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Influence of process parameters in machining the Hybrid Aluminum metal matrix composites in wire cut EDM-An Experimental investigation

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Abstract:

The composite materials are extensively used globally in major industries. It is very difficult to machine the metal matrix composite materials impeded with reinforcement by conventional machining methods. Hence non conventional machining techniques are employed to overcome these difficulties. Wire Electrical discharge machining (WEDM) shows higher capability for cutting complex shapes with high precision for these materials. In this present work the effect of process parameter of Wire Electrical discharge machining such as Voltage, Pulse on- time , pulse -off time and current were studied for the reinforced metal matrix composite and hybrid aluminum metal matrix composites(HAMMCs). Aluminum 7075 reinforced with Silicon carbide (SiC) and boron carbide (B_4C) are fabricated using stir casting process and machining was done in WEDM using design of experiments approach. The material removal rate for different set of experiments were studied. The influence of weight fraction of reinforcement on metal removal rate was discussed. Also the microstructure, Surface roughness, and hardness evaluation were made for the fabricated specimen and results were analyzed. It has been observed that the metal removal rate decreases when the weight fraction of reinforcement increases and surface roughness increases.

Keywords: Reinforcement, Microstructure, hardness, surface roughness, material removal rate, wire electrical discharge machining.

1. Introduction

Due to high strength-to-weight ratio, lower value of coefficient of thermal expansion, high toughness ,good wear resistance, MMCs are widely used in industries [1, 2].When compared to metals, the hybrid Aluminum Metal Matrix Composites are extensively used in many areas where weight and strength are of most important factors. The main advantage of particulate reinforced composite are its different strengthening mechanisms and their formability [3, 4]. The HAMMCs posseses high coefficient of thermal expansion with lesser density[5]. Due to their excellent mechanical properties HAMMCs are widely used in automobile industries [6]. HAMMCs can be fabricated by stir casting process. Homogeneous mixing can be obtained by selecting appropriate processing parameters like stirring speed, time and temperature of the molten metal, preheating temperature of the mould and uniform feed rate of the particles [7, 8]. Among the various aluminum alloys, 7075 is best opted choice to prepare metal matrix composites due to its better formability characteristics. [9-13]. The addition of SiC and B_4C particles into the aluminum matrix increases the hardness and their mechanical properties. In particulate reinforced HAMMCs, reinforcement is added to the matrix of the bulk material to increase its stiffness and strength [14-16].

It is very difficult to machine the metal matrix composite materials impeded with reinforcement by conventional machines. Hence many research work has been carried out to study the metal removal rate using unconventional machining techniques. But wire electrical discharge machining was found to be effective to machine the composite materials[17]. Ahmed et al [18] studied the metal removal rate for the aluminum -silicon carbide –boron carbide and aluminum silcon carbide –glass with various process parameters.

Satish kumar et al [19] reported that increase in SiC particulate in the matrix will decrease the metal removal rate. B.Lawers et al studied the material removal mechanism in EDM using zirconium based ceramic materials [20]. V.C Uvaraja et al analysed the characteristic studies of Al7075 metal matrix embedded with SiC as reinforcement partcicles [21].Many unconventional machining techniques like abrasive jet machining , Electrical discharge machining and laser beam machining can be employed to machine the MMC's. But due to expensive ,wire cut electric discharge machining is used. Wire electrical discharge machining is the unconventional machining technique in which material is removed from the work piece by the application of spark between the wire electrode and workpiece in dielectric medium. Most of the research work is reported on Al 7075 with different reinforcement such as silicon carbide, silicon, boron carbide, titanium, alumina etc. But none of them had attempt for Al 7075 with two types of reinforcements like SiC and B4C. Hence with the view of the above literature the main objective of the present work is to forecast the effect of addition of SiC and B4C particulate in the metal matrix. The effect of weight fraction of reinforcement in the metal has been analysed with respect to metal removal rate.

Table 1—Composition of Al 7075 by weight percentage

Elements	Si	Fe	Cu	Mn	Ni	Zn	Ti	Mg	Cr	Al
% by weight	0.06	0.18	1.63	0.074	0.05	5.62	0.049	2.52	0.22	Balance

2.Experimental procedure:

MMCs and HMMCs Specimens were fabricated using stir casting process. A die with the 100X 100X 50 mm is used to prepare the specimen. Al 7075 was melted above its melting point and the reinforcement silicon carbide 20 microns and boron carbide 8 microns are added. Uniform stirring is done using stirrer. Once the reinforcement are mixed well ,the bottom portion of the furnace is opened and made to flow in the die which was kept down the furnace. After cooling the specimen was taken from the die. Four specimens Al7075 reinforced with 3% SiC, 3% SiC 3% B4C, 7% SiC 4% B4C and 4% B4C composites were made with the same procedure. The stir casting set up is shown in the Fig [1]. Al7075 with reinforcement materials and fabricated specimen are shown in the Fig 2and 3 respectively. Then the machining were conducted on the wire electrical discharge machine manufactured by Electronica India Pvt Ltd Fig [4]. A brass wire of 0.25 mm diameter was used as the cutting tool. Fabricated MMCs and HMMCs of dimension 100x100x 50mm were used as the work piece. The distilled water was used as dielectric medium. The four input process parameters namely voltage (V), pulse-on time (T_{ON}), pulse-off time (T_{OFF}) and current (C) were selected and experiments are conducted based on the design of experiments approach using L18 orthogonal array. The various process parameters were shown in the table 1. A small portion of the composite materials were cut and the surface of the specimens were polished using various grades of emery sheets. Then the mirror finishing was obtained by polishing the specimen on a disc polishing machine using velvet cloth with Alumina suspension. The samples were etched using Keller's reagent and microstructural observation has been done using optical microscope. Rockwell hardness test at load of 100kgf was carried out on the composite samples. Various indentations at a gap of 1mm has been made and the average of hardness readings has been taken as hardness value. The surface roughness on the EDM machined surface was measured using Mitutoyo surface roughness tester(SJ-210). Material removal rate is calculated using the formula below:

$$MRR = (2W_g+D) \times t \times (L/T)\ mm^3/min$$

Where ,

W_g is the spark gap im mm, D is the diameter of the wire, t is the thickness of the workpiece in mm , L is the distance travelled by the tool in mm and T is the time taken to cut one profile in min.

Fig 1 Stir Casting Set up

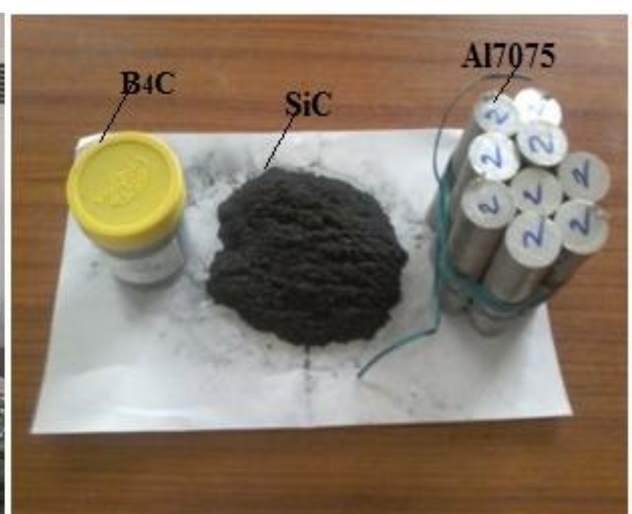

Fig 2 Al 7075 , SiC and B_4C Reinforcement

Fig 3 Fabricated specimen

Fig 4 Wire electrical discharge machine

Table 2 WEDM Process Parameters

S.No	Parameter	Symbol	Level 1	Level 2	Level 3
1	Voltage (V)	V	80	95	-
2	Pulse on time(μs)	T_{ON}	109	115	120
3	Pulse off Time(μs)	T_{OFF}	56	57	58
4	Current (A)	C	100	150	200

Table 3 Input parameters and experimental results of MRR and R_a

Input parameters					Output parameters							
					MRR in mm^3/min				Ra (µm)			
S.No	Voltage	Pulse on time	Pulse Off time	Current	Al7075 3%SiC	Al7075 3%SiC 3%B_4C	Al7075 7%SiC 3%B_4C	Al7075 3%B_4C	Al7075 3%SiC	Al7075 3%SiC 3% B_4C	Al7075 7%SiC 3%B_4C	Al7075 3%B_4 C
1	80	109	56	100	2.95	2.75	2.68	2.82	3.53	3.71	3.87	3.43
2	80	109	57	150	2.75	2.62	2.55	2.68	3.85	4.51	4.58	3.31
3	80	109	58	200	2.45	2.43	2.46	3.24	2.17	3.35	3.63	3.28
4	80	115	56	100	4.91	3.68	2.37	4.53	3.21	4.70	4.90	3.59
5	80	115	57	150	4.71	3.52	3.47	4.72	3.13	3.32	4.72	3.79
6	80	115	58	200	4.31	3.68	2.37	4.86	3.11	5.95	3.99	3.80
7	80	120	56	150	5.32	4.36	3.82	5.29	2.66	3.08	4.57	3.57
8	80	120	57	200	4.53	3.37	3.25	5.23	3.11	4.21	4.36	3.10
9	80	120	58	100	4.23	3.23	3.03	5.32	3.17	4.29	4.41	4.05
10	95	109	56	200	2.93	2.63	1.58	3.22	2.32	4.33	4.45	3.03
11	95	109	57	100	2.95	1.95	1.68	2.63	3.28	4.02	4.16	3.12
12	95	109	58	150	2.62	2.35	2.95	2.92	2.44	3.92	3.65	3.27
13	95	115	56	150	4.01	3.68	3.41	3.43	2.97	3.12	3.80	3.68
14	95	115	57	200	4.72	3.62	3.91	4.33	2.59	3.93	4.09	3.96
15	95	115	58	100	4.41	2.96	3.68	4.73	2.75	4.32	4.08	3.41
16	95	120	56	200	5.27	4.17	4.07	4.80	2.74	4.26	4.01	3.26
17	95	120	57	100	4.23	3.27	3.33	4.28	4.33	3.35	4.57	3.41

18	95	120	58	150	4.22	3.13	2.93	3.23	4.38	3.27	4.67	3.27

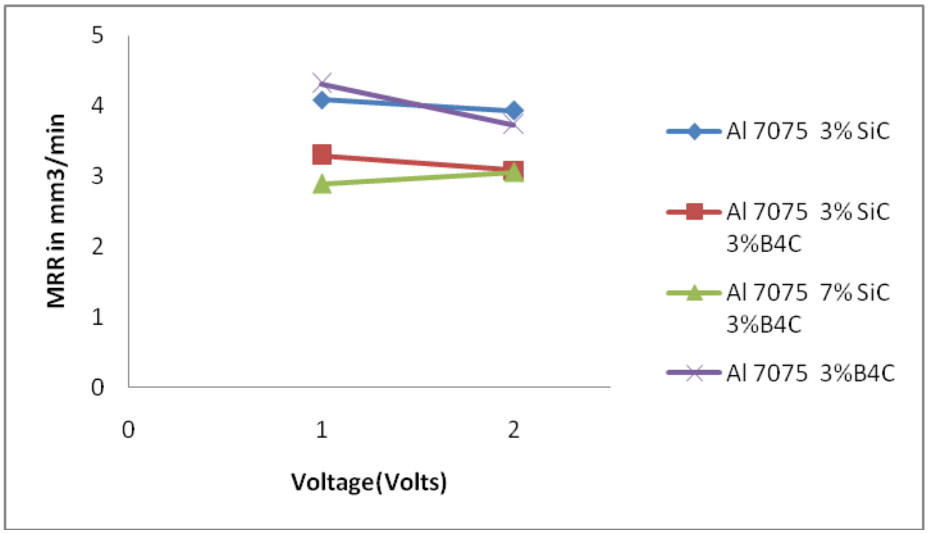

Fig 5(a)

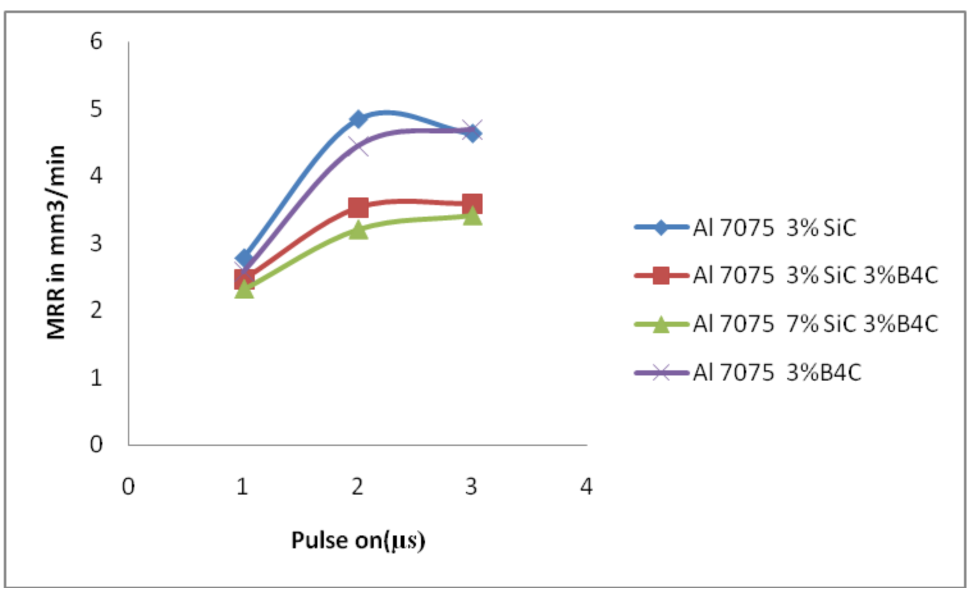

Fig 5(b)

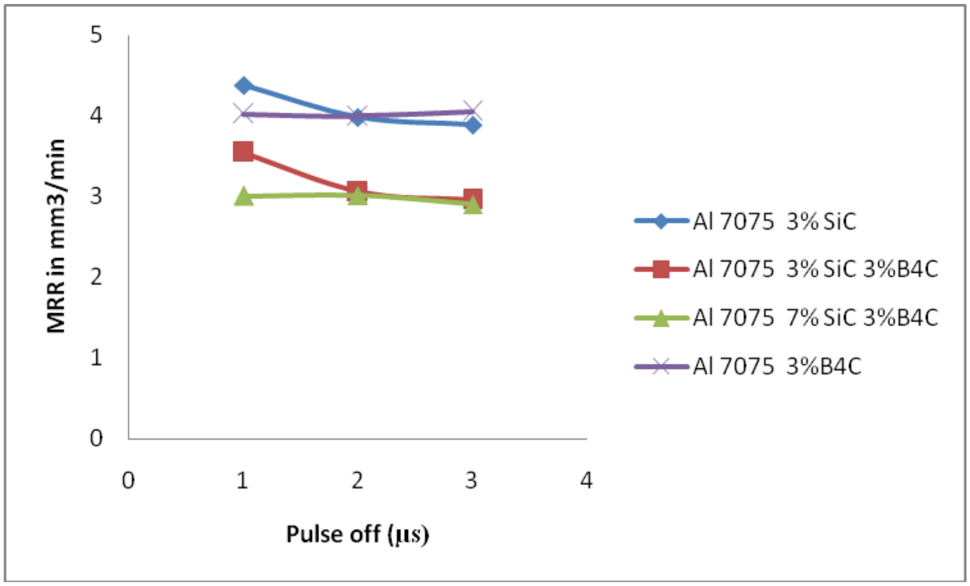

Fig 5 (c)

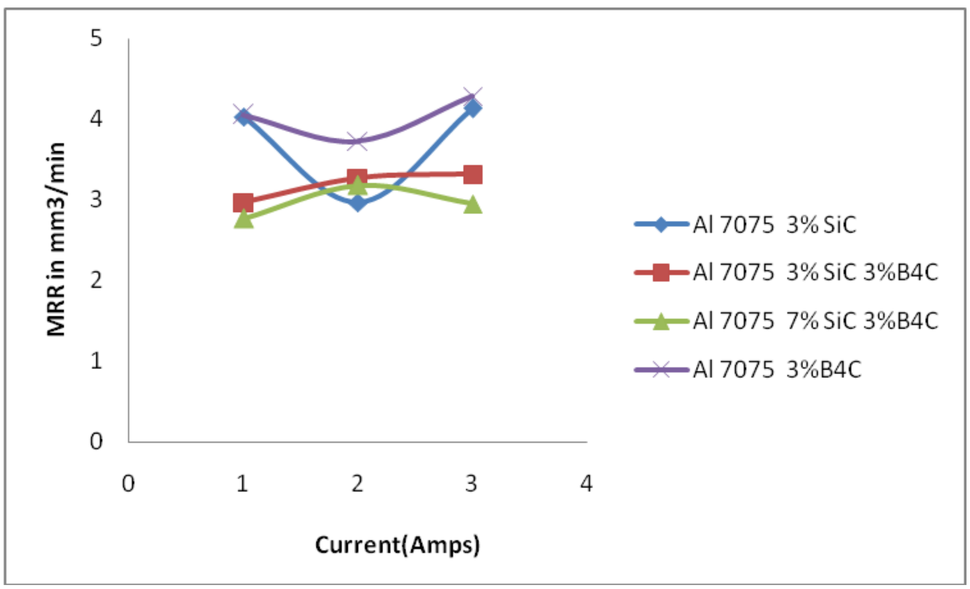

Fig 5 (d)

Fig 5 (a –d) Response graph for MRR

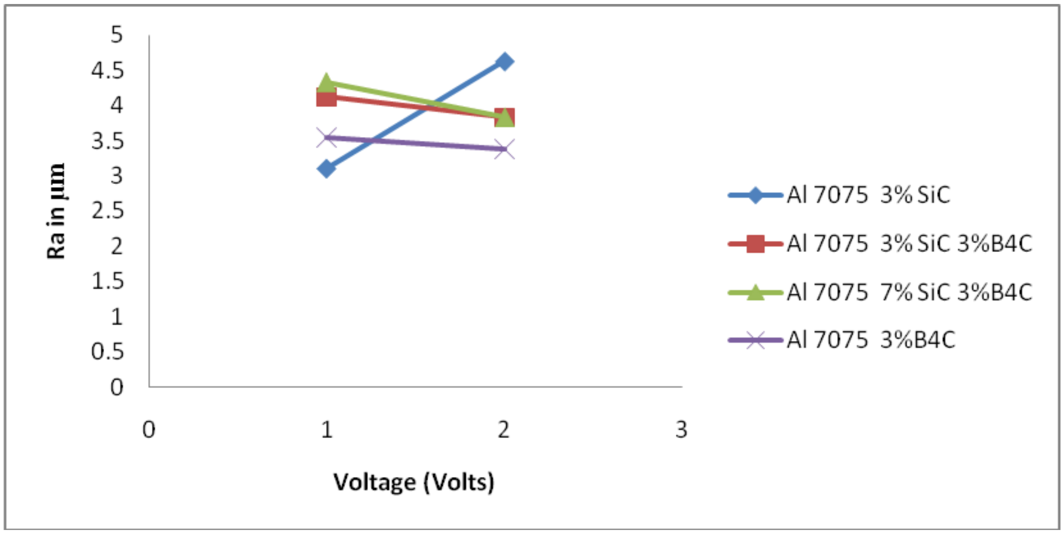
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Ra in µm
0
1
2
3
Voltage (Volts)
Al 7075 3% SiC
Al 7075 3% SiC 3%B4C
Al 7075 7% SiC 3%B4C
Al 7075 3%B4C

Fig 6 (a)

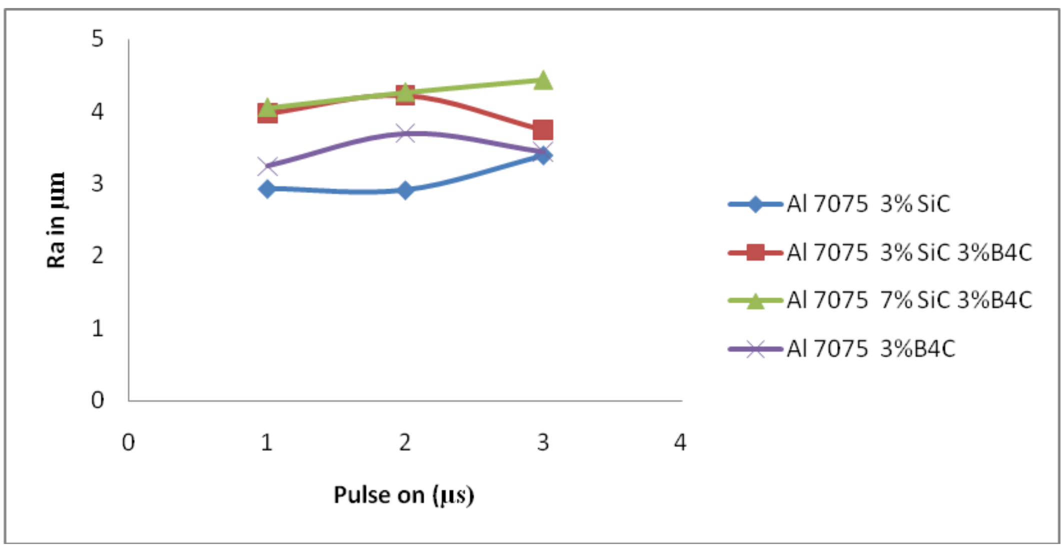
5
4
3
2
1
0
Ra in µm
0
1
2
3
4
Pulse on (µs)
Al 7075 3% SiC
Al 7075 3% SiC 3%B4C
Al 7075 7% SiC 3%B4C
Al 7075 3%B4C

Fig 6 (b)

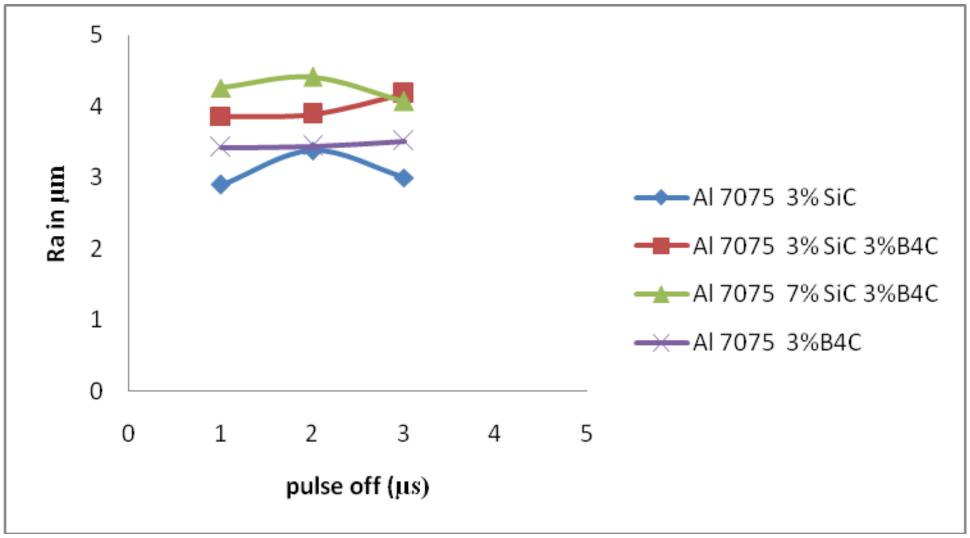

Fig 6 (c)

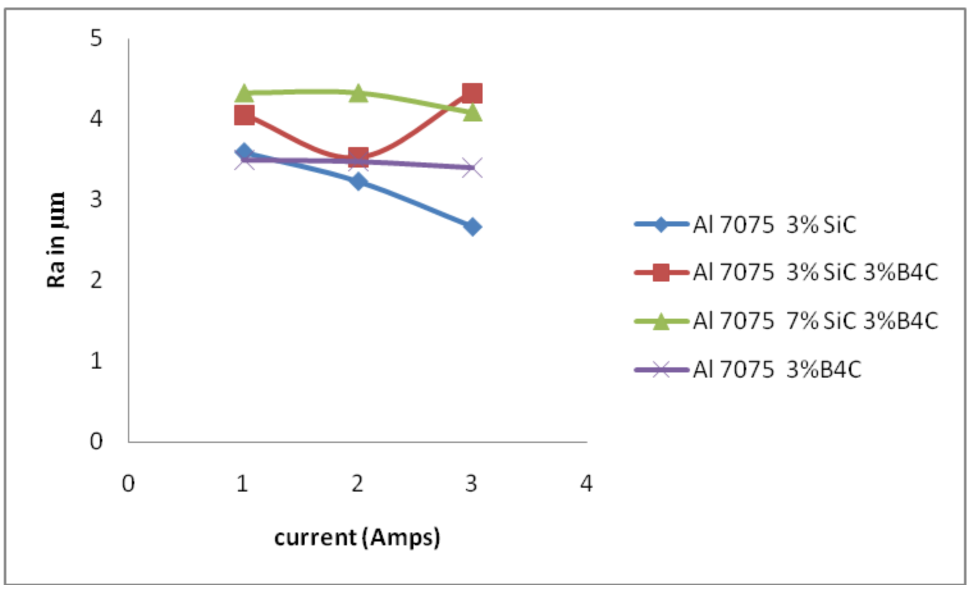

Fig 6 (d)

Fig 6 (a-d)Response graphs for Ra

3.Results and discussion:

3.1Material Removal rate:

It has been observed that the pulse on time and pulse off time are the important influencing factor for HAMMCs considered in this work. From the response graphs Fig 5(a-d) it is seen that for Al7075 7% SiC 3% B_4C high voltage , high pulse on time and low pulse off time and high current resulted in higher Material removal rate. Also low voltage ,medium pulse on time , low pulse off time and low current results in increase in MRR for Al7075 3% SiC composites. The average MRR for Al7075 3% SiC is 3.97mm^3/min and Al7075 3%B4C is 4.01mm^3/min. The average MRR for Al7075 3%SiC 3% B_4C and Al 7075 7% SiC 3% B_4C was found to be 3.18mm^3/min and 2.97mm^3/min respectively. Low pulse on time, high voltage , low pulse off time with high current decreases the material removal rate in this Hybrid aluminum metal matrix composites. Hence the results shows that the increase in weight percentage of SiC and B_4C decreases the Material removal rate in the composite material. The mechanical and thermal properties of HAMMC can be improved with addition of SiC and B_4C particulates.

3.2 Surface roughness:

The size and weight fraction of the reinforcement particles determines the surface roughness . Gradual increase in pulse time gives greater surface finish. From the response graphs it has been observed that the average Ra for Al7075 3% SiC 3%B_4C was found to be 3.98 µm and average value for 7% SiC 3% B_4C was 4.25µm. It has been observed that the Ra value increases with increase in weight fraction of SiC and B_4C particulates. The presence of reinforcement in the aluminum matrix resulted in higher roughness. It has been found that when the intensity of electric spark is more it produces crater on the workpiece and results in poor surface finish. On the other hand increase in pulse off time leads to lower Ra, due to erosion. Hence pulse on time and pulse off time are the most influencing parameters that determine the surface roughness.

3.3 Microstructure and Hardness evaluation:

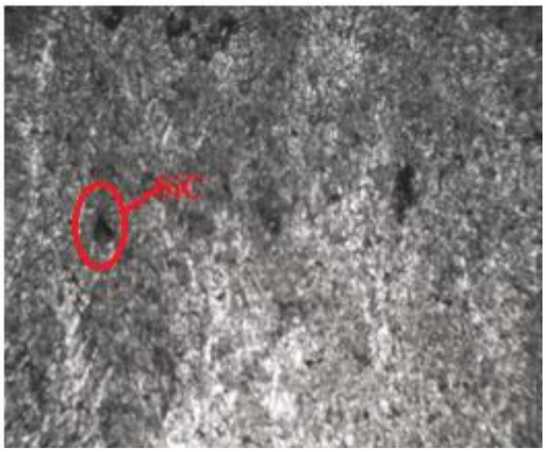

Fig a Al 7075 3%SiC

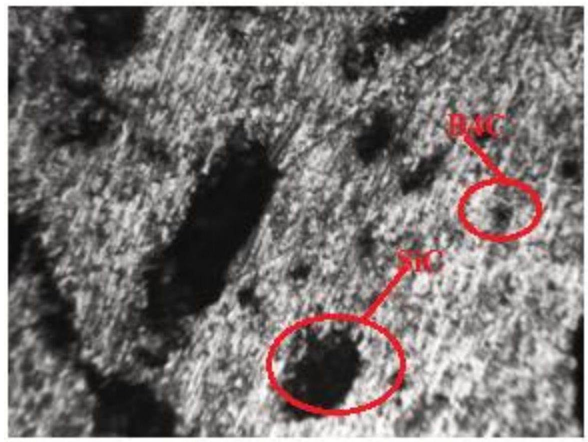

Fig b Al 7075 3%SiC 3%B_4C

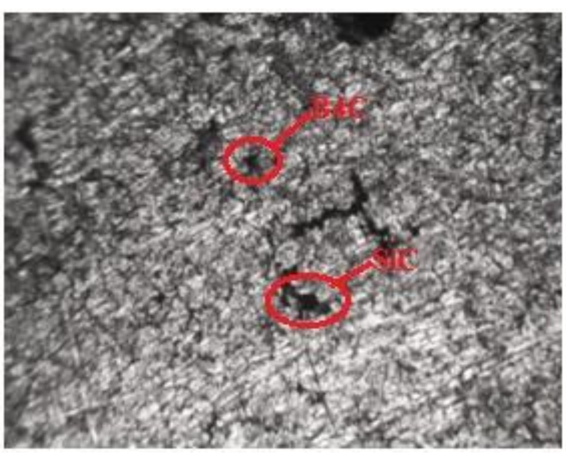

Fig c Al 7075 7%SiC 3%B_4C

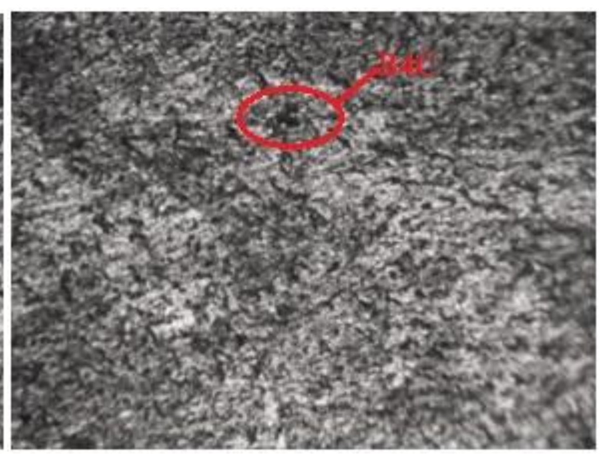

Fig d Al 7075 3%B_4C

Fig 7(a-d)) Optical microscope images of MMC'S and HAMMC'S

From the fig 7(a-d) it has been revealed that the particle distribution are uniform throughout the matrix due to constant speed of the stirrer. Microstructure analysis of these specimens shows that the SiC and B_4C particles are uniformly distributed in the matrix. Presence of porosity around the SiC particles was seen due to wetting behavior of aluminum alloy. The good bonding between the aluminum alloy and particulates was observed. The uniformly distributed particulates within the matrix and dendrites are also seen. Grain boundaries are clearly seen with some precipitates in the grains. Hardness test was carried out using Rockwell hardness tester with six indentations of each sample and then the average values were used to calculate hardness number. A considerable increase in hardness of the matrix was seen with the addition of SiC and B_4C particles .The hardness of HAMMCs increases with the weight fraction of particulate in the alloy matrix.

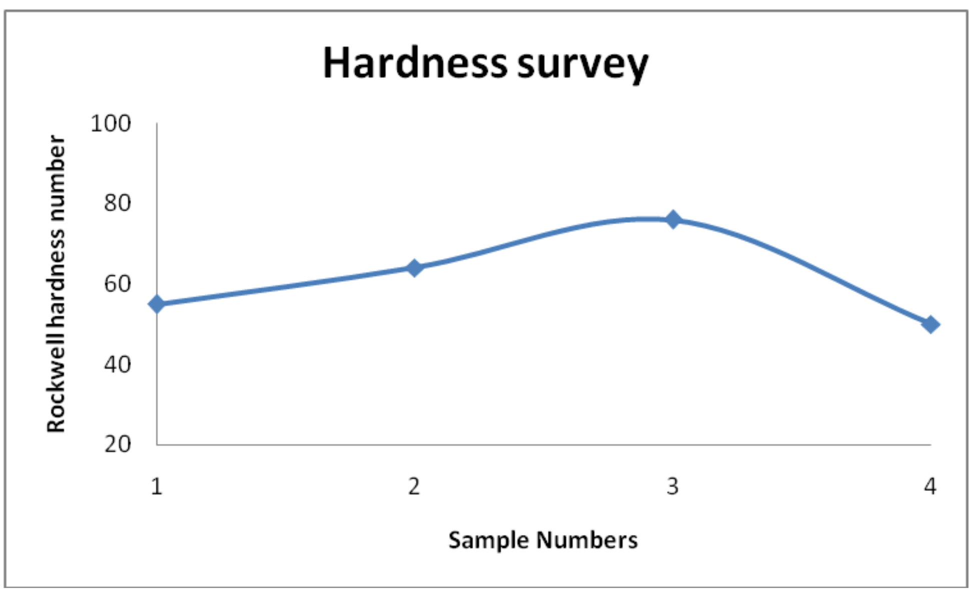

Fig 8 Hardness survey for the composite materials

Sample 1: Al 7075 3%SiC

Sample 2:Al 7075 3% SiC 3% B_4C

Sample 3: Al7075 7% SiC 3% B_4C

Sample 4 :Al7075 3%B_4C

The added amount of SiC and B4C particles enhances hardness, as these particles are harder than Al alloy, which render their inherent property of hardness to soft matrix. The hardness graph Fig 8 shows that the sample with 7 wt% SiC and 3 wt% B4C showed slightly high hardness and low toughness as compare to 3 wt% SiC and 3 wt% B4C. Higher the percentage of particulates in the matrix lesser is the toughness. Composites with higher hardness could be achieved by this technique which may be due to the fact that silicon carbide and boron carbide particles act as obstacles to the motion of dislocation. Therefore, from this study it is evidently indicated that 7wt% SiC and 3 wt% boron carbide composite sample have high hardness and good toughness. Hence this may be considered as the optimum weight percentage of the particulate to achieve better hybrid composite properties for heavy vehicle applications. Also the presence of harder SiC and B_4C reinforcement increases the resistivity of the matrix.

4. **Conclusion:**

From the above discussion the following results are drawn.

- Metal Matrix Composites and Hybrid Metal Matrix composites with different weight fraction of reinforcements were fabricated by stir casting method.
- Uniform distribution of particles were seen which are bonded well in the metal matrix.
- Hybrid composites shows high hardness due to hard phase silicon carbide and boron carbide particulates embedded uniformly in aluminum 7075based matrix.
- Hybrid Aluminum metal matrix composite sample with 7 % SiC and 3wt% B4C composition shows good machining characteristics.
- The input parameters influencing the machining are pulse on time, pulse off time and current.

- Material removal rate decreases due to the addition of Silicon carbide and Boron carbide reinforcement in the composite materials.
- Ra value increases with the addition of reinforcement particles.

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