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Effect of WEDM Parameters on MRR of Carbidic Austempered Ductile Iron

P. L. Pandit[1], Dr. S. A. Patil[2]

[1]M.E student, Production Engineering, Government College of Engineering, Aurangabad, M.S, India

[2]Associate Professor, Government College of Engineering, Aurangabad, M.S, India,

Abstract: ***Industrial and technological development needs high strength, high wear resistance and durable material. So, researchers are developing new material having the above mentioned properties. CADI is newly developing material which can be used for dies, drill bits, piston rings etc. Among the various non-conventional manufacturing processes, Wire Electrical Discharge Machining (WEDM) is one which is used for machining hard material with intricate shapes. In this study, experiments were conducted using Taguchi's L9 orthogonal Array. Optimal levels of process parameters were identified using S/N ratio Analysis and the relatively significant parameters were determined by Analysis of Variance (ANOVA). The variation of output responses with process parameters were mathematically modeled by using linear regression analysis method and the models were checked for their adequacy.***

Keywords: Carbidic austempered ductile iron (CADI), WEDM, MRR. Taguchi and ANOVA

1. Introduction

Austempered Ductile Iron (ADI) is a well known material for its high tensile strength (over 1600MPa for grades 5 and 1, according to the ASTM A-834-95), toughness and high abrasion wear resistance. Due to these properties, forged steel in many industrial applications is replaced by ADI. ADI has the ability to perform very well under different wear mechanisms such as rolling contact fatigue, adhesion and abrasion. Increase in abrasion wear resistance is seen because of the presence of carbides. [1],[2]

CADI is a new class of ADI containing carbides in the ausferrite matrix. CADI is produced by austempering the carbidic ductile iron at different temperatures and time. It is a economical substitute for wrought or forged steel and has been used more and more in automobile, mining, railway and agricultural machinery sectors. Due to its superior properties over other materials it can also be used in applications like piston rings in IC engines, dies, gears, navy ship boards, rollers etc.[3],[4]

While performing experimentation, it is observed that machining CADI with conventional method is very tedious and complicated job because of the high hardness of the material. Considering these difficulties and complexities non-conventional machining is preferred.

There are several non- conventional machining processes available in industries. Among these various non-conventional machining processes, WEDM is one which can be used for machining hard materials with correct dimensional accuracy. It is necessary to set correct parameter to achieve maximum MRR and Surface Roughness. This process is highly dependent on the experience of the operator. In practice it is very difficult to achieve optimal condition for machining. So, with a view to solve this difficulty, a simple but reliable method based on statistically designed experiments is suggested for investigating the effects of various process parameters on MRR.[5]

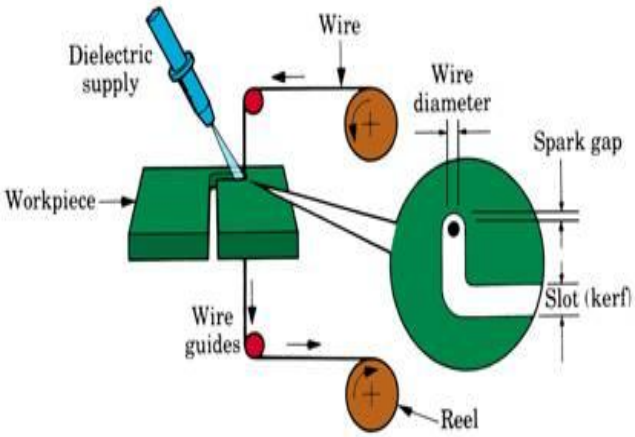


Figure 1: Schematic Representation of WEDM

Lokeswara Rao T. and N. Selvaraj[6], evaluated the effects of machining parameters viz. pulse-on-time, pulse-off-time, peak current, servo voltage and servo feed, on volume material removal rate and surface roughness. Taguchi Analysis approach was used to determine the factors which have significant impact on volume material removal rate and the optimal setting is found by S/N ratio analysis. Equations which correlate machining parameters with material removal rate is found by regression analysis. Results reveal that, pulse and peak current are the most significant factors for the performance measures. Wire tension, servo voltage and servo feed settings are less significant on performance measure.

S.S.Mahapatra and Amar Patnaik [7], used genetic algorithm to find optimal values of parameters viz. discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate for maximization of MRR and minimization of surface roughness.

Y. S. Sable, R. B. Patil and Dr. M. S. Kadam [8], investigated effects of pulse-on-time, pulse-off-time, peak current, servo voltage and wire tension for MRR while machining WC-Co sintered composite using Response

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Surface Methodology. It was found that as pulse-on-time, peak current, wire tension increases and pulse-off-time, servo voltage decreases MRR increases. The Taguchi method is a powerful experimental tool which uses a systematic approach to find out optimal machining parameters. Taguchi approach requires minimum experimental cost and efficiently reduces the effect of the source of variation. The methodology uses Taguchi's experimental design for setting suitable machining parameters in order to effectively control the amount of removed materials and to produce complicated precise components. [10]

2. Experimentation Setup

Carbidic ductile iron (CDI) is developed by incorporating the carbides in the typical matrix of ductile iron (DI). CDI is then austemperd which leads to formation of microstructure of carbides distributed in the typical ausferritic matrix, resulting in to CADI. The reference material used for experimentation is heat treated, which involves austenitizing in the temperature range of 900-920°C in a muffle furnace for 1h, followed by an austempering in a salt bath at the temperature of 325°C for a time period of 2hrs. TABLE 1 shows the chemical composition of As-cast CADI. [9]

Table 1: Chemical Composition of CADI material

Alloying element	*Percent*
C%	*3.6*
Si%	*1.9*
Mn%	*0.64*
S%	*0.0122*
P%	*0.0294*
Cr%	*4.3*
Cu%	*0.61*
Ni%	*0.431*
Ti%	*0.016*
Mg%	*0.044*
CE	*4.23*

Experiments were conducted on a 4-axis WEDM, model: Elektra-Sprintcut 743 f, manufactured by Electronica Machine Tools Ltd., India. De-ionized water was used as a dielectric fluid and a brass wire electrode of 0.25 mm diameter was employed as tool electrode. Fig 2 shows actual picture of machine on which experiments were conducted.



Figure 2: Picture of Elektra Sprintcut 743 f WEDM

In this study, three important WEDM parameters, namely pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}) and peak current (I_P) have been considered with three levels each as shown in TABLE 2. The parameter range was selected on the basis of pilot experiments and literature survey. Other parameters are kept constant at their default settings. The response variable selected for this study is Material removal rate (MRR) this can be calculated using the following expression:

$$MRR = \frac{\text{initial weight} - \text{final weight}}{\text{Machining time}} \quad (1)$$

Table 2: Process parameters and their levels

Sr. No	*Parameters*	*Levels*		
		-1	*0*	*1*
1	*Pulse on Time (TON)*	*116*	*122*	*128*
2	*Pulse off Time (TOFF)*	*30*	*38*	*46*
3	*Peak Current (IP)*	*210*	*220*	*230*

3. Mathematical Modeling

Using L_9 array experiments were designed. Table 3, given below represents MRR values for each experimental run. For analysis of the data and to check the good fit of the model, Analysis of Variance is used. Equation obtained for MRR is given below:

$$MRR = -0.122 + 0.00106\ T_{ON} - 0.000132\ T_{OFF} + 0.000339 I_P \quad (2)$$

Table 3: DoE with Experimental Results

T_{ON} (μs)	T_{OFF} (μs)	I_P (*Amps*)	*MRR (gm/min)*
116	*30*	*210*	*0.067916*
116	*38*	*220*	*0.072306*
116	*46*	*230*	*0.07396*
122	*30*	*220*	*0.07622*
122	*38*	*230*	*0.078652*
122	*46*	*210*	*0.071776*
128	*30*	*230*	*0.089214*
128	*38*	*210*	*0.081769*
128	*46*	*220*	*0.081267*

Table 4 indicates ANOVA of the model for MRR. The value of R^2 and R^2 (adj) are 94.9% and 91.8% respectively, which means that the regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (MRR). The associated P-value for the model is lower than 0.05 (i.e. α= 0.05 or 95% confidence level), indicating that the model is considered to be statistically significant.[12]

Table4: ANOVA of Model

Source	DF	SS	MS	F	P
Regress-ion	3	0.00032	0.00010579	30.77	0.001
Residual Error	5	0.00002	0.00000344		
Total	8	0.00034			

Fig. 3 displays the normal probability plot of the residuals for MRR. Notice that the residuals are falling on a straight line, which means that the errors are normally distributed and the regression model agrees fairly with the observed values.

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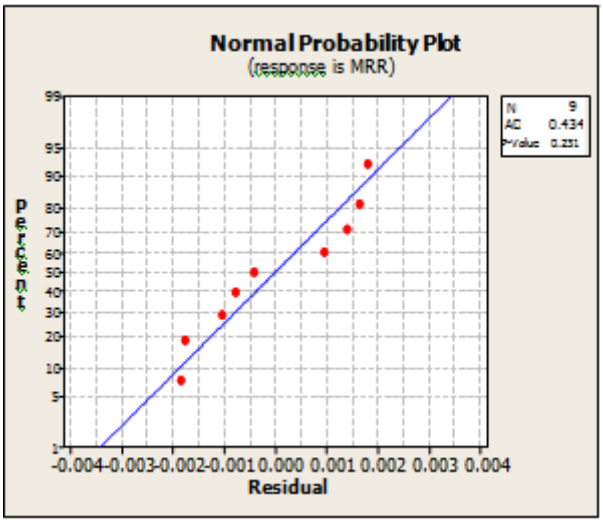


Figure 3: Normal Probability Plot

4. Results and Discussion

4.1 S/N Ratio Analysis

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or larger is better (LB). Larger is better S/N ratio is used here. Larger-the-better quality characteristic was implemented and introduced in this study.

Larger is the better characteristic is given by,

$$S/N = -10 \log10 (MSD) \quad (3)$$

Where MSD= Mean Squared Division

$$MSD= (1/Y_1^2 + 1/Y_2^2 + 1/Y_3^2 + \ldots\ldots..)/n \quad (4)$$

Where Y_1, Y_2, Y_3 are the responses and n is the number of tests in a trial and MSD is the target value of the result. The level of a factor with the highest S/N ratio was the optimum level for responses measured. The higher the signal to noise ratio, the more favorable is the effect of the input variable on the output. Table 5 shows the optimized level of input parameters for MRR are T_{ON}-128, T_{OFF}-38 and I_P-230 which is having higher S/N ratio values.

Table 5: Response Table for Signal to Noise Ratios Larger is better

Level	T_{ON} (µs)	T_{OFF} (µs)	I_P (Amps)
1	-22.93	-22.24	-22.66
2	-22.44	-22.22	-22.33
3	-21.51	-22.43	-21.90
Delta	1.42	0.22	0.76
Rank	1	3	2

Fig. 4 below shows Mean Effective Plot for S/N ratios, which indicates that input parameter level viz. T_{ON} -128, T_{OFF}-38 and I_P-230 is having higher S/N ratio values.

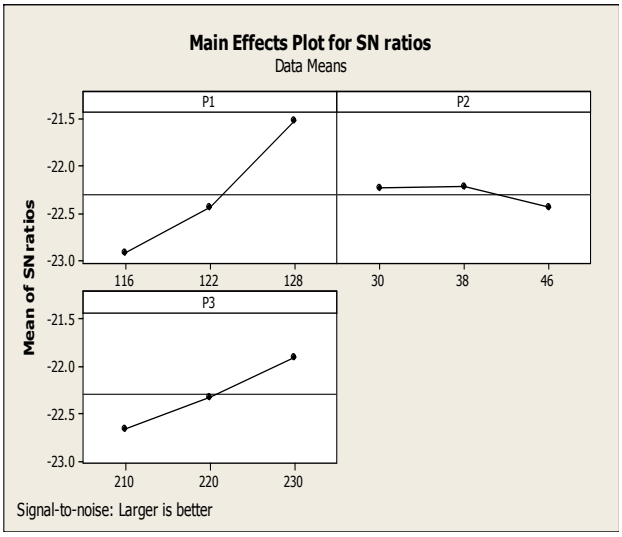


Figure 4: Effect plot of process parameters for S/N Ratio

Analysis of variance is used to study the relative influences of multiple variables, and their significance. Analysis of variance is a standard statistical technique to interpret experimental results. It is widely used to discover the differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant.

ANOVA helps to investigate which process parameters affect significantly the quality characteristic. ANOVA of MMR shown in Table 6, which clearly indicates that most significant factor is T_{ON} and I_P and then followed by T_{OFF}.

Table 6: ANOVA of MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TON	1	0.00024	0.00024	0.00024	70.3	0.000
TOFF	1	0.00001	0.00001	0.00001	1.95	0.221
IP	1	0.00007	0.00007	0.00007	20.1	0.006
Residual Error	5	0.00002	0.00002			
Total	8	0.00034				

5. Conclusion

An attempt was made to determine the important machining parameters for performance measure, MRR in WEDM process for CADI. Factors like T_{ON}, T_{OFF} and I_P have been found to play a significant role in machining for maximization of MRR. Taguchi method was used to investigate the effect of input parameters, L_9 orthogonal array was employed to perform the experimentation and to develop a correlation between the WEDM parameters and each performance characteristics. ANOVA of model and parameters has been done for analysis.

Results are summarized as follows:

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Analysis of variance (ANOVA) on experimental data shows that the model developed is statically significant. ANOVA revealed that TON and IP are most significant parameters and TOFF is least significant parameter for MRR. The Optimal level of process parameter according S/N ratio is found to be A3B2C3 which are listed in Table-7 below.

Table7: Optimum Levels of Parameters for MRR

Parameter	Level
TON. (µs)	128
TOFF (µs)	38
IP (Amps)	230

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Author Profile



Prashant L Pandit is pursuing M.E. (Production), Mechanical Engineering Department, Government College Of Engineering, Aurangabad. Maharashtra, India



Dr. S. A. Patil, is Associate Professor, Government College Of Engg. Aurangabad. Maharashtra. India. He is having a vast experience in teaching. He has done intense research on the material CADI and his PhD thesis is on the topic "Production and characterization of CADI".

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