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Optimization of Different Process Parameter for Wire Electric Discharge Machining using Taguchi's Grey Relational Techniques

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ABSTRACT

Non-traditional machining is a milestone in the manufacturing industries in today's machining process. In precision manufacturing industries such as automobile, aerospace, and sheet metal, non-traditional machining processes such as electro discharge machining (EDM) and wire electric discharge machining (WEDM) play a critical role. Most of the time, the manufacturer's machine tool tables do not meet the machining requirements of a particular material. Surface roughness and wear are influenced by properties such as rigidity and hardness. As a result, materials with high hardness and rigidity produce fine surfaces, while materials with low rigidity, such as Aluminum alloys, produce high surface roughness. We investigated the material removal rate during WEDM of Aluminium silicon carbide composite (Al/SiCp) using molybdenum wire because of its high thermal conductivity and low melting point. The main objective of this study is to determine the optimal sets of WEDM process parameters for Material Removal Rate (MRR) and Surface Roughness (Ra) by examining the effects of various WEDM process parameters such as wire feed, wire speed, pulse time on and pulse time off. For optimizing the process parameters for these composites, to find the machining process is based on a L_9 orthogonal array. The two responses are converted into Grey relational grade (GRG) using Grey relational analysis (GRA). The most influencing factors that affect the process responses are identified for each machining parameter. The results are used to determine the best machining parameters.

Keywords : Non-traditional machining, wire electric discharge machining (WEDM), Material Removal Rate (MRR), Surface Roughness, Grey relational analysis

I. INTRODUCTION

Wire electric discharge machining ((WEDM)) appears to be very promising technique. It has several advantages in many areas of application, including better precision, faster machining rates, and controlled material removal, as well as a wide range of materials that can be machined. Wire-cut type of machine become popular in the 1960s for the purpose of making tools (dies) from hardened steel. The main objective of WEDM manufacturers and users is to improve the process's stability and productivity. To increased use of WEDM in manufacturing is continuing to grow at a rapid pace. WEDM manufacturers and users place a premium on achieving higher machining productivity while maintaining a high level of accuracy and surface finish. WEDM is complex in nature and controlled by large number of parameters as shown in Figure 1.1

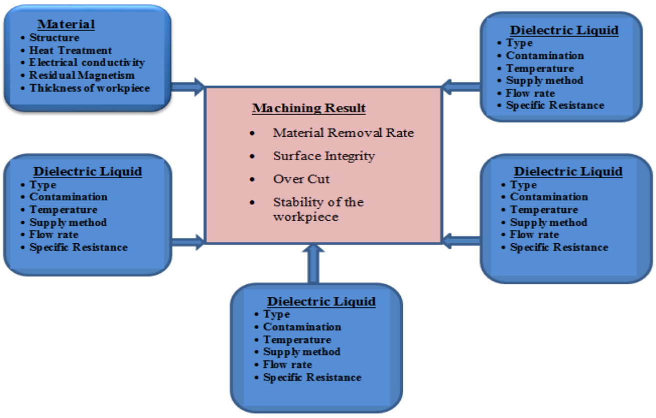

Fig. 1: Factors influencing the WEDM Process

In WEDM, the conductive material is machined with a series of electrical discharges that are produced between an accurately positioned moving wire and the work material. High frequency alternating pulses or direct current is discharged from the wire to the work piece with a very small spark gap through an insulating dielectric fluid (Water). Many sparks can be observed at one time which happens because actual discharges shall occur more than one hundred thousand times per second. The heat of each electrical spark, estimated at around 15000^0Ferodes away a very small bit of material by vaporization and melting from the work piece. These particles (chips) are taken away from the cutting zone with the stream of de-ionized water through the top and bottom flushing nozzles. It is the ON and OFF time of the spark that is repeated over and over that removes material.

Process Parameters: The utilization of the capacity of WEDM process requires proper selection of machining parameters. The performance of the WEDM can be influenced by several factors like Frequency, Wire Positioning, Wire tension, Electrode Wire material, Work piece material and Dielectric fluid

Process Capabilities: Wire EDM has an exceptional capabilities to machine exotic materials like super alloys, medical grade stainless steel, titanium, hast alloy, nimonics, monel, Inconel etc., Work hardened metals, ductile and brittle materials that are difficult to machine by other methods can be shaped effectively and efficiently by WEDM. Wire EDM products are accurate, burr free and have excellent surface finish and ready for immediate use. Since the travelling wire electrode passes through the work piece only once, unless there are internal stresses in the material or heat factors, the first machined part will be identical in the hundredth or thousandth part.

II. LITERATURE REVIEW

The purpose of literature review is to provide background information on the issues to be considered in this work and to emphasize the relevance of the present study in order to predict the MRR and R_a in WEDM process. Several researchers in the past have made attempts to improve the efficiency of WEDM process. **Mohan et al.** have investigated the machining characteristics of SiC/6025 Al composite using rotary electro-discharge machining (EDM) with a tube electrode. Brass was used as the electrode material MRR, pulse duration, hole diameter of the tube electrode, and speed of electrode rotation were used as the input variables to assess the machinability. **Yuan-Feng Chen et al.** have investigated how machining characteristics and surface modifications affect low-carbon steel (S15C) during EDM processes with semi-sintered electrodes. **Pradhan et al.** have attempted the optimization micro-EDM process parameters for machining Ti-6Al-4V super alloy. To verify the optimal micro-EDM process parameters settings, metal removal rate (MRR), tool- wear rate (TWR) and over cut (OC) were chosen as observed performance criteria. **Periyanan et al.** have focused on the Taguchi technique for the optimization in micro-wire electro discharge grinding process to achieve maximum MRR considering the feed rate, capacitance and voltage as the cutting parameters. **Vinayak Nair et al.** have investigated the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. **Pujari Srinivasa Rao et al.** study the effect of wire EDM parameters on Aluminum alloy because of its growing applications in various industries. Wire EDM parameters was performed by Taguchi method on surface roughness (SR) and material removal rate (MRR). **Hsien–Ching Chen et al.** have projected optimization of WEDM parameters on machining Ti-6Al-4V with multiple quality characteristics using the Taguchi method and grey relational analysis by choosing discharge current, open voltage, pulse duration and duty factor as process parameters. **Jong H. Jung et al.** have investigated the Taguchi method is used to determine the relations between machining parameters and process characteristics. **Janardhan et al.** have investigated the effect of machining parameters on the performance of wire electro discharge turning process. After a study of the existing literature, a number of gaps have been observed in machining and optimization of process parameters while machining alloys for WEDM process.

III. METHODOLOGY

3.1 Taguchi Method: Two major tools used in the Taguchi method:-

1. Orthogonal array
2. Signal to noise ratio

1. Orthogonal array: orthogonal array helps in reduction total number of experiments to be conducted. Selection of orthogonal array it totally depends on the degree of freedom of process. Orthogonal array≥ degree of freedom of process

2. Signal to noise ratio: Signal it generally represents desirable quantity and noise its undesirable quantity, higher value of signal to noise ratio is selected because it contain lower noise value. Signal to noise ratio has three types is as follows:

- ❖ Lower the better
- ❖ Normal the best
- ❖ Higher the best

In case of wire electric discharge machining the response variable such as material removal rate is required to be maximum because of that it undergoes higher the best. Surface roughness undergoes lower the better.

Signal to noise ratio is can be calculated as follow:-

$$\text{S/N ratio} = -10 \log (y_{ij})$$

Where

y_{ij} = Loss function

Loss function for lower the better type and higher best type can be calculated as follow:-

The material removal rate is a higher-the-better performance characteristic, since the maximization of the quality characteristic of interest is sought and can be expressed as

$$\text{S/N ratio} = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_{ij}}^2}$$

The surface roughness is the lower-the-better performance characteristic and the loss function for the same can be expressed as

$$\text{S/N ratio} = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}{y_{ij}}^2$$

3.2: Grey relational analysis: The relationship between process parameters and response variable can be found out with help of grey relational analysis.

For single objective optimization Taguchi method is to be used but for multi objective optimization problem. With help of grey relational analysis multi-objective optimization problem can be easily solved. Step by step procedure of Grey relational analysis is explained as follows:

Step-1: Normalization of Collected data:-

Larger is better i.e. MRR, $Z_{ii} = \frac{y_{ij} - min(y_{ij}, i=1,2,3......n)}{max(y_{ij}, i=1,2,3......n) - min(y_{ij}, i=1,2,3......n)}$

Smaller the better i.e. SR, $Z_{ii} = \frac{max(y_{ij}, i=1,2,......n) - y_{ij}}{max(y_{ij}, i=1,2,3......n) - min(y_{ij}, i=1,2,3......n)}$

Step-2: Calculation of deviation sequence:-

$$\Delta_{ij} = |y_{0j} - y_{ij}|$$

Where

$y_{0j} = 1$ (Maximum normalized value)

Step-3: Determination of grey relation coefficient (GRC): The grey relation coefficient (k) for the Kth performance characteristics in the ith experiment can be expressed as following

$$\gamma = (y_{0j}, y_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}}$$

Where

$$\Delta_{min} = min\ \Delta_{ij} = min|y_{0j} - y_{ij}| = |1 - 1| = 0$$

$$\Delta_{max} = max\ \Delta_{ij} = max|y_{0j} - y_{ij}| = |1 - 0| = 1$$

ξ = distinguishing coefficient = 0.5

Step-4: Calculation of grey relational grade:-

$$y_i = \sum w_i(k)\xi_i^k$$

Where

y_i = Grey relational grade $w_i(k)$ = Weightage given to response variable

IV. EXPERIMENTAL SETUP

The experiments carried out on a WEDM machine. In this setup, three major parts of machine tool with control panel, di-electric chamber and work piece. The specifications of WEDM Experimental setup are given below

Table.1 : Specification of WEDM experimental setup

Table Travel(X & Y axes)	300mm× 250mm
Z axes travel	100 mm
Max. Size of workpiece	400 ×250× 100 mm
Wire diameter	0.2 mm
Guide ways	Linear motion guide ways

Fig.2: Experimental setup

The specimens are prepared as a square of 10 mm thickness and 100×100 mm with made of Al/SiC$_p$ which are machined by WEDM. The workpiece is shown in fig. Nine holes of 3mm in diameter are drilled on the work piece. The tool material used was molybdenum wire.

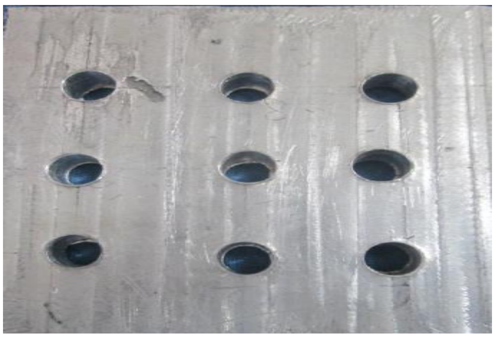

Fig.3: Al/SiC$_p$ Workpiece

Experimental design is widely used for controlling the effect of parameters in many processes. In this work, there are four machining parameters (wire speed, wire feed, pulse time on and pulse time off) were chosen. The machining after WEDM process are evaluated based on two machining performance, MRR (mm^3/sec) and R_a (μm). There are three levels of process parameters are selected for the present work, the minitab software is adopted for the generation of L_9 OA selection. The three levels of control factors are given with the coded value 1, 2 & 3 as shown in Table 2.

Table.2 : Machining parameters and their levels

Process Parameters	Unit	Level 1	Level 2	Level 3
Wire Speed	Rpm	400	800	1200
Wire Feed	mm/min.	0.2	0.4	0.6
Pulse-Time on	μs	115	120	125
Pulse –Time off	μs	40	42	44

Table.3 : Experimental design using L_9 orthogonal array matrix

S. No.	Wire Speed (rpm)	Wire Feed (mm/min.)	Pulse-Time on (μs)	Pulse –Time off (μs)
1	400	0.2	115	40
2	400	0.4	120	42
3	400	0.6	125	44
4	800	0.2	120	44
5	800	0.4	125	40
6	800	0.6	115	42
7	1200	0.2	125	42
8	1200	0.4	115	44
9	1200	0.6	120	40

V. RESULTS AND DISCUSSION

The results obtained through various optimization techniques such as Taguchi's Orthogonal Array and Grey Relational Analysis is used to optimize the process parameters of WEDM for Aluminium composite.

Table.4 : The main effects of the factors on the grey relational grade for Al/SiC_P5%

Symbol	Control Factors	Level 1	Level 2	Level 3
A	wire speed	0.439	0.488	0.7253*
B	wire feed	0.496	0.577	0.588*

C	pulse time on	0.496	0.5888*	0.521
D	pulse time off	0.592*	0.496	0.521

Table.5 : The main effects of the factors on the grey relational grade for Al/SiC$_P$10%

Symbol	Control Factors	Level 1	Level 2	Level 3
A	wire speed	0.4702	0.447	0.8102 *
B	wire feed	0.6207 *	0.5072	0.5995
C	pulse time on	0.6095 *	0.5072	0.5905
D	pulse time off	0.5072	0.6207 *	0.521

Table.6 : The main effects of the factors on the grey relational grade for Al/SiC$_P$15%

Symbol	Control Factors	Level 1	Level 2	Level 3
A	wire speed	0.391	0.6462	0.6478 *
B	wire feed	0.489	0.639 *	0.5568
C	pulse time on	0.4432	0.6278*	0.5598
D	pulse time off	0.439	0.6282 *	0.5468

The optimal factor and its level combination are determined by the grey relational grade graph. Basically, the larger the grey relational grade, the better is the multiple performance characteristic. However, the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately.

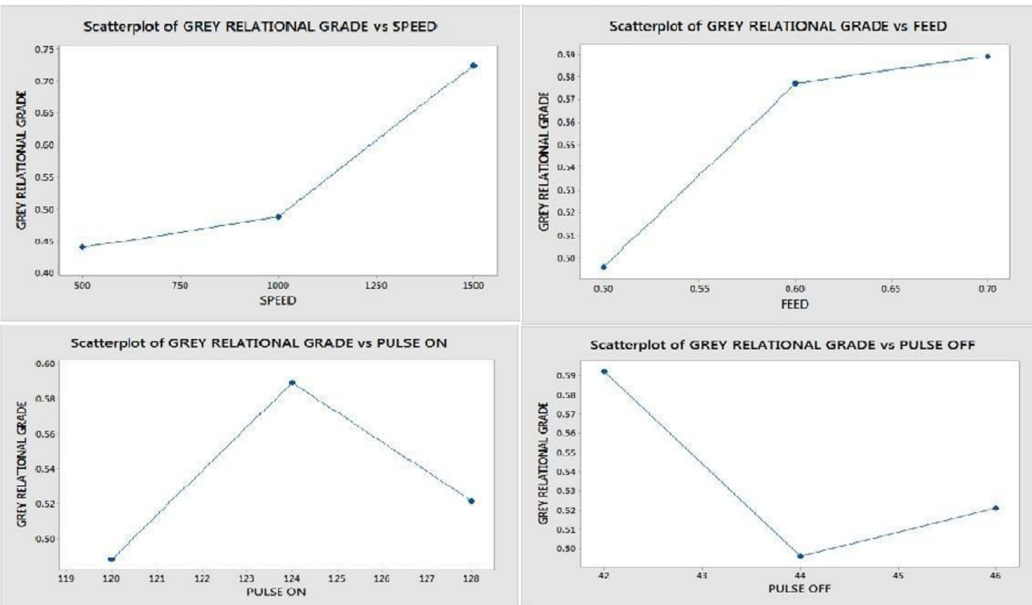

Fig.4: Grey grade vs input parameters of Al/SiC$_P$5%

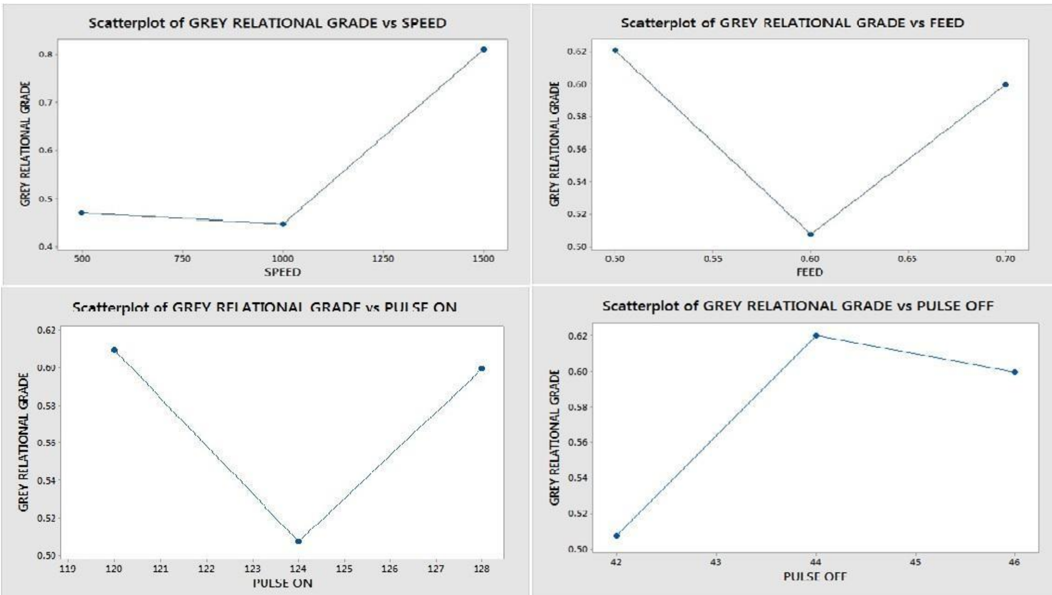

Fig.5: Grey grade vs input parameters of Al/SiC_P10%

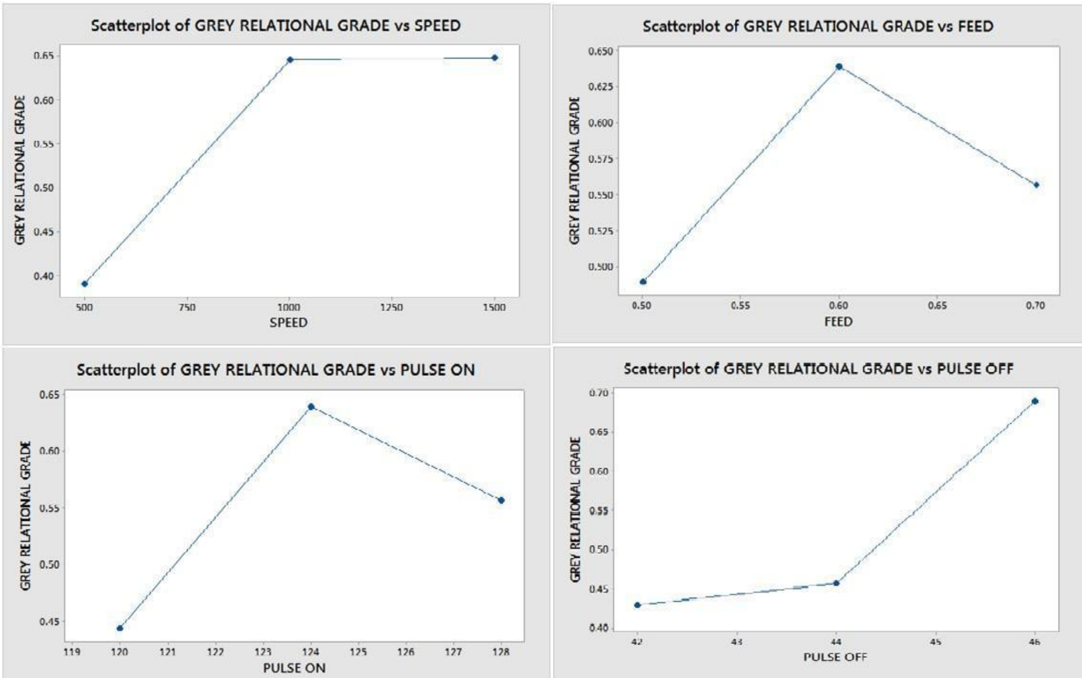

Fig.6: Grey grade vs input parameters of Al /SiC_P15%

Machining parameters wire speed, wire feed, pulse time on and pulse time off have been found to play a significant role for MRR and R_a. Taguchi's method is used to obtain optimum parameters combination for maximization of MRR and minimization of R_a. The conformation experiments were conducted to evaluate the result predicted from Taguchi's Optimization. Then the optimum level of parameters is also compared with the GRA.

VI. CONCLUSION

To improve the multi-response characteristics of MRR (Material Removal Rate), Surface roughness (R_a) in the WEDM of Al/ SiC_P 5%, Al/SiC_P 10% & Al/ SiC_P 15% has been done. As a result, this method greatly simplifies the optimization of complicated multiple performance characteristics

- For Al/SiC_P 5%, the optimal value from the L_9

orthogonal array is with (wire speed – 1500 rpm), (wire feed –0.6 mm/min), (pulse time on – 120µs), (pulse time off – 46 µs). Whereas the optimal value obtained from the Grey relational analysis is (wire speed – 1500 rpm), (wire feed – 0.8 mm/min), (pulse time on – 124µs), (pulse time off – 42 µs).

- For Al/SiC$_P$10% the optimal value from the L_9 orthogonal array is with (wire speed – 1500 rpm), (wire feed– 0.4 mm/min), (pulse time on – 128 µs), (pulse time off – 44 µs) .whereas the optimal value obtained from the Grey relational analysis is (wire speed – 1500 rpm), (wire feed – 0.4 mm/min), (pulse time on – 120 µs), (pulse time off– 44 µs).
- For Al/SiC$_P$15% the optimal value from the L_9 orthogonal array is with (wire speed – 1500 rpm), (wire feed –0.6 mm/min), (pulse time on – 120 µs), (pulse time off – 46 µs), whereas the optimal value obtained from the Grey relational analysis is (wire speed – 1500 rpm), (wire feed –0.6 mm/min), (pulse time on – 124 µs), (pulse time off – 44 µs)
- Taguchi's Grey Method is suitable for the parametric optimization of the WEDM process when using the multiple performance characteristics such as Material Removal Rate (MRR), Surface Roughness (R_a) for machining the Al/SiC$_P$ 5%, Al/SiC$_P$ 10% & Al/SiC$_P$ 15%.

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