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Experimentation on influence of Abrasive particles & Process parameters on abrasive water jet machining of Al 7075 MMC

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Abstract

In the last decade, numerous new and advanced materials are rapidly emerging and developed; it creates considerable interest in the researcher to search out the optimum combination of machining parameters during machining of these materials using advanced machining processes. Different types of abrasives are used in abrasive water jet machining like garnet, aluminum oxide, olivine, silica sand, silicon carbide, etc. The present work gives a comparative analysis of the performance of garnet, aluminum oxide and silicon carbide during abrasive water-jet machining of Al based Metal matrix composite. The study showed that width of cut increases as the stand-off distance of the nozzle from the work is increased which is due to divergence shape of the abrasive waterjet. However, the garnet abrasives produce the smallest width of cut followed by aluminum oxide and silicon carbide. This is because of higher hardness and cutting ability of silicon carbide followed by aluminum oxide and garnet. The performance measures selected are taper of cut, Average width of cut and material removal rate (MRR). It was also noticed that width of cut reduces with the increase of feed rate. With the increase in work feed rate, the work is under the jet for a shorter time which causes a smaller width of the slots. Again, width of cut was found to be the smallest while using garnet abrasives followed by aluminum oxide and silicon carbide. The taper of the cut slot was found to be higher at a greater stand-off distance and work feed rate, but smaller at a higher pressure. Since silicon carbide is very hard, it maintains its cutting ability as the abrasives move down. As a result, the difference of the width at the jet entrance and the jet exit is not significant. This causes a smaller taper of the cut slots. The width of the cut slot was found to increase with increase in jet pressure. At a higher jet pressure, the kinetic energy of the abrasives increases, resulting an enhanced cutting ability of the abrasives and causes widening of the cut slots. Due to higher hardness, silicon carbide produced the maximum width of cut followed by aluminum oxide and garnet.

Keywords: AWJM; Average width of cut; Taper of cut; Water jet, Al7075 MMC

Introduction

Abrasive water jet machining (AWJM) is a well known advance machining process utilized for machining hard to machine materials. This procedure is particularly appropriate for exceptionally delicate, fragile, and stringy materials. It is a machining interaction without a lot of hotness age and the machined surface is essentially with no hotness impacted zone or lingering pressure. Various kinds of abrasives are utilized in AWJM like garnet, olivine, aluminum oxide (Al_2O_3), silica-sand, glass dab, silicon carbide (SiC), zirconium, and so forth Yet, a study shows that 90% of the AWJM is finished utilizing garnet [1]. The calculation cut by the grating water stream is portrayed by the top width of cut, base width of cut, beginning harmed width, introductory harmed profundity, and so on Exertion ought to be given to limit these boundaries. The cut geometry relies upon the kind of abrasives and cutting boundaries like rough fly strain, stalemate distance (SOD) of the nozzle from the objective, work feed rate, grating mass stream rate, and so on.

Endeavors have been made to work on the cutting presentation of the rough water stream. It was found by Chacko et al. [2] that an expansion of polymer to the water stream expands the fly penetration profundity. Hardness is a significant person of the abrasives that impacts on the cut math. The profundity of entrance of the stream increments with the expansion in hardness of the abrasives. Yet, the profundity of stream infiltration extraordinarily relies upon the proportion of the hardness of the objective materials and the hardness of the abrasives. It was expressed that there is a critical improvement in materials evacuation process when the proportion is somewhere in the range of 1.0 and 1.1. Hocheng et al. [3] and Momber et al. [4] examined the top width of cut during AWJM of earthenware production utilizing magnesia and bauxite abrasives and observed that the top width of cut reductions with the work feed. Comparable perceptions were made by Chung et al. [5] and Matsui et al. [6]. Yet, the top width of cut increments with expansion in tension and SOD. In the current work an examination has been carried on to concentrate on the near cutting presentation of garnet, Al_2O_3 and SiC during AWJM of Aluminum (7075) based Metal network composite.

Fig 1 : AWJM Setup

Fig 2 : Al7075 MMC sheet of 10mm thickness

Experimental Procedure

The work material used in this investigation was Al based Metal matrix composite. Three types of abrasives used in the present study were garnet, Al_2O_3 and SiC. Their hardness of the abrasives was 1380, 2200 and 2400 knoops, respectively. The experiments were conducted on a water jet machine WJ 4080. The machine was equipped with a controller type 2100 CNC Control. The nozzle used for the abrasive water jet was made of carbide with the orifice diameter of 0.1 mm. The jet was perpendicular to the work surface[15]. The water jet in cutting process is shown in Fig. 1.

Aluminium–metal matrix composites are most commonly studied MMC as they are widely used in the automotive and aerospace industries. Reinforcement compounds such as SiC, Al , and B_4C can be mixed easily and effectively in molten aluminum. Magnesium–matrix composites have similar advantages, but due to limitations in fabrication and lower thermal conductivity, they are not widely used as compared with aluminum-based MMCs. Al MMC consists of a low-density material (Aluminium as base) reinforced with fibres or particulate of a ceramic materials like silicon carbide or graphite. In the present work, Al7075 is considered as the base material with ceramic materials such as SiC and B_4C are used as reinforcements for the preparation of MMC through stir casting technique. Al 7075 is widely used in Aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, aerospace and defence applications; bike frames, all-terrain vehicle (ATV) sprockets and etc. Due to its high thermal conductivity, there is higher heat dissipation capacity and is suited for high strength and high temperature applications.

Al7075 aluminum alloy's composition roughly includes 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than a half percent of silicon, iron, manganese, titanium, chromium, and other metals. It is produced in many tempers, some of which are 7075-0, 7075-T6, 7075- T651. The MMC used in these experiments is the combination of Silica sand (SiO2), chromate sand (FeCr2O4), or zircon sand (ZrSiO4), 75 to 85%, sometimes with a proportion of olivine, staurolite, or graphite. • betonites (clay), 5 to 11% • water, 2 to 4% • inert sludge 3 to 5% • anthracite (0 to 1%).

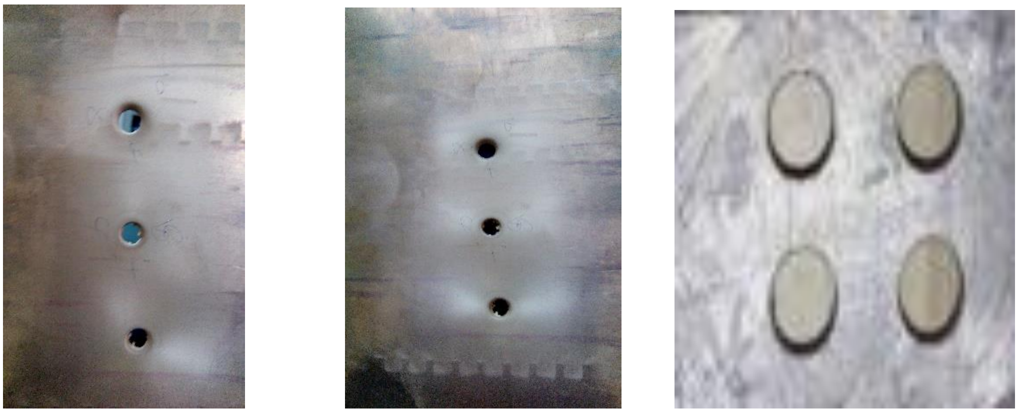
Aluminum alloy 7075+ B_4C 3 % + SiC 10%.

Fig 3. Stirring of Al and other alloys

Fig 4. MMC plate produced after stir casting

Experimentation

Experiments are performed for finding the effect of process parameters on metal removal rate and width of cut. For these experiments three different types of abrasive particles are used, they are garnet, Al_2O_3 and SiC. Drilling of Al 7075 MMC by varying the SOD, Feed rate and pressure. The size of abrasive particles are kept constant.



(a) **(b)** **(c)**

Fig 5. Drilling of Al 7075 MMC by varying process parameter and changing Abrasive particles

Results and discussions

Effect of different parameters on Material Removal Rate (MRR)

The material removal rate in any machining process is imperative parameter to decide the efficiency of the process. The feed rate was found to be the most significant parameter. MRR was found to improve with increased feed rate, Figure 7. The surge in feed rate reduces the time required to complete the process. The feed rate decides the time required to complete the process.

SOD(mm)	Garnet	Sic	Al2O3
1	6.21	7.13	6.48
1.5	8.59	10.76	9.03
2	9.86	15.49	13.97
2.5	8.96	14.61	12.28
3	13.95	14.19	13.2

Table 1: Experimental influence of SOD on MRR (mm^3/sec)

Influence of standoff distance (SOD) of the jet from the target material on the MRR during AWJM with different types of abrasives is illustrated in Fig. 6. It can be observed from that the SiC abrasives produced the largest taper of cut followed by Al_2O_3 and garnet abrasives. Among the three types of abrasives used, SiC is the hardest material and consequently it retains its cutting ability as it moves down. Therefore, the difference between the widths at the top and bottom of the slot is small and consequently, the taper angle is also smaller. As SOD is increased, the jet focus area also increases therefore MRR increases upto certain level and further decreases.

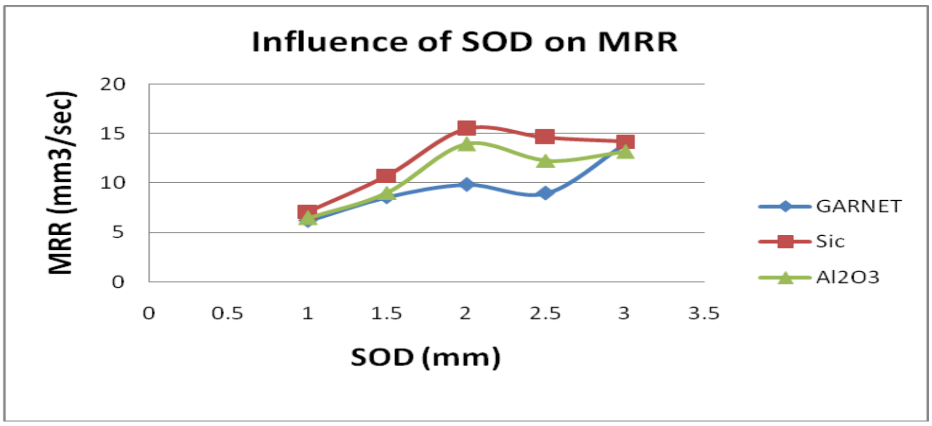


Fig. 6. Effect of SOD on MRR (mm^3/sec)

Fig. 7 shows the relationship between work feed rate and MRR during AWJM using different abrasive materials. For all types of abrasives, the MRR shows an increasing trend with increase in work feed rate. With increase in work feed rate the machining zone is exposed to the jet for a shorter time due to which higher material removal takes place. Cutting process is effective at the jet exit that results an increase in MRR. SiC abrasives demonstrate a high taper of cut followed by Garnet and Al_2O_3.

Work feed rate (mm/min)	Garnet	Sic	Al2O3
10	4.11	6.16	6.07
20	7.39	9.66	9.78
30	10.06	16.91	12.71
40	14.67	17.03	14.68
50	15.8	18.81	14.32

Table 2: Experimental influence of Work feed rate on MRR (mm^3/sec)

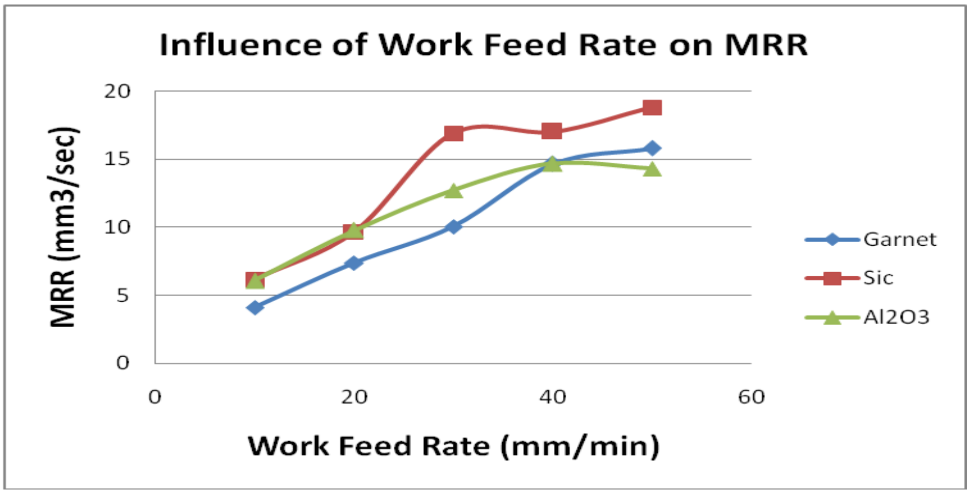


Fig. 7. Effect of Work feed rate on MRR (mm^3/sec)

The effect of pressure on average range of cut during AWJM is shown in Fig. 8. A higher pressure produces a jet of higher energy and capable of more effective cutting. From Fig it is observed that more MRR will be produced by SiC was higher than those produced by Al_2O_3 and garnet abrasives. It can be concluded that hardness is a key property of abrasive materials

Jet pressure(ksi)	Garnet	Sic	Al2O3
10	8.36	9.87	7.61
20	11.94	14.78	10.76
30	16.91	18.91	13.06
40	17.83	19.43	16.67
50	18.81	19.97	17.64

Table 3 : Experimental influence of Jet pressure on MRR (mm^3/sec)

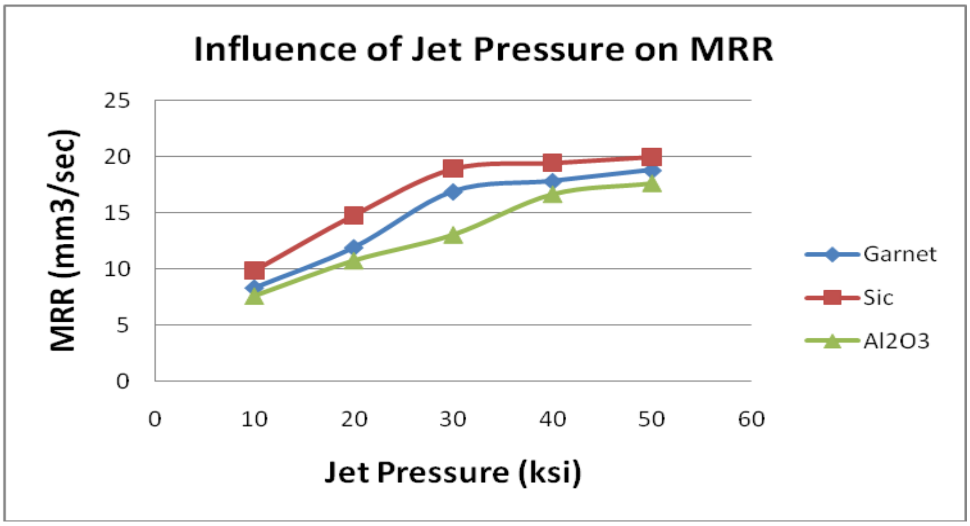


Fig. 8. Effect of Jet pressure on MRR (mm^3/sec)

Effect of different cutting parameters on width of cut

Taper of cut was calculated as suggested by Kitamura et al. [7] according to the mathematical expression; $T_R = (b_T - b_B)/2$, where T_R, b_T and b_B are taper of cut, top width of cut and the bottom width of the cut, respectively. Experimental investigations showed that during abrasive water jet machining with different abrasives, the width of cut at the top of the slot was always greater than that at the bottom of the slots.

It was explained by Wang and Wong [8] and Rahmah [9] that as the abrasive particles move down the jet, they loose their kinetic energy and the relative strength zone of the jet is narrowed down. As a result, the width of cut at the bottom of the slot is smaller than that at the top.

Influence of standoff distance (SOD) of the jet from the target material on the taper of cut during AWJM with different types of abrasives is illustrated in Fig. 9. It can be observed from that the garnet abrasives produced the largest taper of cut followed by Al_2O_3 and SiC abrasives. Among the three types of abrasives used, SiC is the hardest material and consequently it retains its cutting ability as it moves down. Therefore, the difference between the widths at the top and bottom of the slot is small and consequently, the taper angle is also smaller. On the other hand, garnet abrasives loose their sharpness and as a result the bottom width becomes much narrower than the top with. Fig. 9 also shows that for all kinds of abrasives, the taper of cut increases with SOD. This is due to the divergence shape of the jet. As SOD is increased, the jet focus area also increases resulting inc rease in the width of cut.

SOD(mm)	Garnet	Sic	Al2O3
1	0.09	0.05	0.06
1.5	0.12	0.07	0.08
2	0.15	0.12	0.13
2.5	0.18	0.14	0.15
3	0.21	0.15	0.16

Table 4 : Experimentation of SOD on Taper of Cut (Kerf) for different Abrasives

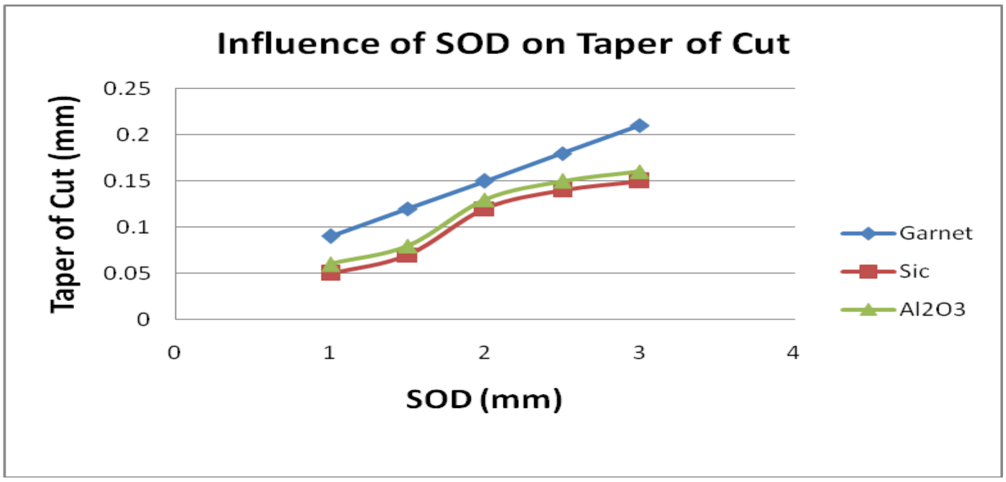


Fig 9 : Influence of SOD on Taper of Cut

Table 5 and Fig. 10 shows the relationship between work feed rate and taper of cut during AWJM using different abrasive materials. For all types of abrasives, the taper of cut shows an increasing trend with increase in work feed rate. With increase in work feed rate the machining zone is exposed to the jet for a shorter time. Cutting process is less effective at the jet exit that results an increase in taper of cut. Conner and Hashish [10] also found similar effect of feed rate on taper of cut during AWJM of aerospace materials using garnet abrasives. Garnet abrasives demonstrate a high taper of cut followed by SiC and Al_2O_3.

Work feed rate (mm/min)	Garnet	Sic	Al2O3
10	0.13	0.09	0.04
20	0.14	0.13	0.12
30	0.15	0.12	0.16
40	0.17	0.17	0.15
50	0.25	0.24	0.18

Table 5 : Experimental Values of Work feed rate on Taper of Cut

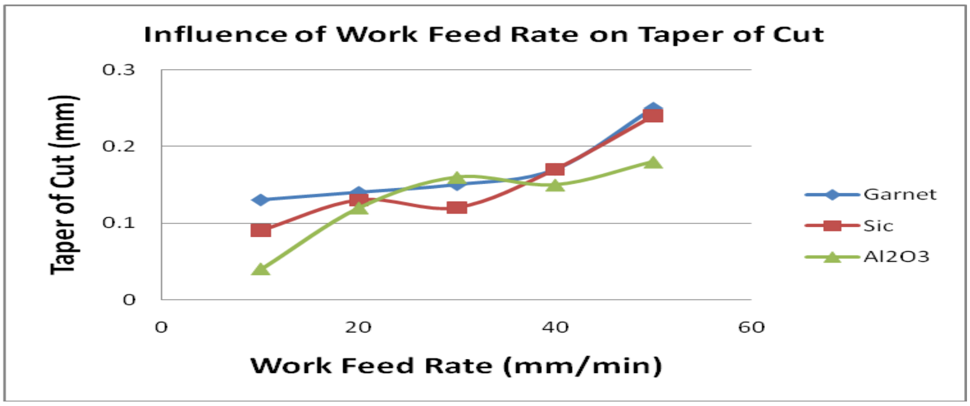


Fig. 10. Influence of Work feed rate on Taper of Cut

Influence of pressure on taper of cut is illustrated in Table 6 and Fig. 11. Taper of cut decreases with increase in jet pressure for all the types of abrasives used. At a higher pressure the abrasives have higher energy and they retain their cutting ability as they move down from the jet entrance to the jet exit.

As a result, taper of cut reduces with increase in jet pressure. Louis et al. [11] indicates some other positive aspects of using higher pressure. He found that the depth of penetration of the jet increases and cutting efficiency improves with increase in pressure. On the other hand, abrasive flow rate can be reduced if the jet pressure is increased. However, taper of cut is smaller for

SiC abrasives followed by Al_2O_3 and garnet. SiC abrasives being harder than Al_2O_3 and garnet abrasives retain their sharp edges both at the entrance and the exit of the jet and produce the smallest width of cut. On the other hand, garnet abrasives being comparatively softer loose the sharpness of their cutting edges when they are near the jet exit.

Jet pressure(ksi)	Garnet	Sic	Al2O3
10	0.19	0.19	0.19
20	0.18	0.15	0.16
30	0.15	0.12	0.14
40	0.13	0.11	0.12
50	0.1	0.07	0.08

Table 6: Experimental influence of Jet Pressure on Taper of Cut

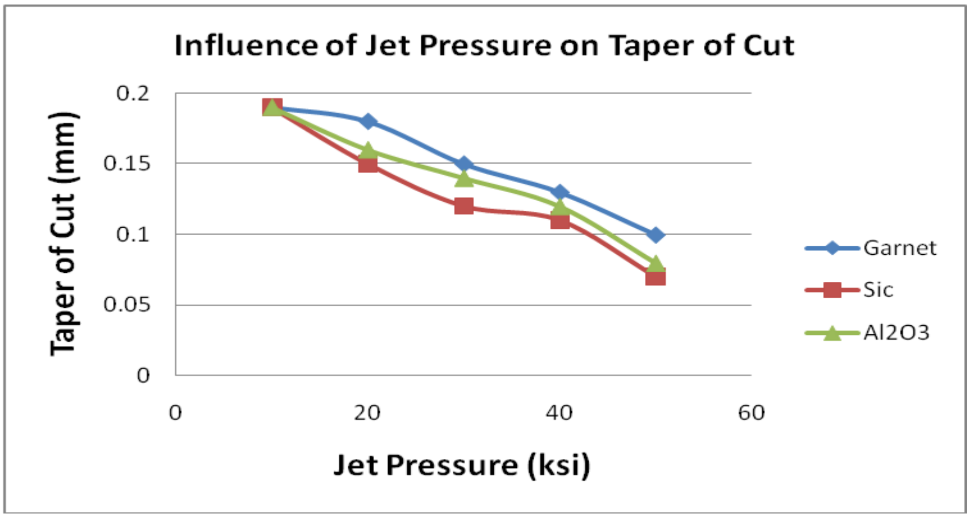


Fig. 11. Effect of Jet Pressure on Taper of Cut.

Influence of work feed rate on the average width of cut is illustrated in Fig. 10. Average width of cut decreases with increase in work feed rate since with the increase in feed rate the work is exposed to the jet for a shorter period. The effect of pressure on average width of cut during AWJM is shown in Fig.11. A higher pressure produces a jet of higher energy and capable of more effective cutting. From Figures it was observed that in all the cases the average width of cut produced by SiC was higher than those produced by Al_2O_3 and garnet abrasives. It can be concluded that hardness is a key property of abrasive materials.

Conclusions

From the above discussions, it can be concluded that taper of cut increases with increase in SOD. Garnet abrasives produce a larger taper of cut followed by Al_2O_3 and SiC. This is due to higher hardness of SiC compared to Al_2O_3 and garnet. Taper of cut also increases with increase in work feed rate. But taper of cut reduces with increase in pressure. A higher pressure increases the kinetic energy of the abrasives, and the divergence of the jet is reduced that causes a decrease in taper of cut. An increase in SOD increases the focus area of the jet and increases the average width of cut. But increase in feed rate reduces the average width of cut since the surface to be cut is exposed to the jet for a shorter time. A higher jet pressure increases the kinetic energy of the abrasive particles and enhances their cutting ability. As a result, increase in pressure causes increase in the average width of cut. SiC is harder than Al_2O_3 and garnet. It is also observed that the maximum MRR is found with SiC. As a result, its cutting ability is also higher than that of Al_2O_3 and garnet. Therefore, the average width of cut produced by SiC is higher than those produced by Al_2O_3 and garnet.

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