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Study on Effect of Blended Powder Mixed Dielectric Fluids in Wire EDM Process

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Abstract: Wire Electric Discharge Machining (WEDM) process is used for machining various materials used in applications that require dimensional accuracy, high surface finish and have intricate shapes. This work includes the study of WEDM process when dielectric fluid is mixed with combination of two metallic powders viz. Silicon Carbide and Aluminium Oxide. The effect of this powder mixing on Material Removal Rate (MRR) and Surface Roughness (SR) is being analysed and optimum level of control parameters is found out. AISI D3 which is also called as die steel is used as workpiece material. Distilled water (30 TDS) is used as dielectric fluid and Zinc cozted Brass wire (CuZn37) is used as wire electrode. DOE is done using Taguchi. Significant parameters are found out using ANNOVA. Lastly GRA is used to find optimum set of parameters.
Keywords: WEDM, ELCAM, Surface Roughness, Material Removal Rate, Analysis of Variance, GRA, Optimization.

I. INTRODUCTION

WEDM is non-traditional process of machining. An electric current is passed through workpiece and the wire which are maintained at certain distance. This gives rise to sparks which causes the material to melt and vaporise. This material is then flushed by dielectric fluid. WEDM is used for machining a variety of materials ranging from hard to soft provided that the material is electrically conductive. Dimensional accuracy, better Surface Finish and ability to machine complex and intricate shapes and contours makes this process used in wide range of applications. A lot of research work is done for increasing the MRR and lowering the SR for WEDM process. Mixing metallic powders into dielectric fluid is one way to increase MRR and Surface Finish. So far mixing of one powder is done. In this study two metallic powders viz. Silicon Carbide and Aluminium Oxide are mixed in dielectric medium. AISI D3 is one of hard to cut materials and is used for experimental work. Dielectric used is distilled water and wire used is Zinc coated Brass (CuZn37) wire. For designing the profile and wire path ELCAM software is used. The same software is used to generate program file which is later feed to machine setup. The main objective of this study is to study the effect of powder mixed dielectric on MRR and SR. Also to study significant parameters affecting WEDM process and to optimise the obtained results.

II. LITERATURE REVIEW

Asarudheen et al. [1] came up with different metallic powder can be used to mix with dielectric medium during machining on WEDM setup. It shows the mechanism of spark discharge when powder particles come in spark gap. The effect of this is that spark discharge becomes more dispersing and hence helps to improve MRR and surface characteristics of finished components. R. Shanmuga et al. [2] has shown that due to addition of Silicon Carbide powder to dielectric medium the MRR and SR are improved. They have used AISI D3 as working material and calculated the MRR and SR values after machining the same material workpieces on WEDM setup by adding SiC powder to dielectric in different concentrations. They showed that dielectric with powder has contributed more MRR than dielectric without and accounts for 15-16% Increment. W. S. Zhao et al. [3] has worked on application of research on PMEDM in surface quality. He has done comparison of SR, machining efficiency of PMEDM and EDM process. He has used these parameters in research paper: Current- 15 A, Ton - 150µs, Toff- 125µs. He concluded that PMEDM is better than EDM process. Basil Kuriachen et al. [4] has studied Modelling of Wire Electrical Discharge Machining Parameters Using Titanium Alloy (Ti-6Al-4V). His research paper is related with SR. he has used these parameters level in his research paper Pulse on time: 20-25 (µs), Pulse off time: 44-50 (µs), Voltage: 25-30 (V), Dielectric pressure: 10-15 (kg/cm^2). He concluded that when the pulse on time is maximum and the voltage increase from 25 v to 30 v, the SR also increases. To achieve minimum SR (Ra), the pulse on time, voltage and dielectric pressure should be set at 20µs, 30V and 15 kg/cm^2 respectively. Anish Kumar et.al [5] has studied SR in WEDM Process based on Response Surface Methodology. WEDM is an adequate process to machine high strength temperature resistant (HSTR) pure titanium (grade-2) with good surface finish and dimensional accuracy. The surface roughness was ranged from 2.48µm to 2.62µm during WEDM of pure titanium. The minimum surface roughness was obtained for the process parameter combination given by Ton=112µs, Toff=56µs, Ip=120A, SV=60V, WF = 7m/min and WT = 980 grams.

The percentage Contribution of input parameters given by Ton: 55%, Toff: 28%, Ip: 8%, SV: 6% and error: 3%. Murahari Kolli et al. [6] has studied Effect of Boron Carbide Powder in EDM Machining of Titanium Alloy. Parameters: Current- 20 A, Ton- 65µs, Toff- 48µs, Powder concentration 1-20g/l. It shows the effect of carbon powder on MRR, SR and TWR in EDM machining it shows positive effect of powder in machining. Parameters like cycle on time, off time and current are used to study the effect of powder on response variables.

III. METHODOLOGY

Firstly training is taken to study the machine setup and ELCAM design software. Depending on machine specifications material for workpiece, wire electrode and metallic powder was selected. Several Demonstration and Hands-on experiments were conducted. Observations of these experiments were used for DOE using Taguchi’s method. Pilot experiments were conducted according to DOE and observations were used to find MRR and SR. Further ANNOVA was done to get significant parameters. Lastly GRA was done to get optimised set of parameters for MRR and SR as response variables.

IV. MACHINE SETUP AND ELCAM SOFTWARE

Before going for any experimental trials it is very essential to know the machine and its component. To work on any machine we need to first understand its basic working. Also for designing the wire path ELCAM software is essential. So in this chapter a brief information about machine setup and ELCAM software is given.

A. Machine Setup

1) *Machine Specifications:* Machine specifications play an important role to check the technical feasibility of the project as well as to understand the working range within which the process parameters operate. Following are the specification of the WEDM setup available in academic campus.
   a) Brand- Electronica India
   b) Product- Ecocut ELPULS 15
   c) Max Table Size- 370 x 600 mm
   d) Max. Height-200 mm
   e) Max. Weight-300 Kg
   f) Display -Colour LCD
   g) Tank Capacity -250 Litres
2) *Range of Parameters for Machining:* Table 1 shows range of parameters for existing WEDM setup. Parameters such as Pulse On time, Pulse off Time, Servo Voltage, Servo Feed, Wire Feed, Wire Tension, etc. can be changed as per requirement. Table shows the limiting values between which the parameters can be set. A special feature of cutting speed percentage allows the users to increase or decrease all the parameters at once in equal percentages. This table greatly simplifies the parameter setting for experiments to be conducted.

TABLE I
RANGE OF PARAMETERS FOR MACHINING

Parameter	Name	Range	Unit
T-ON	Pulse On Time	100-131	µs
T-OFF	Pulse OFF Time	0-63	µs
IP	Peak Current	0-2	A
SFM	Servo Feed Mode	0-2	-
SF	Servo Feed	1-999	10^{th} of mm/min
SV	Spark Voltage	1-99	V
WF	Wire Feed	1-15	m/min
WT	Wire Tension	1-15	Grams
CS%	Cutting Speed %	0-100	%

B. ELCAM Software
To design any cutting profile or geometry on workpiece ELCAM software is used. We can create any profile, wire path, entry and exit lengths for a given component by using this software.

1) *Features of ELCAM:* Following are some features and commands that are offered by ELCAM software-
   a) ELCAM is a CAD/CAM software system for generating NC program for the Electronica CNC WEDM machine.
   b) Using this single software system, one can design and edit the profile to be cut on the machine and generate its NC program.
   c) Profile drawing can be done easily using basic geometric elements viz. points, line segments, circles, and arcs.
   d) Generated drawing can be edited using facilities like trim, fillet, extend etc.
   e) Cutting path can be defined easily from the drawing.
   f) In ELCAM complex profile can be created by connecting profiles on two different layers and defining mapping between them.
   g) ELCAM provides a powerful graphical user interface with popup menus, dialog boxes, Context sensitive help and excellent keyboard and mouse interface.
   h) Toolbars, keyboard shortcuts and floating menu provide fast access to frequently used commands.
2) *Steps for designing a profile:* The steps to design and cut any profile on a component are as follows-
   a) Step 1 :- Make design on ELCAM Using different commands**.** ELCAM offers a wide range of commands and some standard profiles too. You can give entry and exit path lengths. Trace the wire path and convert into machine program using G-codes and M-codes.
   b) Step 2 :- NCOUT Settings. In this step program number is given. There is a provision for wire compensation too. Taper can be given on any edge by giving z-height option. The output of this is an ELCAM output file.
   c) Step 3 :- G-Code and M-Code. Once the design file is created then by clicking on brush icon on ELCAM a coding window is opened and then one can retrace the wire path and save the program file with program name.
   d) Step 4 :- Export drawing to machine setup and set the required parameters. This step include exporting the saved program file to machine computer with help of pen drive or external disk. Then open the same file in ECOWIN software on machine computer and then set the parameters for cutting. TON, TOFF, servo voltage, wire feed, etc. can be set to required values.
   e) Step 5 :- Workpiece Clamping using fixture. Some clamping fixtures are used on default work table. This is because the size of workpiece selected is 80*80*6.8mm and to cut a square profile was not feasible using default arrangement. Once the workpiece is clamped firmly, bring the wire close to start point on workpiece and about a 2mm away from cutting edge of workpiece component. Then set the XY and UV co-ordinates to zero and start the dielectric supply, wire feed and then lastly the spark generation.
   f) Step 6 :- Actual Cutting. Once the program and other parameters are fixed and workpiece is mounted on workbench then actual cutting takes place.

V. MATERIAL SELECTION
Selection of material for research work is of utmost importance. Before selecting any grade/type of material it is necessary to check its compatibility with existing machine setup and also its availability. Cost, technical feasibility, ease of machining and applications are yet some other factors to be considered while going for any material. This chapter focuses on explaining the material selection for workpiece, powder, dielectric, etc.

A. Workpiece material
AISI D3 material is selected for experimental work. Following are the specifications of material-
1) *Name:* AISI D3
2) *Composition:* Table II shows composition of AISI D3

TABLE III
COMPOSITION OF AISI D3 MATERIAL

C	Si	Cr	Mn	Ni	S	P	V	Fe
2.10	0.30	11.5	0.40	0.31	0.03	0.03	1	Balance

3) *Properties:* Following are the properties of AISI D3-
a) Density -7800 kg/m³
b) Melting Point -1421°C
c) Coefficient of thermal Expansion - 12×10^{-6}/°C (20 – 100°C)
d) Modulus of Elasticity – 190-210 GPa
e) Hardness- 63 HRC

4) *Workpiece dimension:* Workpiece dimension is calculated such that a square profile of 10*10mm can be cut at approximate centre of the workpiece. Due to some fixture attachment it was possible to decrease the size of workpiece from 100*100*6.7mm to 80*80*6.7mm. This helped reduce project costing and saving the material too.

B. Wire Electrode

Selection of wire electrode for any workpiece material is mostly influenced by the hardness of workpiece material. For AISID3 Zinc coated Brass wire is mostly compatible. Following are the specifications of wire electrode material-
1) Material: CuZn37 (Brass-Copper-Zinc alloy)
2) Diameter: 0.25 mm diameter

C. Metallic Powder

Metallic powder mixed in dielectric fluid results in improvement of machining. Powder size (mesh size) is so selected that it is compatible with existing filtration process. Table shows mesh size for selected powders. Both the powders have mesh size of 600. It corresponds to average particle size of 25 microns.

TABLE IIIII
POWDER SIZE

Sr. No.	Powder Name	Mesh Size
1	Silicon Carbide	600
2	Aluminium Oxide	600

D. Dielectric Fluid

Dielectric fluid plays a vital role in WEDM cutting process. Its main function is to flush the eroded material and to cool down the heated zone. Here demineralized water of 30 TDS is used as dielectric medium.

VI. EXPERIMENTAL WORK

From machine specifications, observations of Demonstrations experiments and Hands-On experiments; Taguchi's DOE is done using Mini-Tab 17 software.

A. Design Of Experiments

Table IV shows the final levels of parameters for experimentation. Table V shows the L16 array generated for final experimentation.

TABLE IVV
LEVELS OF PROCESS PARAMETERS FOR EXPERIMENTATION

Factors levels	Pulse-On Time (µs)	Pulse-Off Time (µs)	Servo voltage (volts)	Wire feed rate (m/min)	Powder concentration (g/lit)
1	110	52	25	3	0
2	112	54	30	4	1
3	114	56	35	5	2
4	116	58	40	6	3

TABLE V
L16 ARRAY FOR EXPERIMENTATION

Exp. No.	Pulse-On Time (μs)	Pulse-Off Time (μs)	Servo voltage (volts)	Wire Feed rate (m/min)	Powder Concentration (g/lit)
1	110	52	25	3	0
2	110	54	30	4	1
3	110	56	35	5	2
4	110	58	40	6	3
5	112	52	30	5	3
6	112	54	25	6	2
7	112	56	40	3	1
8	112	58	35	4	0
9	114	52	35	6	1
10	114	54	40	5	0
11	114	56	25	4	3
12	114	58	30	3	2
13	116	52	40	4	2
14	116	54	35	3	3
15	116	56	30	6	0
16	116	58	25	5	1

B. *Machined Workpiece Illustration*

Fig. 1 shows a sample workpiece picture for all designed experiments. It shows workpiece dimension, direction of wire traverse (shown with white arrows), removed metallic part and wire path (shown with continuous orange line). The path is a square profile geometry with side 10mm and having and entry length of 5mm. Each of the workpiece is punched with number punches for ease of identification.

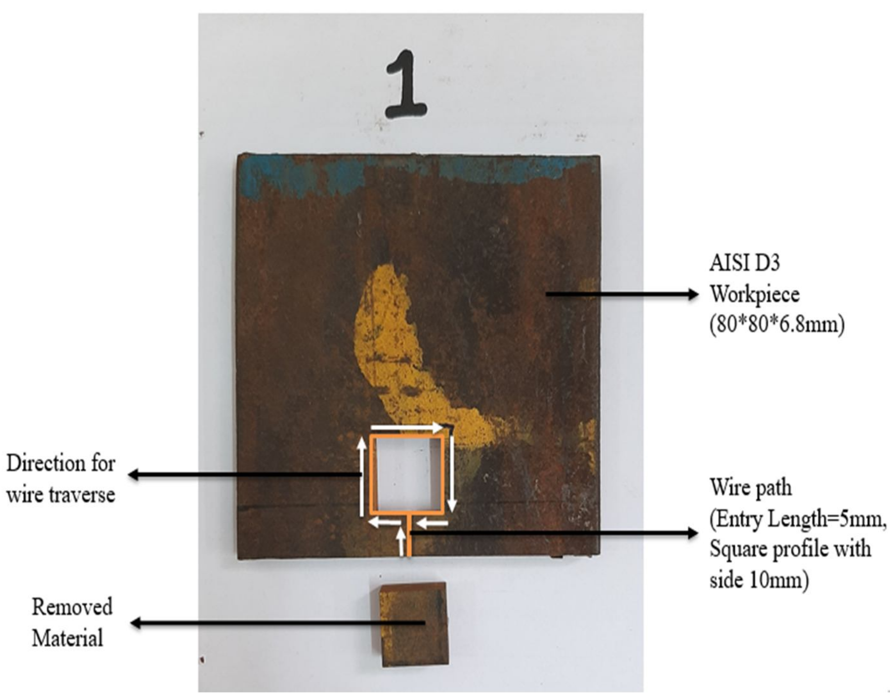

Fig. 1 Sample workpiece picture for all designed experiments

C. Material Removal Rate (MRR) Calculations

In order to calculate MRR following formula was used for all pilot experiments;

$$\boldsymbol{MRR = (Wt.of\ w/p\ before\ machining - Wt.of\ w/p\ after\ machining)/\ Time} \quad \text{...Eq. (1)}$$

Where,

1) MRR = Material Removal Rate in g/min
2) Wt. of w/p = Weight of workpiece in grams
3) Time = time required for machining in minutes

As the time was measured only for square profile, only the square shaped material removed is taken into consideration and material removed in entry path is neglected.

D. Surface Roughness (SR) Measurement

Surface roughness is measured using Taylor Hobson surface tester available in campus laboratory. Roughness is measured on all four cutting edges of removed part. The final value taken is an average of the four sides being measured. This instrument measures the Ra value and gives the result in micrometres.

E. Results for SR and MRR Calculations

Table VI shows the results for designed experiments.

TABLE VI
RESULT TABLE FOR DESIGNED EXPERIMENTS

Exp. No.	Pulse-On Time (μs)	Pulse-Off Time (μs)	Servo voltage (volts)	Wire Feed rate (m/min)	Powder Concentration (g/lit)	MRR (g/min)	SR(μm)
1	110	52	25	3	0	0.11	1.790
2	110	54	30	4	1	0.15	1.021
3	110	56	35	5	2	0.28	1.089
4	110	58	40	6	3	0.38	1.952
5	112	52	30	5	3	0.29	1.021
6	112	54	25	6	2	0.254	1.201
7	112	56	40	3	1	0.31	1.910
8	112	58	35	4	0	0.28	2.230
9	114	52	35	6	1	0.31	1.990
10	114	54	40	5	0	0.36	2.120
11	114	56	25	4	3	0.4	1.510
12	114	58	30	3	2	0.42	1.230
13	116	52	40	4	2	0.52	1.250
14	116	54	35	3	3	0.53	2.123
15	116	56	30	6	0	0.6	2.860
16	116	58	25	5	1	0.61	1.560

F. Analysis of Results

This point presents the various ways in which the analysis of experimental data has been performed. The objectives of this work are-

1) To find effects of various PMWEDM process parameters on different performance characteristics and to find optimum levels of PMWEDM parameters for each response characteristics with analysis of raw data means, ANOVA analysis and S/N ratio.
2) To optimize the multi performance of the PMWEDM process in terms of surface roughness and MRR generated at stainless steel specimen surface with the help of grey relational analysis.

G. Analysis of Variance for MRR

Table VII shows the significant parameters which affects MRR. The TON is most significant because it shows highest F-Value. TOFF is second most significant parameter which affects MRR. The Powder concentration shows the third most significant parameter affecting the MRR.

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Table VII shows the average MRR values at various levels of Pulse-On time, Pulse-Off time, servo voltage, wire feed rate and powder concentration. It indicates that the level 1 of pulse on time i.e. 110µs gives the lowest average MRR value = 0.23 g/min whereas the level 2 i.e. 112 µs gives average MRR value = 0.28 g/min. the level 3 i.e. 114 µs gives the MRR value = 0.37 g/min, at level 4 i.e. 116 µs gives max MRR value 0.565 g/min. Hence it is clear that pulse on time should be kept at level 4 in order to have higher average MRR values.

TABLE VII
SIGNIFICANT PARAMETERS AFFECTING MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.293205	0.058641	21.39	0.000
TON	1	0.239367	0.239367	87.33	0.000
TOFF	1	0.035112	0.035112	12.81	0.005
Servo voltage	1	0.003485	0.003485	1.27	0.286
Wire Feed	1	0.006337	0.006337	2.31	0.159
Powder Concentration	1	0.008904	0.008904	8.25	0.002
Error	10	0.027410	0.002741		
Total	15	0.320615			

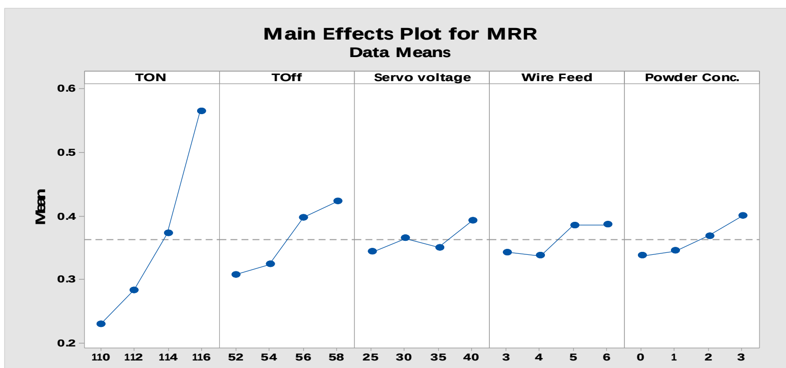

Fig. 2 Main effects plot for MRR

In case of pulse off time, the level 1 i.e. 52 µs gives the average MRR value = 0.30 g/min, level 2 i.e. 54 µs gives MRR value = 0.32 g/min and level 3 i.e. 56 µs gives average MRR value = 0.39 g/min. Max value obtained at level 4 i.e. at 58 µs is 0.4225 g/min. Hence it is clear that pulse-Off time should be kept at level 4 in order to have higher MRR values.

Similarly, the average MRR values at different levels of servo voltage and wire feed rate are shown graphically in Fig. 2. It is clear that level 1 of servo voltage gives maximum average MRR value = 0.3435 g/min, level 2 of servo voltage gives average MRR value = 0.36 g/min and level 3 of pulse on time gives lower average value of MRR = 0.35 g/min. At level 4 it gives 0.3925 g/min. Therefore servo voltage should be kept at its level 4 to have higher average MRR.

For level 1 of wire feed rate i.e.3 m/min there is lower average value of MRR = 0.3425g/min, level 2 of wire feed rate i.e. 4 m/min gives maximum average value of MRR value = 0.337 g/min, level 3 of wire feed rate i.e. 5 m/min gives average MRR value = 0.385 g/min, at level 4 it gives 0.386 so that to have highest MRR wire feed rate should be kept at level 4 i.e. 6 m/min.

For level 1 of powder concentration i.e. 0gm/lit there is average value of MRR = 0.337 g/min, level 2 of powder concentration i.e. 1 g/lit gives MRR value = 0.345 g/min, level 3 of powder concentration i.e. 2 g/lit gives average MRR value = 0.368 g/min and level 4 of powder concentration i.e. 3 g/lit gives average MRR value = 0.410 g/min. For highest MRR, powder concentration should be kept at level 4 i.e. 3 g/lit.

Regression Equation for MRR-

$$MRR = -7.168 + 0.05470\,TON + 0.02095\,TOFF + 0.00264\,Servo\ voltage + 0.0178\,Wire\ Feed + 0.0211\,Powder\ Concentration \quad \text{...Eq. (2)}$$

H. Analysis of Variance for SR

Table VIII shows the significant parameters which effects on SR. Powder concentration is the most significant because it shows highest F-Value after that TON is second most significant parameter which affects SR.

Table VIII shows the average SR values at various levels of Pulse-On time, Pulse-Off time, servo voltage, wire feed rate, and powder concentration. It indicates that the level 1 of pulse on time i.e. 110 µs gives the lowest average SR value = 1.85 µm whereas the level 2 i.e. 112 µs gives average SR value = 1.76 µm. the level 3 i.e. 114 µs gives the SR value =1.86 µm, at level 4 i.e. 116 µs gives max SR value = 2.02 µm. Hence it is clear that pulse on time should be kept at level 1 in order to have lower average SR values.

In case of pulse off time, the level 1 i.e. 52 µs gives the average SR value = 1.95 µm, level 2 i.e. 54 µs gives SR value = 1.92 µm and level 3 i.e. 56 µs gives average SR value = 1.86 µm. Max value obtained at level 4 i.e. at 58 µs is 1.808 µm. Hence it is clear that pulse off time should be kept at level 4 in order to have lower SR values.

Similarly, the average SR values at different levels of servo voltage and wire feed rate are shown graphically in Fig. 3. It is clear that level 1 of servo voltage gives maximum average SR value = 1.98 µm, level 2 of servo voltage gives average SR value = 1.812 µm and level 3 of pulse on time gives lower average value of SR = 1.86 µm. At level 4 it gives 1.84 µm. Therefore servo voltage should be kept at its level 2 to have lower average SR.

For level 1 of wire feed rate i.e.3 m/min there is lower average value of SR = 1.703 µm, level 2 of wire feed rate i.e. 4 m/min gives maximum average value of SR value = 1.91 µm, level 3 of wire feed rate i.e. 5 m/min gives average SR value = 2.045 µm, at level 4 it gives 1.85 so that to have lower SR wire feed rate should be kept at level 4 i.e. 6 m/min.

For level 1 of powder concentration i.e. 0 g/lit there is average value of SR = 1.945 µm, level 2 of powder concentration i.e. 1 g/lit gives SR value = 1.89 µm, level 3 of powder concentration i.e. 2 g/lit gives average SR value = 1.775 µm. The SR at powder concentration level 4 i.e. 3 g/lit is 1.89 µm. The powder concentration should be kept at level 2 for lower SR.

Regression equation for SR-

$SR = -10.50 + 0.0789\,TON + 0.0458\,TOFF + 0.0241\,Servo\ Voltage + 0.066\,Wire\ Feed - 0.222\,Powder\ Conc.$ Eq. (3)

TABLE VIII

SIGNIFICANT PARAMETERS AFFECTING SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.25731	0.051462	0.38	0.853
TON	1	0.16417	0.164167	40.20	0.0498
Toff	1	0.00087	0.000871	0.01	0.938
Servo voltage	1	0.03378	0.033784	0.25	0.630
Wire Feed	1	0.00188	0.001882	0.01	0.0909
Powder Concentration	1	0.05660	0.056605	75.41	0.0434
Error	10	1.36443	0.136443		
Total	15	1.62174			

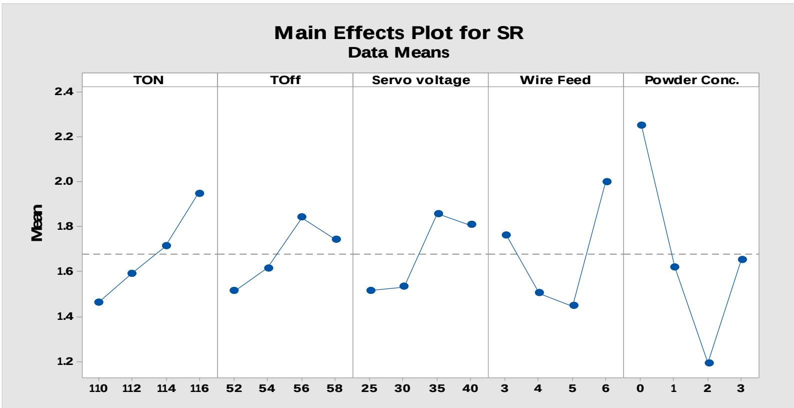

Fig. 3 Main effects plot for SR

I. Grey Relational Analysis

The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A System for which the relevant information is completely known is a 'white' system, while a system for which the relevant information is completely unknown is a 'black' system. Any system between these limits is a 'grey' system having poor and limited information. Grey Relational Analysis (GRA) a normalization evaluation technique is extended to solve the complicated multi-performance characteristics optimization effectively. The following steps are followed to apply GRA which gives optimal value for machining process:

1) Data Pre-Processing
2) Optimization of Results

J. Data Pre-processing

Data Pre-Processing is normally required, since the range and unit in one data sequence may differ from others. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different. The data pre-processing is applied as per the requirement of response variable to researcher. There are two criteria's are used; one is larger the better and second is smaller the better value of response variable. The formulae for the criteria are mentioned below. The eq. (4) represent the larger the better whereas eq. (5) is for smaller the better value.

$$X_{IJ} = \frac{YIJ - MINI(YIJ)}{MAXi\,(YIJ) - MINIi\,(YIJ)} \qquad \text{...Eq. (4)}$$

$$X_{IJ} = \frac{MAXi\,(YIJ) - YIJ}{MAXi\,(YIJ) - MINIi\,(YIJ)} \qquad \text{...Eq. (5)}$$

Where is Y_{IJ} or YIJ the I^{th} performance characteristic in the J^{th} experiment, MAX_i (Y_{IJ}) and $MINI_i$ (Y_{IJ}) are the maximum and minimum values of I^{th} performance characteristic for alternate J respectively.

By normalizing, grey relational co-efficient (GRC) is calculated as eq. (6)

$$K_{IJ} = \frac{MINIi\ MINIj\ |XaJ - XIJ| + K\ MAXi\ |XaJ - XIJ|}{|XaJ - XIJ| + K\ MAXi\ |XaJ - XIJ|} \qquad \text{...Eq. (6)}$$

XaJ is the ideal normalised result for the J^{th} performance characteristics. The grey relational grade (GRG) is obtained by averaging the grey relational co-efficient corresponding to each performance measure.

Grey Relational Grade (GRG) is represented in eq. (7)

$$P_I = \frac{1}{n}\sum_{J=1}^{N} Wr\ KIJ \qquad \text{...Eq. (7)}$$

Here Wr denotes the normalized weight factor and taken as 1. The grey relational grade P_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 also indicates the degree of influence that the comparability sequence could explain over the reference sequence. The above steps are used to identify the optimal value from the experimental results.

K. Optimization of Results

The GRA is applied to designed experiments and the optimal value is identified. The best and worst readings are ranked from 1 to 16. The readings are summarised in Table IX. The GRA gives the set of parameter levels for which best and worst results obtained. The best reading is ranked 1 and its parameters are TON=116 µs, TOFF=58 µs, Servo Voltage=25 V, Wire feed=5 m/min, powder concentration=1 g/lit and the worst reading is TON=110 µs, TOFF=52 µs, Servo Voltage=25 V, Wire feed=3 m/min, powder concentration=0 g/lit. Also highest MRR and SR values are highlighted in red colour and lowest MRR and SR values are highlighted in blue colour.

TABLE IX
GRA OF DESIGNED EXPERIMENTS

Sr. No.	TON	TOFF	Servo Voltage	Wire Feed	Powder Conc.	MRR	SR	SR (GRR)	MRR (GRR)	SR (GRC)	MRR (GRC)	GRG	Rank
1	110	52	25	3	0	0.11	1.79	0.581	0	0.705	0.500	0.602	16
2	110	54	30	4	1	0.15	1.021	1.000	0.08	1.000	0.520	0.760	
3	110	56	35	5	2	0.28	1.089	0.963	0.34	0.964	0.602	0.783	
4	110	58	40	6	3	0.38	1.952	0.493	0.54	0.663	0.684	0.674	
5	112	52	30	5	3	0.29	1.021	1.000	0.36	1.000	0.609	0.804	
6	112	54	25	6	2	0.254	1.201	0.902	0.288	0.910	0.584	0.747	
7	112	56	40	3	1	0.31	1.91	0.516	0.4	0.674	0.625	0.649	
8	112	58	35	4	0	0.28	2.23	0.342	0.34	0.603	0.602	0.602	15
9	114	52	35	6	1	0.31	1.99	0.473	0.4	0.654	0.625	0.639	
10	114	54	40	5	0	0.36	2.12	0.402	0.5	0.625	0.666	0.646	
11	114	56	25	4	3	0.4	1.51	0.734	0.58	0.789	0.704	0.747	
12	114	58	30	3	2	0.42	1.23	0.886	0.62	0.897	0.724	0.811	
13	116	52	40	4	2	0.52	1.25	0.875	0.82	0.889	0.847	0.868	2
14	116	54	35	3	3	0.53	2.123	0.400	0.84	0.625	0.862	0.743	
15	116	56	30	6	0	0.6	2.86	0.000	0.98	0.500	0.980	0.740	
16	116	58	25	5	1	0.61	1.56	0.706	1	0.773	1.000	0.886	1

VII. RESULTS AND CONCLUSIONS

A. Results

1) Parameters affecting the MRR follow the order (most significant first):
   a) Pulse-On Time
   b) Pulse-Off Time
   c) Powder concentration
   d) Wire feed rate
   e) Servo voltage
2) Parameters affecting the SR follow the order (most significant first):
   a) Pulse-On Time
   b) Powder concentration
   c) Servo voltage
   d) Pulse-Off Time
   e) Wire feed rate
3) Highest MRR of 0.61g/min is achieved at TON = 116μs, TOFF = 58μs, Servo Voltage = 25 V, Wire feed = 5m/min, Powder concentration = 1 g/lit.
4) Lowest SR of 1.021μm is achieved at TON = 110μs, TOFF = 54μs, Servo Voltage = 30 V, Wire feed = 4m/min, Powder concentration = 1 g/lit.
5) Best set of parameters for optimum MRR and SR are; TON = 116μs, TOFF = 58μs, Servo Voltage = 25 V, Wire feed = 5m/min, Powder concentration = 1 g/lit.

B. Conclusions

1) Significant parameters affecting the response variables such as MRR and SR during machining of AISID3 material were determined.
2) Effect of various parameters on machining of AISID3 material with and without powder was studied.
3) Effect of various parameters on MRR and SR was studied.
4) Set of parameters for optimum MRR and SR were found.

VIII. ACKNOWLEDGEMENT

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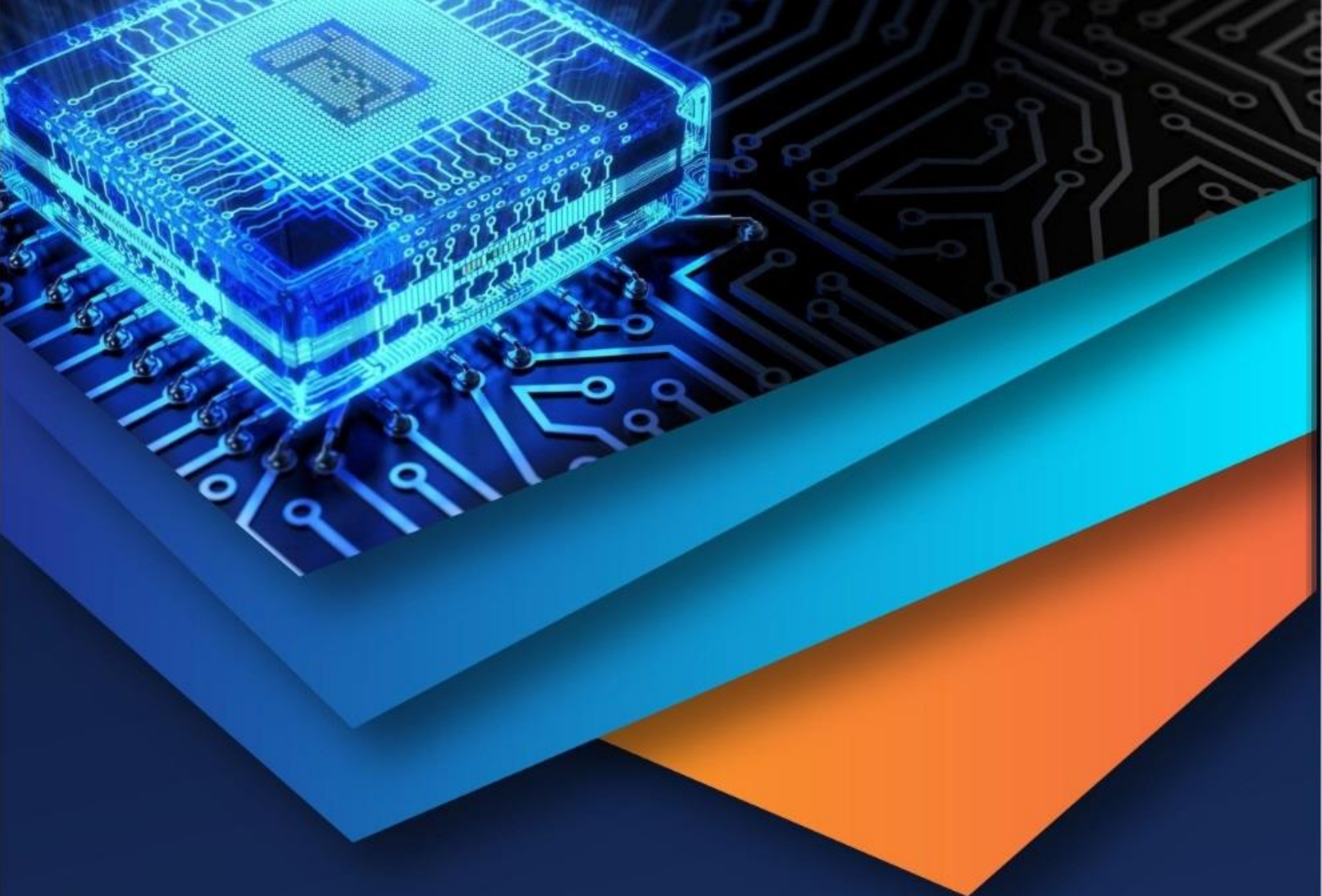

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