Tool Wear and Process Cost Optimization in WEDM of AMMC using Grey Relational Analysis

B. Haritha Bai[1], G. Vijaya Kumar[2*], Anand babu. K[3]

[1]Teaching Assistant, [2]Post Doctoral Fellow, [3]Research Scholar
[1,2,3]Department of Mechanical Engineering, S. V. University, Tirupathi - 517 502, Andhra Pradesh, India

Abstract— *Wire Electrical Discharge Machining (WEDM) endorsed sensation in the production of newer materials, especially for the aerospace and medical industries. Using WEDM technology, convoluted cuts can be made through difficult-to-machine electrically conductive components with the high degree of accessible accuracy and the fine surface quality make WEDM priceless. In other hand Aluminum Metal Matrix Composites (AMMCs) are the precise materials for marine, automobile, aerospace, defense, and sports industries which are difficult to cut by conventional methods of machining. In this paper an optimal set of material and machining parameters is derived using hybrid approach called grey-fuzzy approach. For this AMMC samples are produced as per the taguchi experimental design by considering combined material and wire EDM parameters and machined using WEDM machine. The obtained responses such as kerf width, tool wear, process cost and surface roughness are optimized using grey-fuzzy approach which is obtained by combining grey relational analysis and fuzzy logic.*

Keywords— Wire EDM, AMMCs, Taguchi design, tool wear, process cost Grey-fuzzy.

I. INTRODUCTION

Aluminum Metal Matrix Composites (AMMCs) are the well-defined materials for marine, automobile, aerospace, defense, and sports industries, as they have high strength to weight ratio, and possess superior physical and mechanical properties compared to non-reinforced alloys and traditional metals. However, the presence of abrasive reinforcements in the ductile matrix causes rapid tool wear and hence tool failure. This leads to an increase in machining cost, production time and poor quality of machined components. On the other hand, some techniques such as electric discharge machining (EDM) and wire electric discharge machining (WEDM) are quite successful for machining of AMMCs. EDM has limited applications as it can be used only for drilling purpose. WEDM seems to be a better choice as it conforms to easy control and can machine intricate and complex shapes. The setting for the various process parameters required in WEDM process play crucial role in achieving optimal performance. Effective and economical WEDM of AMMCs will open new areas of applications for AMMCs.

II. LITERATURE REVIEW

Very few studies have been undertaken in WEDM of MMCs. Further, most of these studies have been done by using one-parameter-at-a-time approach, which may not explain the effects of interaction among various parameters. Some of past studies on WEDM of MMCs are follows. Sahandilya.P, Jain.P.K. & Jain.N.K [1] investigated made on consider the effect of voltage, pulse-on time, pulse-off time and wire feed rate on MRR and kerf in WEDM of SiCp/6061 AlMMC. Effect of input process parameters show that maximum value of MRR and minimum value of kerf are obtained at lower level of voltage, lower level of pulse-on time. D.Satish kumar & M. Kanthababu & V.Vajjiravelu [2] investigated WEDM of Al/SiCp MMCs in various volume fractions (5%, 10% and 15% of SiC) prepared through stir casting process considering MRR and Ra as outputs. And they concluded the microstructure of stir cast composite shows discrete localized pool/agglomeration of SiC particles indicating constrain of the process for attaining uniform microstructure. Rajesh Kumar Bhuyan, B.C.Routara, Arun Kumar Parida, A.K.Sahoo [3] investigate the effect of process parameters such as pulse on time(Ton), peak current (Ip) and flushing pressure (Fp) , metal removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) during electrical discharge machining (EDM) of Al-SiC12% MMC .The experiment is followed by Central composite design (CCD) method under different combination of process parameters. K.Zakariaa, Z.Ismaila, N.Redzuana and K.W.Dalgarnob [4] investigate the effect of wire EDM cutting parameters for evaluating of Additive Manufacturing Hybrid Metal Material. Hybrid metal materials produce through Additive Manufacturing of Indirect Selective Laser Sintering. It high light those important parameters to be considered in wire cutting process of FeCuSn hybrid metal material produce by Additive Manufacturing of

Indirect Selective Laser Sintering process for fabricating the near net shape metal component. Ravindranadh Bobbili, V.Madhu, A.K.Gogia [5] investigates wire-EDM process parameters of ballistic grade aluminium alloy. Experimentation has been planned as per Taguchi technique. Three performance characteristics namely material removal rate (MRR), surface roughness (SR) and gap current (GC) have been chosen for this study. Yonghua Zhao,Masanori Kunieda, Kohzoh Abe [6] were experimentally investigated the performance of EDM slicing of SiC wafers, the fundamental characteristics of EDM of SiC single crystal. Ibrahem Maher, Liew Hui Ling, Ahmed A, D.Sarha, M. Hamdi [7] experimentally investigated the WEDM for improving process parameters. They concluded that the peak current and pulse on time are the most significant parameters affecting the cutting speed, surface roughness and heat affected zone. The wire tension has minor effect on the cutting speed and heat affected zone but it has great effect on the surface roughness. Cheol-SooLee, Eun-YoungHeo, Jong-MinKim, In-HughChoi, Dong-WonKim [8] investigated this paper presents an effective model to estimate the electrode wear of EDM. The wear amount depends on discharging environment such as material type and hole shapes. The electrode wear makes it difficult to control precise electrode feeding. Therefore, this study proposes an electrode wear estimation model. V. Chengal Reddy, N. Deepthi, N.Jayakrishna [9] studied the effect of various process parameters such as pulse on time, pulse off time, wire tension, current, upper flush and lower flush for Aluminium HE30. Vukcevic and Delijic, [10] were observed an increased interest on metal matrix composite, mostly light metal based, which have found their applications in many industry branches, among others in the aircraft industry, automotive, and armaments ones, as well as in electrical engineering and electronics, etc. M. Rosso, [11] studied applications of the metal matrix and ceramic matrix composites and their process technologies. M. Dyzia, J. OEleziona, [12] have developed and studied the mechanical properties of Aluminium matrix composites reinforced with AlN particles formed in stir casting. G. Rajyalakshmi, Dr. P. Venkata Ramaiah [13] Factors like pulse on time, pulse off time, corner servo voltage, wire feed rate, wire tension, servo feed, spark gap voltage and dielectric flow rate have been found to play a significant role in rough cutting operations for maximizations of MRR, minimization of surface roughness and minimization of spark gap in WEDM. Dewan Muhammad Nuruzzaman [14] investigated aluminium-aluminium oxide MMCs of different percentages of aluminium oxide. It is observed that density of the composite specimen increases with increase in aluminium oxide volume fraction and the density of the composites are higher for 20 ton compaction load than density obtained for 10 compaction load. H. K. Shivanand, Mahagundappa M. Benal, S. C. Sharma, N. Govindraju,[15] compared Powder Metallurgy method and stir casting method for producing the AMMC through testing of mechanical properties and conclude that stir casting method is best suitable for preparation of AMMC. Mr. Anand and S. Shivade [16] attempt was made to review the different multi-optimization method used in WEDM for optimization of process parameters such as MRR, Surface roughness, kerf width, machining time, dimensional deviation. Both the performance parameters, MRR and surface roughness are optimized in one optimal input setting using Grey relational analysis method. According to the literature survey it observed that very little work has been reported on WEDM of MMCs. Past studied not clearly concluded the list of input parameters and responses. So, there is much more scope to see effects of input parameters on outputs. Kerf width, tool wear response is not focused more. Surface roughness is mostly used which essential to measure because it states the quality of machining. Compared six and seventh series of aluminium alloys. seventh series is not used more and fifth series of aluminium alloys are also less. Coming to reinforcement materials silicon carbide is mostly used and fly ash and aluminium oxide is not used more. So this research is focused on WEDM of AMMCs which are reinforced with fly ash, aluminium oxide and silicon carbide by considering kerf width, surface roughness, tool wear and process cost as machining responses and one in each series of fifth, sixth and seventh series of aluminium alloys as base material.

III. DESIGN OF EXPERIMENTS AND PREPARATION OF ALUMINIUM METAL MATRIX COMPOSITES

In the present work nine AMMC samples are produced using stir casting furnace as per Taguchi L27 experimental design (Table. 2) which is obtained by considering material and WEDM parameters (Table 1). To produce AMMCs, First the stir casting furnace with graphite crucible is switched on and allow it to raise the temperature up to 500^{O}C then the required amount of base material is poured into the crucible and the temperature is raised up to 850^{O}C and allow it to maintain the same up to complete melting of base material. At 675^{O}C, the wetting agent Mg of 1% is added to the base material. Then the reinforcement particles are added slowly to the molten base material while the stirrer rotating. Before adding the reinforcement particles they are heated for 2 hrs upto 1000^{O}C to oxidise their surfaces. After mixing, the temperature of the slurry is raised upto 850^{O}C for getting improved fluidity and stirring is continued upto 5 minuits. Then the mixed slurry was poured in different preheated steel dies to produce the samples.

TABLE 1
INFLUENTIAL PARAMETERS AND THEIR LEVELS

S. No.	Influential parameters	Level 1	Level 2	Level 3
Material Parameters				
1	Base material (BM)	Al5052	Al6082	Al7075
2	Type of reinforcement material (RM)	SiC	Al_2O_3	Flyash
3	Percentage of reinforcement particle (PRFM)	2.5	5	10
WEDM Parameters				
4	Pulse on time(Ton)	108	110	112
5	Pulse off time (Toff)	56	58	60
6	Water pressure(wp)	3	7	10
7	Wire feed (Wf)	1	2	3
8	Servo feed (SF)	1030	1050	1070

TABLE.2
TAGUCHI DESIGN OF EXPERIMENTS

Exp. Run No	AMMC Sample No.	Material parameters			WEDM parameters				
		BM	RFM	PRFM	Ton	Toff	Wf	Wp	SF
1	1	5052	FA	2.5	108	56	1	3	1030
2		5052	FA	2.5	108	58	2	7	1050
3		5052	FA	2.5	108	60	3	10	1070
4	2	5052	SIC	5	110	56	1	3	1050
5		5052	SIC	5	110	58	2	7	1070
6		5052	SIC	5	110	60	3	10	1030
7	3	5052	Al2O3	10	112	56	1	3	1070
8		5052	Al2O3	10	112	58	2	7	1030
9		5052	Al2O3	10	112	60	3	10	1050
10	4	6082	FA	5	112	56	2	10	1030
11		6082	FA	5	112	58	3	3	1050
12		6082	FA	5	112	60	1	7	1070
13	5	6082	SIC	10	108	56	2	10	1050
14		6082	SIC	10	108	58	3	3	1070
15		6082	SIC	10	108	60	1	7	1030
16	6	6082	Al2O3	2.5	110	56	2	10	1070
17		6082	Al2O3	2.5	110	58	3	3	1030
18		6082	Al2O3	2.5	110	60	1	7	1050
19	7	7075	FA	10	110	56	3	7	1030
20		7075	FA	10	110	58	1	10	1050
21		7075	FA	10	110	60	2	3	1070
22	8	7075	SIC	2.5	112	56	3	7	1050
23		7075	SIC	2.5	112	58	1	10	1070
24		7075	SIC	2.5	112	60	2	3	1030
25	9	7075	Al2O3	5	108	56	3	7	1070
26		7075	Al2O3	5	108	58	1	10	1030
27		7075	Al2O3	5	108	60	2	3	1050

IV. EXPERIMENTATION

The experiments were conducted at ultra cut WEDM Machine (supplied by Vellore Wire Cut. Pvt. ltd) as per the taguchi design of experiments and the experimental data is recorded in the Table 3. For these experiments, brass wire is used as electrode and water as dielectric fluid.

V. IDENTIFICATION OF OPTIMUM PARAMETERS COMBINATION

Step 1: Pre-processing of Experimental Data

Data pre-processing is required where the range and unit in one data sequence may differ from the others. In data pre-processing, the original sequence is transformed to a comparable sequence. Depending on the quality characteristic of a data sequence, there are various methodologies of data pre-processing are available.

For quality characteristic of the "larger – the - better", the original sequence can be normalized as

$$x^*_i(k) = \frac{x^o{}_i(k) - \min x^o{}_i(k)}{\max x^o{}_i(k) - \min x^o{}_i(k)} \quad (1)$$

For quality characteristic of the "smaller – the - better" the original sequence, can be normalized as

$$x^*_i(k) = \frac{\max x^o{}_i(k) - x^o{}_i(k)}{\max x^o{}_i(k) - \min x^o{}_i(k)} \quad (2)$$

Where $i = 1\ldots, m$; $k = 1\ldots, n$. m is the number of experimental data items and n is the number of parameters. $x^o{}_i(k)$ Denotes the original sequence, $x^*{}_i(k)$ the sequence after the data pre-processing, max $x^o{}_i(k)$ the largest value of $x^o{}_i(k)$, min $x^o{}_i(k)$ the smallest value of $x^o{}_i(k)$, and x^o is the desired value. For the experimental values of, tool wear and process cost, smaller-the-better is applicable. Hence, its experimental values are normalized using Eqs1&2 as shown in Table 3.

TABLE 3
EXPERIMENTAL RESULT AND NORMALIZED VALUES OF EXPERIMENTAL RESULTS

Exp. No	Experimental results		Normalized values of experimental Results	
	Tool wear	Process Cost	Tool wear	Process cost
1	0.018	633.76	0.3043	0.6652
2	0.01	519.94	0.6521	0.7828
3	0.014	533.65	0.4782	0.748
4	0.018	477.10	0.3043	0.8271
5	0.025	395.013	0	0.9119
6	0.018	569.51	0.3043	0.7316
7	0.015	698.01	0.4347	0.5988
8	0.011	705.15	0.6086	0.5915
9	0.018	1277.726	0.3043	0
10	0.013	567.53	0.5217	0.7336
11	0.009	394.61	0.6956	0.9123
12	0.012	346.43	0.5652	0.962
13	0.019	781.30	0.2608	0.5128
14	0.013	822.94	0.5217	0.4698
15	0.013	987.93	0.5217	0.2993
16	0.015	408.89	0.4347	0.8975
17	0.016	658.75	0.3913	0.6394
18	0.009	510.02	0.6956	0.7937
19	0.019	569.12	0.2608	0.732
20	0.014	394.61	0.4782	0.9123
21	0.016	414.84	0.3913	0.8194
22	0.014	352.18	0.4782	0.9561
23	0.002	309.74	1	1
24	0.014	568.32	0.4782	0.7328
25	0.013	470.60	0.5217	0.8338
26	0.012	600.17	0.5652	0.9996
27	0.015	561.82	0.4347	0.7394

TABLE 4
GREY RELATIONAL COEFFICIENTS AND GREY RELATIONAL GRADE

S.No	Grey Relational Coefficients		Grey Relational Grade
	Tool wear	Cost	
1	0.6216	0.429	0.5253
2	0.4399	0.389	0.41445
3	0.5111	0.4	0.45555
4	0.6216	0.376	0.4988
5	1	0.3541	0.67705
6	0.621	0.4059	0.51345
7	0.534	0.455	0.4945
8	0.451	0.458	0.4545
9	0.6216	1	0.8108
10	0.4893	0.405	0.44715
11	0.4182	0.354	0.3861
12	0.4693	0.3419	0.4056
13	0.6572	0.4936	0.5754
14	0.4893	0.5155	0.5024
15	0.4893	0.6255	0.5574
16	0.5349	0.3585	0.4467
17	0.5609	0.4388	0.49985
18	0.4182	0.3864	0.4023
19	0.6572	0.4058	0.5315
20	0.511	0.354	0.4325
21	0.5609	0.3789	0.4699
22	0.5111	0.3433	0.4272
23	0.333	0.33	0.3315
24	0.5111	0.4055	0.4583
25	0.4893	0.3748	0.43205
26	0.4693	0.4167	0.443
27	0.5349	0.4033	0.4691

Step II: Determine the grey relational coefficient

After data pre-processing, the grey relation coefficient $\xi_i(k)$ for the k th performance characteristics in the i^{th} experiment can be determined using the Eq.3

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\,\Delta_{\max}}{\Delta_{oi}(k) + \zeta\,\Delta_{\max}} \tag{3}$$

Where, Δ_{oi} is the deviation sequence of the reference sequence and the comparability sequence?

$$\Delta_{oi} = \| x^*_o(k) - x^*_i(k) \|$$

$$\Delta_{\min} = \min_{\forall j \epsilon i} \min_{\forall k} \| x^*_o(k) - x^*_j(k) \|$$

$$\Delta_{\max} = \max_{\forall j \epsilon i} \max_{\forall k} \| x^*_o(k) - x^*_j(k) \|$$

$x^*_o(k)$ denotes the reference sequence and $x^*_i(k)$ denotes the comparability sequence. ζ is distinguishing or identification coefficient and its value is between '0' and '1'. The value may be adjusted based on the actual system requirements. A value of ζ *is* the smaller and the distinguished ability is the larger. ζ = 0.5 is generally used. The Grey Relational coefficients of tool wear and process cost are shown in the Table.4.

Step III: Determination of Grey relational grade

The grey relational grade is defined as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \qquad (4)$$

The grey relational grade γ_i represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical, then the value of grey relational grade is equal to 1. The grey relational grade values are calculated for each factor at each level and the optimal level for each factor is identified based on their individual grey relational grade values. The optimal level of any influential factor has highest grey relational grade (GRG) value among their considered levels. Grey relational Grade is shown in the Table 4.

TABLE 5
GRG FOR EACH LEVEL OF INFLUENTIAL FACTORS

GRG for each level of influential factors								
Level	**BM**	**RM**	**PRFM**	**TON**	**TOFF**	**WP**	**WF**	**SF**
1	0.538267	0.452006	0.440128	0.486072	0.486511	0.454544	0.478250	0.492272
2	0.469211	0.504611	0.474700	0.496894	0.460150	0.490283	0.478006	0.490739
3	0.443894	0.494756	0.536544	0.468406	0.504711	0.506544	0.495117	0.468361
Delta	0.094372	0.052606	0.096417	0.028489	0.044561	0.052000	0.017111	0.023911
Rank	2	3	1	6	5	4	8	7

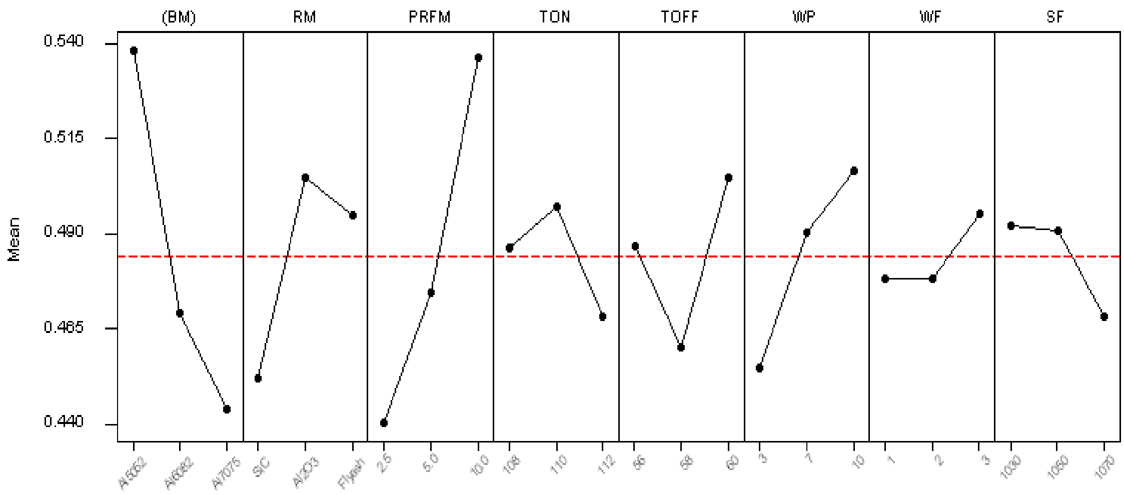

FIG 1: GRG FOR EACH LEVEL OF INFLUENTIAL FACTORS

Step V Obtaining optimal combination of influential factors

After determining the GRG, the effect of each parameter is separated based on GRG at different levels. The mean values of GRG for each level of the influential factors and the effect of influential factors on multi responses in rank wise are summarized in Table 6 Basically, larger GRG means it is close to the product quality. Thus, a higher value of the GRG is desirable. From the Table 6 and fig 1, the optimal combination of influential factors is BM1RM2PRM3TON2TOFF3WP3WF3SF1. This means Base material at level 1 ie; 5052, Reinforcement material at level 2 ie; AL2O3 Percentage of Reinforcement material at level 3 ie; 10, TONat level 2 ie; 112, TOFF at level 3 ie; 60, WP at level 3 ie; 10, WF at level 3 ie; 3, SF at level 1 ie; 1050.

VI. CONFORMATION TEST

For the obtained optimal combination, confirmation test has been conducted and compared the results with initial set of parameters. These results are satisfactory as the responses for optimal combination shows better performance.

TABLE 6
COMPARISON OF RESPONSES BETWEEN AMMC WITH INITIAL COMBINATION AND OPTIMAL COMBINATION

Combination	Combination of Controllable Parameters	Tool wear	Process cost	GRG
Initial set		0.018	476	0.5812
Optimal set	BM1RM2PRM3TON2TOFF3WF2WP3SF1	0.008	350	0.7902
Gain	N/A	0.01	126	0.2090
% of Gain	N/A	55.55	26.47	35.96

VII. CONCLUSIONS

After analyzing the data of obtained influential factors combination, it is concluded that PRFM, BM and RM are the most significant parameters which influence th multi responses WP and TOFF are the medium influenced parameters on multi responses TON, SF and WF are influenced lastly the multi responses. Also grey relational grade of the optimal combination is increased about 35.96%

REFERENCES

[1] **Shandilya. P, Jain. P. K, Jain. N. K "**Wire electric discharge of metal matrix composite**".** Damm International scientific book, 2011. pp. 383-400.

[2] **D. Satishkumar, M. Kanthababu, V. Vajjiravelu** "Investigation of wire electrical discharge machining characteristics of Al6063/SiCp composites." International Journal of advanced manufacturing technology." October 2011. 56:975–986.

[3] **3.Rajesh Kumar Bhuyan, B.C.Routara, Arun Kumar Parida, A.K.Sahoo** "Parametric optimization of Al-SiC12% metal matrix composite machining by EDM." 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014.

[4] **K. Zakaria, Z. Ismaila , N.Redzuana and K.W. Dalgarnob** "Effect of wire EDM cutting parameters for evaluating of Additive Manufacturing Hybrid Metal Material." 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, 4-6 February 2015, Bali Indonesia 532 – 537.

[5] **Ravindranadh Bobbili, V. Madhu, A.K. Gogia** "Multi response optimization of wire-EDM process parameters of ballistic grade aluminium alloy." Engineering Science and Technology, an International Journal 18 (2015) 720e726.

[6] **Yonghua Zhaoa, Masanori Kuniedaa, Kohzoh Abeba** "Study of EDM cutting of single crystal silicon carbide." Science Direct Precision Engineering 38 (2014) 92– 99.

[7] **Ibrahem Maher, liew Hui Ling** "Improve WEDM performance at different machining parameters." IFAC(2015) 105-110.

[8] **Cheol-Soo Lee, Eun-YoungHeo, Jong-MinKim, In-HughChoi,Dong-WonKim** "Electrode wear estimation model for EDM drilling." Robotics and Computer-Integrated Manufacturing 36(2015)70–75.

[9] **V. Chengal Reddya, N. Deepthib, N.Jayakrishna** "Multiple Response Optimization of Wire EDM on Aluminium HE30 by using Grey Relational Analysis." Materials Today: Proceedings 2 (2015) 2548 – 2554.

[10] **Vukcevic, M. and Delijic, K. "**Some New Directions in Aluminum Based PM Materials for Automotive Applications" Materials in Technological, 2002 36, pp101-105.

[11] **M. Rosso** "Ceramic and metal matrix composites: Routes and properties" Journal of Materials Processing Technology 175 (2006) 364–375.

[12] **M. Dyzia, J. OEleziona** "Aluminium matrix composites reinforced with AlN particles formed by in situ reaction" Archives of Materials Science and Engineering Volume 31, Issue 1, May 2008, Pages 17-20.

[13] **G. Rajyalakshmi** "Simulation, Modelling and Optimization of Process parameters of Wire EDM using Taguchi –Grey Relational Analysis." ISSN: 2278-7844 2012 IJAIR.

[14] **Dewan Muhammad Nuruzzaman** "Fabrication and Mechanical Properties of Aluminium-Aluminium Oxide Metal Matrix." International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol:15 No:06.

[15] **Mr. Anand and S. Shivade1** "A review on advanced multi-optimization methods for WEDM." International Journal of Scientific Research Engineering & Technology (IJSRET) Volume 2 Issue 7 pp 435-439 October 2013.