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Optimization of WEDM process during machining of Al-Al_2O_3 composite using Taguchi based Grey Relational Analysis

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Abstract- Aluminium ceramic (Al-Al2O_3) is used comprehensively all over the world. In this paper, input parameters on Al-Al2O_3 workpiece are applied to investigate the MRR and surface roughness by the process of wire electrical machining (WEDM).Four varying input parameters (Ton, Toff, Wf and Cs%) were tabulated for nine samples using L9 orthogonal array design technique whereas keeping wire tension as constant. Tool wear is calculated as the change in initial thickness and final thickness after cutting operation using screw gauge. The surface roughness is found using surface roughness tester.Minitab is used to plot the graph between input parameters against various output parameters. To find the impact of process parameters, ANOVA (Analysis of Variance) is used .

Key Words: Parametric Optimization- 1, Particulate Reinforced Metal Matrix Composites- 2, Taguchi- Grey RelationalAnalysis-3,WEDM-4.

1. Introduction

A composite material is an amalgamation of two or more than two materials that are disparate and separated by two different aspects and phases. It has two phases in which the discrete constituent (reinforcement) is distributed in a continuous phase called the matrix. The two phases have different geometry and form and the properties at the interface decide the properties of the composite. The reinforcement phase is responsible for imparting mechanical properties like stiffness, hardness, and abrasive nature etc. The matrix phase is continuous and is responsible for distribution of load amongst the reinforced members. The properties of the composites are inherently better than both its parent constituents matrix and reinforcements.

Aluminium metal matrix composites(AMMC) is the most commonly used MMC in the industry today. Aluminium due to its many favourable properties like high strength to weight ratio, low weight, and high corrosion resistance makes it as extensively used in today's market. Aluminium alloys of different series and composition are used generally, reinforced with abrasive ceramics like Sic (silicon carbide), Al2O_3 (Aluminium oxide) and ZrO2 (Zirconium dioxide)etc.

There are many ways to manufacture and produce these composites like there are the liquid route, solid-state route or even semisolid route. The liquid state route has processes like stir casting which is a very widely used and economical method to make composites, solid state process consists of methods like powder metallurgy, sintering process and semisolid has methods like vapour phase deposition and in situ fabrication. Due to the high strength to weight ratio, high strength and high stiffness, high wear resistance etc .MMC find their application in aerospace and automobile industries these days, but however, due to these reinforced ceramics which are responsible for making the composite very hard, makes its machining a very complicated process. Due to its hard and abrasive nature, the composite becomes harder to the machine, this leads to the discovery of efficient machining methods. These can be machined by conventional techniques in a difficult manner, which leads us to the innovation of many non-traditional machining processes and makes it a more efficient process for cutting this type of material. It is much better than conventional process because conventional process causes more wear of the tool due to the presence of abrasive ceramics.

1.1. WEDM Process

It is a non-traditional machining process most widely used for removing materials especially used on electrically conductive difficult to machine metal matrix composites. It is a thermoelectric method of machining , the arc of electricity is passed and the heat generated by the spark causes the composite to melt and then finally erode. The composite must be electrically conductive so that the material can be removed. It does not involve tool-to workpiece contacts like in conventional machining process thereby leading to the high amount of wear produced due to excessive friction at the tool and work piece interface. It also causes a large amount of noise and vibrations causing damage to both tool and workpiece.
The material is removed when there is a series of electrical discharge between the workpiece and the electrode. The electrode is a very thin wire of about 5 mm diameter made up of tungsten, brass, copper etc, a material that is capable of withstanding very high temperature without melting or breaking. The temperature within the sparking zone is in the range of 8000 - 12000-degree Celsius, that can be controlled by a dielectric fluid that is generally used as a coolant and it makes the cutting operation more effective also. Water is

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generally used as a dielectric fluid which even gets ionized when passed through the wire-work piece interface. The movement of the thin wire electrode used to cut complex and intricate shapes on the workpiece is controlled by a small microprocessor on auto-cad software that will determine the toolpath of the wire with a very high level of precision. There are many factors that influence the WEDM process but if they are wrongly selected it may lead to harmful consequences like short-circuiting or wire breakage. Hence there is a need to develop a very careful and methodical way of developing a mathematical model and to maximize the efficiency of the process to find out the optimum process parameters like pulse on (TON), pulse off (TOFF), wire tension (WT) and for these process parameters many optimization techniques have been developed and put into practice.

2. Literature Review

The volume fraction of alumina is directly proportional to the surface roughness of Al/Al2O3p. The relation can be characterized because of the low fluidity of the melt and SiC particulates in the spark gap leads to channel discharge to spread up. The surface roughness in Al/Sic composites is inversely proportional to the volume fraction of SiC reinforcements. The trend was found to be characterized to the protrusions of the alumina particulates on the processed surface. (Nilesh G. Patil and P.K. Brahmankar,2016).

Sensitivity put up more impact on material removal rate whereas parameters like wire feed rate, pulse on time and pulse off time contributes Negligibly Karthik.C, Rimmie Duraisamy, Rajyalakshmi.G,2015).The spark on time and the input current have a statistically significant impact in case of aluminium and mild steel respectively. The spark on time has more contribution to the surface roughness of Aluminium whereas in case of mild steel input current has more influence.(Shivkant Tilekar, Sankha Suvra Das ,P.K. Potwari).(Boopathi et al. 2012) studied dry WEDM as an earnest attempt to improve machining process to put an end to the use of a dielectric. There are so many parameters which makes it a difficult task to set up suitable working conditions. Pulse peak current and pulse on time are the influencing factors on the surface roughness during machining by WEDM of DC53 die steel. The surface roughness of workpiece is directly proportional to both pulse on time and pulse peak current (Kanlayasiri K & Boonmung). H. R. Tonday and A. M. Tigga 2016 studied the effects of various cutting parameters of WEDM on MRR and surface integrity. The found that the output parameters are not affected by the change in wire tension. (Alias,2012) found that the feed rate affects the performance measures like MRR and Surface Roughness. So, along with Pulse ON Time, Pulse OFF Time and CS%, Wire Feed Rate (WF) is also taken as an input parameter.M. Sangeetha1, A. Institute of Technology, Toucheng, I-Lan, Taiwan et al found that process responses such as MRR, Tool Wear and surface morphology can be optimized by both Srinivasulu Reddy, G. Vijaya Kumar et al studied about the optimization of die-sinking EDM process parameters in AMMC using reinforcements of (flyash,Sic ,Al2O3) using weight percentage of 2.5%,5% and 10% and machining parameters of current (Ip),pulse on time(Ton),pulse off time(Toff),tool lifting time(TL).Based on experiments performed as per Taguchi design of experiments and responses such as MRR and SR(surface roughness), electrode wear rate and cost are measured and optimized. After an analysing the data with the help of a desirability function they concluded that reinforcement material, current and tool lifting time are most significant parameters, %reinforcement and pulse time are medium sized parameters which reduced electrode wear rate, increase in MRR, cost decreased and surface roughness reduced.N. Jamuna, A. Sreenivasulu Reddy et al studied about the impact of parameters like kerf width,tool wear, process cost and surface roughness are optimized using grey relational analysis and fuzzy logic as per the taguchi based design of experiments,and after analysing the data they concluded that percentage of reinforced material (PRFM), base material (BM), type of reinforced material are the most influential parameters,WP AND TOFF are medium based influential parameters and TON,SF and WF are lastly the multi responses.(Y.S. Tarng, S.C. Ma, and L.K. Chung) discussed about finding ways to solve the intricate parameters to enhance the cutting performance within the allowable constraints of working conditions The application of simulated annealing algorithm can greatly influence the performance characteristics. The use of SA annealing in neural networks help to find the peak results and thereby they were able to improve the cutting process by WED M using this approach. K. P. Somashekhar & Jose Mathew & N. Ramachandran International Journal Advanced Manufacturing Technology (2012) 61:1209–1213 et al investigated about the demanding and taxing task of micro wire edm and its effects on MRR, surface roughness and overcut of a single pass machining of aluminium. The MRR is set to be maximized whereas the surface roughness and overcut are to be kept as low as possible .SA annealing is implemented to find out the response nature as a function of output variables by keeping all control factors like discharge current, capacitance ,gap voltage and feed rate .Application of Taguchi, Fuzzy-Grey Relational Analysis for Process Parameters Optimization of WEDM on Inconel-825 G. Rajyalakshmi1* and P. Venkata Ramaiah et studied on inconel-825 metal and it's response optimization of more than one parameters like wire feed, wire tension, servo feed, spark gap voltage to improve output parameters like MRR, spark gap voltage, and surface finish. The algorithm being used to arrive at the optimal results is fuzzy grey relational analysis which converts multi-objective into single objective and thereby simplifies the method of optimization. C. L. Lin, J. L. Lin and T. C. Ko Department of Automatic Engineering, Lan Yang

approaches i.e, grey relational analysis without using SN ratios and fuzzy logic. However, when it comes to multiple process response the grey relational method

without using SN ratios is more suitable in this case than fuzzy logic method .Optimization of EDM Process with Taguchi, Grey Relational Analysis, and Fuzzy Logic Technique Mr. Ganesh Pandurang Jadhav, Dr. Narendra Narve, Prof. Vyankatesh Mundhe observed that Taguchi method is very much useful for experimental setup design. It helps to minimize trial and run time drastically. Taguchi method very much important in DOE (design of experiment) , GRA (Grey Relational Analysis) is purely mathematical Optimization method which highlight importance of numbers and its calculations but fuzzy logic help to use some logic (AND, OR, NOT) and more detail study of response of input parameter in all direction and sense. Multi-Objective optimization of parameters during EDM of aluminium alloys using grey relational analysis. The optimal combination of process parameters was achieved by GRA. Further predicted response values were in agreement with corresponding experimental results.
A.H.A. Shah et al (2016) IOP Conf. Ser.: Material. Science. Engineering. 114 012023 studied on the improvement of turning operation by finding out the most suitable parameters by taguchi grey relational analysis for S45C steel. Multiple process parameters can be improved on CNC turning by this method. Four parameters MRR, surface roughness, Tool Wear and power consumption are to be optimized at the same time. Taguchi Experimental Design helps to reduce the no of experiments and keep to a bare minimum level.

Multi-Objective Optimization of Machining Parameters for Al7075 Metal Matrix Composite Using Grey - Fuzzy Technique Ramanan G Edwin Raja Dhas J did experimentation on al7075 alloy with active charcoal as reinforcement .The measurement of samples with high value of density, hardness ,impact strength , ultimate tensile strength is selected for wire electric discharge machining. Output of these are used for maximizing MRR and minimizing surface roughness for optimal process parameters using fuzzy grey relational analysis

.3.Experimental Details

3.1. Work material

The composites used in this study are Aluminium Metal matrix Composites (AMMC). Aluminium matrix is reinforced with Aluminium oxide with percentage composition of 10%.

Table 1. Type of Materials used for experimentation

S. No	B.M	R.F.M	P.R.F.M
1	Al	Al_2O_3	10

The details of work piece material and properties of aluminium materials are given in Table 1 and Table 2.

3.2. Experimental Set up and Experimental Procedure

In this research work, the material used is Al-Al2O3 ceramic which is prepared by the process of stir casting. The workpiece is cut into 9 cuboidal pieces having length and breadth as 10mm and 12mm respectively. A series of electrical pulses generated by the pulse generator unit is applied between the workpiece and the traveling wire electrode.The positioning and dimensioning are done by auto-cad software.
The brass wire with the diameter of 0.25mm is used to cut the workpieces because of its high mechanical strength and wire durability.

Table 2. Properties of Aluminium 6063

Density (g/cm^3)	3.69
Maximum use temperaure (°C)	1700
Modulus of Elasticity (GPa)	300
Thermal Conductivity (W/m·K)	18
Hardness (kg/mm^2)	1175
Co-Efficient of Thermal Expansion (m/m·°C)	$8.1x10^{-6}$

To provide ease and simplicity to the operator an appropriate set of machining variables table is to be constructed The Taguchi based algorithm is applied to attain suitable arrangement of input to output responses. In order to proceed to optimize output responses minitab results are generated. Thus, using grey relation analysis, conclusions are made

3.3. Machining parameters and their levels for WEDM machining

There is a 3 level taguchi L9 orthogonal array design for the experiments to find out most feasible machining process parameters for various responses. The four control factors like pulse on time, pulse off time , wire feed and servo voltage are controlled in 3 stages. If unsuitable parameters are choosen, it may lead to decrease in efficiency of the process leading to high lead time.The selection of improper factors may also cause breakdown of machine and problems like wire breakage or short circiuiting or even damage to the workpiece. The Tool wear,MRR and surface roughness are the output features to be improved. Aluminium composite and it's machining factors are selected carefully based on it's properties and nature.various process parameters were taken as given in the table 3 along with different levels.

Table 3. Process parameters and their Levels for WEDM

Symbol	Control Factor	Level-1	Level-2	Level-3
				-
A	Pulse On Time(µs)	106	109	112
B	Pulse off Time(µs)	60	56	52
C	Wire Feed(mm/min)	2	4	6
D	CS%	60	70	80

3.4. Measurement of Response Characteristics

Three response values of tool wear, surface roughness and material removal rate was measured by using different instruments and techniques.
MRR was measured as the ratio of the total volume of the cuboidal box to the total machining time. The volume of the work specimen is the product of the area of the workpiece and the depth of cut. The time of cut was noted against the four different varying input. Thus, different four speeds at midpoints of each edge were noted and their average value gives the observed MRR. Experimental MRR can be calculated by the following formula.

Observed MRR=(S1+S2+S3+S4)/4, where S1,S2,S3,S4 is the speed of the wire discharge at the midpoint of each edge.

Other response characteristic like surface roughness is measured by surface profilometer. The measured value of R_a is the root mean square or RMS value of surface roughness being measured. Three different readings are taken to achieve accuracy.
Other response parameter is tool wear rate is measured by screw gauge. Tool wear is calculated as the change in initial diameter and the final diameter of wire after cutting operation. The final diameter of the wire is calculated by screw gauge. Three values of the diameter of wire are calculated and the mean is taken as the final change in the wire diameter. Table 4, the final wire diameter is tabulated below with three different readings for accuracy

4. Analysis of Results

Using Taguchi's analysis and the Grey relational analysis, the optimal parameters for all three parameters of MRR,SR AND TWR are shown in the table below.

4.1. Multi Objective Optimization using Grey Relational Analysis

Experimental design is done by using Taguchi's L9 orthogonal design

Table 4. Experimental results

TON	TOFF	CS%	MRR	TWR	SR
106	60	60	2.594	.002	2.804
106	56	70	3.018	.003	3.284
106	52	80	3.339	.002	2.758
109	60	80	3.608	.002	3.215
109	56	60	4.496	.004	2.932
109	52	70	4.183	.004	2.715
112	60	70	3.443	.002	3.193
112	56	80	4.515	.004	3.769
112	52	60	5.433	.005	3.311

4.1.1. Formulation of the problem

The problem deals with a multi-objective optimization problem. The parameters like surface roughness and tool wear rate are to be minimized whereas material removal rate has to be maximized. The multi objective function is converted into single objective function under the constraints of parameters of TON, TOFF, CS%, WF. The values of the grey relational grade(GRG) values are found out, whose values range from 0≤GRG≤ 1.

Step1: The values obtained from earlier tables are converted into corresponding S/N ratio values. For MRR larger the better characteristic is choosen and for SR and TWR smaller the better is choosen.S/N ratio for MRR can be calculated by the formula as

$$S/N= -\log_{10}(1/n)\sum y_{ij}^2 \qquad (1)$$

y_{ij} = observed response value

i=1, 2... ....n; j = 1, 2...k
n = number of replications
The surface roughness is the lesser-the-better performance characteristic and the loss function for the same is expressed by the above formula.

Table 5. Signal to Noise ratios

S/N MRR	S/N TW	S/N SR
8.2794	53.9794	-8.9565
9.5944	50.4576	-10.3281
10.4723	53.9794	-8.8138
11.1453	53.9794	-10.1439
13.0565	47.9588	-9.3448
12.4298	47.9588	-8.6760
10.7387	53.9794	-10.0856
13.0932	47.9588	-11.5259
14.7008	46.0206	-10.3992

Step2:Now in order to bring the S/N ratio to a acceptance level we go for normalizing the data and keep its range from 0 to 1.All the values of S/N ratio are normalized and transformed to bring the data within an acceptable range. The S/N ratio is normalized as Z_{ij} ($0\leq Z_{ij}\leq 1$).The normalized MRR corresponds to larger the better and surface roughness and tool wear smaller the better. It can be calculated by the following formula

$Z_{ij}= y_{ij}$- Min y_{ij}/Max y_{ij}-Min y_{ij}. (2)

Step 3:The grey relation coefficient used for predicting the optimization values can be found out from normalized values using the given below equation

$y(x_o(k),x_i(k))=\Delta_{min}+\Delta_{max}/\Delta_{oi}(k)+ \xi\ \Delta_{max}$. (3)

Step4:The grey relation grade is obtained by finding out the average for all the values of grey relational coefficient ,the overall performance of the parameters depends on the value of grey relational grade. The higher value of grey relation grade corresponds that the value is closer to the optimized value or the desired value .It converts multi response characteristics into a single response problem.

Step 5:Determination of optimum parameters

The grey relational grade is taken as response and its larger value indicates the better value of performance. In case of the experiments performed experiment no 8 has the highest value hence TON 112,TOFF 56,WF 2,CS%80 is to be taken as the optimized value.

5. Result and Analysis

Table 6. Two-way ANOVA: GRG

Source	DF	SS	MS	F	P	% Contribution
A	2	0.0220302	0.0110151	1.56	0.315	34.3
B	2	0.0137936	0.0068968	0.98	0.451	21.53
C	2	0.0236196	0.0118098	1.32	0.363	36.89
D	2	0.0046016	0.0023008	0.26	0.785	7.185
Error	0	0	0			
Total	8	0.0640449				

S = 0.09464 R-Sq = 74.06% R-Sq(adj) = 0.00%

Table 7. Grey RelationalGrade

GRC MRR	GRC TW	GRC SR	GRG
1	0.333	0.356	0.563
0.709	0.472	0.543	0.575
0.594	0.333	0.344	0.423
0.528	0.333	0.507	0.456
0.401	0.672	0.395	0.489
0.436	0.672	0.333	0.480
0.566	0.333	0.497	0.465
.400	0.672	1	0.690
0.333	1	0.558	0.630

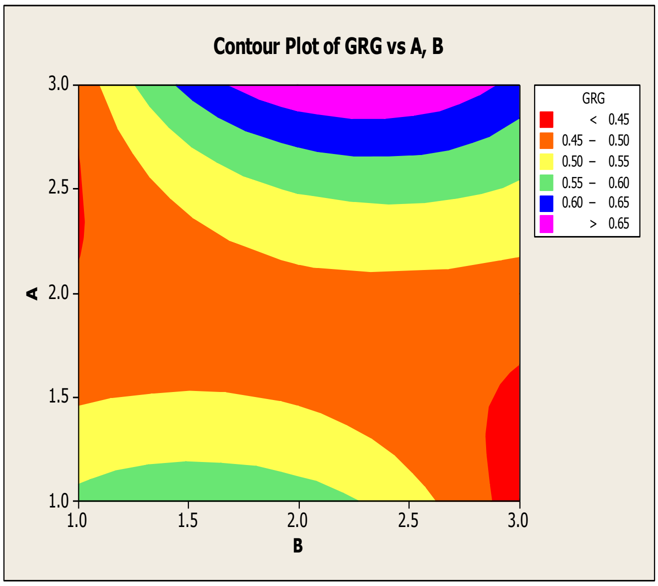

Fig. 1. Contour Plots of GRG vs A,B

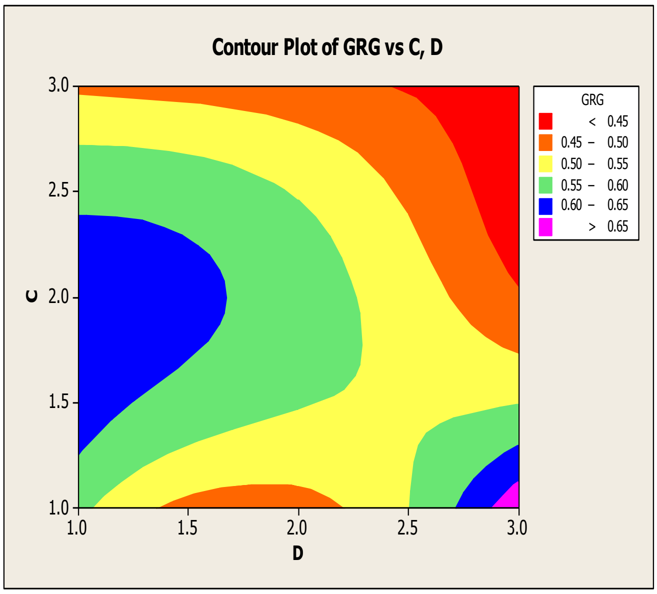

Fig. 2. Contour plots for GRG vs C,D

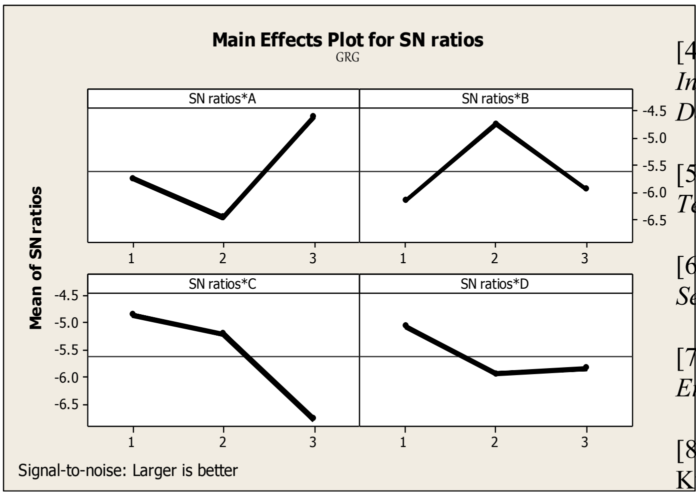

Fig. 3. Main effect Plots for SN ratios.

Conclusions

- ✧ Orthogonal array shows the different level for machining parameters as A3, B2, C1 and D3 based on maximum values shown in response table. But optimized SN ratio gave the different level of machining parameter as A3, B2, C1 and D1.
- ✧ Contour plot vs A,B shows that maximum value of GRG can be attained by taking the value range of A between 2.9-3 and for B between 1.6-2.9.
- ✧ Contour plot vs C,D shows that maximum value of GRG can be attained by taking the value range of C between 1-1.1and for D between 2.9-3.
- ✧ From Fig 1.3, it can be seen that from A1 -A2 GRG values is decreasing slowly while A2-A3, change is drastic. Similarly the relation between input SN ratios and GRG value can be concluded.
- ✧ Based on the ANOVA studies C has the highest contribution of 36.89% in GRG value followed by parameter A with 34.3% then B with 21.53% and then finally with D 7.185% having the least influence.

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