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Surface Roughness of Carbides Produced by Abrasive Water Jet Machining

Ahsan Ali Khan, Mohd Efendee Bin Awang and Ahmad Azwari Bin Annuar
Department of Manufacturing and Materials Engineering, Faculty of Engineering,
International Islamic University Malaysia, P.O. Box 10, 50728 Kuala Lumpur, Malaysia

Abstract: This study presents the effect of jet pressure, abrasive flow rate and work feed rate on smoothness of the surface produced by abrasive water jet machining of carbide of grade P25. Carbide of grade P25 is very hard and cannot be machined by conventional techniques. Cutting was performed on a water jet machine model WJ 4080. The abrasive used in investigations was garnet of mesh size 80. It was tried to cut carbide with low and medium level of abrasive flow rate, but the jet failed to cut carbide since it is too hard and very high level of energy is required. Minimum rate of abrasive flow that made it possible to cut carbide efficiently was 135 g min^{-1}. It was found from the investigations that with increase in jet pressure the surface becomes smoother due to higher kinetic energy of the abrasives. But the surface near the jet entrance is smoother and the surface gradually becomes rougher downwards and is the roughest near the jet exit. Increase in abrasive flow rate also makes the surface smoother which is due to the availability of higher number of cutting edges per unit area per unit time. Feed rate didn't show significant influence on the machined surface, but it was found that the surface roughness increases drastically near the jet entrance.

Key words: Carbide, surface finish, abrasive flow rate, abrasive waterjet, garnet

INTRODUCTION

Carbides are well known for their high wear resistance and hardness, especially hot hardness. Due to these properties they have gained popularity as a tool material. They are extensively used for making dies and cutting tools. Hardened materials as well as difficult-to-machine materials can be machined by carbides. These carbides, made by powder metallurgy are difficult to machine by conventional techniques due to their high hardness. In order to cut carbide, first a fracture is to be developed. A fracture can be developed in the material if the force applied is more than the inter-granular bonding force. It was suggested that inter-granular fracture dominates the material removal at perpendicular impact angles[1,2]. Guinot *et al.*[3] and Magnnsson and Ohlsson[4] also worked on force parameters involved in abrasive water jet machining. In the present work an attempt has been made to machine carbides with high pressure water jet. Carbide is a brittle material, but water is a soft material and produces a smooth surface. Again, since water jet machining is a cool machining technique without much heat generation, no metallurgical changes occur on the machined surface and the surface is almost free of residual stress[5]. It was stated by Tikhomirov *et al.*[6] that material removal rate decreases almost linearly with increase in work material hardness. Since carbides are very hard materials, only high pressure water jet can be used to machine them. In the present work it was found that the minimum water pressure required to machine carbides is 35 ksi. Due to high pressure the abrasive grains are broken into small elements. Ohlsen[7] introduced a new character called disintegration number to quantitatively evaluate the process of abrasive particle disintegration. He found that disintegration number increases with increase in pump pressure, increase in abrasive flow rate and decrease in focal length of the jet. Literature survey shows that a lot of works have been done on machining of different metallic, non-metallic and composite materials with water jet machining, but a little research was found on machining of carbides. In the present research, investigations has been done on surface finish produced by abrasive water jet machining with different pressure, abrasive flow rate and work feed rate.

MATERIALS AND METHODS

The abrasive used in the present study was garnet with the mesh size of 80. The work material was carbide of P 25 grade. Its approximate composition is 78.5% tungsten carbide, 8% tantalum carbide and 10.5% cobalt. Its hardness is about 1400 HV50 and density is 13.5 g cm^{-3}.

Corresponding Author: Dr. Ahsan Ali Khan, Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, P.O. Box 10, 50728 Kuala Lumpur, Malaysia

The size of the carbide pieces was 13×13×3.18 mm. The cutting operations were performed on a water jet machine of model WJ 4080. The machine was equipped with the controller type 2100 CNC Control. The nozzle used for the abrasive water jet was of carbide with the orifice diameter of 0.1 mm. During cutting operations, the jet was held perpendicular to the work surface.

In the present study the machining variables were the jet pressure, abrasive flow rate and the work feed rate. The range of pressure was from 35 to 50 ksi, the range of abrasive flow rate was from 135 to 175 g min^{-1} and the range of work feed rate was from 1.36 to 5 mm min^{-1}. The output parameter of the work was surface finish produced by the abrasive water jet. Surface roughness was measured at the depths of 0.5, 1.5 and 2.7 mm from the jet entrance. Surface roughness was measured using a surface roughness measuring equipment model SURFPAK SV-514. The cut surface was also observed under a microscope.

RESULTS AND DISCUSSION

Influence of pump pressure on surface roughness: Carbide is a very hard material and the strength of bonding among the particles is very high. As a result, a very high force is to be applied to overcome the bonding strength. In the present study the minimum pressure required for cutting carbide was 35 ksi. The effect of pressure on surface roughness at different depths from the jet entrance is illustrated in Fig. 1 and Fig. 2. During these investigations the work feed rate was 1.36 mm min^{-1}, stand-off distance of the nozzle from the work surface was 2 mm and the abrasive flow rate was 135 g min^{-1}. From Fig. 1 it is obvious that with increase in pressure, surface roughness gradually decreases. Due to increase in pressure, kinetic energy of the particles increases which enhances their cutting ability. Again, at a higher pressure the abrasive particles break down into smaller particles that produce a smoother surface. Similar result was found by Kovacevic *et al.*[8].

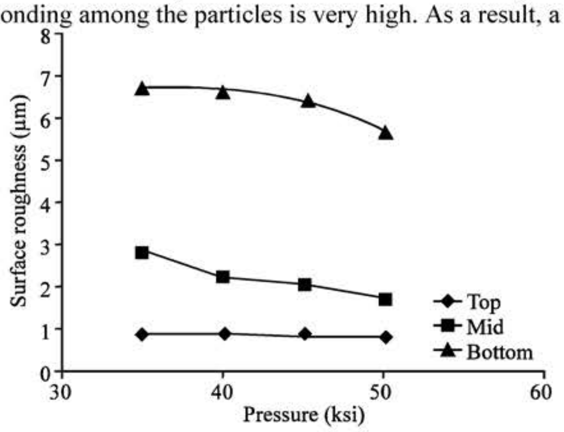

Fig. 1: Effect of pressure on surface roughness

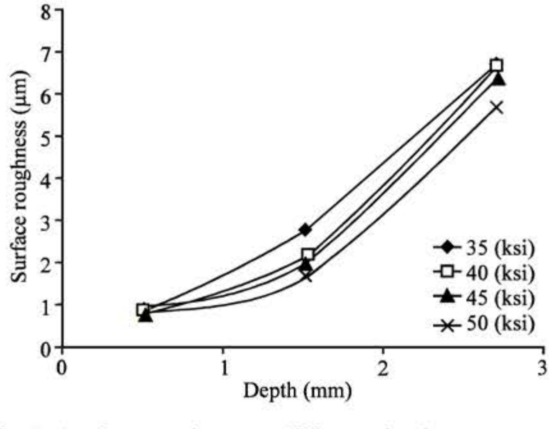

Fig. 2: Surface roughness at different depths

Pressure: 35 ksi

Pressure: 40 ksi

Pressure: 45 ksi

Pressure: 50 ksi

Fig. 3: Serration of the machined surface at various jet pressures

Figure 2 shows that surface roughness rapidly increases at a higher depth. This is due to the fact that as the abrasive particles move down, they loose their kinetic energy and produce an inferior surface. It is obvious from the Fig. 3 that with increase in pressure the height of the zone before clear serration marks increases with increase in pressure.

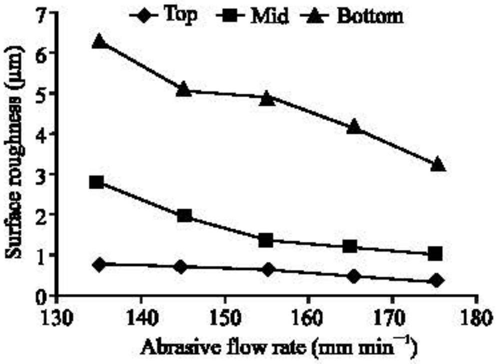

Fig. 4: Influence of abrasive flow rate on surface roughness

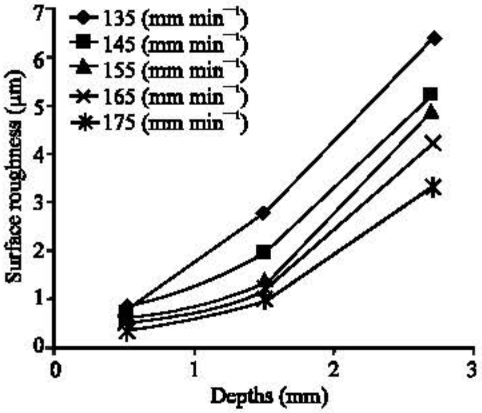

Fig. 5: Surface roughness at different depths and abrasive flow rates

Effect of abrasive flow rate on surface roughness: It was found in the present situation that a low flow rate of abrasive particles cannot cut carbide at all. It needs a large number of impacts per unit area under certain pressure to overcome the bonding strength of carbide particles and cut the work material. In the present work, at a jet pressure of 45 ksi, it was found that the minimum abrasive flow rate required to machine carbide satisfactorily is 135 g min^{-1}. In this case the jet pressure was 45 ksi and the stand-off distance of the nozzle from the work was 2 mm. It can be observed that with 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. With an abrasive flow rate of 175 g min^{-1}, the average value of surface roughness at a depth of 0.5 mm below the jet entrance was only 0.403 μm which may be considered to be a very good surface finish (Fig. 4).

Abrasive flow rate: 135 mm min^{-1}

Abrasive flow rate: 145 mm min^{-1}

Abrasive flow rate: 155 mm min^{-1}

Abrasive flow rate: 165 mm min^{-1}

Abrasive flow rate: 175 mm min^{-1}

Fig. 6: Serration of machined surface at different abrasive flow rates

Abrasive flow rate determines the number of impacting abrasive particles as well as total kinetic energy available. Therefore, higher the 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. Again, kinetic energy available per particle is also reduced due to increase in abrasive flow.

It is evident that the surface is smoother near the jet entrance and gradually the surface roughness increases towards the jet exit (Fig. 5).

Figure 6 shows the microscopic views of the machined surface, cut at a pressure of 45 ksi, work feed rate of 1.36 mm min^{-1} and at various abrasive flow rates.

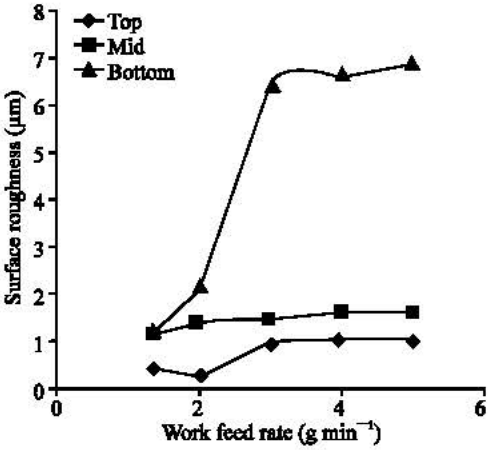

Fig. 7: Influence of work feed rate on surface roughness

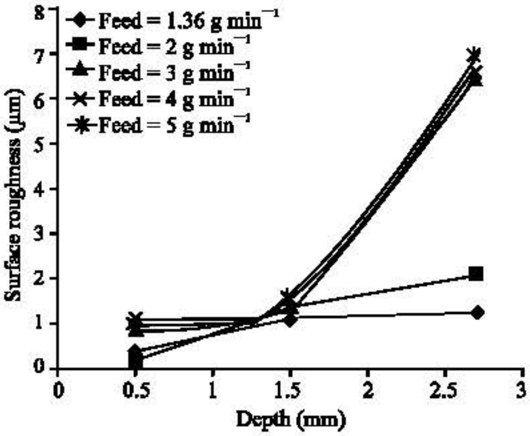

Fig. 8: Surface roughness at different depths and feed rates

It can be observed that the radius of curvature of serration at the bottom zone of the machined surface is larger at higher abrasive flow rate.

Effect of feed rate: The jet pressure, abrasive flow rate and stand-off distance of the nozzle from the work were 45 ksi, 150 g min^{-1} and 2 mm min^{-1} respectively (Fig. 7). It can be concluded that surface roughness gradually increases with increase in feed rate. 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.

Feed rate: 1.36 g min^{-1}

Feed rate: 2 g min^{-1}

Feed rate: 3 g min^{-1}

Feed rate: 4 g min^{-1}

Feed rate: 5 g min^{-1}

Fig. 9: Machined surfaces at different feed rates

It is obvious that surface roughness increases rapidly towards the jet exit (Fig. 8). Figure 9 shows the cut surface produced by machining carbide at a constant pressure of 45 ksi, abrasive flow rate of 165 g min^{-1} and at various feed rates ranging from 1.36 to 5 mm min^{-1}. These photographs clearly show that the width of waviness increases at a higher feed rate resulting a rough surface. In the present investigation, the process failed to cut the work of 3.18 mm thickness beyond a feed rate of 5 mm min^{-1}.

CONCLUSIONS

From the above discussions the following conclusions can be drawn:

1. A jet of very high pressure is required to machine carbide. A jet pressure below 35 ksi failed to cut carbide under the conditions considered. With increase in jet pressure, the kinetic energy of the abrasive particles increases enhancing their cutting ability. As a result the cut surface becomes smoother at a higher pressure.
2. Minimum abrasive flow rate that made it possible to machine carbide was 135 g min^{-1}. As abrasive flow rate is increased, more number of cutting edges of the particles passes through unit area. As a result, with increase in abrasive flow rate, surface roughness reduces.
3. Work feed rate didn't show a prominent influence on surface roughness. But with increase in work feed rate the surface roughness increased. Width of serration waviness increases with increase in feed rate. Under the conditions of the present investigations, the jet pressure failed to cut carbide at a feed rate higher than 5 mm min^{-1}.
4. In all the investigations it was found that the machined surface is smoother near the jet entrance and gradually becomes rougher towards the jet exit. This is due to the fact that as the particles moves down, they loose their kinetic energy and their cutting ability deteriorates.

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