Effects of Al-SiC Composite Tool Fabricated through Stir Casting Method on Process Parameters of EDM

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Abstract—*In this research, a metal matrix composite tool has been fabricated through stir casting technique and used for machining of EN-31 steel workpiece by electric discharge machining (EDM). Al-6061 is used as matrix material and silicon carbide particles as reinforcing material for the fabrication of composite tool. This composite tool is used to investigate the effect of material removal rate, tool wear rate and electrode wear ratio while electric discharge machining of En-31 workpiece. Current, pulse on time, pulse off time and SiC% in tool material are selected as input parameter. Material removal rate (MRR), Tool wear rate (TWR), Electrode wear ratio (EWR) are selected as output parameter. Experiments have been designed and perform according to Taguchi technique. L_{32} orthogonal array is selected for experimentation.*

Keywords: *MMC, Al-SiC Tool, Taguchi, MRR, TWR, EWR etc.*

INTRODUCTION

Metal matrix composite materials are made up of two or more materials having different properties which remain distinguish. In metal matrix composite material, identity of individual materials is retained. Generally MMCs are made up of two constituent materials: matrix and reinforcement. The reinforcement provides good properties due to its high strength and stiffness as compared to matrix or base material [1]. Metal matrix composite materials have good properties like high stiffness & strength, high electrical & thermal conductivity, corrosion resistance, low density, high temperature stability, improved wear resistance [2]. Commonly used matrix materials in MMC includes Al, Mg, Ni and Cu. Reinforcing particles increase the stiffness, strength, resistance to high temperature & reduces density in MMCs. Reinforcement is selected according to dimensions, shape, chemical composition and spatial distribution in the matrix [4]. Most commonly used reinforcement elements are silicon carbide, aluminium oxide, titanium diboride and graphite [5]. Fabrication of MMCs can be done by different techniques such as liquid phase fabrication, solid phase fabrication, vapour state fabrication etc. Stir casting method is selected for production of MMCs due to advantage as compared to others method such as its low cost, process simplicity and suitability for mass production [6]. Electrical discharge machining (EDM) is the most broadly used non-conventional machining process for shaping hard materials and materials having complex geometrical shapes. Thus it is commonly employed in manufacturing of automotive parts, moulds, dies, aerospace and surgical components [7]. The most important advantage of EDM process is that it is unaffected by the mechanical properties of the materials (to be machined) like brittleness, strength and high hardness that are crucial in machining process [8]. In EDM, the material is removed by a series of sparking between tool and work piece, both immersed in a dielectric fluid. High temperature plasma is developed from thermal energy which erodes the work piece material. EDM tool electrode should have properties like high electrical conductivity, thermal conductivity, high melting point, less wear rate, and deformation resistance during machining. In this work, an investigation has been made to determine the effect of Al-SiC composite tool on electrode wear rate while EDM machining on EN-31 tool steel. Material Removal Rate can be defined as amount of material removed per unit time from workpiece and is denoted by MRR. Tool can be defined as wear of tool per unit time and is denoted by TWR. Electrode wear Ratio can be defined as the ratio of TWR to MRR and it is denoted by EWR.

EXPERIMENTAL WORK

Material and Methods

Aluminium alloy 6061 is used as matrix phase & SiC is used as reinforcing phase for fabrication of composite tool. Composition of Al-6061 is depicted in Table 1. The aluminium alloy is reinforced with 4%, 8% & 12% SiC particles having particles size of 400 mesh (37 μm). Composite tool is manufactured by using stir casting technique. In the experiments, Al-6061 and Al-SiC (4, 8 and 12%) composite tool of cylindrical shape having diameter 16 mm and length 30mm been used as tool material. EN 31 Tool Steel block of 20mm*20mm*10mm size hardened up to 741 HV is used as material for work-piece. Sparkonix electrical discharge machine (model S-25) is used to carried out the experiments on EN-31 Tool steel by using Al-6061 and Al-SiC tool electrode (4%, 8% and 12%). Side flushing system having EDM grade oil (dielectric fluid) is used. Each experiment is conducted for time period of 10 min.

Table 1: Composition Analysis of Al-6061 [9]

Components	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Weight%	Balance	0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.10

MRR can be calculated as follows [10]:

$$MRR = \frac{(W_{wi} - W_{wf})}{(\rho_w * T)} \quad (1)$$

TWR can be calculated as follows [10]:

$$TWR = \frac{(W_{ti} - W_{tf})}{(\rho_t * T)} \quad (2)$$

Whereas, W_{wi}= tool weight (before machining), W_{wf}= tool weight (after machining), ρ_w= workpiece density,

T is machining time.

EWR can be calculated as follows:

$$EWR = \frac{TWR}{MRR} \quad (3)$$

Experimental Design

Using taguchi technique, design of experiments (DOE) is formulated and the experiments are performed in random order according to taguchi technique (OA) in Minitab 16. In this study, pulse off time (μs), pulse on time (μs), current (Amp), and SiC (%) in electrode material are taken as input machining parameter. Levels of variable parameters are depicted in Table 2. Material removal rate (MRR), tool wear rate (TWR) and Electrode wear ratio (EWR) are taken as output parameter. The values of fixed parameters are also shown in Table 3. L_{32} orthogonal array is used for conducting the experiments. Weight of work pieces & tool samples is measured before and after every experiment performed to calculate the MRR, TWR and EWR.

Table 2: Levels of Machining Parameters

Parameters	Unit	Level 1	Level 2	Level 3	Level 4
Pulse off duration	(μs)	65	75	-	-
Pulse on duration	(μs)	75	100	200	400
Current	(Amp)	6	8	10	12
SiC (%) in electrode material	(%)	0	4	8	12

Table 3: Fixed Machining Parameters

Sr. No.	Fixed Parameter	Value
1	Voltage	50 V
2	Flushing Pressure	$0.7 \frac{kgf}{cm^2}$
3	Tool Polarity	Positive
4	Work Material	En-31

RESULT AND DISCUSSIONS

Results of Scanning Electron Microscopy (SEM)

Proper distribution of reinforcement throughout the matrix is investigated by SEM. Homogenous distribution of SiCp is seen in matrix. Few clusters of reinforcing particles are visible in case of 12% SiC. Samples are metallographic ally polished before the analysis. SEM images of fabricated composites are obtained by scanning electron microscope instrument. The microstructures of composite tool material are studied with JOEL model JSM-6610LV.

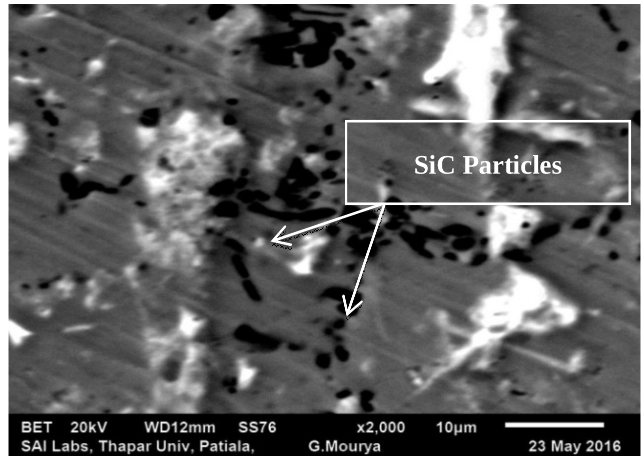

Fig. 1: SEM Image Shows Distribution of SiCp (4%) in Al-6061

It can be seen from Fig. 1, in small portion of fabricated composite tool sample, SiC particles having weight percentage of 4% in Al-6061 metal matrix are homogeneously distributed.

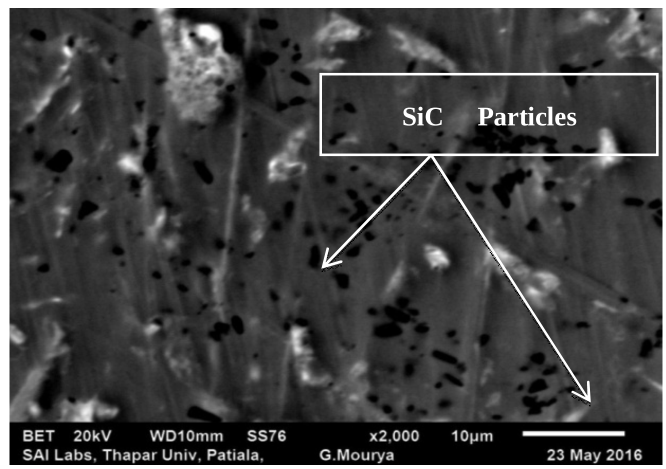

Fig. 2: SEM Image Shows Distribution of SiCp (8%) in Al-6061

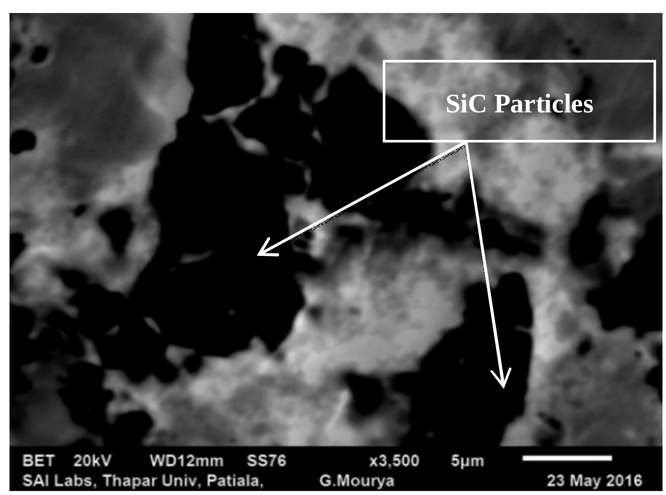

Fig. 3: SEM Image shows Distribution of SiCp (12%) in Al-6061

It can be seen from Fig. 2, in small portion of fabricated composite tool sample, SiC particles having weight percentage of 8% in Al-6061 metal matrix are homogeneously distributed. We can see from figure that SiC particles are more randomly distributed as compared with other weight percentages.

It can be seen from Fig. 3, in small portion of fabricated composite tool sample, SiC particles having weight percentage of 12% in Al-6061 metal matrix are homogeneously distributed. It is clear from Fig. that clustering of SiC particles are observed with higher weight percentage of reinforcing particles.

Experimental Results

32 experiments were conducted at different setting of controlled parameters. After performing EDM of work material EN-31 with the fabricated composite tool, the results obtained like material removal rate (MRR), tool wear rate (TWR) & Electrode wear rate corresponding to input parameters like pulse off duration, pulse on duration, current & SiC% in electrode material are mentioned in Table 4.

Table 4: Results of Experiments

Sr. No.	Pulse off Duration (μs)	Pulse on Duration (μs)	Current (Amp)	SiC% in Electrode Material	MRR ($\frac{mm^3}{min}$)	TWR ($\frac{mm^3}{min}$)	EWR in%
1	65	75	6	0	16.127	11.3046	70.096
2	65	75	8	4	21.1210	10.7698	50.9909
3	65	75	10	8	26.1146	10.9796	42.0440
4	65	75	12	12	35.6815	13.9423	39.0743
5	65	100	6	0	20.0891	13.5285	67.3424
6	65	100	8	4	25.0191	11.7320	46.8923
7	65	100	10	8	27.1592	12.4584	45.8717
8	65	100	12	12	40.0891	15.9393	39.7597
9	65	200	6	4	21.7579	7.47594	34.3595
10	65	200	8	0	21.6178	9.63676	44.5778
11	65	200	10	12	27.6560	7.61834	27.5467
12	65	200	12	8	41.6942	11.4972	27.5750
13	65	400	6	4	25.8980	8.32716	32.1535
14	65	400	8	0	24.9808	9.71089	38.873
15	65	400	10	12	36.4331	8.54289	23.4481
16	65	400	12	8	45.2611	12.0517	26.6271
17	75	75	6	12	25.5031	9.2085	36.1075
18	75	75	8	8	24.5222	11.2014	45.6787
19	75	75	10	4	20.8662	10.3256	49.4851
20	75	75	12	0	32.3821	16.0859	49.6754
21	75	100	6	12	29.1974	12.4630	42.6852
22	75	100	8	8	27.7324	14.3438	51.7220
23	75	100	10	4	23.1719	12.7683	55.1024
24	75	100	12	0	36.687	19.1252	52.1296
25	75	200	6	8	24.5987	9.83364	39.9762
26	75	200	8	12	28.7898	9.61538	33.3985
27	75	200	10	0	28.2165	11.3417	40.1953
28	75	200	12	4	37.1592	12.3982	33.3651
29	75	400	6	8	27.6815	9.68576	34.99
30	75	400	8	12	31.6815	10.3180	32.5682
31	75	400	10	0	32.5350	12.0459	37.0248
32	75	400	12	4	42.5732	13.2124	31.034

Effect of SiC% in Electrode Material on EWR

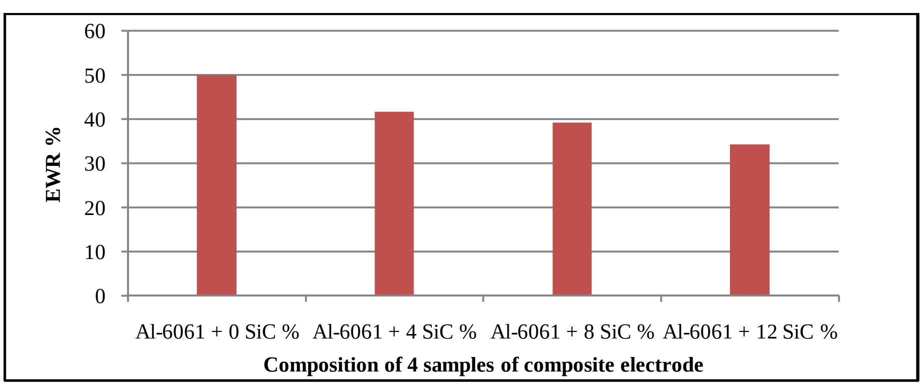

Fig. 4: Effect of SiC% in EWR

In Figure 4, Effect of SiC% in EWR is shown. It is clear from figure 4 that SiC% has great impact on electrode wear rate. It is calculated by taking average EWR of four different compositions used in this project. We can see from mentioned figure that by increasing SiC% in electrode the EWR is decreasing simultaneously.

CONCLUSIONS

Within the selected range of parameters for study following conclusion can be made:

1. Best results of MRR are obtained at the setting of current (12Amp), Pulse on time (400µs), Pulse off time (65µs) and SiC% in electrode material (8%).
2. Best results of TWR are obtained at the setting of current (10 Amp), Pulse on time (200µs), Pulse off time (65µs) and SiC% in electrode material (12%).
3. EWR decreases by increasing the SiC% in electrode material.

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