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Development of Al-SiC MMC by bottom pouring stir casting and parametric analysis on EDM

Jay A. Patel[1], Chirag P. Patel[2]

[1]Post Graduate Scholar, Department of Advanced Manufacturing Systems, U.V. Patel College of Engineering, Ganpat University, Mehsana, Gujarat, India
[2]Associate Professor, Mechanical Engineering Department, , U.V. Patel College of Engineering, Ganpat University, Mehsana, Gujarat, India.

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Abstract - *Development of metal matrix composite (MMC) to study about the microstructures, hardness of as cast silicon carbide (SiC) reinforced with aluminum metal matrix composite. Aluminum (HE 30) and Silicon carbide reinforced particles metal-matrix composites (MMCs) were fabricated by bottom pouring stir casting technique. The MMC are prepared with varying the reinforced particles of SiC by weight fraction ranging from 10,15,20 in percentage. The average reinforced particles sizes of SiC is 400 mesh. Hardness for all cast composite and microstructure of Al-15% SiC composite are analyzed.*

Non-conventional processes such as electrical discharge machining (EDM) could be one of the best suited methods to machine such composites. Prepared specimens of Al-SiC MMC are used as work piece (anode), copper electrodes are used as tool (cathode) and kerosene oil is used as the dielectric fluid. Four machining parameters such as discharge current I (5,12,20 Amp), pulse on time (100,500,1000 µs), gap voltage Vg (10,20,30 Volts) and material property weight fraction of SiCp (10,15,20)and responses like material removal rate (MRR), tool wear rate (TWR), and surface roughness (Ra) are considered in this study. Taguchi method is adopted to design the experimental plan. The influence of each parameter on the responses is established using analysis of variances (ANOVA).

Key Words: *Metal matrix composite, stir casting, hardness, Microstructure, Electrical discharge machining, Anova*

1. INTRODUCTION

Composite materials play an important role in the field of engineering as well as advance manufacturing in response to unprecedented demands from technology due to rapidly advancing activities in aircrafts, aerospace and automotive industries.[1]

There are two major reasons for the current interest in composite materials. The first is simply the need for materials that will outperform the traditional monolithic materials. The second and more important in the long run is that composite offer engineers the opportunity to design totally new materials with the precise combination of properties needed for specific tasks.[2]

1.1 Al-SiC MMC

Aluminum is used widely as a structural material especially in the aerospace industry because of its light weight properties. Its low strength and low melting point of aluminum were always a problem. An effective method of solving these problems is to use a reinforced element such as SiC particles and whiskers. The main objective of using silicon carbide reinforced aluminum alloy composite system for advanced structural components to replace the existing super alloys.

1.2 Stir casting process

In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting as shown in figure 1.

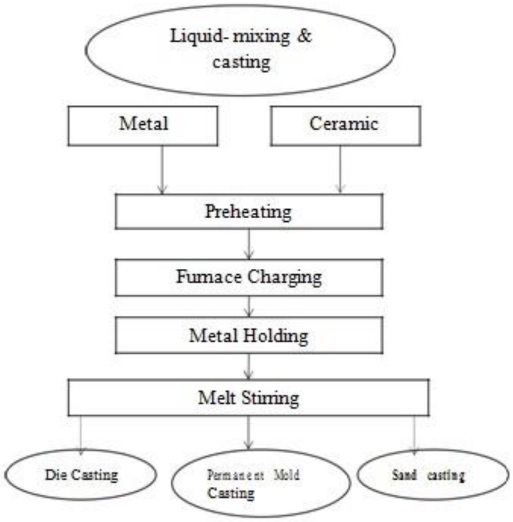


Fig - 1: Process of Stir Casting [3]

Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical. For that reason, stir casting is currently the most popular commercial method of producing aluminum based composites. [4]

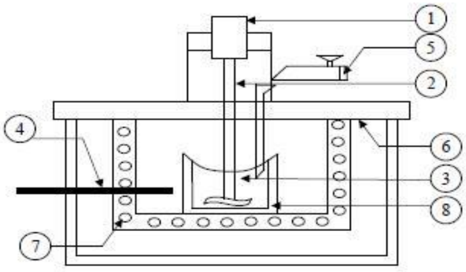


Fig - 2: Schematic view of setup for Fabrication of composite [5]

1. Motor	2. Shaft
3. Molten aluminum	4. Thermocouple
5. Particle injection chamber	6. Insulation hard board
7. Furnace	8. Graphite crucible

2. Literature review on development of MMC

K.Umanatha,S.T.Selvamanib,K. PalanikumarKc and D.Niranjanavarmaa et. al. [7] Aluminium alloy (AA6061) hybrid metal matrix composites (HMMCs) with 5 to 25% vol. fractions of Silicon Carbide and Aluminium Oxide reinforcements were created by stir casting technique. metal to metal wear behavior of hybrid composite and that of un-reinforced alloy was investigated by pin-on-disc wear testing machine. The optical micrographs of hybrid composites produced by stir casting methodology shows that the allocation of SiC and Al particulates in MMC is homogeneous. The porosity of the test material increases with increase in vol. fraction of reinforced particles.

A. Ourdjini, K.C. Chew, B.T. Khoo et. al. [8] Isothermal holding of A356 Al alloy reinforced with 20 wt. % of SiC And examination on microstructure for settling of particles during liquid processing of composite. and get in results, settling measurements during isothermal holding show that the SiC particles settle at much lower rates than predicted by isothermal model. Qualitative examination of the settling phenomenon shows that composites reinforced with low volume fraction of particles tend to settle faster particularly if the melt temp is high.

S.Balasivanandha Prabu, L.Karunamoorthy, S.Kathiresan, B.Mohanb et. al. [9] fabricated A384 aluminium alloy with stirring speeds have been taken as 500, 600 and 700 rpm and the stirring times taken were 5, 10 and 15 min for this study. and results revealed that stirring speed and stirring time influenced the microstructure and the hardness of composite. From the microstructure analysis, it has been found that during lower speed and lower stir time particle clustering occurred in some places, and some places were identified without SiC inclusion. By increasing the stirring speed and stirring time better homogeneous distribution of SiC in the Al matrix were found. Better distributions of SiC were found at 600 rpm and 10 min stirring time condition. It was found from the hardness test.

J. Hashim, L. Loony, M.S.J. Hashmi et. al. [10] mechanical stirring is necessary to help to promote wettability of SiC particles in the matrix alloy A356 and magnesium as a wetting agent. Increasing the volume percentage of SiC particles in the matrix alloy decrease the wettability. Using magnesium enhances wettability increasing the contact above 1 wt. % Mg increases the viscosity of the slurry to the detriment of particles distribution.

Md. Habibur Rahmana, H. M. Mamun Al Rashedb et. al.[11] investigated microstructures, vickers hardness, tensile strength and wear performance of the prepared composites were analyzed. and get in out form of addition of SiC in Al matrix increased vickers hardness and tensile strength of composites. when compared with unreinforced Al. 20 wt. % SiC content AMC showed maximum hardness and tensile strength. Wear resistance of SiC reinforced AMCs showed an increase with increasing SiC content in Al matrix. 20 wt. % SiC reinforced AMC showed maximum wear resistance.

3. DEVELOPMENT OF Al-SiC MMC

In the present work HE 30 aluminum alloy is taken as matrix and SiCp (400 mesh size) is selected as reinforcement. Al-SiC composites were developed through bottom pouring stir casting process by varying percentage of weight fraction for SiCp (10 %, 15 %, and 20 %) in melt aluminum matrix at SwamEquip, Chennai. and then after Hardness and microstructure of cast sample analyzed.

Table - 1: composition of HE 30 alloy

Element	Contain %
Si	0.8
Fe	0.2
Cu	0.03
Mn	0.65
Mg	0.92
Zn	0.039
Ti	0.025
Cr	0.035
Ni	0.005
Al	97.20

3.1 Bottom pouring type stir casting furnace

A special designed furnace in which pouring of melt into the mould happens from its bottom through a remote control switch. This type of furnace does not require the user to lift and pour the melt into the mould.

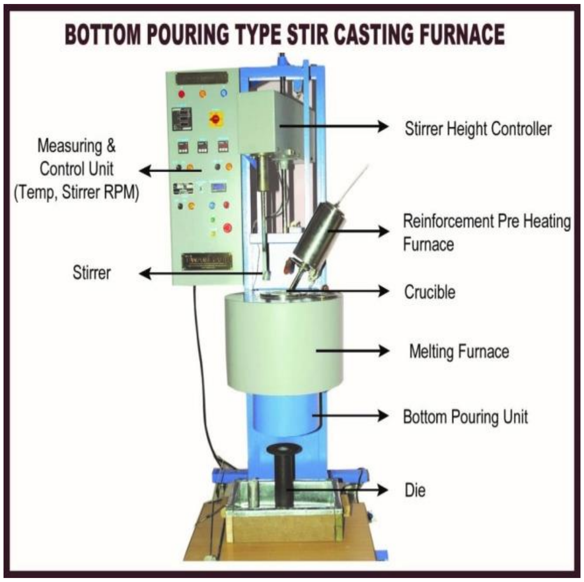


Fig - 3: Bottom pouring type stir casting furnace [12]

3.2 Fabrication Method

First of initial start the furnace. Ingots of aluminium alloy (HE 30) were melted at 720ºC and mixing the SiC particles were preheated at 300ºC for 30 min to make in hot air oven. Degasser 22 tablet was added during melting of aluminium alloy and after addition of SiC particles.

The furnace temperature was first raised above the liquids to melt the alloy ingot completely and was then cooled down to 600 ºC. the liquids to keep the slurry in a semi-solid state. At this stage the preheated SiC particles (10 %, 15 %, and 20 %) were added. To overcome wettability problem 1% magnesium was added in slurry.

After sufficient mixing was done, the composite slurry was reheated to a fully liquid state and then automatic mechanical mixing was carried out for 10 minutes at a stirring rate of 600 rpm. In the final mixing process, the furnace temperature was controlled within 720 ± 100ºC. Pouring of the composite slurry has been carried out in bottom pouring die.

Five Al-SiC stir cast product produced with percentage of weight fraction of 10, 15, 20 SiC are shown in Table 2.

Table - 2: Experiment Table

No	(% SiC)	SiC in gm	Al in gm	Mg in gm	Shielding gas (Argon)	Strring speed (RPM)	Stirring time (minute)
1	10	100	1065	10(1 %)	-	500	10
2	10	150	1500	-	1LPM	600	10
3	20	300	1500	-	-	600	10
4	10	150	1500	15(1 %)	-	600	10
5	15	225	1500	15(1 %)	-	600	10

Fig - 4: Cast part

By visual inspection it is observed that SiC particles are not incorporate in Al-SiC MMC. It might be due to poor wettability of particles or Settlement of silicon carbide particle. But 10% of Al-SiC part is faithfully pass in the hardness test.

4. Hardness test

Theoretically the hardness of the cast part should be uniform from the top to the bottom. However, other factors such as cooling rate, gravity effect and non-uniform distribution of the particles in the cast part will give different values of hardness. The experimental data shows the hardness of the cast part.

here show that the hardness of all Al-SiC cast sample is tested by Vickers hardness testing machine (ASTM E 384).

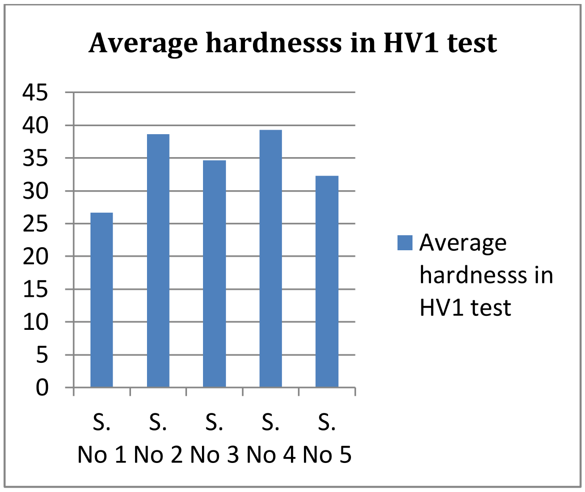
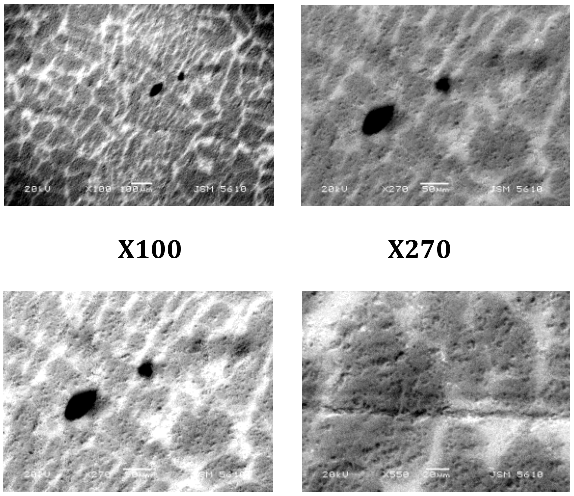


Chart - 1: Hardness value of cast sample with different composites

From above chart 1, it is seen that hardness of composite which reinforced with 10% SiC (S. No 2 & 4) compare to Md. Habibur Rahman et. al obtained that 42.30 ± 2.43 HV hardness of Al alloy - 10% SiC (200-270 mesh size). which is faithfully satisfied compare to present composite result.[10]

5. Microstructure analysis

The microstructure of sample is studied using scanning electron microscopy analysis (SEM) and it is presented in Figure 5.



X100 **X270**

X270 **X500**

Fig - 5: scanning electron microscopy analysis (SEM) of cast sample (Al-15% SiCp)

The particles are unevenly distributed macroscopically (SEM test) in fig 5, because of some particle-free zones due to particle pushing effects during solidification and some particle agglomeration.

6. Literature review on Electric discharge machining

Manish Vishwakarma et. al. [12] reviews the recent developments and advances in the field of high performance manufacturing environment using Die Sinking EDM, WEDM, Dry EDM and RDE-EDM. The review is based on prominent academic publications researches. EDM process, its working principle, and basic process parameters are discussed. The results obtained indicate that Al/SiC MMC is machinable by using some non-conventional machining processes. The findings show that EDM process is suitable for machining particle reinforced metal matrix composite (PRMMCs), but the process is very slow. The research work focuses mainly on influence of reinforcement on surface quality of machined material. So EDM has emerged as the most cost effective and high precision machining process in past years. The machining capacity to remove hard and difficult to machine parts has made EDM as one of the most important machining processes.

C.Velmurugan,R.Subramanian,S.Thirugnanam,B.Ananadavel et, al. [13] investigated the effect of parameters like Current(I), Pulse on time(T), Voltage(V) and Flushing pressure(P) on metal removal rate (MRR),tool wear rate(TWR) as well as surface roughness(SR) on the machining of hybrid Al6061 metal matrix composites reinforced with 10% SiC and 4%graphite particles. Composite was fabricated using stir casting process. A central composite rotatable design was selected for conducting experiments. Mathematical models were developed using the MINITAB R14 software. The method of least squares technique was used to calculate the regression coefficients and Analysis of Variance (ANOVA) technique was used to check the significance of the models developed. Scanning Electron Microscope (SEM) analysis was done to study the surface characteristics of the machined specimens and correlated with the models developed. They found that metal removal rate of the composite increases with increase in current, pulse on time and flushing pressure of the dielectric fluid while it decreases with increase in voltage. Tool wear rate of the developed composite increases with increase in current and voltage and it decreases with increase in pulse on time and flushing pressure of the dielectric fluid. They found that surface roughness of the composite during electric discharge machining increased with increase in current, pulse on time, voltage and flushing pressure.

Harpreet Singh, Amandeep Singh et, al. [14] EDM is generally used for machining for those materials which are cannot processed by conventional machining process. In this studied we compared the material removal rate achieved using different tool materials. Workpiece used is AISI D3 and tool materials used copper and brass electrode with pulse on/pulse off as parameter. The electrolyte used is kerosene oil. In case of brass electrode the MRR increases with the increase in the pulse on-time from 50-100µs. This may be reason that as the MRR of brass electrode is less as compare to copper electrode so less debris are produced which can be easily flushed away in pulse off time of 50µs. the increase in pulse off time from 15µs to 20µs the MRR increased for both copper and brass electrodes . At short pulse off time (15µs) MRR is less due to the fact that with short pulse off time the probability of arcing is very high, because the dielectric in the gap between the work piece and electrode cannot be flushed away properly and the debris particles still remain in discharge gap and this results in arcing, due to which MRR decreases. With the increase in pulse-off time, better flushing of debris take place from the inter-electrode gap, resulting in increase in MRR.

7. DESIGN OF EXPERIMENT

In the Taguchi method the results of experiments are analyzed to achieve one or more of the following objectives:

- To establish the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trends of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on an EDM process.

7.1 Selection of process parameters

Most researchers identified EDM process parameters that greatly affect response parameters. Process parameters like Current, Pulse ON time, Pulse OFF time, Voltage, Flushing pressure, Duty cycle are most frequently used for research work. Thus in this study Current (A), Gap voltage (V), and pulse on time (µs) and Material (% of SiCp) of developed material taken to identify influential parameter on response variables like Material removal rate (MRR), Tool wear rate (TWR), Surface roughness (Ra).

Table - 3: Machining parameters with level value

Sr no.	Machining parameter	Level 1	Level 2	Level 3
1	Current (amp)	5	12	20
2	Gap Voltage (Volt)	10	20	30
3	Pulse on time (µs)	100	500	1000
4	Material (% of $SiC_{p)}$	10	15	20

Table - 4: Fixed variables

Sr no.	Fixed Parameter	Set value
1	Pulse off time (µs)	50
2	Tool Electrode	Copper
3	Dielectric fluid	Kerosene + oil

As per table 5, L27 orthogonal arrey of "Taguchi method" has been selected for experiment design in MINITAB 17.

Table - 5: Experiment Design of L27

Sr No.	Current (amp)	Gap voltage (v)	Pulse on time (µs)	Material (% of SiC_p)
1	5	10	100	10
2	5	10	100	10
3	5	10	100	10
4	5	20	500	15
5	5	20	500	15
6	5	20	500	15
7	5	30	1000	20
8	5	30	1000	20
9	5	30	1000	20
10	12	10	500	20
11	12	10	500	20
12	12	10	500	20
13	12	20	1000	10
14	12	20	1000	10
15	12	20	1000	10
16	12	30	100	15
17	12	30	100	15
18	12	30	100	15
19	20	10	1000	15
20	20	10	1000	15
21	20	10	1000	15
22	20	20	100	20
23	20	20	100	20
24	20	20	100	20
25	20	30	500	10
26	20	30	500	10
27	20	30	500	10

7.2 Response variables evaluation

Metal removal rate (MRR) is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time, i.e.

$$MRR = \frac{Wjb - Wja}{T} \quad g/min$$

Where, Wjb and Wja are the weights of the work piece before and after machining, and T is the machining time.

Tool wear rate (TWR) is expressed as the ratio of the difference of weight of the tool before and after machining to the machining time, i.e.

$$TWR = \frac{Wtb - Wta}{T} \quad g/min$$

Where, Wtb and Wta are the weights of the tool before and after machining and T is the machining time. [13]

Surface roughness (SR) of the machined work piece is evaluated using a Mitutoyo talysurf tester SJ-210 with a diamond stylus tip.

Table 6, shows the result in terms of response variables as a MRR, TWR and SR values for all 27 experiments.

Table - 6: L27 Experiment data

Sr No.	Current (amp)	Gap voltage (v)	Pulse on time (µs)	Material (% of SiC_p)	MRR (g/ min)	TWR (g/ min)	SR (µm)
1	5	10	100	10	0.016	0.007	3.46
2	5	10	100	10	0.015	0.006	3.16
3	5	10	100	10	0.016	0.007	3.52
4	5	20	500	15	0.021	0.009	5.16
5	5	20	500	15	0.021	0.009	4.78
6	5	20	500	15	0.020	0.010	4.37
7	5	30	1000	20	0.031	0.012	6.45
8	5	30	1000	20	0.032	0.011	6.52
9	5	30	1000	20	0.033	0.010	6.53
10	12	10	500	20	0.034	0.012	10.93
11	12	10	500	20	0.033	0.013	10.29
12	12	10	500	20	0.034	0.012	11.45
13	12	20	1000	10	0.037	0.009	11.21
14	12	20	1000	10	0.037	0.010	11.22
15	12	20	1000	10	0.036	0.012	11.22
16	12	30	100	15	0.033	0.016	7.17
17	12	30	100	15	0.035	0.014	7.06
18	12	30	100	15	0.034	0.015	6.72
19	20	10	1000	15	0.048	0.018	12.25
20	20	10	1000	15	0.050	0.016	13.76
21	20	10	1000	15	0.052	0.014	13.70
22	20	20	100	20	0.046	0.020	11.96
23	20	20	100	20	0.043	0.023	11.53
24	20	20	100	20	0.044	0.022	11.68
25	20	30	500	10	0.042	0.019	8.54
26	20	30	500	10	0.041	0.020	8.54
27	20	30	500	10	0.043	0.018	8.37

8. Anova analysis

The experimental results obtained are plotted for main effect on MRR, TWR, SR.

- **Main effect plots for MRR**

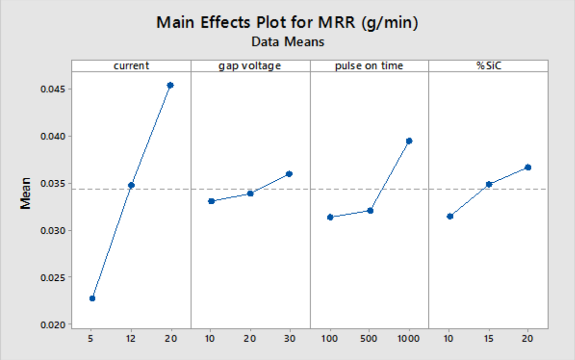


Fig - 6: Graph of input parameters v/s Material removal rate

In EDM process the impact of different machining parameters likes current, pulse on time, gap voltage and material has significant impact on MRR, as shown in above the figure 6.

In this work, Current is relatively depend on MRR in the range of 5A to 20A. This is expected way to outcome because when increase in pulse on time then current produced strong spark. which produced higher temperature at that time moreover material to melted and removed from the work piece. Apart from it is clearly seen that the another factors does not affect more then compared to current.

when increase the current from 5A to 20A material removal rate increased. But MRR decreased monotonically with the increase in pulse on time. In this experiment gap voltage has no more significant effect shown on MRR because of the value of gap voltage taken is 10V, 20V, 30V.

It is well known truth that the spark energy increases with pulse on time. MRR generally starts to decrease when the value of pulse on time increase up to maximum limit. This was due to higher pulse on time, the plasma produced between inter electrode gap in reality hinder transferred energy and thus reduced MMR.

And the material has been used in EDM process it is shown that $\%SiC_p$ is increase than MMR is also increase, because of the reinforcement is added by weight of percentage then material become more harder so the that effect on the MMR it shown.

- MRR is 20 Amp (current), 30 volt (Gap Voltage), 1000 µs (pulse on time), 20 %SiCp (Material). it is observed from the graphs and obtained that it is optimum value of MRR.

➢ **Main effect plots for TWR**

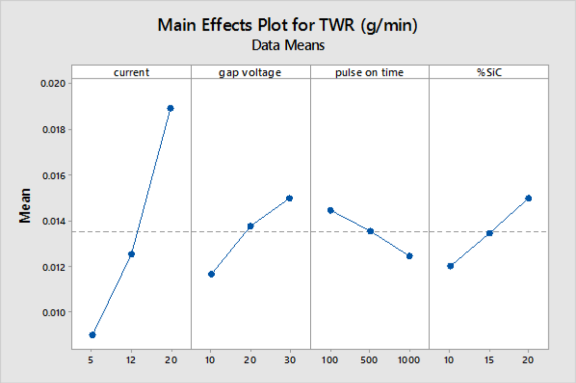


Fig - 7: Graph of input parameters v/s Tool wear rate

In EDM process the impact of different machining parameters likes current, gap voltage, pulse on time and material has significant impact on TWR as shown in above figure 7.

When current increase then pulse energy also increase and therefore additional heat energy has been produced in the tool work piece, leading to increase in melting and evaporation of the electrode.

Current is directly impact on TWR and pulse on time is relatively to reduced tool wear rate.

- 5 Amp (current), 10 volt (Gap Voltage), 1000 µs (pulse on time), 10 %SiCp (Material). it is observed from the graphs and obtained that it is optimum small value of TWR.

➢ **Main effects plots for SR**

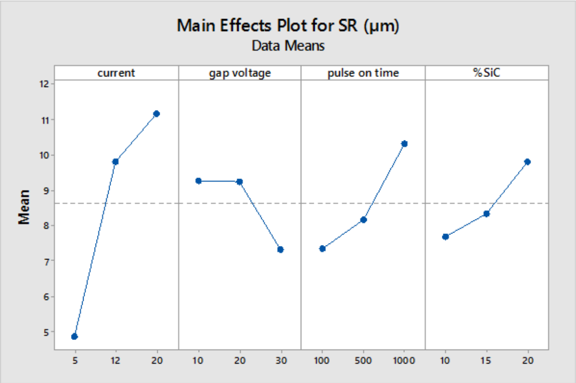


Fig - 8: Graph of selected process parameters v/s Surface roughness

In EDM process the impact of different machining parameters likes current, gap voltage, pulse on time and material has significant impact on SR, as shown in above figure 8.

In this work, Current is relatively depend on MRR in the range of 5A to 20A. it is expected way to outcome because when increase in pulse on time then current produces strong spark. which produced creation a bigger crater at the place of discharge and therefore rougher surface is produced. Apart from it is clear that the other factor does not influence much as compared to current.

Related trends of surface roughness are obtained through the increase of pulse on time and with increase in gap voltage SR decrease as shown in figure 8.

- 5 Amp (current), 30 volt (Gap Voltage), 100 µs (pulse on time), 10 %SiCp (Material). it is observed from the graphs and obtained that it is best surface finish value of SR.

8. CONCLUSION

In the present work the preparation of Al-SiC metal matrix composite through bottom pouring stir casting and the parametric analysis on Electrical discharge machining of MMC. A taguchi design and Anova analysis method is proposed to find the optimal setting of process parameters to give better machining characteristic. From the project work following conclusions can be drawn, based on the experimental results.

- Bottom pouring stir casting technique could not be successfully developed with 15 and 20 percentages of SiC reinforcement caused with poor distribution of SiC particles in the metal matrix composite (MMC).

- During experimentation work it observed that the porosity in aluminium - silicon carbide (Al-SiC) composite is increased with from 10 to 15 and 20 volume fraction of SiC reinforced particles in Aluminium matrix.

- It has been seen that higher hardness value in which reinforcement with 10 percentage SiC composite is 39.33HV1 compare to 15 and 20 percentage are 32.33 and 34.67HV1 respectively.

- In scanning electron microscopy analysis particles are unevenly distributed in 15 percentage of SiC in Al-SiC composite.

- Based on the conducted experimentation of Al-SiC MMC were used 10, 15, 20 percentage of SiC reinforced, but highly recommend that must not go after 10 percentage of SiC for MMC, because of it is not given the better result.

- From the Anova analysis find that for MRR, current was the most influential factor and then pulse on time. MRR increased 0.023 to 0.048 g/min with the current from 5A to 20A and as the pulse on time extended after certain limit then MRR decreased monotonically.

- In tool wear rate, current 5A to 20A has a significant direct effect on TWR and pulse on time 100µs to 1000µs is relative to reduce 0.015 to 0.012 g/min for the tool wear rate. gap voltage has no much more major effect shown on TWR because of it range is to smaller.

- About Surface roughness(SR), the most important factor was current but during experiment observed that at 10 gap voltage creation a bigger crater at the place of discharge and therefore rougher surface is produced. while increased pulse on time 100µs to 1000µs effect on SR increased 7.06 µm to 13.76 µm was observed.

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