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Mach inability Studies on Metal Matrix Composite's Using Abrasive Water Jet Machining

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Abstract: The non-traditional machining of particulate reinforced metal matrix composites is relatively new. This paper covers studies on match inability of aluminium - Boron carbide metal matrix composites (Al-B4C MMCs) with abrasive water jets (AWJs). Two different compositions of Al-B4C MMCs were processed with various mesh size, abrasive flow rate, transverse rate and water pressure with a view to identify the performance of the abrasive water jet machine for effective processing of MMCs with AWJs. The maximum penetration ability of AWJs in different MMCs was examined by conducting the experiments on trapezoidal shaped Al-B4C MMC specimens, prepared with stir casting method. Optical micrographs of MMC samples and scanning electron microscopic (SEM) examination of AWJ cut surfaces enabled to explain the trends of material removal by the abrasives. Analysis of results clearly indicated the choice of 80 mesh size abrasives, higher water pressure and flow rate and lower transverse rate for effective processing of Al-B4C MMCs with AWJs.

Keywords: Metal Matrix Composites, Abrasive water jet machining, Depth of cut.

1. Introduction

MMCs are materials consisting at least two material constituent parts (reinforced). In the case of MMCs one is an alloy such as aluminium, Magnesium and titanium etc and other is reinforcement material such as SiC, B_4C and Al_2O_3 in various forms (particles, whiskers and fibers). The MMCs are important engineering materials due to their excellent mechanical properties such as low thermal expansion, good dimensional stability, high wear resistance, corrosion resistance, stiffness etc. Metal Matrix Composites are emerging as advance engineering materials are widely used in various applications such as defence, aerospace, automobile, medical, sport equipment etc. However, conventional machining make it difficult to machine the composite materials. Therefore, researches have made an attempt to machine MMC using different non- traditional machine techniques such as Electro chemical machining (ECM), Ultrasonic Machining (USM), Laser beam Machining (LBM), Abrasive Waterjet Machining (AWJM) etc., Among these non-traditional machining processes, AWJM has the unique advantage such as no thermal distortion, minimum stiffness as the target material, high versatility, high flexibility etc. AWJM can cut complex shape and difficult machining materials including MMCs. But only limited attempts have been made by researchers to machine different MMCs using AWJM process.

The nature of AWJ process is a stream of small abrasive particles such as garnet, silicon carbide, aluminium oxide is introduced in the high velocity stream of water in such manner that Waterjet's momentum is partly transferred to the abrasive particles. The main role of water is primarily to accelerate large quantities of abrasive particles to a high jet velocity and directed through an abrasive Waterjet nozzle at the target material to perform cut. The process parameters of AWJM are broadly classified into four categories namely (i) hydraulic parameter: pump pressure, orifice diameter, water flow rate, etc. (ii) mixing chamber and acceleration parameters: focus nozzle diameter and focus nozzle length, etc. (iii) cutting parameters: traverse rate, number of passes, stand-off distance, impact angle, etc. (iv) abrasive parameters: abrasive flow rate, abrasive particles diameter, abrasive size distribution, abrasive particle shape, abrasive particle hardness, etc. Various operations that can be performed in the AWJM are straight cut, contour cutting, drilling, milling, turning, cleaning, paint removal, nuclear plant dismantling, etc. The main process quality measure included attainable depth of cut, kerf width, kerf taper angle, material removal rate and surface roughness. Therefore number of techniques for improving depth of cut, metal removal rate and surface roughness has been future. In order the selection of appropriate machining parameter different MMC materials is a difficult task it depends on machining the composites material due the various proportion abrasive particles.

2. Literature Review

Savrun and Taya (1988) investigated the machining aspect of MMCs (Al2014 + 25% SiC_w) and CMC (Al_2O_3) + 7.5% SiC_w). AWJM process parameter such as Waterjet pressure, abrasive flow rate and abrasive particles size are maintained constant and traverse rate is varied. They have observed that increase Waterjet pressure results is increase Ra. The traverse rate is more significant for achieving lower Ra.

Hamatani and Ramulu (1990) studied the slot cutting of MMC and CMC. The experiments were carried out the various garnet abrasive the mesh size #80, #100, #150. They observed that increase abrasive particle size leads to increase the kerf taper in both MMC and CMC. They have also observed that increase traverse rate and abrasive particle size leads to increase in Ra. The Ra values achieved with mesh size #80 found to twice than that of achieved with abrasive of mesh size #100. They have also observed higher depth of cut is achieved with mesh #80 abrasive and lower depth of cut is observed with mesh size #100 and # 150.

Ramulu et al (1993) studied the machining aspects of MMC (Al 6061 + 30% SiC_p). The experiments were carried by varying the abrasive flow rate, abrasive mesh size and jet impact angle (5^0, 10^0, 15^0 and 20^0). They have observed that increase in the jet impact angle results in the increase erosion rate at target material at constant abrasive flow rate. They also found that #100 mesh sizes abrasive produce lower rate erosion than that noticed with #80 mesh size. They have observed that erosion rate increase in MMC at the impact angle of 15^0 and the observed that more wear resistance and less waviness the machined surface of MMC.

Kok et al (2011) investigated the Al (7075 + Al_2O_3). The Al_2O_3 is added in different particles 16μm and 66 μm. The Al_2O_3 is added in the Al 7075 in various proportions such as

10%, 15% and 20%. They have observed that MMCs with reinforced particle 66µm lead increase Ra. From the surface characteristic studies they have observed that cutting wear mechanism occurs in the upper region and the deformation wear mechanism occurs in lower region.

Srinivas and Rameshbabu (2011) have studied the MMC (Al + SiCp). The SiC is added in the Al alloy in various proportions (5%, 10%, 15% and 20%) by using stir casting process. Experiments are carried out to study the influence of different abrasive particles and such as SiC and garnet in various mesh size (#60, #80 and #120). They have observed that higher depth of cut is achieved with mesh size # 80 and lower depth of cut is achieved with mesh size #120. They have found that SiC abrasive resulted in higher depth of cut. This is due to the fact of SiC is lighter than that of the garnet abrasive.

Srinivas and Rameshbabu (2011) observed that higher depth of cut is observed in the unreinforced alloy than the MMCs (Al + SiC_p). This is due to the fact that the higher percentage of SiC_p in the MMC leads to increase mechanical properties.

From the literature review, it can be seen that several attempts have been made to study the effect of AWJC of MMCs consists of aluminium reinforced with SiC_p in different proportions such as Al (2014) + 25% of SiC_w, Al (LM_9) + 15% of SiC_p, Al (2618) + SiC_p and Al (6061) + 30% of SiC_p is probable to change some advance engineering material in various applications due to superior properties. Further, there is no attempted to machine MMC consisting of Al2024 and B_4C using AWJC process. An attempted has been made by Gopalakannan et al. to machine MMC consisting of Al7075 with B_4C by using EDM process. Chen et al. to machine MMC consisting of Al2024 with B_4C by using friction stir welding.

3. Experimental Setup

The experiments were conducted using non-traditional machining facility available at Anna University, Chennai. Waterjet Germany make AWJ Machining Center (Model: S 3015) used for experimentation. The machining is carried out in Aluminium alloy with boron carbide in various proportions. The work pieces are cut into trapezoidal shapes such that depth of cut ($d=h_{max}\sin 25^o$) can be determined.

4. Process Parameters

Input Process Parameters

1. Pressure (P)
2. Traverse rate (TR)
3. Mesh size (#)
4. Abrasive Flow rate

Output Process Parameters

- Depth of cut (DOC)
- Materials selected
- Aluminium + Boron Carbide

5. Experimental Procedure

5.1. Preparation of Al2024-B_4C Metal Matrix composites

MMC can be fabrication by using several techniques which can be a solid, liquid and vapour state. Stir casting (Liquid state) techniques always used to manufacture AMMCs. In stir casting method, MMCs are produced by introducing reinforcement into molten matrix material by applying stirring action and pouring in the die and then solidified. To produce large size of MMC components in the stir casting processes it very simplest and the most cost effective method in the liquid state fabrication. A special trapezoidal shape (angle as 25^0 wedge shape) of the target material has chosen for experimental and investigating the maximum depth of cut of abrasive water jet pressure in different MMCs components for performs AWJC. By measuring the maximum depth of cut (h_{max}) in the target material which chosen the appropriate process parameters can be determined by employing the relation $h\ max = L\ \sin 25^0$ where L is the length of cut on slant surface of the wedge shape. The MMCs used in this investigation consist of Al2024 alloy reinforced with B_4C particulate of 400 mesh sizes (37 micron). The Table 1 chemical composition of Al2024 alloy obtained with optical emission spectrometer as per ASTM E1251 standard and presented in Table 1.

Table 1. Composition of Al2024 alloy.

Alloy	SiC	Fe	Cu	Mn	Mg	Zn
Al 2024	0.69	0.34	0.77	0.09	0.27	0.01

Table 1 shows the composition of Al2024 alloy. The amount of Al2024 alloy and B_4C particles reinforcements to produce unreinforced aluminium alloy and various percentage composites such 8%, 16% volume percentage of B_4C are taken by weight basic required amount of B_4C particulate with aluminium alloy. Aluminium alloy (Al2024) were charged into gas–fired crucible furnace and heated to a temperature of 750^0 C, to melt the matrix completely and the cooled down to just below the melting temperature 600^0 C to keep in semi-solid state. The B_4C preheated up to 400^0 C to 500^0 C for 1hours, to improve the wetness properties by removing the absorbed hydroxide and other gases. The composites was then reheated to full liquid state and added into the mechanical stirring at 300rpm for 15 minutes. Degassing tablet (hexa chloro ethane) is poured in the molten metal was removed the slag from the molten metal. The preheated B_4C particles were added the mixed mechanical stir performed at a speed of 300rpm for 10 minutes and furnace as maintained the temperature 750^0 C. The stir lead is kept below the 65% from the molten metal level in crucible furnace and above the 35% the bottom of crucible furnace at the stage this are help to useful to uniform distribution of the Al2024 and B_4C. Figure 1 and 2 show Gas-fried furnaces and Setup stir casting and pouring mixture of MMCs in Trapezoidal shape.

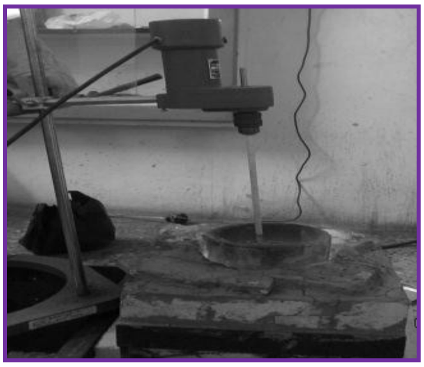

Figure 1. Gas fired furnace and Set up of stir casting.

Figure 2. Pouring mixture MMCs in wedge shaped die.

During pouring of the melt into a wedge shape die at the temperature maintained at around 600^0C which was allowed to solidify in the wedge shape die. The Figure 3 show the trapezoidal shape of specimen produced the stir casting process.

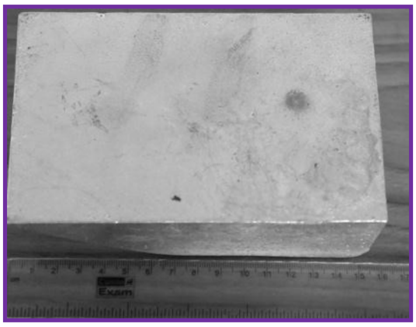

Figure 3. Casted Composite

The presence of reinforcement through the specimen was inspection by cutting the casting at different locations and under microscopic test, tensile test, SEM and EDAX test.

6. Experimental Method

To study the influence of water jet pressure, traverse rate, abrasive flow rate size and abrasive particles were conducted on different specimens by using AWJM system. The target material was fabricated trapezoidal shape. A fixture was designed to hold the specimens so as to avoid its displacement during machining. In AWJM arrangement the jet was made to impinge the specimen at an angle of 90^0 and maximum depth of cut was observed for single pass.

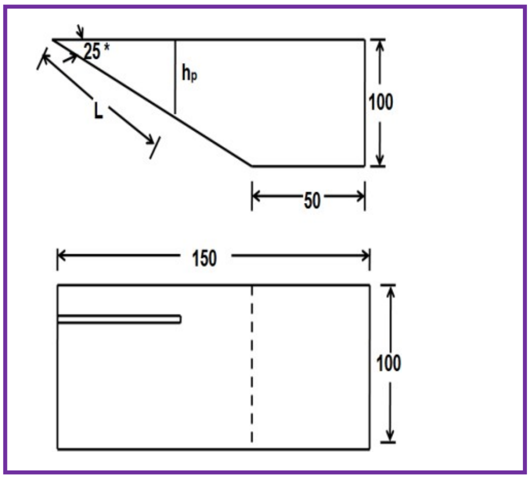

Figure 4. Machined Work piece

The maximum depth of cut of jet into target material was realized by observing the splashing of jet. Experiments were conducted with of standoff distance of 1.5 mm maintained between the bottom surface of the nozzle and the top surface of target material. The cutting experiments were conducted on each specimen by considered the four input parameters factors such as Waterjet pressure, traverse rate, abrasive flow rate and abrasive mesh size with each of the factor being varied at three levels. Table 2 present the ranges chosen for each of the parameters.

The machined workpiece is shown in the below Figure 4.

Table 2. Process Parameters. Input Process parameter

Sl. No.	Process Parameters	Low	Medium	High
1	Abrasive Mesh Size	80	100	120
2	Waterjet Pressure	125	200	275
3	Abrasive Flow rate	0.24	0.34	0.44
4	Traverse rate	60	90	120
5	Diamond waterjet orifice diameter (mm)	0.25		
6	Focusing nozzle diameter (mm)	0.75 and material is tungsten carbide		
7	Abrasive materials	Garnets		
8	No of passes	1		
9	Angle of cutting	90˚		

Figure 5. Photograph of Aluminium Work piece.

7 Results and Discussions

7.1. SEM TEST (Scanning Electron Microscopy)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition.

The most common mode of detection is by secondary electrons emitted by atoms excited by the electron beam. On a flat surface, the plume of secondary electrons is mostly contained by the sample, but on a tilted surface, the plume is partially exposed and more electrons are emitted. By scanning the sample and detecting the secondary electrons, an image displaying the topography of the surface is created. Since the detector is not a camera, there is no diffraction limit for resolution as in optical microscopes and telescopes. The SEM test of two composition is shown in Figure 6.1. and 6.2.

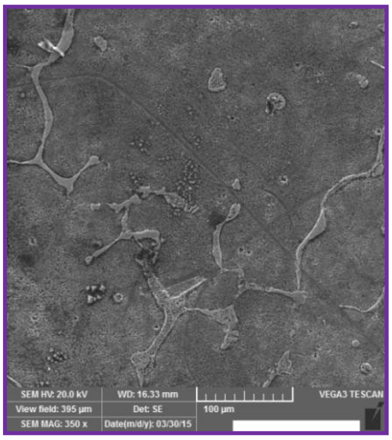

Figure 6.1. Pure Al

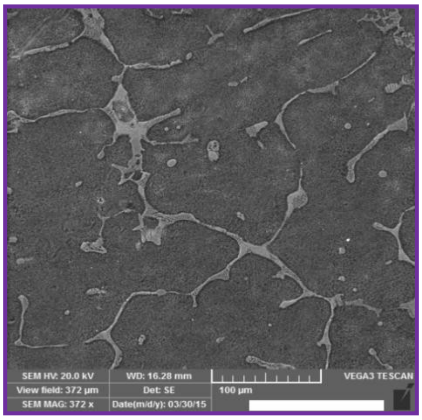

Figure 6.2. 8%B4C & 92%Al.

7.2. Hardness Measurement

The hardness of the specimen was evaluated using a Vickers hardness tester Wilson Wolert-Germany micro hardness tester to study the effect of B4C hardness of each specimen. In the test, load 0.5 Kg was applied on the specimen for 10 sec. The measurements were taken multiple times on each specimen and the average value taken as a measure of the hardness of specimen. The Table 3 shows the trends of increase the hardness value and test specimen.

Table 3. Hardness value for Metal Matrix composites.

Sample	**Hardness measurement (HRB)**			**Average hardness (HRB)**
Al2024	44.2	41.4	46.7	**44.1**
Al2024 + 8% B_4C	48.9	48.9	49.6	**49.13**

Increased average hardness can be observed in composite consisting of Al 2024+8%B_4C when compared to pure Aluminum.

7.3 Tensile Test

The tensile test was carried out on the prepared specimen and the following results are obtained.

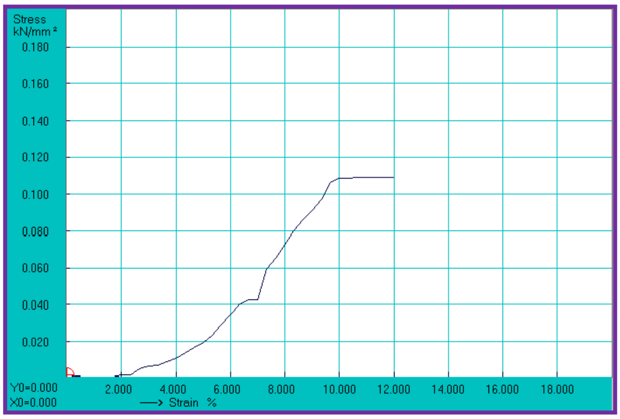

Figure 7.1 Pure Aluminums.

The above graphs 7.1. & 7.2. shows the tensile strength of the pure aluminium alloy cast and boron carbide reinforced aluminium alloy cast. From the results, it is found that the breaking load increases with increase in reinforcement. Figure 7.2. shows that the breaking point occurs suddenly as a result of increase in brittleness, which is a property of composites.

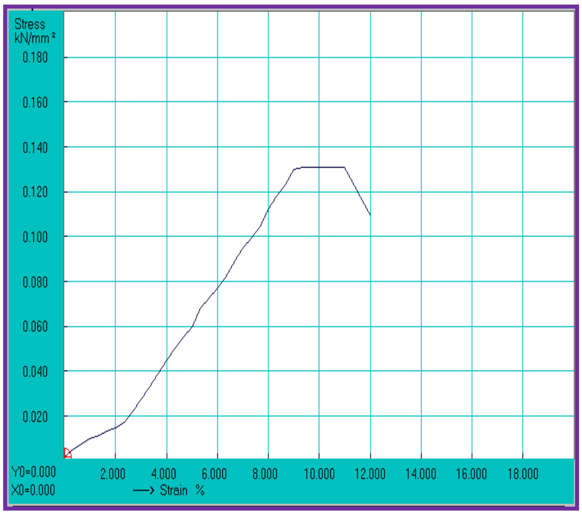

Figure 7.2. 8%B4C & 92%Al.

8. Depth of Cut

The prepared specimen is machined with the following input parameters such as Abrasive Mesh Size, Abrasive Flow Rate, Water Jet Pressure and Traverse Rate are varied.

From the experiments, it is observed that the depth of cut values are increased with decrease in Abrasive Mesh size and also higher depth of cut is achieved with maximum abrasive flow rate, water pressure with minimum traverse rate. These observations can be easily visualized through a 3Dimensional graph which is shown below.

The following Figures 8.1, 8.2, 8.3, & 8.4 show the 3 dimensional analysis graphs of depth of cut readings of the pure aluminium alloy casts.

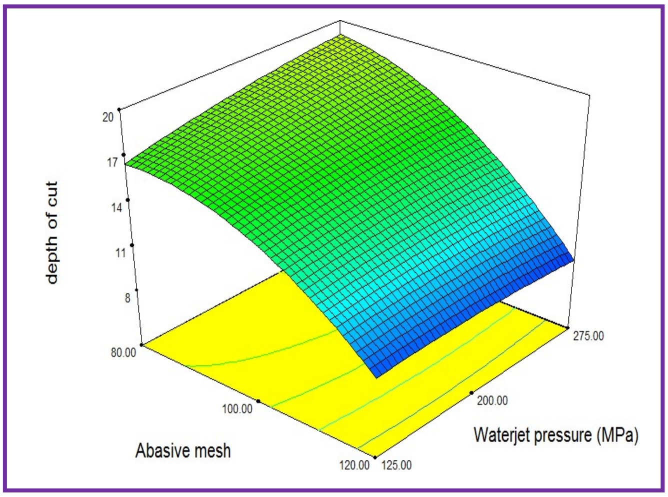

Figure 8.1. Abrasive mesh vs. Jet pressure.

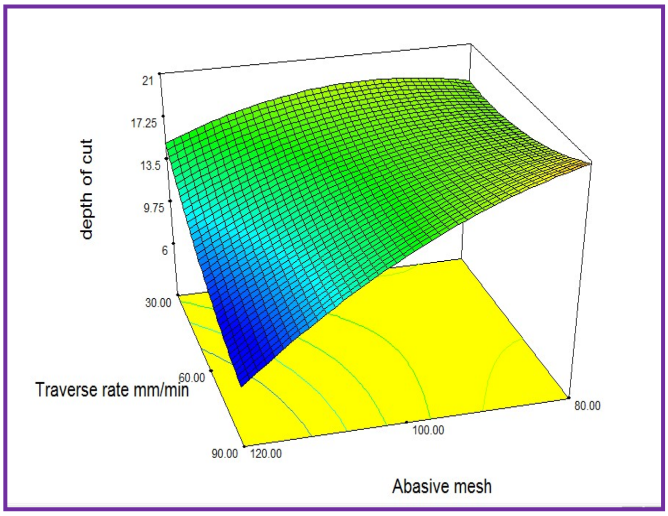

Figure 8.2. Traverse rate vs. Abrasive mesh.

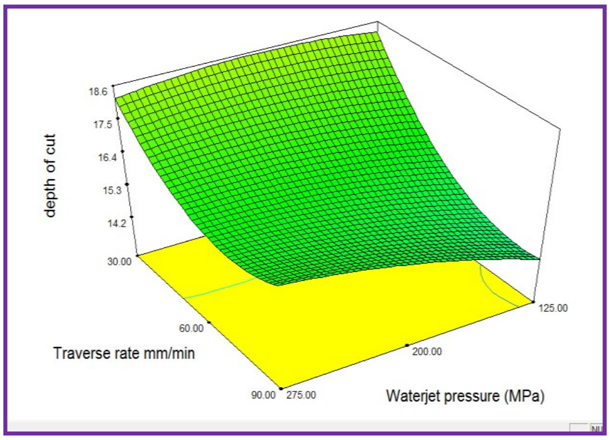

Figure 8.3. Traverse rate vs. Jet pressure.

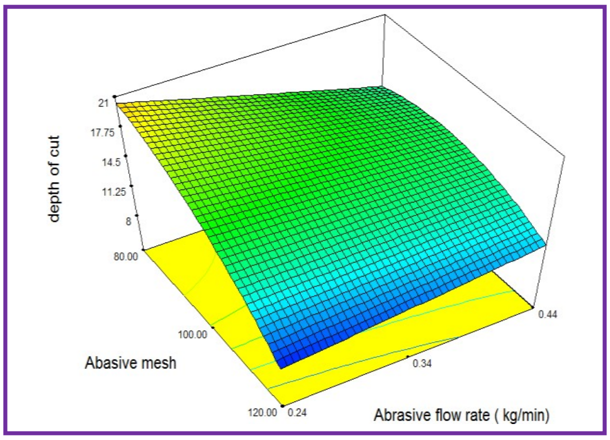

Figure 8.4. Abrasive mesh vs. Abrasive flow rate.

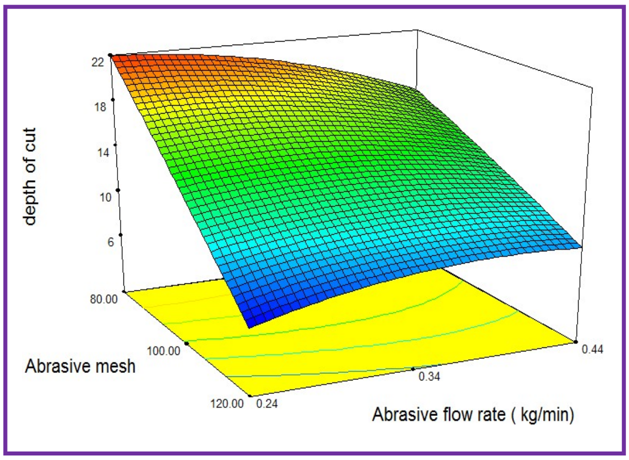

Figure 9.1. Abrasive mesh vs. Abrasive flow rate.

The above graphs shows that the depth of cut values are increased with decrease in Abrasive Mesh size and also higher depth of cut is achieved with maximum abrasive flow rate, water pressure with minimum traverse rate.

The following graphs Figure 9.1,9.2,9.3,& 9.4 Show the analysis of depth of cut on the 8% Boron Carbide reinforced Aluminium composite The above figures show the Analysis of Depth of Penetration For MMCs (AA 2024 +8%B4C).

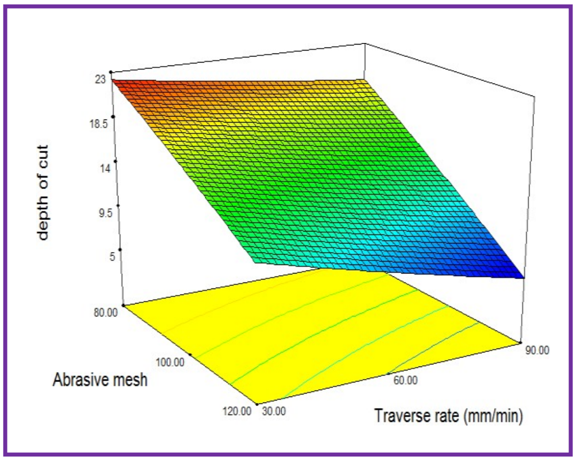

Figure 9.2 Abrasive mesh vs. jet pressure.

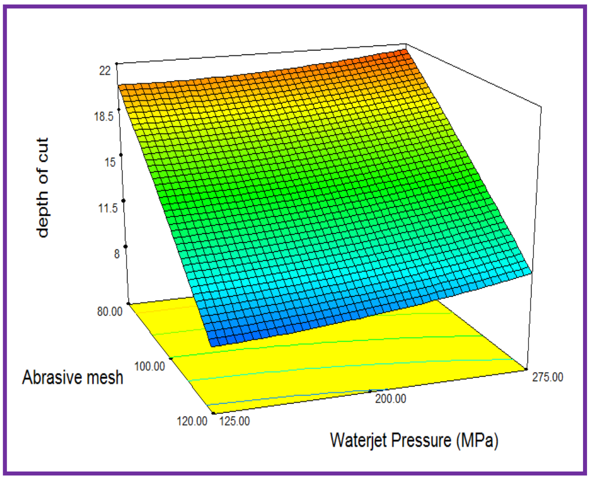

Figure 9.3 Abrasive mesh vs. traverse rate.

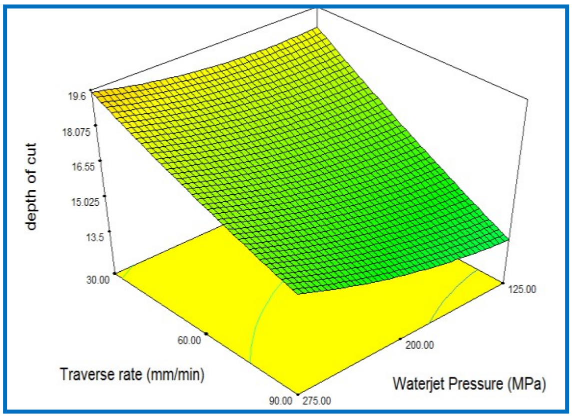

Figure 9.4 Water jet pressure vs. traverse rate.

The above figures show the Analysis of Depth of Penetration For MMCs (AA 2024 + 8%B4C). The depth of cut values are increased with decrease in Abrasive Mesh size and also higher depth of cut is achieved with maximum abrasive flow rate, water pressure with minimum traverse rate. Higher depth of cut is observed in the unreinforced aluminium alloy than that of the MMC (AA 2024 + 8% B4C).

9. Conclusion

From the observations the following conclusions are summarized. Increase in the water jet pressure and abrasive flow rate leads to higher depth of cut. Increase in traverse rate leads to lower depth of cut. Higher depth of cut is achieved with mesh size (# 80) and lower depth of cut is achieved with mesh size (# 120). Higher depth of cut is observed in the unreinforced aluminium alloy than that of the MMC (AA 2024 + 8% B4C). This is due to the fact that the higher percentage of B4C in the MMC leads to increase in the mechanical properties.

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