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A Study on Abrasive Water Jet Machining of Aluminum with Garnet Abrasives

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Abstract: In this study the effect of some cutting variables on the quality of the surface produced during abrasive water jet machining of aluminum has been investigated. The type of abrasive used was garnet of mesh size 80. The machining was done on the abrasive water jet machine WJ4080. The cutting variables were stand-off distance of the nozzle from the work surface, work feed rate and jet pressure. The evaluating criteria of the surface produced were width of cut, taper of the cut slot and work surface roughness. It was found experimentally that in order to minimize the width of cut; the nozzle should be placed close to the work surface. Increase in jet pressure results in widening of the cut slot both at the top and the at exit of the jet from the work. However, the width of cut at the bottom (exit) was always found to be larger than that at the top (at a stand-off distance of 3 mm and the work feed rate of 15 mm min^{-1}). It was found that the taper of cut gradually reduces with increase in stand-off distance and was close to zero at the stand-off distance of 4 mm (at a jet pressure of 30 ksi and a work feed rate of 15 mm min^{-1}). The feed rate of the work should be kept within 40 mm min^{-1} (at the jet pressure of 30 ksi and the stand-off distance of 3 mm), because a feed rate beyond 40 mm min^{-1} results in sharp increase in taper angle. The jet pressure does not show significant influence on the taper angle within the range of work feed and the stand-off distance considered. Both stand-off distance and the work feed rate show strong influence on the roughness of the machined surface. It was concluded that stand-off distance should be kept within 3 mm (at a jet pressure of 30 ksi and a work feed rate of 15 mm min^{-1}) and the work feed rate should be kept within 30 mm min^{-1} (at a jet pressure of 30 ksi and a stand-off distance of 3 mm) in order to have a good surface finish, since beyond those values of the parameters the roughness of the machined surface rises sharply. Increase in jet pressure shows positive effect in terms of smoothness of the machined surface. With increase in jet pressure, the surface roughness decreases (at a stand-off distance of 3mm and work feed of 15 mm min^{-1}). This is due to fragmentation of the abrasive particles into smaller sizes at a higher pressure and due to the fact that smaller particles produce smoother surface. It was also found that within the jet pressure considered, the work surface is smoother near the top surface and gradually it becomes rougher at higher depths.

Key words: AWJM, stand-off distance, feed rate, jet pressure, surface roughness

INTRODUCTION

Abrasive Water Jet Machining (AWJM) is being used in different industries for a long time. This technique gives a clean cut without any heat affected zone. AWJM is especially suitable for machining of brittle materials like glass, ceramics and stones as well as for composite materials and ferrous and non-ferrous materials. The characteristics of surface produced by this technique depend on many factors like jet pressure, type of abrasive used, stand-off distance of the nozzle from the target, feed rate, abrasive flow rate, work materials, etc. Many researches have been carried out on different parameters of AWJM. Fekaier *et al.*[1] and Ohlsson and Magnusson[2] investigated the force parameters involved during AWJ machining. Tikhomirov[3] worked on the possible feed rate depending on the stand-off distance of the nozzle. Andreas and Kavaeevic[4] investigated the properties and structures of high speed water jets. Momer *et al.*[5] investigated the influence of abrasive grain size distribution on abrasive water jet machining process. Though abrasive water jet machining is a cool cutting process and stress development on the machined surface is insignificant, some interesting works have been done by Arola and Ramulu[6] on residual stress of metals machined with abrasive water jet. In the present study detailed investigations have been carried out on the effect of a few parameters like stand-off distance, feed rate and

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jet pressure on width of cut, taper of cut and surface finish produced during machining of aluminum.

MATERIALS AND METHODS

The experiments were carried out in an abrasive water jet machine of model WJ 4080. The machine was equipped with the controller type Acramatic 2100 CNC control. The work material used was aluminum with the following main properties: tensile strength-90MPa, modulus of elasticity-69 GPa and density-2.71 g cm^{-3}. The abrasive used was garnet with mesh size of 80 and hardness of 7.5 Mohs. The cutting parameters investigated were stand-off distance of the nozzle from the work (from 1 to 5 mm), feed rate of the work table (from 10 to 50 mm min^{-1}) and jet pressure (from 12 to 50 ksi). The jet was perpendicular to the work surface and the nozzle diameter was 0.75 mm. Small rectangular aluminum blocks were cut by abrasive water jet half way along the length. This was done to measure the width of cut at the top and bottom of the block. After measuring the width of cut, the blocks were cut to the full length and the surface roughness was measured on the vertical cut surface. Surface roughness was measured by a surface roughness measuring equipment model SURFPAK SV-514. Surface roughness was measured at distances of 10, 20, 30 and 40 mm from the top of the surface.

RESULTS AND DISCUSSION

Effect on width of cut

Effect of stand off distance on width of cut: Figure 1 shows the effect of stand-off distance on widths of cut (B_{top}-width at the top and B_{bottom}-width at the bottom) of the vertical cut surface of the aluminum blocks. During the cutting process the jet pressure was 30 ksi and the work feed rate was 15 mm min^{-1}. B_{top} has increased by 0.542 mm due to the increase in stand-off distance from 1 to 2 mm. Then, it has changed its trend and width of cut decreases until the stand-off of 5 mm. It can be concluded that increasing the standoff distance will increase the width of cut up to the stand-off distance of 2 mm, because of the taper shape of the jet. Some researchers[7,9] also concludes that width of cut increases with nozzle distance. But as the stand-off distance increases beyond 2 mm, the stream becomes weaker and as a result, the width of cut decreases.

Effect of pressure on width of cut: Figure 2 shows the relationship between width of cut and abrasive water jet pressure ranging from 10 to 50 ksi. Both B_{top} and B_{bottom}

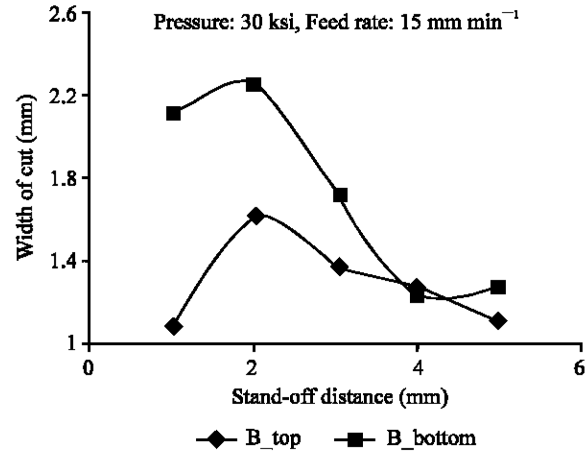

Fig. 1: Effect of stand-off distance on width of cut

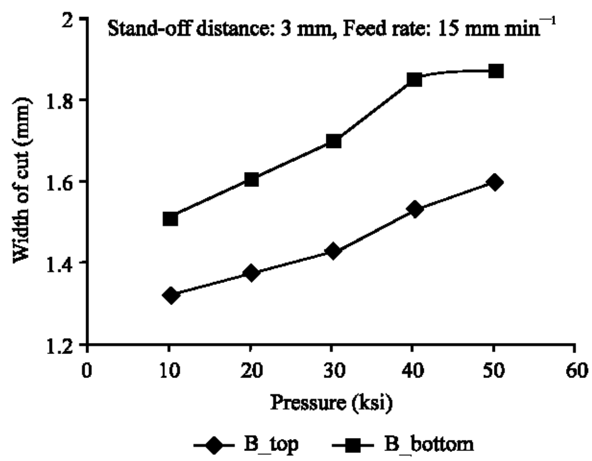

Fig. 2: Effect of pressure on width of cut

show the same pattern. Their increasing trend is almost parallel, starting from 10 to 50 ksi. It is obvious that with an increase in jet pressure the energy of the stream increases which causes the widening of the kerfs. Similar results were obtained by Momber[9].

Effect on taper of cut: The taper of cut (T_R) is defined as a non-dimensional ratio between the top cut width and the bottom cut width. It can be calculated as follows:
$T_R = (B_{top}\text{-}B_{bottom})/2$. Machining parameters should be selected so that the taper of cut is as small as possible.

Effect of stand-off distance on taper of cut: Figure 3 shows the trend of change of taper of cut with the change in stand-off distance of the nozzle from the work. The taper of cut gradually reduces to the minimum value as the stand-off distance is increased from 1 to 5 mm. At low stand-off distance the jet is strong and it has a diverging shape. That's why the top width of the cut is smaller than

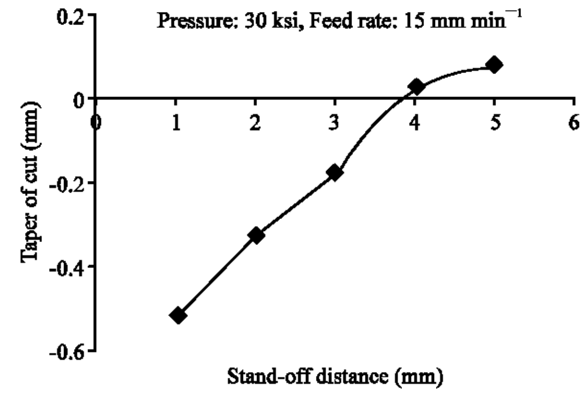

Fig. 3: Effect of stand-off distance on taper of cut

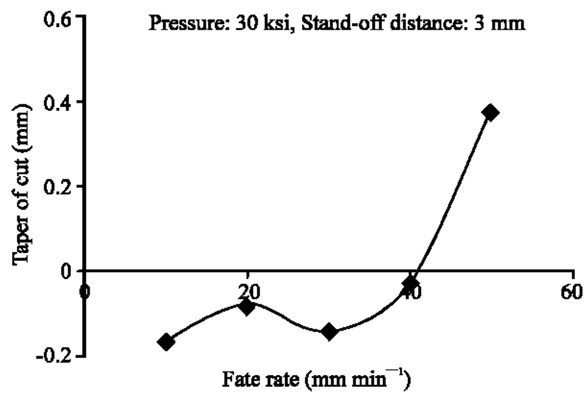

Fig. 4: Effect of feed rate on taper of cut

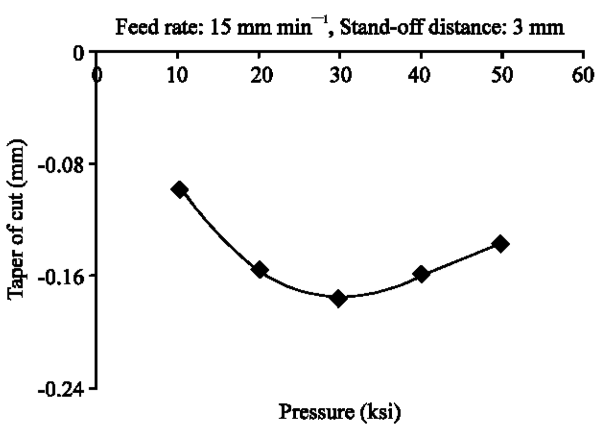

Fig. 5: Effect of pressure on taper of cut

that of the lower and the taper angle is negative. But as the stand-off distance is increased, the jet becomes weaker and near the exit the jet looses its kinetic energy and the width of cut at the bottom becomes smaller than that of the top one. The negative values indicate that the upper width of cut is lower than bottom width of cut.

Effect of feed on taper of cut: Figure 4 shows the relationship between taper of cut and feed rate. The general trend of the curve shows that increase in work feed rate results in increase in taper of cut. Rankin and Kavocevic[8] also shows some interesting relationship between feed rate and depth of cut. Momber[9] showed that with increase in traverse rate, the top width of cut decreases. But the decrease in width of cut with increase in work feed rate is more prominent near the exit of the slot since at the exit the jet becomes weaker. As a result taper of cut gradually increases with increase in work feed rate.

Effect of pressure on taper of cut: Figure 5 shows the trend in change in taper of cut with increase in jet pressure during machining of aluminum. As the jet pressure is increased from 10 ksi, the taper of cut gradually increases to a maximum value at a jet pressure of 30 ksi. This trend is similar to the results obtained by Momber and Kovacevic[9]. But the taper angle reduces again with further increase in jet pressure. This is due to the more straightening of the jet at a higher pressure.

Effect on surface finish

Effect of stand off distance on surface finish: Figure 6 shows the effect of stand-off distance of the nozzle from the work surface and the surface roughness of the vertical cut surface at different depths from the top surface. Jet pressure and work feed rate in this illustration are 30 ksi and 15 mm min^{-1}, respectively. The general trend of increase in surface roughness with increase in stand-off distance is obvious. It is also to be observed that work surface roughness increases rapidly beyond a stand-off distance of 3 mm. At a stand-off distance of 4 mm it is clear that further the surface is from the top, rougher it is.

Effect of feed rate on surface finish: Figure 7 shows the effect of feed rate on roughness of the vertical machined surface at various depths from the top surface. In the Fig. 7 the jet pressure and the stand-off distance of the nozzle were 30 ksi and 3 mm, respectively. Increasing the feed rate causes the increasing of striation formation of the jet and hence the surface roughness increases with increase in feed rate. Thus at a feed rate of 50 mm min^{-1} the value of surface roughness at a depth of 40 mm from the top of the surface is 11.84 μm where as the value is 5.58 μm at a feed rate of 10 mm min^{-1} at the same depth. It can also be observed from the Fig. 7 that in general the machined surface is smoother near the top of the surface and becomes rougher at greater depths from the top surface.

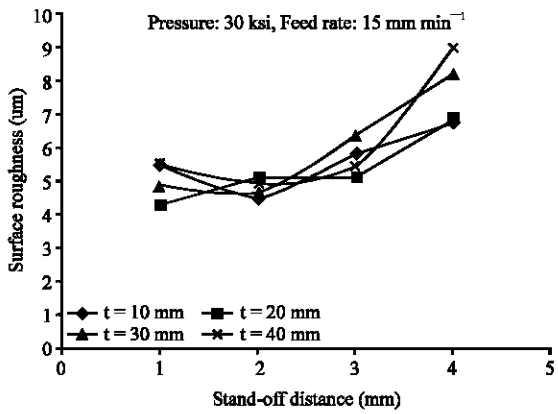

Fig. 6: Effect of stand-off distance on surface finish

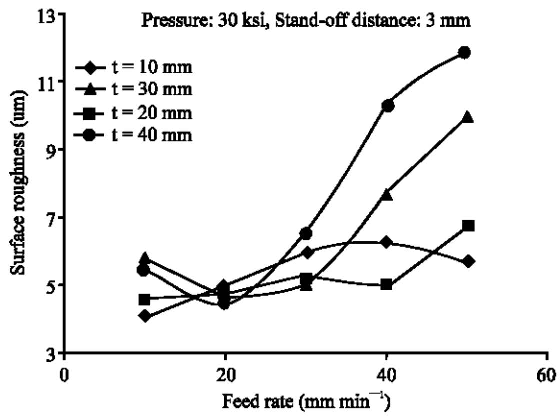

Fig. 7: Effect of feed rate on surface roughness

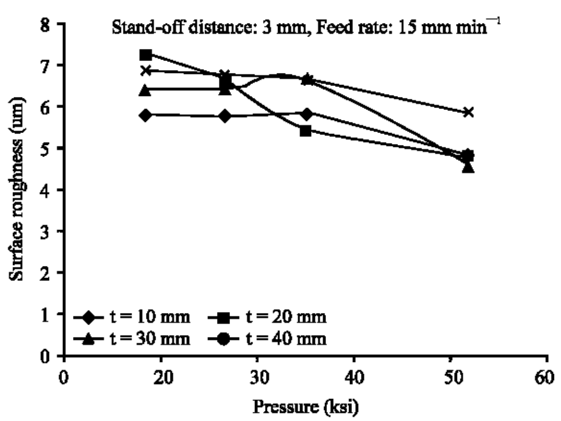

Fig. 8: Effect of pressure on surface roughness

Effect of pressure on surface finish: Figure 8 shows the effect of jet pressure on surface roughness at different depths from the top surface (at a work feed rate of 15 mm min^{-1} and a stand-off distance of the nozzle of 3 mm). It can be observed from the Fig. 8 that as the pressure increases, the surface roughness gradually decreases. This result is similar to those obtained by Kovacevic[10]. With increase in jet pressure, brittle abrasives break down into small 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. It can also be observed that the highest value of surface roughness is at the greatest depth of the machined surface.

CONCLUSIONS

In the present study experimental investigations have been carried out for specific cutting parameters of jet pressure, stand-off distance of the nozzle and feed rate. It was observed that for a moderate pressure of 30 ksi and feed rate of 15 mm min^{-1}, the width of cut increases with increase in stand-off distance, but further increase in stand-off distance causes narrowing the slot due to a weak jet. Again, both the top and the bottom widths increase with the increase in pressure due to higher kinetic energy of the abrasives and water. Therefore, pressure should be kept as low as possible in order to reduce the wastage of material, though it would reduce the productivity of machining.

Taper of the kerf is another important factor in machining accuracy and it should be as small as possible. Experimental investigations reveal that a stand-off distance of around 4 mm (at a feed rate of 15 mm min^{-1} and a jet pressure of 30 ksi) produces the smallest width of cut. Again, in order to minimize the width of cut (at a jet pressure of 30 ksi and a stand-Off distance of 3 mm) feed rate should be kept within 40 mm.

Surface finish is of great concern for AWJM. It was found that the cut surface is smoother near the top surface and gradually becomes rougher at higher depths. Surface roughness increases with increase in stand-off distance and the results show that the stand-off distance should be kept within 3 mm (at a pressure of 30 ksi and a work feed rate of 15 mm min^{-1}) in order to obtain a reasonably smooth surface. Similarly, increase in work feed rate results a poorer surface. It is advisable to limit the feed rate within 30 mm min^{-1} (at a jet pressure of 30 ksi and a stand-off distance of 3 mm) which gives a good surface finish.

Jet pressure plays an important role in surface finish. As the jet pressure increases, surface becomes smoother. This is due to fragmentation of the abrasive particles into smaller ones as a result of high pressure and small particles give a smoother surface. Again, surface is smoother near the top of the work surface and gradually it becomes rougher at higher depths.

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