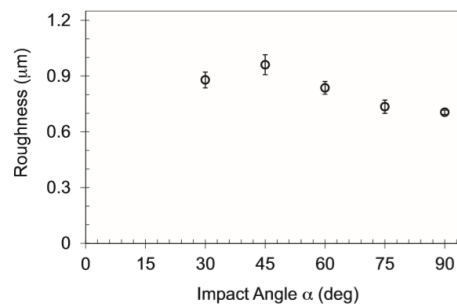


Fig.2: Graph plotted between Impact angle and Surface Roughness

Standoff Distance

The standoff distance is the distance between the nozzle and the workpiece. Since the standoff distance determines the mechanical force applied over the machined surface in abrasive water jet machining process, it has the most significant role on determining the surface roughness. If abrasive flow rate is higher than the optimized value, then the larger craters will be formed over the machined surface due to the higher mechanical energy happened between the abrasive and the work piece surface. [1]

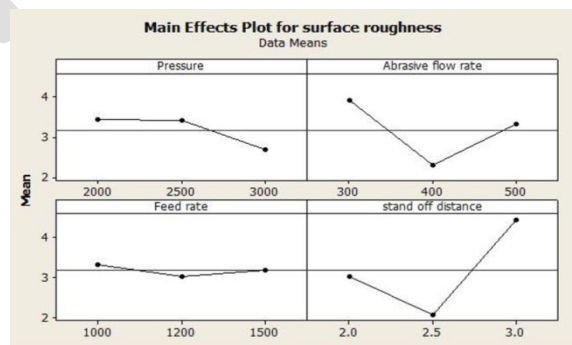


Fig.3 Graph between various parameters and Surface Roughness

Material Thickness

The surface roughness is directly related to the material thickness. As the material thickness increases, the surface roughness increases. An example of this case can be seen in the following figure. The effect of the depth of cut on the surface roughness is most prominent on bottom of the cut. An increase in material thickness caused an increase in surface roughness, especially on the bottom of cut. The smallest change in the surface roughness was occurred at the lower traverse speeds. The traverse speed has no greater effect on the surface roughness at the beginning of cut. By increasing the depth of cut and the traverse speed, the surface roughness increases. As shown in Fig.4, the traverse speed strongly depends of the material thickness, by increasing the material thickness, the traverse speed decreases.[10]

Transverse Speed

As transverse speed increases, the surface roughness also increases. Depth of cut and transverse speed are closely related.

It can be seen that the surface roughness increases by increasing of traverse speed. Also, it can be observed that the roughness R_a slightly changes through the whole depth of cut surface at low traverse speeds e.g. at a speed of 139 m/min and less. The surface roughness increases by increasing of the depth of cut surface, especially at the higher traverse speeds. The cut sample was considered unacceptable at a speed of 350 mm/min, because the roughness has been unable to measure at the depth of 13 mm from the entry jet.

Experiments were made at the constant value of abrasive mass flow rate, $m = 390$ g/min. It can be seen that the roughness R_a , which was measured at the depth of 2 mm and 10 mm from the entry jet, slightly changes by increasing of traverse speed. But the roughness R_a , which measured at the depth of 28 mm from the entry jet, rapidly increased at the traverse speeds higher than 69 mm/min. So, the cut sample was considered unacceptable at a speed of 130 mm/min, because the roughness has been unable to measure at the depth of 20 mm and 30 mm from the entry jet.

Based on the above results, the optimal traverse speed was 139 mm/min and 69 mm/min during AWJ cutting of aluminum plate of 15 mm and 30 mm thickness, respectively.[10]

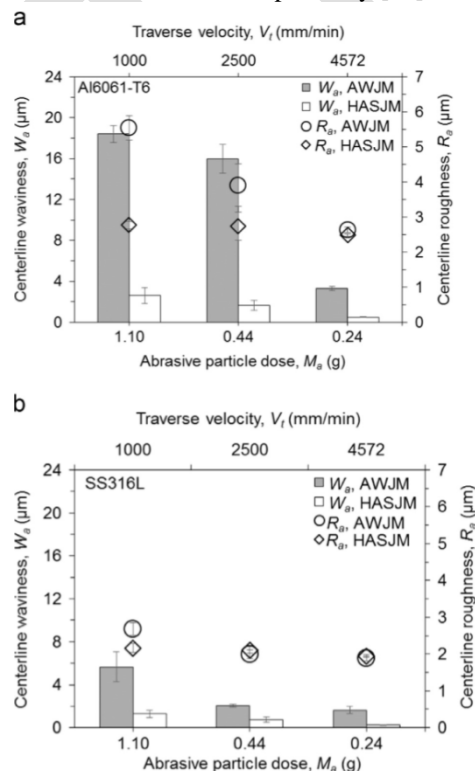


Fig.4: Graph plotted between Transverse velocity, Abrasive Flow Rate and Surface Roughness

At low depths of cuts, the surface roughness increases slightly with increase in transverse speed whereas with higher depths of cuts, the surface roughness rapidly increases with increase in transverse speed. AWJ experimental research has shown that traverse speed is the main factor influencing the cutting depth achieving the admissible surface roughness:

- the use of traverse speed of 37.8 mm/min allows cutting the 30 mm 6082-Al alloy workpiece in the range of surface quality 3.75-4.0 μm ,
- the use of traverse speed of 48.9 mm/min allows cutting the 26 mm workpiece in the range of surface quality 4.0-4.75 μm ,
- the use of traverse speed of 68.1 mm/min allows cutting the 22 mm workpiece in the range of surface quality 4.0-4.6 μm ,
- the use of traverse speed of 97.2 mm/min allows cutting the 20 mm workpiece in the range of surface quality 4.5-5.2 μm ,
- the use of traverse speed of 163.5 mm/min allows cutting the 16 mm workpiece in the range of surface quality 4.7-5.2 μm .

It has been noticed that the traverse speed of 37.8 mm/min in cutting 6082-Al alloy allows to achieve the surface roughness of $R_a = 3.9 \mu\text{m}$ for the workpiece with the wall thickness of 30 mm. Also it has been found, that the decrease of traverse speed from 163.5 mm/min to 37.8 mm/min decrease the surface roughness by 1 μm . But here the limitation of cutting depth to 16 mm is achieved, by using the highest traverse speed.[39]

Pressure

The surface roughness of the machined workpiece is related directly to the pressure of the waterjet. The amount of variation differs for different material. For example, in ductile and composite materials, the surface roughness increases slightly with increase in pressure whereas in steel and aluminum alloys, it increases sharply. This increase in surface roughness has been measured to be around 1.5 fold increase. Thus increase in pressure of the waterjet has a certain and proportional effect on the surface roughness.

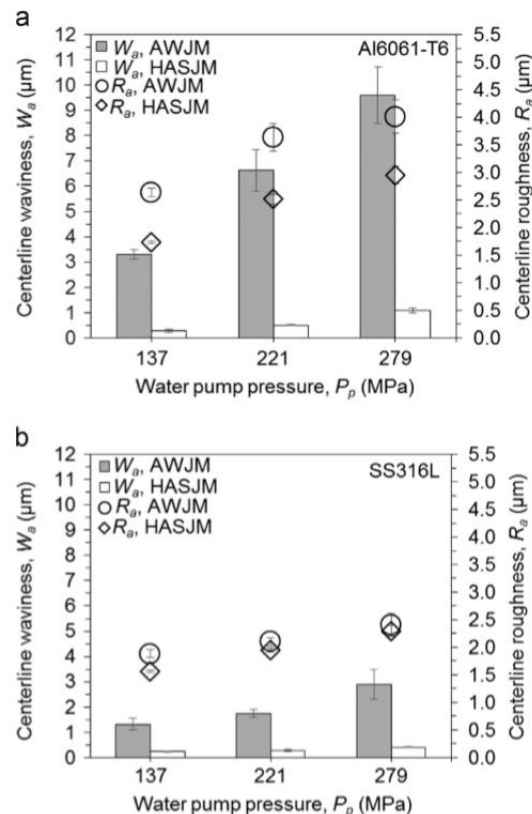


Fig.5 Graph plotted between Pressure and Surface Roughness

Abrasive Flow Rate

The surface roughness increases upon increasing the abrasive mass flow rate. This is due to the reason that as more abrasive particles hit the workpiece per second, a smoother and lower surface roughness is obtained. It has been observed that the higher surface roughness has been observed higher abrasive flow rate. The energy is influenced by the mass flow rate of the abrasive particle. Since the higher abrasive flow rate has generated higher energy, it has removed the more material removal from the work piece specimens.

A usual effect of abrasive flow rate is that increase in abrasive flow rate beyond a critical value will reduce the depth of cut.[20]

When higher flow rate has been used with higher standoff distance, the material has been removed in higher level with random in nature. Hence it has produced higher surface roughness.[1]

The surface roughness decreases by increasing of abrasive mass flow rate. Under the certain conditions, the effect of abrasive mass flow rate depends of the cut's depth. The effect of abrasive mass flow rate on the surface roughness increases as the cut's depth increases.

Based on the above observeds results, the optimal abrasive mass flow rate was 250 g/min and 320 g/min during AWJ cutting of aluminum plate of 15 mm and 30 mm thickness, respectively.[10]

Depth of Cut

The depth of cut has a positive effect on the surface roughness of the machined surface. As the depth of cut increases, the amount of material to be removed is greater. Thus, the surface roughness increases. The surface roughness depending on depth of cut also varies with the transverse speeds, i.e., at different depths of cuts, the surface roughness varies.

The cut layer of the material is characterized by two AWJ parameters: 1) cutting zone or smooth roughness zone and 2) deformation zone or rough roughness zone. Smooth roughness and rough roughness zones are limited by critical depth h_{crit} . The so-called critical depth h_{crit} [20] can be found in each surface [41]. The zone above the critical depth is cutting zone h_c and the zone below it is the deformation zone h_d . [39]

3. Conclusion

It can be concluded that the main parameters of AWJ[38] which describes surface quality are: pressure, traverse speed (cutting speed) and abrasive material as well dimension.[39] From the above observed parameters can be concluded that standoff distance and abrasive flow rate have the greatest effect on the surface roughness of the machined surface. The standoff distance determines how far the nozzle is from the workpiece. Surface roughness increases as abrasive flow rate increases. As the standoff distance crosses an optimum value, the surface varies greatly as craters are formed due to high kinetic energy of particles. The kinetic energy of the particles can be also increased by uncreasing the transverse speed of the particles, but this does not have as great of an effect as abrasive flow rate. Transverse speed and depth of cut are closely related. Surface roughness varies slightly when depth of cut and transverse is low and varies greater when those two parameters are increased.

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