Ann Modelling and Parametric Optimization of Powder Mixed Electrodischarge Machining by using Taguchi Method for AISI 1046 Steel

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Abstract - In this paper, the machining operation of AISI 1046 Steel material using Powder Mixed electro discharge machining (PMEDM) with copper electrode and chromium in form of powder mixed into the dielectric fluid in machining tank, by using Taguchi methodology has been reported and so it is modeled by ANN. In Powder Mixed Electric discharge machining, there are four general categories of process parameters i.e. Electric parameters, Electrode Parameters, Non-Electrical Parameters and Powder Parameters. In this report, Powder parameters i.e. Concentration and Grain Size of Powder are considered. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each Powder parameter on the machining characteristics, and to predict the optimal choice. It is found that these parameters have a significant influence on machining characteristic such as material removal rate (MRR), and Surface Roughness (Ra). The analysis using Taguchi method reveals that, in general the Concentration and Grain Size of Powder significantly affects the MRR, and Ra. Keywords: EDM, PMEDM, Taguchi method, Artificial Neural Network (ANN), AISI 1046 Steel, material removal rate, and Surface Roughness.

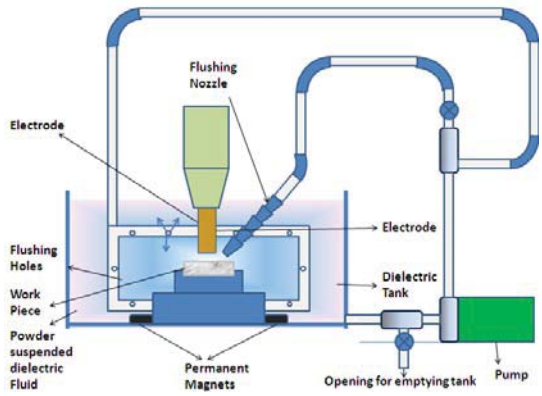
I. INTRODUCTION

Electrical discharge machining is an important manufacturing process for tool mould and dies industries. Application of this process is increasing day by day because of its ability to produce geometrically complex shapes and ability to machine materials irrespective to their hardness. However, poor surface finish and low machining efficiency are some limitations to this process which restricts its applications in many industries. To dissolve this limitation, Powder likes (Chromium, Aluminum, Copper, Silicon carbide). Powder mixed electrical discharge machining (PMEDM) is a derivative of Electro Discharge Machining with an advantage of improved machining efficiency and surface finish because of presence of powder mixed dielectric fluid.

The working principle of powder mixed electrical discharge machining process had been discussed by many researchers. In this process, an electric field in the range of 105–107 V/m is created, when a voltage is applied between the electrode and the work piece facing each other with a gap in a same axis. As a result of which powder particles present in the spark gap get energized and these charged powder particles are accelerated by the developed electric field which makes them behaving like a conductor. The main role adapted by these conductive charged particles to promote breakdown in the gap and increase the spark gap between tool and the work piece. In the region of sparking area, these particles came closer to each other and get themselves arranged in chain like structures between both the electrodes. This chain like structure provides an interlocking between the different powder particles, in the direction of current flow. This Interlocked chained structure helps in bridging the discharge gap between electrodes and also results in decreasing the insulating strength of the dielectric fluid. Now easy short circuit takes place between the electrode and work material, causing early and frequent explosion in the gap which results in series discharges under the electrode area. The rate of sparking directly links with the material removal rate i.e. faster the sparking within a discharge, faster will be the erosion from the work piece surface and hence increase in the material removal rate (MRR). At the same time, the added powder also modifies the plasma channel making it enlarged and widened. Due to which the sparking is uniform and is uniformly distributed among the powder particles, which degrades the electric density of the spark. This degradation of electric density and uniform distribution of sparking among the powder particles produces shallow craters on the surface of work piece resulting in improvement in surface finish. *Figure 1* shows the line diagram of

Powder Mixed Electro Discharge Machining.

Figure 1. Line diagram of experimental setup



AISI 1046 steel material was the target material used in this investigation as no machining data of AISI 1046 steel material on basis of Grain Size and Concentration is available. AISI 1046 is a medium carbon steel which responds to heat treatment, flame and induction hardening, but it is not recommended for carburizing and cyaniding. Owing to its excellent mechanical and metallurgical properties this finds extensive use in manufacturing of plates , intensity of general building and all kinds of engineering machinery , links, excavators, the rig with electric wheel, mine cars, loaders, bull dozers, all kinds of cranes, coal hydraulics support, etc. AISI 1046 is one of the most difficult-to- machine medium carbon steels in order to satisfy production and quality requirement. This difficulty in machining is attributed to its ability to maintain hardness at elevated temperature which otherwise is very useful for hot working environment. The Properties like Mechanical, Physical, Thermal and Chemical compositions of AISI 1046 are shown in Table 1.

II. EXPERIMENTAL DETAILS

2.1 Machine Tool

For Machining ***Elecktra plus S-50 ZNC*** oil die-sinking electric discharge machine with copper electrode is used. The selection of experimental setting is based on machine specification, literature review and personal experience, which is then tabulated in table1.

Table 1: Experimental setting Table

Polarity	Positive
Current	6 Amp
Voltage	35 Volt
Pulse On Time	150 µs
Duty Factor	0.7

2.2 Work Material

In our Experimental study, Powder Mixed Electro Discharge Machining was performed on AISI 1046 Steel. The composition and other properties of AISI 1046 are given in Table 2 and 3.

Table 2: Properties AISI 1046 Steel material

Property	Unit	Value
Elastic Modulus	GPa	190-210
Shear Modulus	GPa	80
Bulk Modulus	GPa	140
Ultimate tensile strength	MPa	650
Yield Strength	MPa	545
Hardness, Brinell		187
Hardness, Knoop		209
Hardness, Rockwell B/C		90/10
Hardness, Vickers		196
Poisson's Ratio		0.27-0.30
Elongation at break (in 50 mm)		12%
Density	g/cc	7.85
Average Coefficient of Thermal Expansion	µm/m·°C	11.5
Thermal Conductivity	W/m·K	49.8

Table 3: Composition of AISI 1046 Steel material

Element	Weight Percentage(%)
Iron, Fe	98.41-98.88
Magnesium , Mg	0.70-
Carbon, C	0.420-0.50
Sulphur , S	≤
Phosphorus, P	≤

2.3 Process Parameter

In PMEDM, there are four different categories of parameters which can be considered for study i.e. Electrical Parameters, Non- Electrical Parameters, Electrode Parameters and Powder Parameters. Among these parameters, Powder parameters are considered for our study. Powder Parameters comprises of two sub categories i.e. Grain Size of Powder and Concentration of Powder in Dielectric Fluid. Here, the machining operation is performed by keeping various parameters like Current, Voltage, Pulse- in time, Duty cycle etc. are made constant and Varying the two parameters i.e. Grain size of Chromium powder and Concentration of Chromium Powder.

2.4 Tool Electrode Material

Electrolytic Copper Electrode (99.9%) has been used as tool electrode Material. The Properties of Copper electrode is given in table 4.

Table 4: Properties of Tool Electrode Material

Electrode	Density	Specific heat	Thermal conductivity	Electrode Resistivity	Hardness(BHN)
Copper	8.9	386	399	1.69	48

2.5 Conductive material selection

The Status of Chromium powder particles mixed into the dielectric fluid has a very significant role in evaluation of Material removal rate and Surface finish. And so the parameters like Grain Size and Concentration of Chromium Powder is considered here for our study. The properties associated with Chromium Powder are given in Table 5.

Table 5: Properties of Chromium Powder

Powder	Chromium
Density	7.15 (g/cm^3)
Thermal Conductivity (at 300K)	93.9 W.m^{-1}.K^{-1}
Electrical Resistivity (at 20 C)	125 nΩ.m
Melting Point	2180 K
Boiling Point	3944 K
Young's modulus	279 GPa
Shear modulus	115 GPa
Bulk modulus	160 GPa
Poisson ratio	0.21
Vickers hardness	1060 MPa
Brinell hardness	1120 MPa

The process parameters and levels used in the experiment are shown in Table 6.

Table6: Level values of input factors

Levels	**Variables**	
	Grain Size of Chromium Powder (µm)	**Concentration of Chromium Powder (gm/ltr.)**
Level 1	Fine (150)	2
Level 2	Medium (200)	4
Level 3	Coarse (250)	6

III. DESIGN OF EXPERIMENTS

3.1 Taguchi Method:

Taguchi methods are the most recent additions to the toolkit of design, process and manufacturing engineers, and quality assurance experts. Here we have used L9 Orthogonal Array and a set of rule for S/N ratio i.e. Larger is better for Material Removal Rate (MRR) and lower is better for Surface Roughness (Ra).

In L9 array, 9 rows represent the 9 experiment to be conducted with 2 columns at, 3 levels of the corresponding factor as shown in Table 7. The design matrix form of these arrays is shown in Table 8, where 1, 2, 3 in the table represents the level of each parameters.

Input Factors:-

1) Grain Size of Chromium Powder
2) Concentration of Chromium Powder

Responses measured:-

1) Material Removal Rate (MRR),
2) Surface Roughness (Ra),

Table7: Taguchi L9 Orthogonal array Design Matrix

Experiment	Parameter 1	Parameter 2
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Table 8:L9 Design Matrix

Experiment	Grain/Mesh Size of Cr Powder	Concentration of
1	15	2
2	15	4
3	15	6
4	20	2
5	20	4
6	20	6
7	25	2
8	25	4
9	25	6

2 ANN Modelling

Experiments were carried out to collect the data. These Data needs to be preprocessed before starting the training of ANN. Data is divided into input pattern and target vector. Input pattern consists of the values of input parameters taken in experimentation and the corresponding performance measures are taken as target vector. The scaling or normalization of input and output data needs to be done, specially, when the operating ranges of the parameters are different. Scaling or normalization helps in avoiding skewing the results by any particular variable significantly while training ANN. All the input parameters are equally important in training the network after scaling. For scaling, following formula is used to map each term between -1 and 1.

IV. RESULTS AND DISCUSSION

4.1. Material Removal rate (MRR)

For calculation of Material Removal Rate, below given equation is used.

$$MRR(mm^3/min) = \frac{[Initial\ workpiece\ weight(gm) - Final\ workpiece\ weight(gm)]}{Density\left(\frac{gm}{mm^3}\right) * machining\ Time\ (min)}$$

The density of AISI 1046 Steel is taken as 7.85 g/cc.

4.2 Surface Roughness (Ra)

Surface roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness can be measured by manual comparison against a "surface roughness comparator", but more generally a Surface profile measurement is made with a profilometer that can come into contact with the surface. In this work Roughness measurement has been done by a portable stylus-type profilometer, Mitutoyo- Surftest SJ- 201P/M.

4.3 Response Table

As per the design matrix, Response Table is shown in Table 9.

Table 9: Response Table of Ra and MRR

Experiment	Grain/Mesh Size of Cr Powder	Concentration of Cr Powder (gm/ltr.)	Work-piece Material	Machining Time	MRR (mm3/	Surface Roughness (µm) Length
1	0	0	1.455	9	22.6	5.935
2	150	2	1.49	9	22.5	6.483
3	150	4	1.516	9	23.1	5.76
4	150	6	1.572	9	23.84	5.205
5	200	2	1.624	9	25.56	7.32

6	200	4	1.685	9	27.78	6.385
7	200	6	1.62	9	24.88	5.005
8	250	2	1.287	9	20.81	6.26
9	250	4	1.473	9	22.46	4.66
10	250	6	1.473	9	23.78	5.49

4.3 Analysis of Single Response Stage

With the Taguchi Design approach, Means and optimal values for Ra and MRR are determined as shown in Table 10 and 11. From table it is observed that parametric variables i.e. grain size and concentration of Cr powder possess a considerable effect on the performance characteristics i.e. Ra and MRR.

Table 10: Means of MRR & Surface Roughness as per Taguchi Design

Level	Mean Value of R_a		Mean Value of MRR	
	Grain Size	Concentration	Grain Size	Concentration
1	5.816	6.876	23.146	22.956
2	6.236	5.601	26.073	24.446
3	5.47	5.233	22.35	24.166

Table 11: Individual Optimal Values & Corresponding Setting of Process Parameters as per Taguchi Design

Performance Characteristic	Optimal Parameter Level	Optimum Level
R_a (μm)	A3-B3	5.3515
MRR (mm^3	A2- B2	25.2595

4.4 Analysis Of Plot For MRR

As per the data gathered form experimentation, data is analyzed using single stage response S/N ratio method. This analysis provides us the optimal values of the process parameter for MRR, shown in Table 12. Plot for the optimal values of MRR vs. Grain size and concentration of Cr powder is shown in Fig 2 and Fig3. As per the experimental data collected process variable i.e. Grain size are categorized into four class: Null, fine, Medium and Coarse. Similarly, levels of concentration are categorized as 0 gm/ltr, 2 gm/ltr, 4 gm/ltr and 6 gm/ltr.

Table 12: Optimal Values for MRR

Grain/Mesh Size	Concentration
22.6	22.6
23.146	22.956
26.073	24.446
22.35	24.166

Based on Grain Size of Powder

Fig.2, the plot between MRR and Grain size of Cr powder, shows that when No Cr powder is used, MRR is low. As we start mixing Fine grain Cr powder in EDM oil, MRR increases. Again when we mix medium Grain Cr powder, MRR increases. But when coarse grain Cr powder is used, MRR decreases. So, it is well concluded that maximum MRR is obtained when medium Grain Cr powder is used.

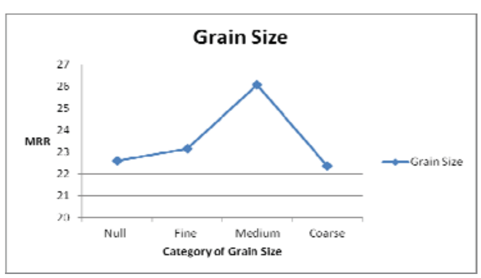


Fig. 2 - Response Graph for Material Removal Rate "MRR", Grain Size of Cr powder

Based on Concentration of Powder

Fig.3, the plot between MRR and concentration of Cr powder, shows that when no powder is used with EDM oil, MRR is low. As we start with 2 gm/ltr of Cr powder as concentration, MRR increases. Again when we increase the concentration from 2gm/ltr to 4 gm/ltr, MRR increases. But, when the concentration is increased from 4 gm/ltr to 6 gm/ltr, MRR decreases. So it is well concluded that maximum MRR is obtained when concentration of Cr powder is 4 gm/ltr.

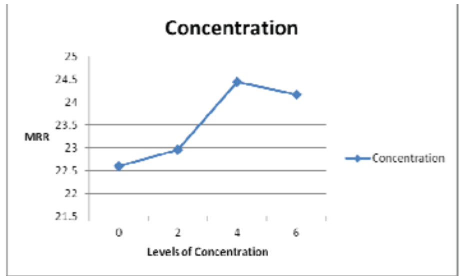


Fig.3: Response Graph for Material Removal Rate "MRR" and Concentration of Cr powder

4.5 Analysis Of Plot For Surface Roughness

Analysis using single stage response S/N ratio method provides us the optimal values of the process parameter for Ra, shown in Table 13. Plot for the optimal values of Ra vs. Grain size and concentration of Cr powder is shown in Fig 4 and Fig5.

Table 13: Optimal Values for Surface Roughness

Grain/Mesh Size	Concentration
5.935	5.935
5.816	6.876
6.236	5.601
5.47	5.233

Based on Grain Size of Powder

Fig.4, the plot between Ra and Grain size of Cr powder, shows that when No Cr powder is used , Ra is high. As we start mixing Fine grain Cr powder in EDM oil, Ra increases. Again when we mix medium Grain Cr powder, Ra decreases. But when coarse grain Cr powder is used, Ra decreases further. So, it is well concluded that minimum Ra is obtained when coarse Grain Cr powder is used i.e. Coarse Powder gives the best surface finish.

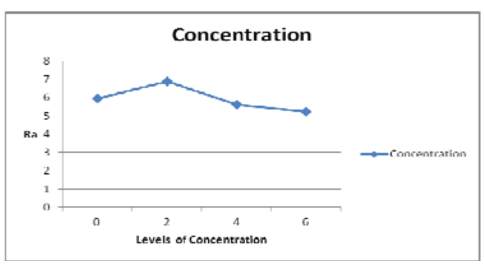


Fig. 4 Response Graph Surface Roughness (Ra), and Grain Size of Cr powder

Based on Concentration of Powder

Fig.5, the plot between Ra and concentration of Cr powder, shows that when no powder is used with EDM oil, Ra is high. As we start with 2 gm/ltr of Cr powder as concentration, Ra increases further. Again. When we increase the concentration from 2gm/ltr to 4 gm/ltr, Ra starts decreasing. But, when the concentration is increased from 4 gm/ltr to 6 gm/ltr, Ra decreases more. So it is well concluded that minimum Ra is obtained when concentration of Cr powder is 6 gm/ltr.

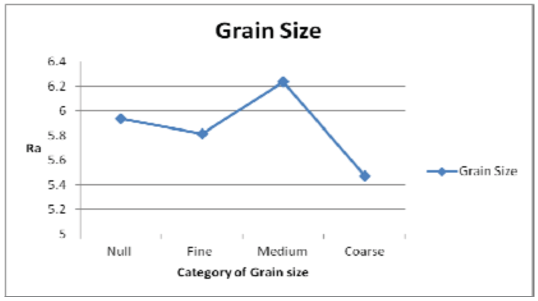


Fig. 5: Response Graph for Surface Roughness "Ra" and Concentration of Cr powder

4.6 Analysis of Multi-Response Stage

Till now we have gone through the single stage response. Now to make our results and analysis we will opt multiple stage response methodology based on Taguchi technique. Taguchi proposed different possible S/N ratios to obtain the optimum parameters setting. Here two of them are selected.

(a)Smaller the better type S/N ratio for R_a

$$[\eta_1] = -10\log_{10}\left[R_a^2\right];$$

(b)Larger the better S/N ratio for MRR

$$[\eta_2] = -10\log_{10}\left[\frac{1}{MRR^2}\right]$$

The utility concept is also used here for optimizing the multiple responses (Ra and MRR) and the multi-response S/N ratio of the overall utility value is given by

$$\eta_{obs} = W_1\eta_1 + W_2\eta_2$$

Where W_1 & W_2 are the weights assigned to the R_a and MRR. In this work equal importance is given to both Ra and MRR. (W_1 & W_2 = 0.5). The design matrix table with multiple response S/N ratio as per the concept of utility is shown in Table 14. Similarly, the Mean Value of η_{obs} for Process Parameters at different levels is shown in Table 15.

Table 14: Design Matrix with Multi-Response S/N Ratio

S. No.	Grain/ Mesh Size Of Chromium Powder (µm)	Concentration Of Chromi um Powder (gm/ltr.)	Surface Roughness (µm)	η_1 for Ra	MRR (mm^3 /min.)	η_2 for MRR	η_{obs}
1	0	0	5.935	-15.4684	22.6	27.08217	5.806877
2	150	2	6.483	-16.2355	22.5	27.04365	5.404065
3	150	4	5.76	-15.2084	23.1	27.27224	6.031895
4	150	6	5.205	-14.3284	23.84	27.54613	6.608855
5	200	2	7.32	-17.2902	25.56	28.15122	5.430498
6	200	4	6.385	-16.1032	27.78	28.87464	6.385713
7	200	6	5.005	-13.9881	24.88	27.91701	6.964463
8	250	2	6.26	-15.9315	20.81	26.36544	5.216977
9	250	4	4.66	-13.3677	22.46	27.0282	6.830238
10	250	6	5.49	-14.7914	23.78	27.52424	6.366395

Table 15: Mean Values Of ηobs At Different Levels

Levels	Mean Value of η_{obs} for Process Parameters	
	Grain Size	Concentration
Level 1	6.0149	5.3505
Level 2	6.2602	6.4159
Level 3	6.1378	6.6465

The individual optimal values and its corresponding setting of process parameter for Surface roughness (R_a) and material removal rate (MRR) is shown in Table 16 and Table 17.

Table 16: Optimal Values for MRR & Surface Roughness

Grain Size	Concentration
5.8068	5.8068
6.0149	5.3505
6.2602	6.4159
6.1378	6.6465

Table 17: Individual Optimal Values and Its Corresponding Settings Of Process Parameters

Performance Characteristics	Optimum Parameter Level	Optimum Level
η_{obs}	A2-B3	6.4533

4.7 Analysis of Plot

Optimum values obtained from Multi-response table has been developed and the optimum values are plotted in the form of graph. In this plot x-axis indicates the value of each process parameter at different levels (i.e. Grain Size of chromium powder and Concentration of chromium powder), whereas y-axis indicates the response value as shown in Fig. 6 and Fig. 7.

Based on Grain Size of Powder

Fig.6, is the plot between the optimum values obtained from Multi- response table on y-axis and Grain size of chromium powder on x- axis. This graph shows that when No Cr powder is used , optimum value is low. As we start mixing Fine grain Cr powder in EDM oil, optimum value increases. Again, when the medium Grain Cr powder is mixed, the optimum value decreases. Furthermore, when coarse grain Cr powder is used, optimum value decreases. So, it is well concluded that we get best result on medium sized Chromium Powder i.e. when medium Grain Cr powder is used for MRR and Ra.

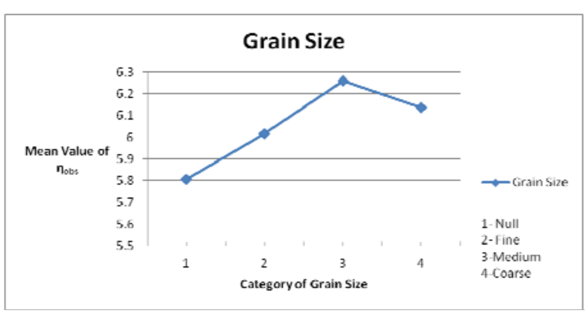


Fig. 6: Multi-Response S/N Ratio Graph (Mean Value and Grain Size of Cr Powder)

Based on Concentration of Powder

Fig.7, is the plot between the optimum values obtained from Multi- response table on y-axis and Concentration of chromium powder on x-axis, also represents the combined result for MRR and Surface Roughness. When no powder is used with EDM oil, optimum value is low. As we start with 2 gm/ltr of Cr powder as concentration, optimum value increases further. Again, when we increase the concentration from 2gm/ltr to 4 gm/ltr, optimum value keeps increasing. Furthermore, when the concentration is increased from 4 gm/ltr to 6 gm/ltr, optimum value still increases. So, it is well concluded that we get best result on obtained when concentration of Cr powder is 6 gm/ltr.

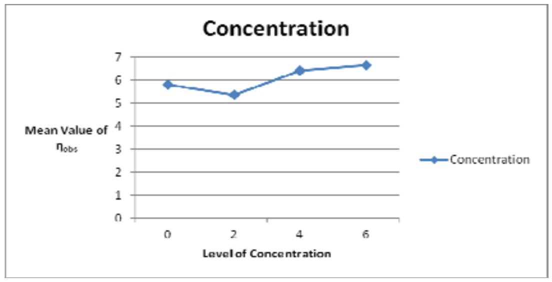


Fig. 7: Multi-Response S/N Ratio Graph (Mean Value and Concentration of Cr Powder)

4.8 ANN Modelling Of PMEDM

With the help of ANN modeling software i.e. *Tiberius*, below given data Table 18 And 19 are obtained and the complete data table with comparative analysis of experimental and Modelled Value is given in Table 20, and its respective graph is shown in fig 8 and 9.

Table 18: Data Plot Obtained From Tiberius Software for Surface Roughness

Surface				
S.	Actual	Modelled	Error	Data Type
1	5.935	5.84412	-	Train
2	6.483	6.72236	0.23936	Train
3	5.76	6.05022,	0.29022	Te
4	5.205	5.43461,	0.22961	Train
5	7.32	6.88787,	-	Train
6	6.385	5.77962,	-	Train
7	5.005	4.92761,	-	Te
8	6.26	6.5223,	0.2623,	Train
9	4.66	5.16273,	0.50273	Train
1	5.49	5.28729,	-	Train
RM	Train	0.367438	Te	0.38954

Table 19: Data Plot Obtained From Tiberius Software for MRR

M				
S.	Actual	Modelled	Error	Data Type
1	22.6	22.64902	0.04902	Train
2	22.5	22.38193	-0.11807	Train
3	23.1	23.37757	0.27757	Test
4	23.84	23.67211	-0.16789	Train
5	25.56	25.57872	0.01872	Train
6	27.78	27.22453	-0.55547	Train
7	24.88	25.47123	0.59123	Test
8	20.81	20.80866	-0.00134	Train
9	22.46	22.51225	0.05225	Train
1	23.78	23.63122	-0.14878	Train
R	Train	0.283706	Test	0.284319

Table 20: Comparative Chart For Experimental and ANN Modelled Value of MRR and Surface Roughness

S. No	Grain/ Mesh Size Of Cr Powder (µm)	Concentration Of Cr Powder (gm/ltr.)	Experimental Surface Roughness (µm)	ANN Modeled Surface Roughness (µm)	Experimental MRR (mm^3/min.)	ANN Modeled MRR (mm^3/min.)
1	0	0	5.935	5.84412	22.6	22.64902
2	150	2	6.483	6.72236	22.5	22.38193
3	150	4	5.76	6.05022	23.1	23.37757
4	150	6	5.205	5.43461	23.84	23.67211
5	200	2	7.32	6.88787	25.56	25.57872
6	200	4	6.385	5.77962	27.78	27.22453
7	200	6	5.005	4.92761	24.88	25.47123
8	250	2	6.26	6.5223	20.81	20.80866
9	250	4	4.66	5.16273	22.46	22.51225
1	250	6	5.49	5.28729	23.78	23.63122

Fig. 8: Comparative Graph Between Experimental and ANN Modelled Value on MRR

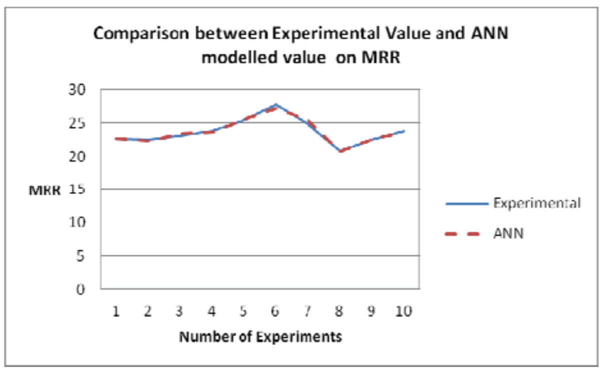
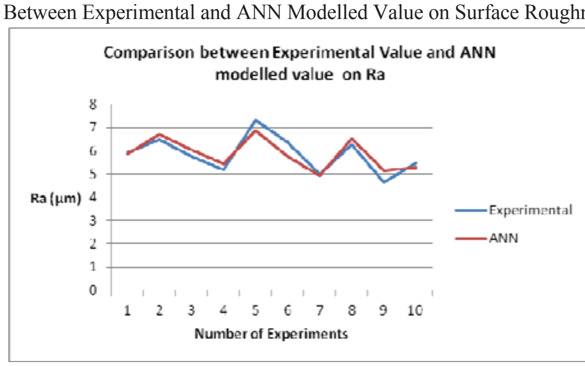


Fig.9: Comparative Graph Between Experimental and ANN Modelled Value on Surface Roughness (Ra)



V. GENERAL CONCLUSIONS

The aim of this work is experimental investigations and optimization of the process parameters during Powder Mixed electro-discharge machining of AISI 1046. For this, a number of experiments were carried out for the wide range of input parameters. Taguchi's design of experiments has been employed for experiment design. Analysis of means has been employed for experimental investigations. Taguchi's method has been employed as single-objective optimization technique to find to optimal combinations of input parameters for each performance measures. Process modeling of P M EDM has been done by artificial neural network by using Tiberius Software. A neural-network-based approach has been proposed. On the basis of experimental results and their analysis, the general conclusions of the entire work are given in the subsequent section:

- AISI 1046 can easily be machined on PMEDM with reasonable speed and surface finish. It is difficult to machine AISI 1046 on conventional machining because of shorter tool life and severe surface abuse due to its outstanding high temperature strength and extreme toughness.
- The most important factors affecting the PMEDM of AISI 1046 have been identified as Grain Size and Concentration of Chromium Powder for response MRR and Surface Roughness.
- Optimal factor/level combination of process parameters for MRR and Ra are obtained by employing Taguchi's method as single objective optimization technique. A2B2 and A3B3 are recommended as optimum factor/level combination ion for MRR and Ra respectively.
- Artificial neural network is found effective to model EDM process.
- The ANN predicted values are in close proximity with the experimental values.

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