Parametric Analysis on Different Metals by Abrasive Water Jet Machining

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Abstract— Abrasive water jet machine (AWJM) is a non-conventional machining processes. This is process of removal of materials by impact erosion of high pressure (1500-4000 bars), high velocity of water and entrained high velocity of grit abrasives on a work piece. In recent years, researchers have explored a number of ways to improve the AWJM process performance by analyzing the different factors that affect the quality characteristics. The experimental and theoretical studies show that process performance can be improved considerably by proper selection of machining parameters. Different types of abrasives are used in abrasive water-jet machining like garnet, aluminum oxide, silica sand, silicon carbide etc. Ti–6Al–4V alloy was machined under varying traverse speeds abrasive water jet machining. In Abrasive Water jet cutting, orifice and focusing nozzle diameter undergo continuous change in their dimensions due to erosive nature of high velocity abrasive water jet. This particular phenomenon can affect the efficiency and quality of the process. The aim of work to study the influence of orifice and focusing nozzle diameter variation on the performance of abrasive water jets in cutting 6063-T6 aluminum alloy. The performance was assessed in terms of different parameters such as depth of cut, material removal rate, cutting efficiency. Experimental investigations were conducted to study the effect of using different chemicals on material removal rate (MRR), with varied standoff distances (SOD) and chemical concentration in abrasive water jet machining. The use of such chemicals on the taperness of drilled holes is also studied. Surface roughness (Ra) and kerf taper ratio characteristics of an abrasive water jet machined surfaces of glass/epoxy composite laminate were studied. Taguchi's design of experiments and analysis of variance were used to determine the effect of machining parameters on Ra and TR.

Key words: AWJM, MRR, Surface roughness, Taper of cut, Kerf taper ratio, Abrasive materials, width of cut

I. INTRODUCTION

Abrasive water jet (AWJ) cutting has various distinct advantages over the other cutting technologies, such as no thermal distortion, high machining versatility, high flexibility and small cutting forces, and has been proven to be an effective technology for processing various engineering materials. The mechanism and rate of material removal during AWJ depends both on the type of abrasive and on a range of cutting parameters. Abrasive water jet machine can cut hard and brittle materials like Steels, Non-ferrous alloys Ti alloys Ni- alloys ,Polymers, Metal Matrix Composite, Ceramic Matrix Composite, Concrete , Stone – Granite, Wood, Reinforced plastics, Metal Polymer Laminates, Glass Fiber Metal Laminates [1].

A. Process Principle of AWJM

Abrasive water jet cutting is using high pressure water being forced through a small hole onto a concentrated area to cut materials. The Abrasive water jet cutting machine starts with a water pump. The water pump pressurizes the water and pumps it from a water tank or other water supply to the nozzle. If there is an abrasive added it is normally added at the nozzle which has shown in Fig. 1.

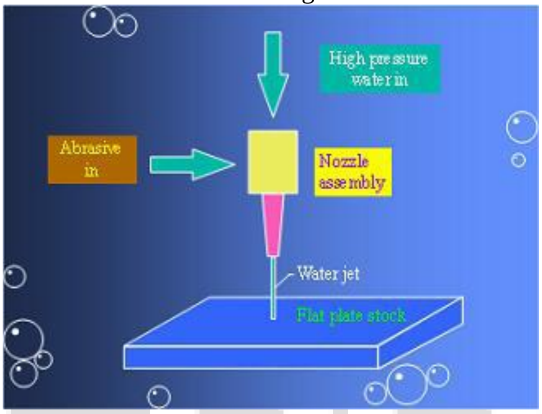

Fig. 1: Mixing of abrasive with water

A lot of water is forced through a small nozzle. This creates water with a lot of pressure. This pressure makes the particles "accelerate" and hits a very small area on the piece being cut. All of the pressure onto the material being cut makes the material crack. It creates very small cracks and the pressure washes away the particles of material. The pressure eventually removes all of the material in the small area and this is the cut. The water is normally raised to just above the material to reduce the splash that may occur during cutting. All of the material that is being removed goes into the catch tank and can later be removed. The cutting head normally moves in an x, y axis across the material [2].

B. Purpose of Study

In Abrasive water jet machine, improper selection of machining parameters may cause of poor machining rate or performance. This is due to material removal rate characteristic. Less MRR needs more time for machining process and become waste and not goods for production. Therefore, studying machining parameter and related significant factors would be effective to enhance the machining productivity and process reliability.

II. LITERATURE REVIEW

A. A. Khan, M.M. Hague had worked on Performance of different types of abrasive materials like garnet, aluminum oxide and silicon carbide during abrasive water jet machining of glass. They have used varying parameter as Abrasive flow rate (gm/min), work feed rate (mm/min), SOD (mm) and analyze for Taper of cut and average width of cut with different abrasive materials. Fig. 2 shows that the taper of cut increases with SOD with abrasive materials like garnet, aluminum oxide and silicon carbide. As SOD is increased, the jet focus area also increases resulting increase in the width of cut.

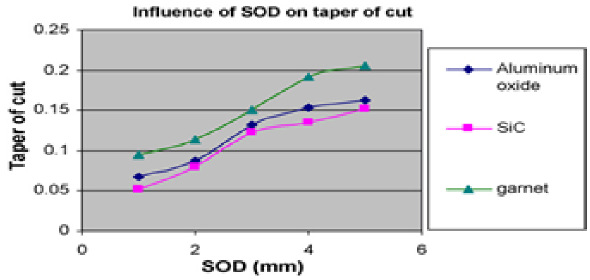

Fig. 2: Influence of SOD

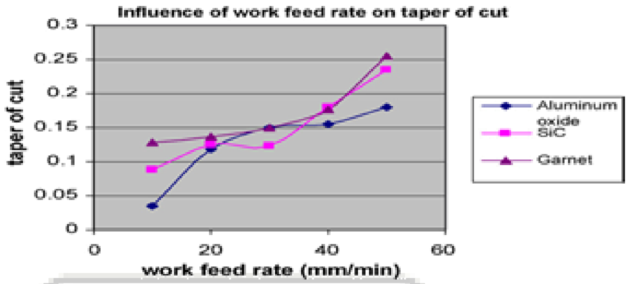

Fig. 3: Influence of feed rate on taper of cut.

Fig. 3 shows the relationship between work feed rate and taper of cut during AWJM using different abrasive materials From Fig.4 shows that the average width of cut increases with increase in SOD which is due to the divergence shape of the jet. It was found that SiC produced the widest slot followed by Al2O3 and garnet. In Fig. 5 Average width of cut decreases with increase in work feed rate since with increase in feed rate the work is exposed to the jet for a shorter period. In Fig. 4-5 it was found that in all the cases the average width of cut produced by SiC was higher than those produced by Al2O3 and garnet abrasives. As a result they found that taper of cut increases with increase in SOD. Garnet abrasives produce a larger taper of cut followed by Al2O3 and SiC. Taper of cut increases with increase in work feed rate. SiC is harder than Al2O3 and garnet. As a result, its cutting ability is also higher than that of Al2O3 and garnet. Therefore, the average width of cut produced by SiC is higher than those produced by Al2O3 and garnet [3].

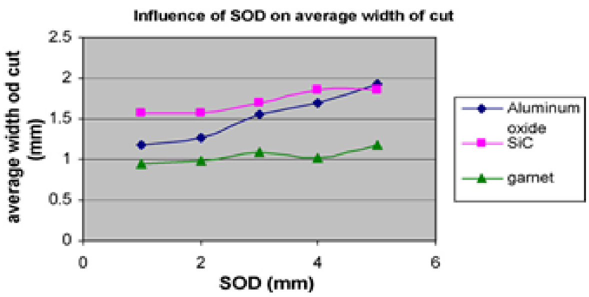

Fig. 4: Effect of SOD on width of cut

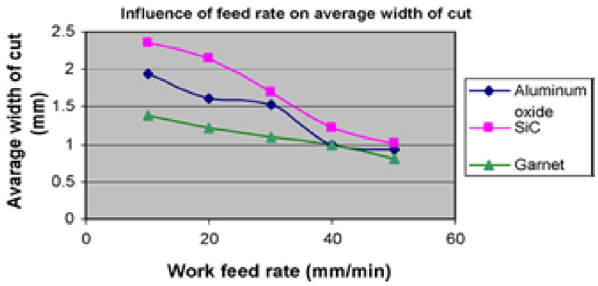

Fig. 5: Effect of feed on width of cut

Ahmet Hascalik, Ulas Caydas had worked on Effect of traverse speed on abrasive water jet machining of Ti–6Al–4V alloy. They have used varying traverse speeds of 60, 80, 120, 150, 200, and 250 mm/min by abrasive water jet (AWJ) machining. After machining, the profiles of machined surfaces, kerf geometries and microstructural features of the machined surfaces were examined using surface profilometry and scanning electron microscopy (SEM). Fig. 6 shows cutting surface view of samples machined at traverse speed of 60–200 mm/min, respectively.

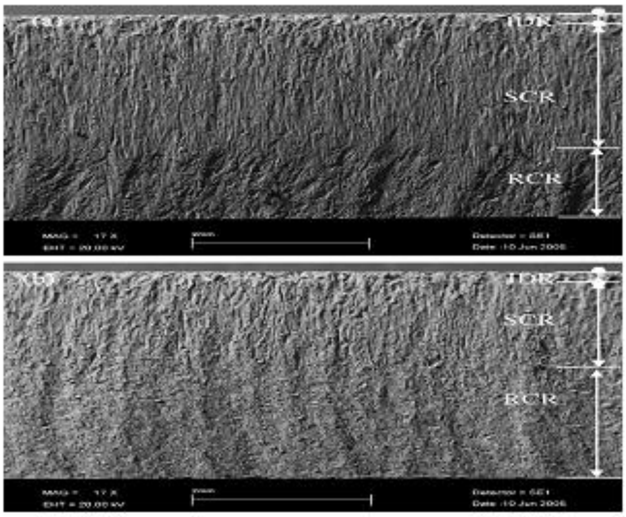

Fig. 6: Typical AWJ-machined surface: (a) for traverse speed of 60 mm/min and (b) for traverse speed of 200 mm/min.

Microstructural evaluation of the cutting surfaces of samples revealed three distinct zones which were identified as: (1) a initial damage region (IDR), which is cutting zone at shallow angles of attack; (2) a smooth cutting region (SCR), which is cutting zone at large angles of attack; (3) a rough cutting region (RCR), which is the jet upward deflection zone. Fig.7 shows surface roughness versus depth of measurement with respect to traverse speed. From this Fig., the surface roughness is approximately constant as the depth of the cut gets deeper in SCR. After that, the surface quality deteriorates because the jet loses its energy due to the jet–material interaction and mutual particle impacts.

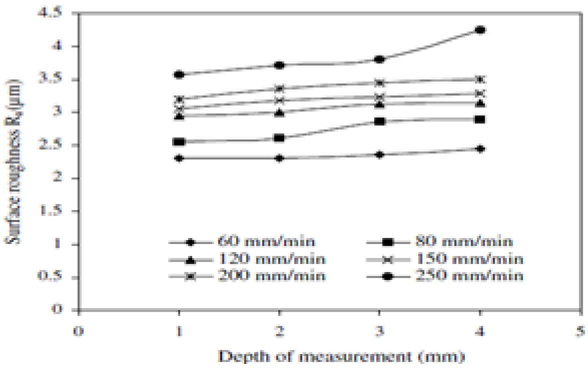

Fig. 7: Surface roughness versus depth of measurement for different traverse speeds.

From the experimental results, they found that an increase in the traverse speed causes a constant increase in the surface roughness. Surface roughness values (Ra) were measured as jet entry) in the traverse speed of 60– 250 mm/min, respectively. They found that the surface roughness increment amount is about 1.27 µm in SCR. Fig. 8 shows the depth of smooth cutting regions for different traverse speeds. With increasing traverse speed, the smooth cutting region depth of samples decreases.

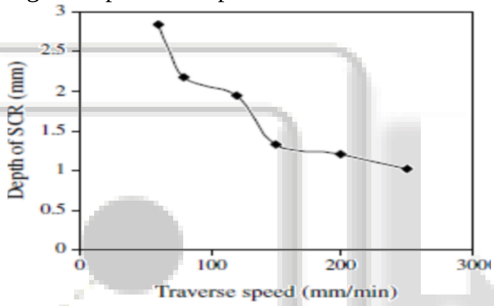

Fig. 8: The depth of smooth cutting regions for different traverse speeds

At high traverse speed, the SCR decreased to about 25% of the total cutting surface area, while this ratio is about 60% at low traverse speed. Hence, the traverse speed appears to be the significant parameter on a depth of the SCR. With increasing traverse speed, the smooth cutting region depth of samples decreases. At high traverse speed, the SCR decreased to about 25% of the total cutting surface area, while this ratio is about60% at low traverse speed. Hence, the traverse speed appears to be a significant parameter on the depth of the SCR [4].

J. John Rozario Jegaraj, N. Ramesh Babu had worked on strategy for efficient and quality cutting of materials with abrasive water jets considering the variation in orifice and focusing nozzle diameter in cutting 6063-T6 aluminum alloy. The performance was assessed in terms of different parameters such as depth of cut, material removal rate cutting efficiency.

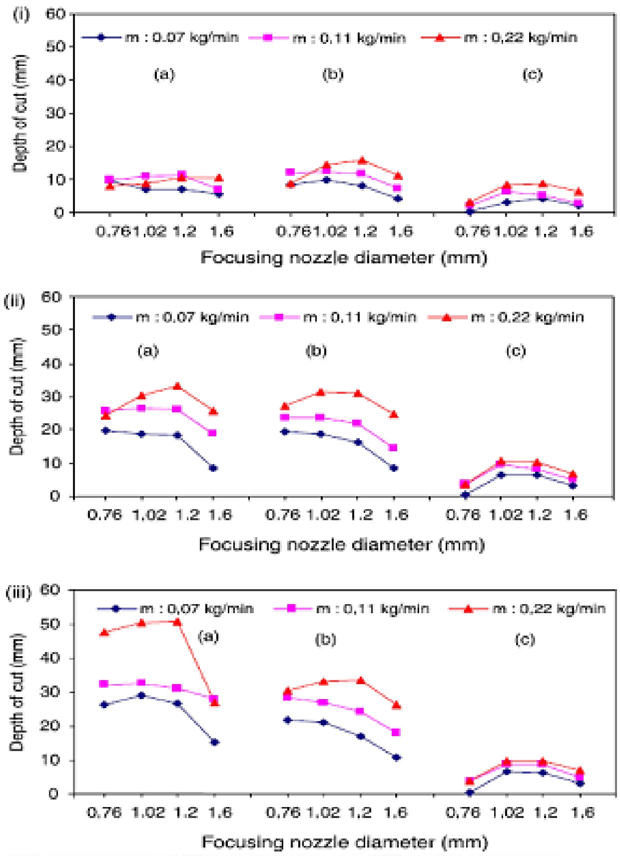

Fig. 9: Variation of depth of cut with different sizes of orifice ((a) 0.25 mm; (b) 0.30 mm; and (c) 0.40 mm) and focusing nozzle at different water jet pressure and abrasive flow rate (i) P=100 MPa; (ii) P=175 MPa; and (iii) P=250 MPa

Fig.9 shows the variation in depth of cut with different sizes of orifice and focusing nozzle. This variation is based on three different jet pressures and abrasive flow rate. From the results, it can be noticed that the depth of cut increased with an increase in water jet pressure for different combinations of orifice and focusing nozzle size. Similarly, the depth of cut has increased with an increase in abrasive flow rate with different combinations of orifice and focusing nozzle. Further, it may be noticed that the depth of cut is found to be maximum when the focusing nozzle size to orifice size is in the range of 3–4.5 for orifice of 0.25 mm and 2.5–3.4 for an orifice of 0.3 mm diameter. The variation in focusing nozzle is tolerable up to 1.2 mm beyond which it should be replaced.

In Fig. 10 from the results, they found that the volume of material removed increased with an increase in abrasive flow rate and water jet pressure.

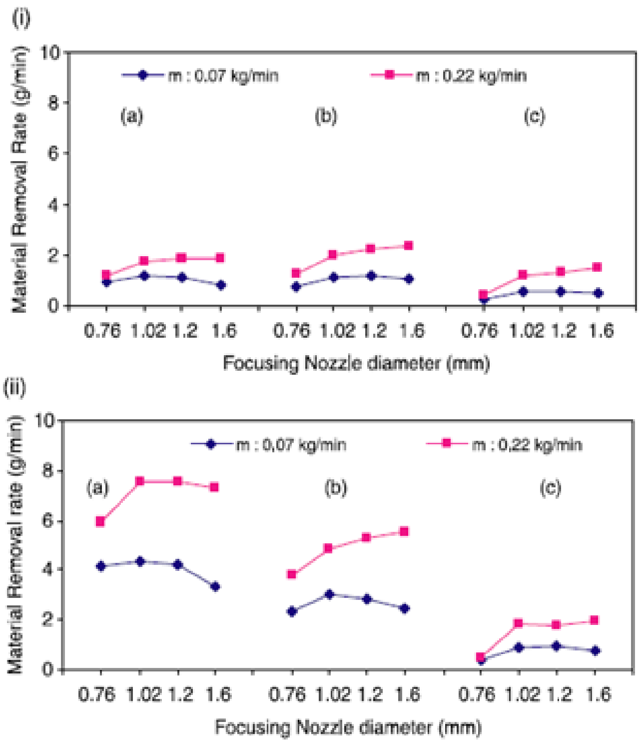

Fig. 10: Variation of material removal rate with different sizes of orifice ((a) 0.25 mm; (b) 0.30 mm; and (c) 0.40 mm) and focusing nozzle at different water jet pressure and abrasive flow rate (i) P=100 MPa and (ii) P= 250 MPa.

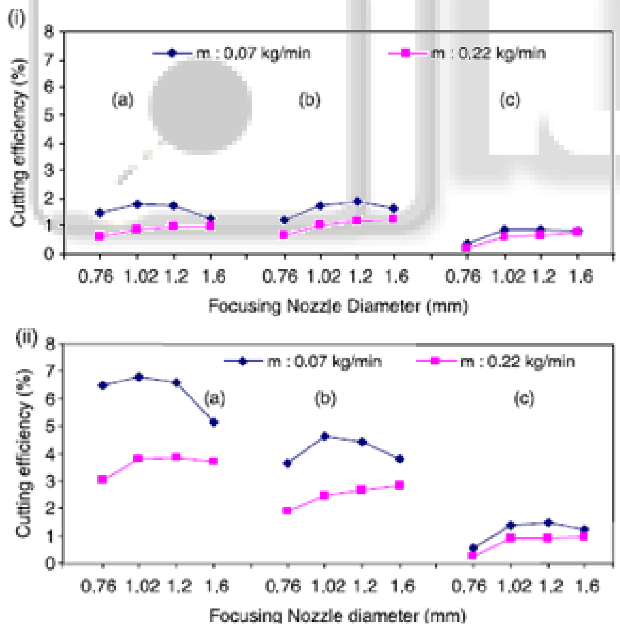

Fig. 11: Variation of cutting efficiency with different sizes of orifice ((a) 0.25 mm; (b) 0.30 mm; and (c) 0.40 mm) and focusing nozzle at different water jet pressure and abrasive flow rate (i) P=100 MPa and (ii) P= 250 MPa.

The rate of material removed decreased with an increase in the size of orifice and is found to be substantially low with an orifice size of 0.4 mm. At the same time, also found the higher volume of material removal with higher water jet pressures(i.e. 250 MPa) employed with a smaller size of orifice. The volume of material removed increased with an increase in the size of focusing nozzle up to 1.2 mm diameter. Beyond this, it is reduced. Fig. 11 from the results, the cutting efficiency of abrasive water jets is low with lower water jet pressure of 100 MPa. On the other hand, a higher water jet pressure of 250 MPa employed with different sizes of orifice and focusing nozzle enhanced the cutting efficiency. It is interesting to note that the cutting efficiency is high for lower abrasive flow rate and orifice size of 0.25 and 0.3 mm. They found that both quality and efficiency in cutting with abrasive water jets can be maintained by keeping the orifice sizes in the range of 0.25–0.3 mm and maintaining the focusing nozzle sizes in the range of 0.76–1.2 mm with the ratio of focusing nozzle size to orifice size in between 3 and 4.5 [5].

Mahabalesh Palleda had worked on study of taper angles and material removal rates of drilled holes in the abrasive water jet machining process under different chemical environments like acetone, phosphoric acid and polymer (polyacrylamide) in the ratio of 30% with 70% of water. By varying S-O-D, MRR is measured by noting the initial and final weight of a specimen keeping blasting time 2 min, then they found various observations.

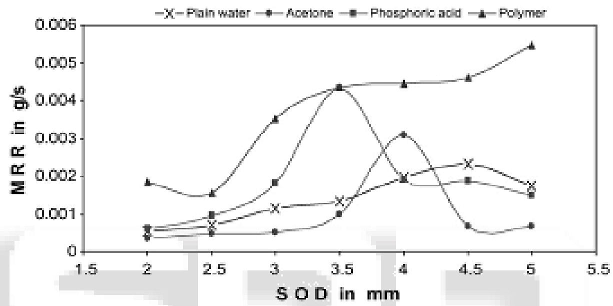

Fig. 12: Effect of variation of S-O-D on material removal.

Fig. 12 that maximum material removal was observed at an S O-D of 4.5mm using plain water in the slurry, at 4mm for acetone with slurry and at 3.5mm for the slurry mixed with phosphoric acid. But the fourth curve which is due to the slurry added with polymer shows highest material removal than the other three slurries with an increase of SOD.

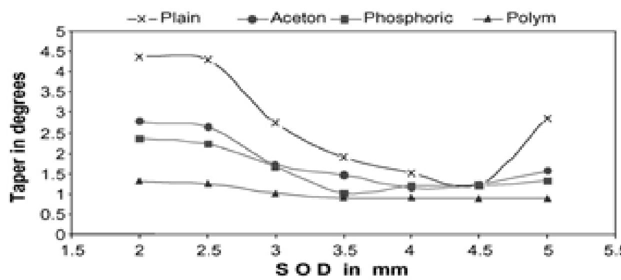

Fig. 13: Effect of variation of S-O-D on taperness

Fig. 13, they found that there is a reduction in the taper of the drilled holes as the S-O-D is being increased. The reduction in taper is assumed to be due to more momentum gained by the abrasive particles with an increase in S-O-D and also more number of abrasive particles might take part in impacting on the work surface and eroding the work material. The taper hole observed to be less in case of phosphoric acid combination with slurry than the plain water slurry and the slurry with acetone combination.

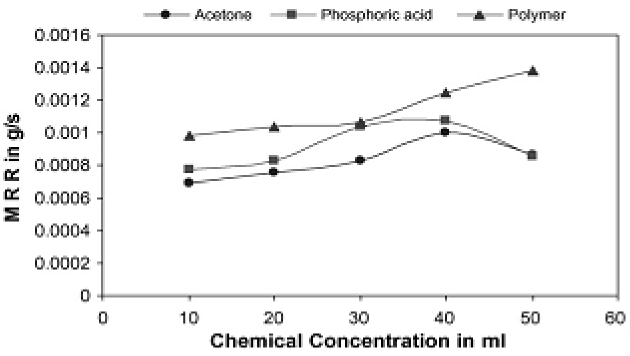

Fig. 14: Effect of variation of chemical concentration on material removal

From Fig.14, they found that at lower concentration of chemicals used, material removal seems to be less. The material removal is observed to be increasing with increase of chemical concentration of acetone and phosphoric acid in the slurry up to a certain level and then receding. But in case of polymer used with the slurry shows a continuous increase in material removal.

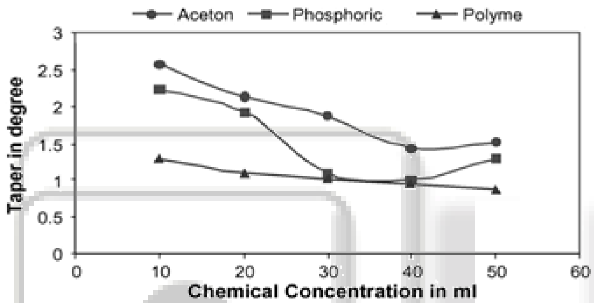

Fig. 15: Effect of variation of chemical concentration on taperness.

Fig.15 in case of phosphoric acid combination, the taper of the hole is comparatively less than acetone combination. The taper in case of polymer combination is observed to be very less or it can be said as nil, due to effective impact of narrow beam of slurry jet on the work surface leading to higher material removal eliminating the taper. The material removal was found to be more in presence of chemically active liquids such as acetone and phosphoric acid rather than plain water in the slurry. The material removal increases with the increase in S-O-D, up to certain limit and further increase in the S-O-D beyond the limit result in decrease of the material removal [6].

M.A. Azmir, A.K. Ahsan had worked on study of abrasive water jet machining process on glass/epoxy composite laminate. They have used Taguchi's design of experiments and analyses of variance were used to determine the effect of machining parameters on surface roughness and kerf taper ratio. The use of harder abrasive material such as silicon carbide and aluminium oxide resulted in retaining its cutting capability. Consequently, the surface of cuts became smoother as seen in Fig.16 (a). In case of hydraulic pressure, a higher hydraulic pressure increases the kinetic energy of the abrasive particles and enhances their capability for material removal. As a result, the surface roughness decreases as illustrated in Fig. 16(b). In case of standoff distance, it is desirable to have a surface due to increased kinetic energy as shown in Fig. 16(c). In case of abrasive flow rate, the roughness increases with an increase in abrasive mass flow rate up to a certain limit and beyond that limit it was found to decrease as illustrated in Fig. 16(d). In this case, a lower traverse rate is desirable to produce a better surface finish as shown in Fig.16 (e). Cutting orientation is relatively significant in influencing the surface roughness as illustrated in Fig.16 (f).

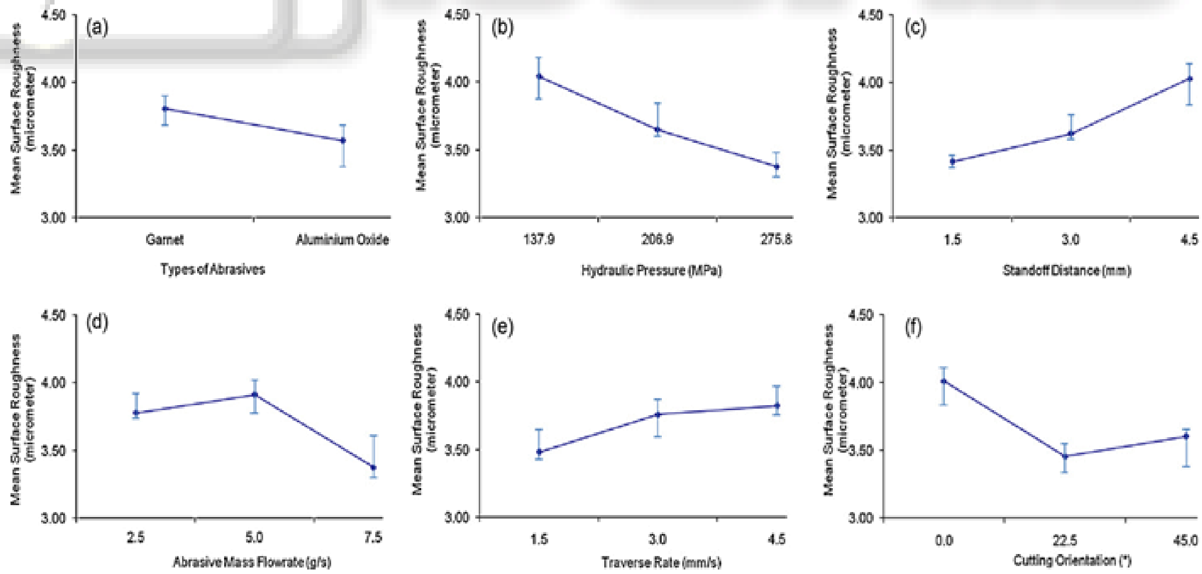

Fig. 16: Effect of (a) types of abrasives, (b) hydraulic pressure distance, (c) stand of distance, (d) abrasive mass flow rate, (e) traverse rate and (f) cutting orientation on surface roughness

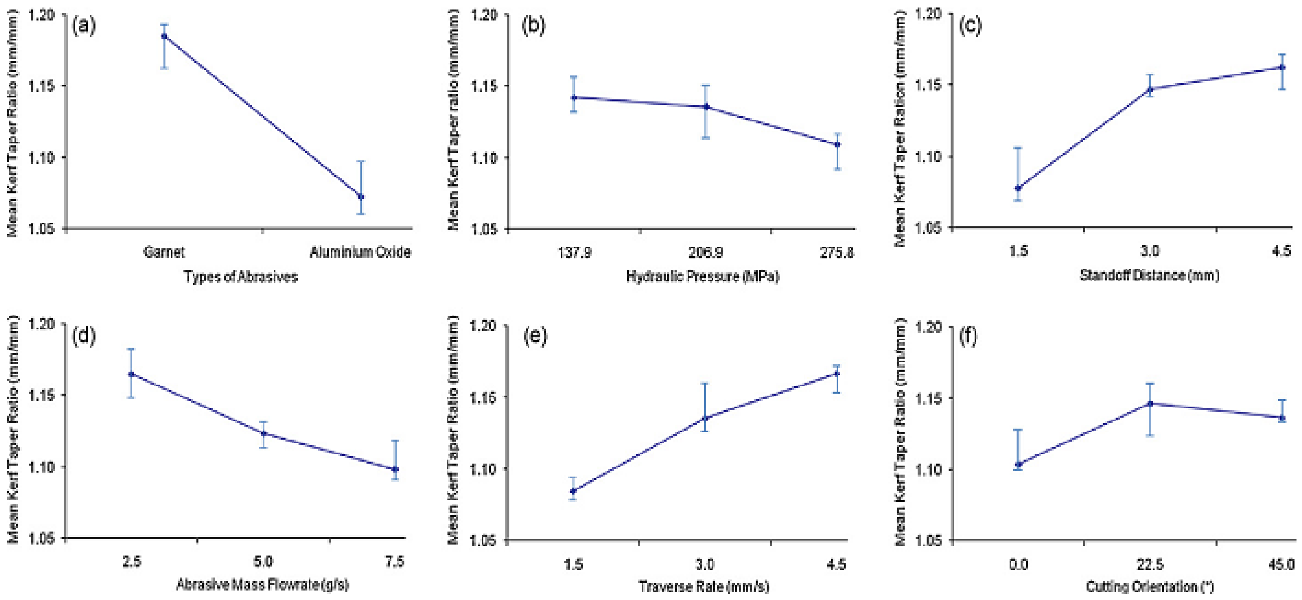

Fig. 17: Effect of (a) types of abrasives, (b) hydraulic pressure, (c) standoff distance, (d) abrasive mass flow rate, (e) traverse rate and (f) cutting orientation on kerf taper ratio

In fig. higher hardness of abrasive particles tends to produce lower taper ratio as shown in fig.17 (a). The kerf taper ratio calculated as the ratio of top to the bottom width is reduced with further increase of supply hydraulic pressure due to the more rapidly increasing of top kerf width compared to the bottom kerf width. This is clearly illustrated in fig.17 (b). Fig.17(c), the kerf taper ratio increases with the increase in Standoff distance. As Shown in Fig.17 (d), with the increase in abrasive mass flow rate consequently the kerf taper ratio is approaching to 1 as the penetration capability increases. Actually, the effect of traverse rate on the kerf taper was also found to be similar to that observed on the surface roughness as shown in Fig.17 (e). As shown in Fig.17 (f), there is no clear trend to indicate the effect of different cutting orientations on the average kerf taper ratio. From experimental results they found following conclusions for effective machining of glass/epoxy composite by AWJM process as follows:

- Hydraulic pressure (MPa) and type of abrasive materials (i.e. garnet and aluminium oxide) were considered as the most significant control factor in influencing Ra and TR, respectively.
- Increasing the hydraulic pressure and abrasive mass flow rate may result in a better machining performance for both criteria.
- Meanwhile, decreasing the standoff distance and traverse rate may improve both criteria of machining performance.
- Cutting orientation does not influence the machining performance in both cases [7].

III. SUMMARY

From the above study, we see that the influence of different process parameter is not purely linear and is affected by value of other parameters. Also parametric influence is different for different materials. From literature review, very less work has been reported in AWJM with EN8 material. So we have planned to conduct an experimental work with this material which will show the effect of varying parameter as Abrasive flow rate (gm/min), Traverse speed (mm/min), Standoff distance (mm) and analyze for MRR (gm/min) and Surface roughness (μm) for EN8 material of abrasive water jet machine.

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