Experimental Study on Machinability of Metal Matrix Composite by Abrasive Water Jets

B. Siddharthan and A. Kumaravel

Abstract The unconventional machining of ceramic reinforced metal matrix composites is innovative. The machinability of aluminium alloy and boron carbide metal matrix composite with the abrasive water jets is discussed here. Two discrete proportions of Al-B_4C metal matrix composites were prepared with different mesh size, transverse rate, flow rate of abrasives and water pressure so as to distinguish the effectiveness of the AWJ machine for possible handling of metal matrix composites with abrasive water jets (AWJs). The penetration capability of abrasive water jets in various cases of metal matrix composites (MMCs) was experimented in trapezoidal-shaped aluminium boron metal matrix composite specimens which are prepared by stir casting method. Optical micrographs of metal matrix composite tests and scanning electron microscopic (SEM) examination of abrasive water jet cut surfaces empower to clarify the trends of material evacuation by the abrasives. Examination of results distinctly demonstrated the decision of abrasives of mesh size 80 with high water pressure and stream rate and low transverse rate results in effective processing of Al-B_4C MMCs with AWJs.

Keywords Metal matrix composites · Abrasive water jets · Depth of cut

1 Introduction

Metal matrix composites (MMCs) are materials comprising of at least two material constituents (matrix and reinforcement). On account of MMCs, matrix materials are like aluminium, magnesium, titanium, etc., and other is the reinforcement materials like silicon carbide, boron carbide and alumina in different structures (particles,

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G. Kumaresan et al. (eds.), *Advances in Materials Research*, Springer Proceedings in Materials 5, https://doi.org/10.1007/978-981-15-8319-3_100

whiskers and fibres). The unconventional machining processes, especially abrasive water jet machining plays an interesting role in the field of space vehicles and automotive sectors [1]. The samples were experimented for different input parameters of feed rate and transverse rate with fixed standoff distance. The machinability index of the composites was determined. Srivastava et al. [2] deals with the microhardness measurements on an aluminium alloy-based hybrid metal matrix composite with alumina and boron carbide as the reinforcements. In this work, the composites were machined by wire cut EDM and abrasive water jet turning process. The results reflect that the hardness value and the residual stress of the composite show better results when compared to wire cut EDM machined samples. The kerf taper angle and width were the ban to the machining of the composites. It was optimized using Taguchi's method by Gupta et al. [3]. The result reveals that optimizing the transverse speed of nozzle minimizes the kerf width and taper. The carbon fibre reinforced polymer (CFRP) composites along with the metallic material is conducted with 3D cutting and 2.5D cutting by Putz et al. [4]. In this case, the composite is prepared by the alternation layers of CFRP and metals for the dimensions of 2.5D and 3D machining, and it is concluded as 3D machining were promising for maximum tolerable forces. When a number of literatures were discussing about the testing, mathematical modelling [5] discussed the surface integrity of the machined surfaces. In this case, aluminium, magnesium, titanium and copper alloys were taken as the test sample materials. The materials were reinforced with ceramics and they are machined by electro discharge machining and were tested for microhardness and detected for surface defects. James and Narkhede [6] experimented with CFRP and titanium and with the submerged abrasive water and the find out that the higher the reinforcement, higher will be the hardness and lower will be the machinability.

Hejjaji et al. [7] conducted experiments with the carbon fibre reinforced epoxy composite specimens. The specimens were milled with abrasive water jets to study about their impact and tensile behaviour. It is concluded that the milling depth is purely influenced by the jet pressure and transverse speed of jet. Surface waviness is the result of variation in the standoff distance and the machined surfaces exhibit higher tensile strength for best machining parameters. CFRP with multidirectional chopped reinforced composites were studied by Deepak and Paulo Davim [8], El-Hofy et al. [9]. They experimented with the CFRP laminates with abrasive water jets for multilaminates with varying input parameters like feed rate and standoff distance and are evaluated by ANOVA technique. The results show that kerf width increase with increasing pressure and standoff distance. Uhlmann amd Männel [10] modelled titanium aluminide in ductile and brittle states and tested with abrasive water jets for kerf cutting operations. Josyula et al. [11], James and Narkhede [6] explained about the non-traditional method of machining the metal matrix composites using liquid nitrogen. In this method, the liquid nitrogen is sprayed over the conventional tool such that the wear of the conventional tool gets reduced.

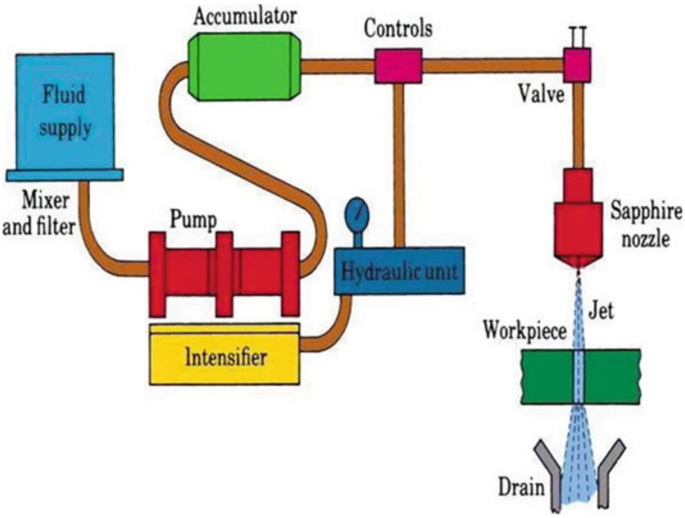

Fig. 1 Schematic view of abrasive water jet machining

2 Experimental Setup

The schematic view of the abrasive water jet machining is shown in Fig. 1. In the setup, the water at high pressure and the abrasive particles are mixed together and passed through the nozzle to achieve the machining [12, 13]. The machining is carried out in aluminium alloy with boron carbide in various proportions. The workpieces were fabricated into trapezoidal shapes by stir casting method such that the depth of cut $d = h_{\max} \sin 35°$ can be estimated.

3 Process Parameters

Various parameters were utilized in the process of machining of composites by abrasive water jets. The input parameters include pressure, transverse rate, mesh size and flow rate of abrasives. Depth of cut is the net output of the process.

Materials selected.

Aluminium + Boron Carbide.

4 Experimental Procedure

4.1 Preparation of Al7075-B_4C Metal Matrix Composites

Stir casting method is constantly utilized to fabricate aluminium metal matrix composites. In stir casting technique, metal matrix composites were fabricated by dispersing reinforcement into the matrix material in molten state by continuous stirring activity and transferring it into the die and then solidified. To fabricate complex size, metal matrix composites by stir casting process, it is least difficult and the savviest technique to manufacture. A special shape of sample in trapezoidal shape at 35° of the objective material has been selected for trial and maximum depth of cut is investigated by abrasive water jet pressure in the various MMC samples performed by abrasive water jets cutting. The maximum depth of cut (h max) in the manufactured composites with chosen suitable process parameters can be evaluated using the relationship $h_{\max} = L \sin 35°$, where L is the slant length of cut in the wedge shape. The metal matrix composites utilized in this examination comprise of Al7075 compound strengthened with boron carbide (B_4C) particulate of 400 work sizes. Table 1 gives the chemical composition of Al7075 alloy.

Table 1 gives the various proportions of materials in Al7075 alloy. The quantity of Al7075 alloy and B_4C required to fabricate unreinforced aluminium alloy and 5% volume level of B_4C are taken by weight basic requirements. Aluminium alloy (Al7075) were placed in gas-fired crucible and elevated to temperature of about 500 °C to melt the matrix material completely and place it in semi-solid state [14]. The boron carbide is preheated up to 400–500 °C for 60 min to remove the moisture property by expelling the retained water molecules and different gases. The heated matrix material at liquid state is introduced with the stirring action at 200–300 rpm for 10 min. Degassing tablet (cupflux) is introduced into the molten mixture to expel the slag. The preheated boron carbide particles were included into the molten matrix material by stirring action at a velocity of 20 m/s for 10 min, and the furnace is kept at the temperature of 750 °C. The blend is kept underneath, the 75% of the liquid metal in crucible furnace and more than 25% at the base of furnace at this stage. This helps the valuable to uniform distribution of the Al7075 and B_4C. Figures 2 and 3 show gas-fired furnaces and the blend is transferred to the die in trapezoidal shape.

During pouring, the molten melt into a wedge shape die at the temperature maintained around 600 °C which was allowed to solidify in the wedge shape die. Figure 4 shows the pictorial of trapezoidal shape of casted composite specimen produced by the stir casting process.

Table. 1. Al7075 alloy—composition

Alloy	Zinc	Magnesium	Copper	Silicon	Manganese	Titanium	Chromium	Aluminium
Al7075	5.6—6.1	2.1–2.9	1.2–2.0	0.4	0.3	0.2	0.2	87.1–91.4

Fig. 2 Gas-fired furnace and setup of stir casting

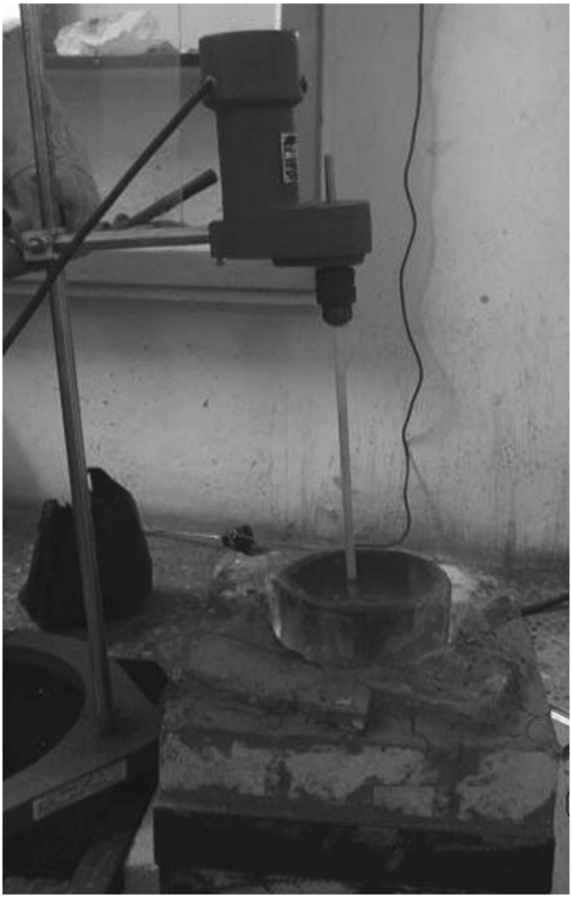

Fig. 3 Pouring mixture MMCs in wedge-shaped die

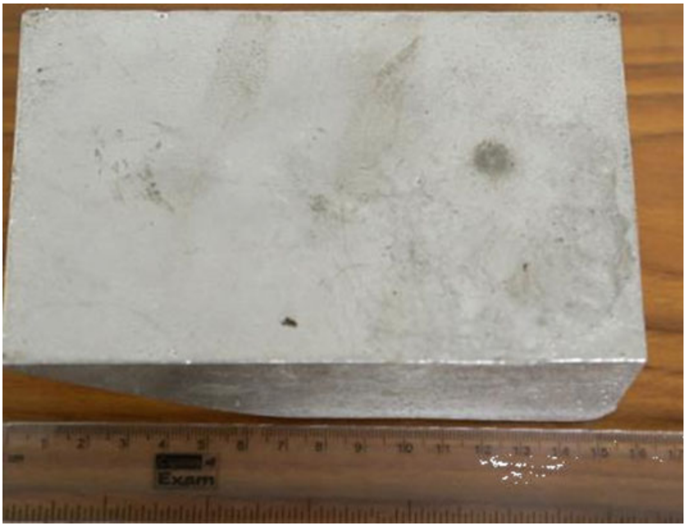

Fig. 4 Casted composite

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.

5 Experimental Method

To contemplate the impact of water jet pressure, transverse rate, abrasive flow rate and size of abrasive particles were experimented on various specimens by utilizing abrasive water jet machining system. The objective material was manufactured to trapezoidal in shape. An apparatus was intended to grasp the specimens in order to evade its dislocation during the process. In abrasive water jet machining course of action, the stream was made to impinge the sample at a point of 90° and most extreme depth of cut was noted. The extreme depth of cut of water stream into the objective material was acknowledged by analyzing the sprinkling of jet. With a standoff distance of 2 mm between the nozzle and the base material, trials were conducted with considering the input parameters factors like water jet pressure, traverse rate and flow rate of abrasive and mesh size of abrasives with the entire factor being changed at various levels as shown in Table 2.

Table 2 Process parameters

S. No	Process parameters	Minimum	Medium	Maximum
1	Size of abrasive particles (μm)	80	100	120
2	Water jet pressure (Mpa)	125	200	275
3	Abrasive flow rate (kg/min)	0.24	0.34	0.44
4	Traverse rate (mm/min)	60	90	120
5	Diamond water jet orifice diameter (mm)	0.25		
6	No. of passes	1		
7	Angle of cutting (degree)	90°		
8	Abrasive material	Calcite		
9	Focusing nozzle diameter (mm)	0.75		

5.1 Input Process Parameter

The machined workpiece is shown in Fig. 5. The figure indicates the wedge-shaped workpiece in which the lines show the number of passes that the machining of the workpiece has undergone. Totally, a series of 21 passes has been done on each sample with the aid of ANOVA method.

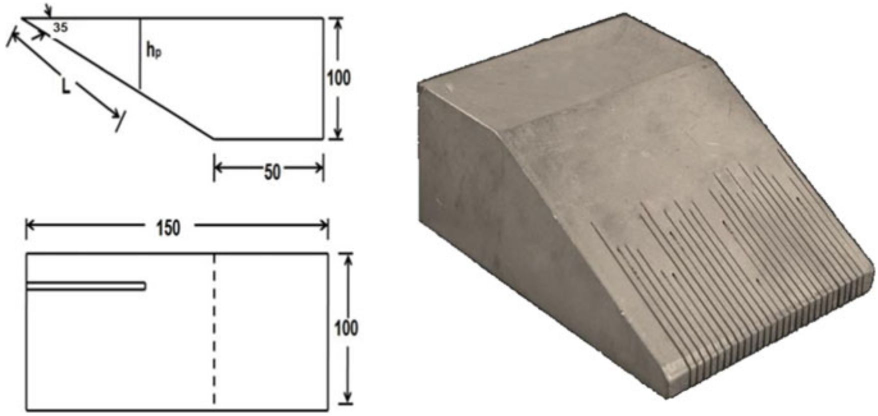

Fig. 5 Photograph of aluminium work piece

6 Results and Discussion

6.1 SEM TEST (Scanning Electron Microscopy)

The device that produces the images of the target material by utilizing the converged light emission of the electrons is the scanning electron microscope (SEM). The electrons emitted from the source examine and publish information about the surface of the target specimens and their chemical compositions.

The most comprehensively strategy of acknowledgment is by secondary electrons transmitted by particles invigorated by the electron beam. On a target surface, the tuft of secondary electrons is commonly contained by the target, yet on a tilted surface, the outside is mostly secured and more electrons are released. By checking the example and recognizing the secondary electrons, an image demonstrating the topography of the surface is made. Since the marker is not a camera, there is no diffraction limit for goals as in optical magnifying lens and telescopes. The SEM test of two compositions is appeared in Fig. 6a, b. The images are captured at the magnification of 100 µm. Figure 6a shows the microstructure of the pure aluminium, which is dominantly covered with grey surface. The lines show the presence of other constituents in the aluminium 7075 grade. Figure 6b indicates the microstructure of boron carbide reinforced composite samples. The dispersion of boron carbide is clearly visible at the 100 µm magnification.

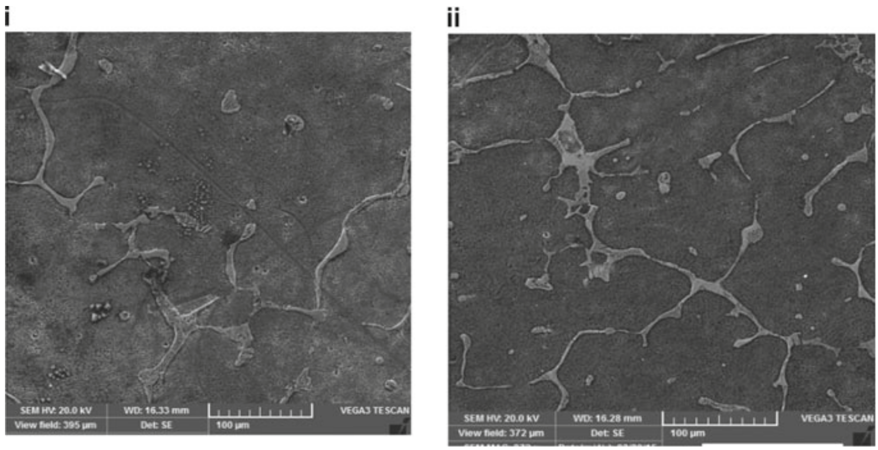

Fig. 6 **a** Pure Al. **b** 5% B_4C and 95% Al

Table 3 Hardness value for metal matrix composites

Sample	Hardness measurement (HV) at various locations			Average hardness (HV)
Al7075	60.2	60.4	59.7	60.1
Al7075 + 5% B_4C	64.9	65.1	64.6	64.3

6.2 Hardness Measurement

The hardness test was carried in Vickers hardness tester which has a testing load range of 10 g–1 kg load and testing scale used is HV. The prepared samples have undergone a load of 0.5 kg with reside time 10 s in three locations of each sample. The hardness value of the specimen is determined by taking the average of the hardness values taken at multiple locations as stated in Table 3.

6.3 Tensile Test

The tensile tests were conducted on the prepared specimen and the following results are obtained.

The above graphs 7a, b show the tensile strength of the pure aluminium alloy cast and boron carbide reinforced aluminium alloy cast. The stress–strain curve for the pure aluminium indicates the elastic and plastic flow of the material. When the load is further increased the material undergoes plastic deformation and reaches the ultimate point. At the same time, the 5% B_4C reinforced aluminium composite fails at the same loading condition, where the pure aluminium alloy yields. This is due to the presence of reinforcement in the aluminium alloy. From the results, it is found that the breaking load increases with increase in reinforcement. Figure 7b show that the breaking point occurs suddenly as a result of increase in brittleness, which is a property of composites.

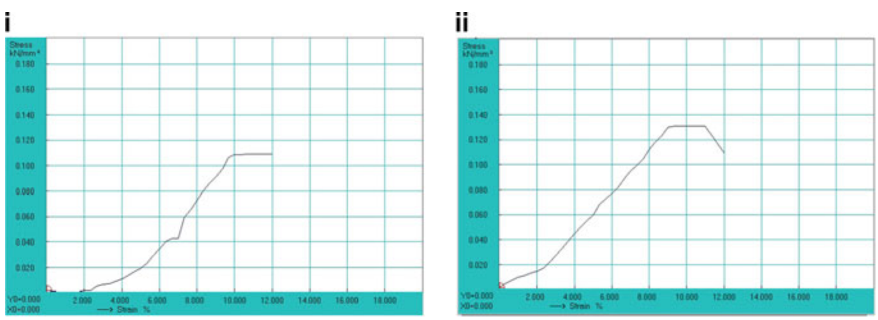

Fig. 7 **a** Pure aluminium. **b** 5% B_4C and 95% Al

7 Depth of Cut

The prepared sample is machined by varying the associated input parameters. From the experiments, it is seen that the depth of cut value decreases with increase in mesh size of abrasives, and furthermore maximum depth of cut is accomplished with maximum flow rate of abrasives, maximum water pressure with lower traverse rate. These observations can be easily visualized through a three-dimensional graph which is shown below.

Figure 8a–d shows the three-dimensional analysis graphs of depth of cut readings of the pure aluminium alloy casts.

The above graphs show that the depth of cut values increase with decrease in size of abrasive particles. Maximum depth of penetration is achieved with higher water pressure and abrasive flow rate with low traverse rate.

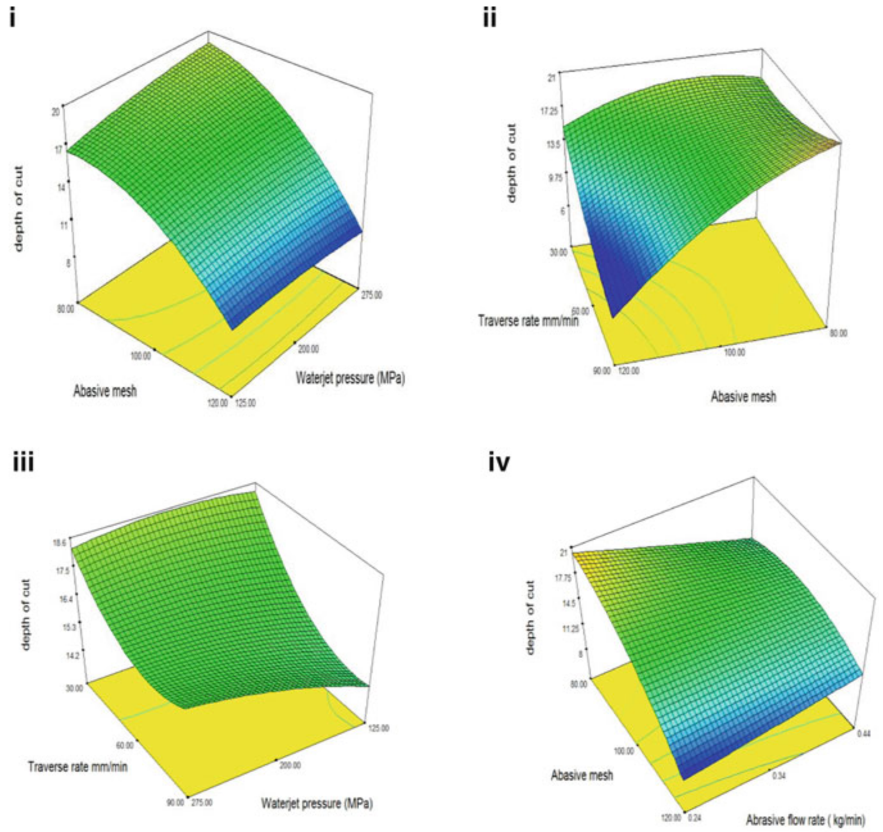

Fig. 8 **a** Abrasive mesh versus jet pressure. **b** Traverse rate versus abrasive mesh. **c** Traverse rate versus jet pressure. **d** Abrasive mesh versus abrasive flow rate

In following graphs, Fig. 9a–d 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 (Al7075 + 5% B_4C). With decrease in the mesh size of abrasives, the depth of cut value increases. Higher depth of penetration is achieved with higher water pressure and abrasive flow rate with lower traverse rate. Unreinforced aluminium alloy exhibits higher depth of cut than that of the aluminium metal matrix composite (Al7075 + 5% B_4C).

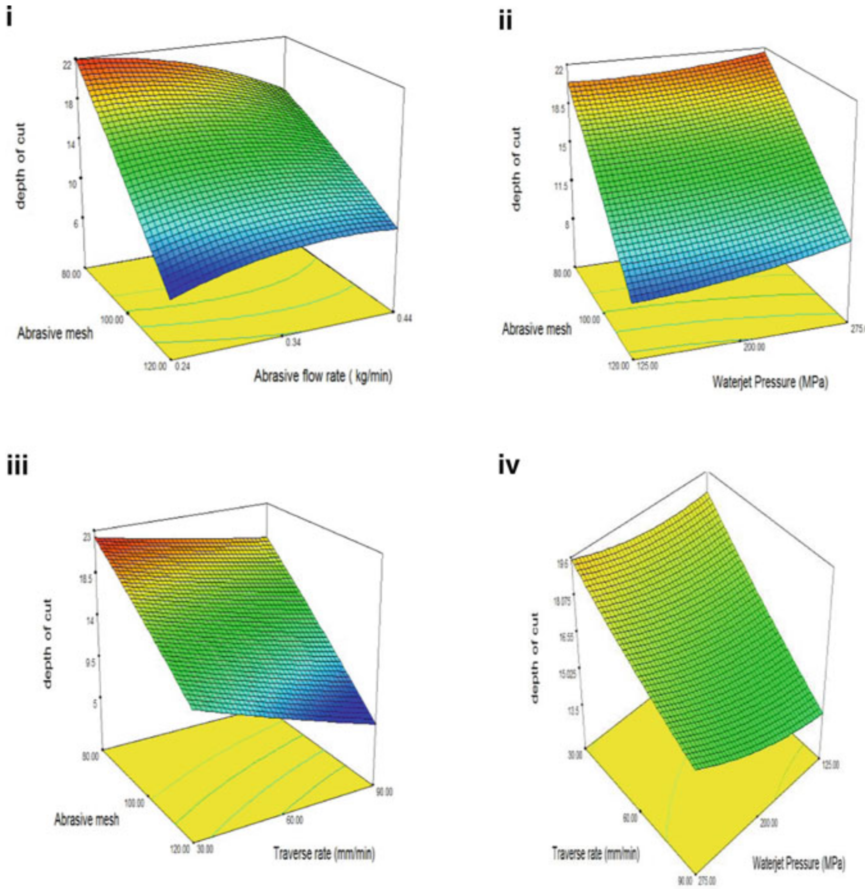

Fig. 9 **a** Abrasive mesh versus abrasive flow rate. **b** Abrasive mesh versus jet pressure. **c** Abrasive mesh versus traverse rate. **d** Waterjet pressure versus traverse rate

8 Conclusion

From the perceptions, the results were concluded as follows: The presence of boron carbide reinforcement in the aluminium alloy enhances the material properties like hardness and tensile strength of the composite. The improvement is due to the brittle nature of the ceramic reinforcement boron carbide. Depth of cut can be increased decreasing the transverse rate of machining. Maximum depth of cut is accomplished when the abrasive flow rate and water jet pressure are maximum. At a lower mesh size, higher depth of cut is achieved. The abrasive size of #80, water jet pressure of 275 psi, abrasive flow rate of 0.44 g/s and the transverse rate of 60 m/s give the perfect machining of the composites. Pure aluminium alloy exhibits higher depth of cut than that of the metal matrix composite (Al7075 + 5% B_4C). This is because of the reality that the higher level of boron carbide in the metal matrix composite prompts improvement in the mechanical properties.

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