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Prediction and Control of Cutting Parameters for Machining Al-Sic MMC Material by Wire Cut EDM Process

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ABSTRACT

Wire cut Electric Discharge Machining (WEDM) is a vital technology, which is required for high – speed cutting and high – precision machining to enhance productivity and accuracy for manufacturing of press tools, moulds, prototype parts and complicated contours etc. The machining system involves many input parameters effecting output. The main objective of this work is to determine the optimum values of machining parameters for attaining economical and competent performance for machining Al-3% SiC metal matrix composite (MMC). The MMC material is made by stir casted and the specimen is prepared for machining and testing. The cutting operations are carried out on WEDM by varying the machining current on work pieces of thickness ranging from 5mm to 80mm. The machining current, cutting speed, spark gap, and surface roughness value is measured. The material removal rate (MRR) is computed by measuring cutting width using Profile projector. The optimal current value at which the machining is stable with the high cutting speed is identified. Mathematical correlations are developed by using Origin software to determine the cutting parameters, machining current, cutting speed, spark gap, the MRR and Surface roughness. The developed correlations are useful for evaluating the machining parameters for different machining situations arising out of customer requirements and machining time calculation in turn to change cost of machining.

Keywords:- WEDM, Al-3% SiC MMC, Machining Current, Cutting Speed, Spark gap, Surface Roughness, MRR, Origin, Mathematical Correlations.

I. INTRODUCTION

The Wire cut Electrical Discharge machining (WEDM) is a High- precision machining process in the field of conducting and hard – to machining materials. Electrical sparks are produced between the wire as one electrode and work piece as another electrode. The electrodes are flushed with the de-ionized water as di- electric. The material will be cut and removed in the form of tiny particles by the way of melting and vaporization after freezing once the spark jumps between the electrodes. Fig.1 shows the schematic view of the WEDM process.

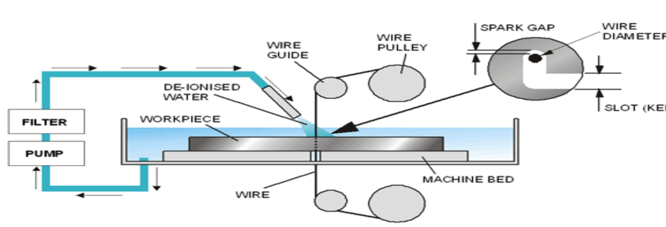


Fig.1 Machining in Wire EDM

WEDM machining uses a thin single strand metal wire usually brass is fed through the work piece. The wire, which is constantly fed from a spool, is held between upper and lower guides. The guides move in the X-Y plane. This gives the wire EDM the ability to be programmed to cut very intricate shapes.

WEDM is considered as one of the most versatile process for machining intricate, complex shapes and difficult to machine materials. A number of research works have been carried out on different materials to study the influence of different process parameters. Al has the properties of high corrosion resistance and good machinability, because of these properties it is commonly used for construction of air craft structures such as wings and fuselages. MMCs are the materials consisting of two or more constituent materials in which a metal is reinforced with high strength materials such as SiC etc. in various proportions. This leads to MMCs with enhanced properties like high strength, high wear resistance. However, the reinforcement material in various forms (particulate, whiskers and continuous fibers) makes it difficult to machine using traditional machining methods due to its hardness.

In the present investigation, Aluminium is used as the matrix material typically characterized by properties such as fluidity, corrosion resistance, castability and high strength – weight ratio. Its strength increases, when Aluminium matrix is reinforced with the hard ceramics particles like Al_2O_3, MoS_2 [1].

II. LITERATURE REVIEW

Rajesh Kumar et al. [2] explained the overview on stir casting process, process parameter, & preparation of AMC material by using aluminium as matrix form and SiC, Al2O3, graphite as reinforcement by varying proportion.

Khalid Almadhoniet al. [3] explained the importance of stir casting for production of aluminium metal matrix composites, various process parameters of stir casting process, such as stirrer design, stirrer speed, stirring temperature, stirring time (holding time), preheat temperature of reinforcement, preheated temperature of mould, reinforcement feed rate, wettability promoting agent and pouring of melt, and difficulties encountered in the fabrication of AMMC's via stir casting technique.

Amir Hussainidrisi et al [4] has developed the metal matrix composite materials by combining the desirable attributes of metals and Ceramics. Here Aluminium 5083 is used as the matrix material in which Sic is added as the reinforced material and studied behavior of Aluminum 5083 with Sic as reinforcement produced by stir casting method and ultrasonic assisted stir casting method. Different percentages of reinforced particles are mixed and different specimens are made.

Sanjeev KR. Garg et al. [5] investigated the machining characteristics and the effect of wire EDM process parameters while machining of Al-ZrO_2 particulate reinforced metal matrix composite (PRMMC). Central composite design (CCD) of response surface methodology (RSM) considering full factorial approach was used to design the experiments. The input parameters for optimization were pulse width, time between pulses, short pulse time, servo control mean reference voltage, wire feed rate and wire tension. The response measures considered are surface roughness and cutting velocity. The multi optimization results obtained by initial input parameters setting, grey relational techniques and response surface methodology are compared and validated by confirmation experiments.

Anand Sharma et al. [6] experimentally investigated the influence of process parameters namely pulse on time (Ton), pulse off time (T off), peak current (IP) and servo voltage (SV) on cutting rate (CR) using wire electric discharge machining (WEDM) on Al 6063 + $ZrSiO_4$(p) (5%) metal matrix composite. A Box-Behnken design approach of response surface methodology (RSM) was used to plan and analyze the experiments. To determine optimal values of cutting rate mathematically, the mathematical relationships between WEDM input process parameters and response parameter were established. The Analysis of variance (ANOVA) and F test were performed to obtain statistically significant process parameters. The optimal process conditions were verified by conducting confirmation experiments and predicted results were found to be in good agreement with experimental findings. It was concluded that on increasing the pulse on time and peak current, the cutting rate increased, whereas on increasing the pulse off time and servo voltage it decreased the cutting rate. Surface topography of the machined surface showed that large size craters and cracks were formed on the surface when pulse on time was increased to a high level and pulse off time was decreased at a lower level. It is found that the effect of production of crates are more pronounced on the surface of the machined work piece when peak current is increased to a high level and servo voltage is kept at lower level.

Shandilya et.al. [7], attempted to optimize the Kerf in machining of SiC/6061 Al MMC using response surface methodology (RSM). Properties of the machined surface have been examined by using SEM and Mathematical model have been developed for response parameter.

Narender Singh et. al.[8] investigated the effect of WEDM process parameters on Al–10%SiCP MMC with pulse on time, current and flushing pressure as process parameter and MRR, tool wear rate, taper, radial overcut, and surface roughness as responses using brass wire electrode of diameter 0.27 mm. Taguchi L27 orthogonal array has been used for experimental design. Mathematical model has been developed by regression analysis and optimized using gray relational analysis technique. The results revealed that pulse on are the most significant factor.

Siva Naga MalleswaraRao et.al [9] evaluated the optimal parameters for machining different tool materials with WEDM using Origin software and derived mathematical correlations. These correlations are useful in finding the parametric settings on machine for a wide range of thick jobs.

III. EXPERIMENTAL METHODOLOGY

The experiments are designed by using Taguchi L_9 array with the machining parameters as shown in Table.1

Table: 1 Machining parameters and their factor levels used in the experiments

Parameter	Units	Level		
		L1	L 2	L3
Pulse on time (T_{on})	µs	6	8	10
Pulse off time T_{on})	µs	4	5	6
Peak current (I_p)	A	4	3	2
Wire feed (W_F)	mm/min	1	2	3

Electronica - make 4 - axis CNC Wire electrical discharge machine shown in fig.2 is used for the experimentation. De-ionized water is used as dielectric fluid and brass wire of 0.25mm diameter as electrode.

Fig. 2. Experimental set up
(Courtesy: Sri Ratna Tools, Hyderabad)

The following parameters selected as pre setting on the machine [9].

Machine : Electronica make
Dielectric : De-ionized water
Wire material : Brass
Wire tension : 70N
Wire velocity : 3 m/min
Gap voltage : 80 Volts
Wire diameter : 0.25 mm
Flushing pressure : 1 Bar

The Al-3% SiC specimens of 25mm X 70mm size on thicknesses 5, 7.5, 10, 12.5, 15, 17.5, 20,25,30,35,40,45,50,55,60,65,70,75 and 80mm are prepared. The experiments are conducted on the work piece of every thickness by cutting L shape by varying the machining current as per the design of experiments. The cutting speed, spark gap and surface roughness values are measured, MRR is calculated for every experiment and tabulated. The surface roughness is measured on 'L' cut using Talysurf and the cutting width is measured by using Profile Projector. The spark gap is calculated from cutting width.

Cutting width, W= d+ 2 x Sg, Where d is the wire diameter and Sg is the Spark gap.

The MRR is calculated as, MRR = T x W x Cs where Cs is the cutting speed.

The optimum values of machining current, cutting speed, spark gap and MRR for every thickness are used for plotting the curves and best fit curve is selected using software. The mathematical relation is generated for this best fit curve and statistical analysis is performed to find the fitness of the curve.

Experimental Data is shown in the following Table.

S.NO	T, mm	I, amp	$C_{S'}$ mm/min	$S_{g,}$ µm	MRR,mm^3/min	SR, Ra, µm
1	5	5.3	5.25	56.32	9.433	3.51
2	7.5	5.56	4.68	37.95	10.59	3.69
3	10	5.82	4.11	19.58	11.74	3.87
4	12.5	6.05	3.82	17.34	12.74	3.92
5	15	6.28	3.53	15.11	13.75	3.97
6	17.5	6.51	3.24	12.88	14.64	4.03
7	20	6.74	2.95	10.65	15.75	4.13
8	25	6.88	2.50	10.105	16.02	4.62
9	30	7.03	2.06	9.56	16.29	5.05
10	35	7.26	1.93	7.535	17.35	5.14
11	40	7.49	1.81	5.51	18.41	5.25
12	45	7.74	1.80	5.265	20.52	5.37
13	50	8.01	1.79	5.02	22.64	5.50
14	55	8.25	1.78	4.775	24.73	5.62
15	60	8.51	1.77	4.53	26.82	5.75
16	65	8.31	1.56	3.52	24.65	5.82
17	70	8.97	1.36	2.43	22.49	5.89
18	75	9.16	1.15	1.62	20.33	6.01
19	80	9.32	0.95	1.52	18.17	6.00

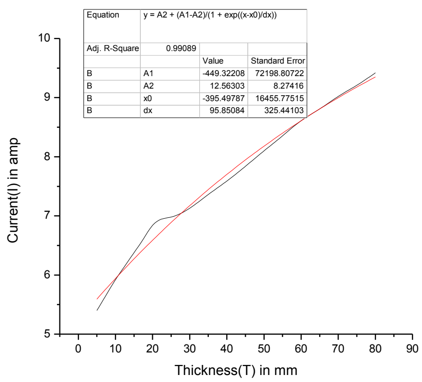
The results are plotted for work piece thickness and current, cutting speed, spark gap, MRR as well as surface roughness using Origin software. The best fit curve was selected based on the results of ANOVA. Mathematical correlations are developed.

IV. RESULTS AND DISCUSSIONS

Fig.3 shows the variation of current required for machining different thick jobs of the material under present investigation. The plot shows that the machining current requirement is increasing with increase in work piece thickness. This is due to increment in volume of material which demands more energy. The variation is also appears to be directly proportional. The best fit curve for all the points is selected for which the standard deviation is 0.01191, lowest. ANOVA was conducted and Regression coefficient, R^2 is 0.99241, nearer to 1. The mathematical correlation for the plot is generated and shown in equation (1).

$$\mathbf{I= 12.56303 - \{461.88511/ [1+exp [(T+395.4979)/95.85084]]\}} \qquad \mathbf{(1)}$$

Where I is the machining current in amp, T is work piece thickness in mm



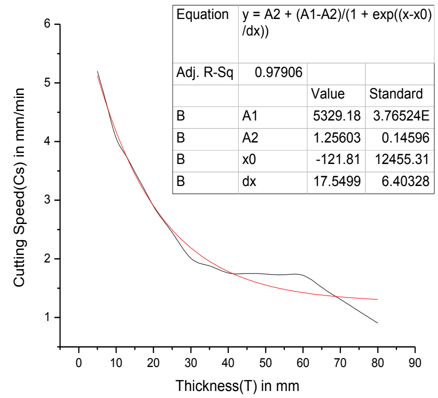


Fig.3 Effect of thickness on current **Fig.4 Effect of thickness on cutting speed**

Fig.4 shows the variation of cutting thickness achieved for machining different thick jobs of MMC. The cutting speed is observed to be decreasing with increase in job thickness. This is due to increase in volume of material to be cut and removed, however the energy input is within the machine limit. The variation is following hyperbolic path. The best fit curve for the values is identified with respect to ANOVA. The mathematical correlation generated is shown in equation 2. The equation is useful in calculating the cutting speed for any given thickness of work piece material under present research.

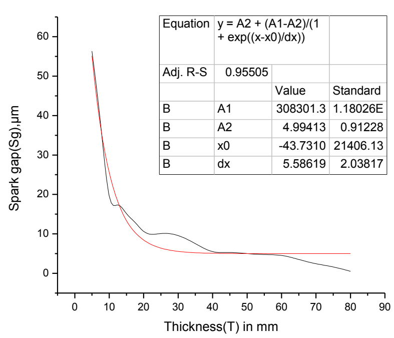
$$C_s = 1.25603 + \{5327.93081 / [1+\exp[(T+121.8194)/17.54991]]\} \quad (2)$$

Where C_s is cutting speed in mm/min, T is work piece thickness in mm

Fig.5 shows the change in spark gap obtained for machining different thick jobs of MMC. The overcut that occurs due to spark jump also called spark gap is calculated by measuring the width of cut using Profile projector. The plot indicates that the spark gap is decreasing with increase in thickness of job. The value is essential to program the machining for achieving accuracy. The mathematical correlation generated is shown in equation 3.

$$S_g = 4.99413+ \{304936.2124 / [1+ \exp[(T+43.66972)/5.58618]]\} \quad (3)$$

Where S_g is Spark gap in micro meter, T is work piece thickness in mm



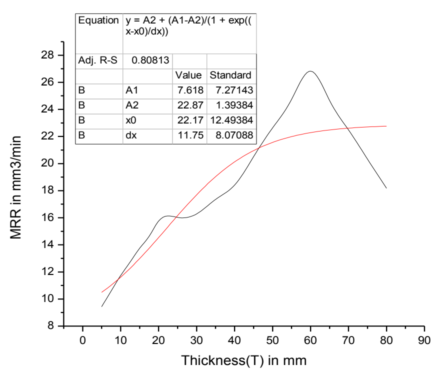


Fig. 5 Effect of thickness on Spark gap **Fig.6. Effect of job thickness on MRR**

Fig. 6 is drawn for the variation of MRR with thickness of work piece using Origin. It is observed that the MRR is increasing with increase in work piece thickness up to 60mm and then declining .The MRR is increasing with increase in work piece thickness and the input machining current. Beyond 60mm thickness the cutting speed decreased drastically as the current cannot be raised due to machine limitations. This may be the reason for decrement in MRR even though thickness is increasing beyond 60mm. The best fit curve is selected based on regression quotient and standard deviation, shown in red colour. The mathematical correlation, equation 1 is developed for determining the MRR and is

MRR= 22.87292 - {15.25477/ [1+exp (T-22.17531)/11.75745]} [4]

Where MRR is Material Removal Rate in mm^3/min, T is work piece thickness in mm

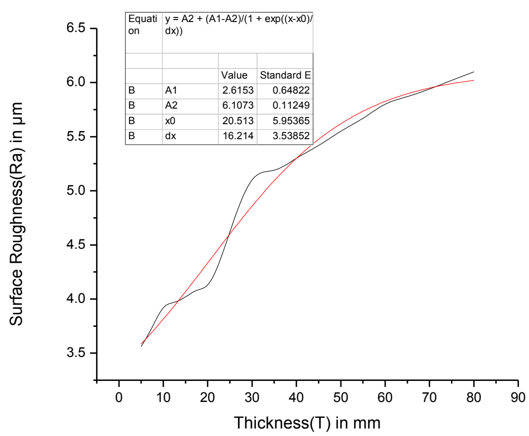


Fig.7 Effect of job thickness on Surface Roughness

Fig. 7 is drawn for the variation of Surface Roughness with thickness of work piece using Origin. It is observed that the Surface Roughness increasing with increase in work piece thickness. The Surface Roughness is increasing, in turn finish is decreasing with increase in thickness of work piece. This is due to higher material removal rate at higher current values demanded by the thickness of the work piece. At higher current values the spark will jump longer and causing more material removal in turn higher roughness. The best fit curve is selected based on regression quotient and standard deviation, shown in red colour using Origin software. The mathematical correlation, equation 3 is developed for determining the Surface Roughness and is

R_a= 6.10731- {3.49197/ [1+exp [(T-20.51324)/16.21468]]} [5]

Where R_a is Surface roughness in µm, T is work piece thickness in mm

V. CONCLUSIONS

In the present work the effect of thickness of Al-3% SiC MMC work piece on machining current, cutting speed, spark gap, MRR and Surface Roughness are evaluated and optimized using Origin software. Mathematical correlations are developed as single objective criteria. The Industry or Academia can utilize any of the correlation for setting up of the machining parameters. These results are useful to make the Wire EDM system to be efficiently utilized in the modern industrial applications like die and tool- manufacturing units for parametric setting, machining time, cost calculations and also for process planning.

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