JOURNAL OF CRITICAL REVIEWS

ISSN- 2394-5125 VOL 7, ISSUE 11, 2020

Formulating Empirical Model of MRR in Wire-EDT

Baki Naresh[1], A Chennakesava Reddy[2]

[1]Research Scholar, Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Hyderabad, Kukatpally, Telangana, INDIA. Email: flytonaresh@gmail.com

[2]Professor, Department of Mechanical Engineering, Jawaharlal Nehru Technological University,Hyderabad, Kukatpally, Telangana, INDIA. Email: dr_acreddy@yahoo.com

Received: 04.03.2020 Revised: 05.04.2020 Accepted: 06.05.2020

Abstract In this paper, material removal rate (MRR) of Wire-electrical Discharge Turning process is investigated. Experiments are conducted with a Taguchi OA L_{27} considering five input parameters viz. percentage of Cobalt in Tungsten carbides material, spindle rotational speed, pulse on-time, pulse-off time and wire feed with three levels each.For process response, a suitable first order regression equation was obtained by applying analysis of variance (ANOVA) and student t-test procedure to check modeling goodness of fit and select proper forms of influentially significant process variables within 95% of confidence interval (p-value less than equal to 0.1). The experimental result shows that,pulse on-timeis the most effective input parameter 55% on the MRR. The MRR increases by selecting higher level of pulse on-time, lower level of spindle rotational speed and higher percentage of Cobalt content. Finally, the experimental models are examined and validated.

Keywords: Wire-EDT, MRR, Empirical model, tungsten carbide composite

1 Introduction

In today scenario, improvement in the machining process is key research area in the field of manufacturing.Electro-Discharge Machining (EDM), the oldest and most popular non-traditional machining method. It is an electro-thermal process where a workpiece and electrode, usually submerged in a liquid dielectric medium. Due to absence of mechanical cutting force, WEDM is used to cut complex and precise geometric shapes material components, such as composites, ceramics, carbides, heat resistant steels, super alloys etc. Now, WEDM is widely used in aerospace, aeronautics, nuclear industries, fabrication of the stamping and extrusion tools and die and mold making industries [1].However, further improvements are still required for the demand of product precision from the manufacturing industries. Recently, this process is significantly used in producing cylindrical components for high quality and high accuracy parts which made of carbide (WC-Co) material.

Tungsten carbide is belonging to a family of carbide ceramics [2] such as titanium carbide, tantalum carbide, silicon carbide and chromium carbide. Tungsten, titanium and chromium carbide are having high hardness, excellent corrosion resistance and wear resistance at elevated temperature properties [3-4], these properties make them useful for cutting tool applications. Tungsten carbide is a non-metal combined with a metallic binder such as cobalt is called as a cemented carbide or cermet (WC).Due to poor surface characteristics, low material removal rate and high cutting forces in machining of tungsten carbide composite with conventional machining processes [3,5,8]. In recent years, as an alternative method to machine WC, wire electrical discharge machining (WEDM) has gained wide acceptance.

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Wire-Electrical discharge Turning (WEDT) is one of the most recently developed variant of WEDM process, which combines the conventional turning process and un-conventional process of wire electrical discharge machining (WEDM). Where the material is removed through continuous discharge of sparking in the dielectric mediumbetween workpiece and wire electrode in the presence of dielectric medium without being in contact with the workpiece, which eliminates mechanical forces and chatter problems [5-6].The region in which discharge occurs is heated locally to extremely high temperature, so that the workpiece surface is melted and removed [7]. A lot of works being done with other materials but there have not been significant research publications till today on processing of these hard WC-Co composite materials by WEDT. Mohammadi et al. [9] fist applied wire electrode to perform an electrical discharge turning process to machine cylindrical parts. Haddad et al. [10] investigated the cylindrical wire electrical discharge turning (CWEDT) by using Design of experiments (DOE) method. The results show that bigger discharge energy and deeper cutting depth to lead to a higher machining efficiency, but machined surface quality is poor and the roundness error exceeds 30µm.

Despite of many research evaluations on WEDT, investigation on material removal of tungsten carbide is still missing. Moreover, there is no technological data is available to the tool manufacturer on WEDT of WC-Co composite. Therefore, in present work, an experimental investigation has been carried out for turning operation in WEDT of WC-Co composite. Taguchi’s design of experiment method has been adopted to evaluate the influence of WEDT parameters on material removed in turning operation. Present work will solve the problem of selection of accurate process parameters to achieve high material removal rate. A Technological data has been provided for machining of WC-Co composite on WEDT.

2 Experimental Setup and Methodology

Schematic working diagram of Wire-EDT is shown in Fig.1The tungsten carbide rods of threevariations in composition (WC-8% Co, WC-10% Co and WC-12% Co) are used as workpiece material and copper as tool electrode which has 0.25 mm diameter. A conventional WEDM machine is integrated with the rotating axis mechanism for workpiece. The workpiece rotational mechanism is designed and developed by the author to get three rotational speeds 10, 20, 30 rpm. The workpiece is attached to the rotating spindle using 3 jaw check and this spindle is connected to the geared dc motor through stepped pully to get the desired speeds.Tool wire is continuously fed in to the dielectric medium for generating sparks. Servo mechanism controls the wire feed in axial direction as well as in radial direction as material is removed by series of sparks generated at the dielectric medium.

Weight loss method is used to measure the MRR and given in Eq. 1

$$\mathrm{MRR} = \frac{\text{Weight before machining} - \text{Weight after machining}}{\text{Time taken for machining}} \qquad (1)$$

The five input parameters namely percentage of %Co, spindle speed, pulse on-time, pulse off-time and wire feed are chosen for the experiment. The basic parameters and input parameters are tabulated in Table 1 and Table 2 respectively. Taguchi L_{27} OA design is used to collect the raw values of MRR. The raw data of MRR is transferred into S/N ratio for Taguchi study. MRR has ‘higher-the-better, HB’ characteristics, thus corresponding value of S/N ratio is measured by using Eq. 2.Effect of each process parameters on the machining performance is determined on both raw data and S/N ratios to find the significant process parameters.

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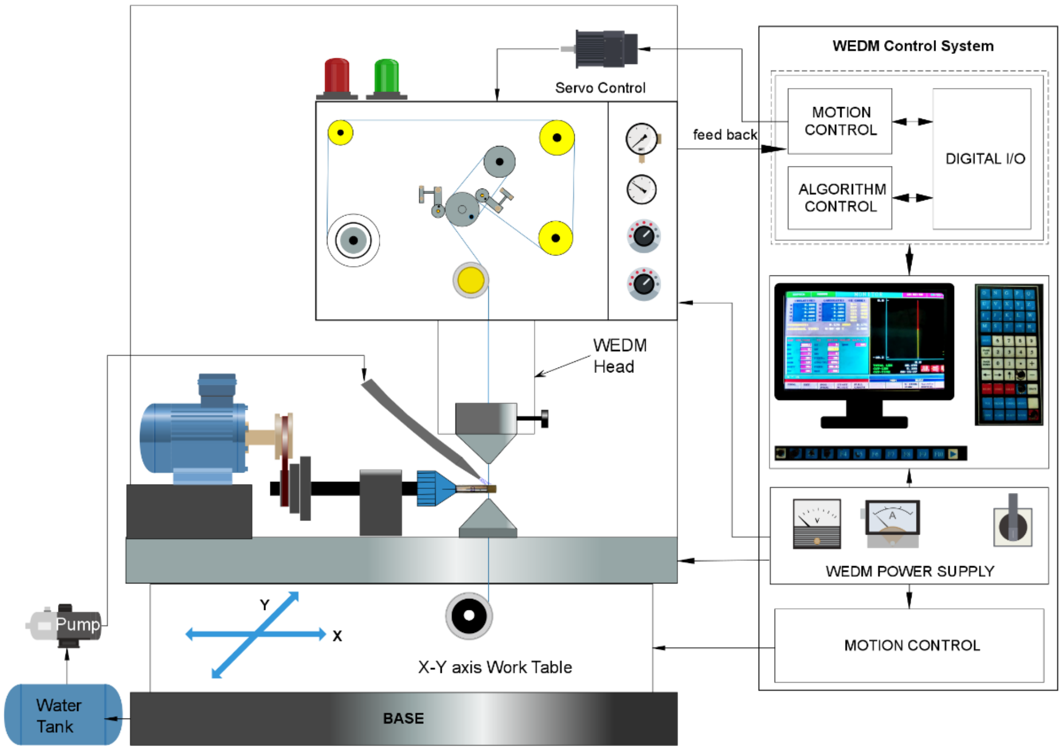
$$S/N_{HB} = -10\log_{10}\left[\frac{1}{n}\sum_{n=1}^{n}\frac{1}{y_i^2}\right] \quad (2)$$

Fig. 1: Schematic working diagram of Wire-EDT Machining



3 Results and discussion

The measured experimental data of MRR and corresponding S/N ratios are shown in Table 3.

Table 1: Constant machining conditions

a)	Wire: uncoated brass wire of diameter 0.25 mm
b)	Work piece material: tungsten carbide
c)	Work piece dimensions: 10 mm dia. × 25mm L
d)	Length of cut: 10 mm
e)	Angle of cut: vertical
f)	Dielectric fluid: distilled water
g)	Wire tension : 9 Kg
h)	Servo Voltage : 30 V
i)	Arc ON : 10 µs
j)	Arc OFF: 35 µs
k)	Length of cut: 10 mm
l)	Depth of cut : 0.15mm

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Table 2: Wire-EDT process parameters and levels

Process parameters	Units	Level 1	Level 2	Level 3
A. Material composition (%Co)	%	8	10	12
B. Rotational speed	rpm	10	20	30
F. Pulse ON-time (P_{ON})	µs	7	10	13
C. Pulse OFF-time (P_{OFF})	µs	30	35	40
D. Wire Feed	m/min	6	9	12

Table 3: Experimentally measured data and S/N ratio data of MRR

Exp No	WC-Co (% Co)	Spindle speed (rpm)	Pulse-On (µs)	Pulse-off (µs)	Wire feed (m/min)	MRR (g/sec)	S/N ration of MRR
1	8	10	7	30	6	0.131	-2.853
2	8	10	10	35	9	0.148	-1.110
3	8	10	13	40	12	0.169	1.868
4	8	20	7	35	9	0.106	-8.404
5	8	20	10	40	12	0.123	-4.293
6	8	20	13	30	6	0.144	2.345
7	8	30	7	40	12	0.107	-26.021
8	8	30	10	30	6	0.124	-4.152
9	8	30	13	35	9	0.145	-0.819
10	10	10	7	30	9	0.111	-0.355
11	10	10	10	35	12	0.128	0.749
12	10	10	13	40	6	0.149	2.671
13	10	20	7	35	12	0.122	-4.583
14	10	20	10	40	6	0.139	-2.734
15	10	20	13	30	9	0.160	3.807
16	10	30	7	40	6	0.102	-15.391
17	10	30	10	30	9	0.119	-1.310
18	10	30	13	35	12	0.140	0.984
19	12	10	7	30	12	0.143	1.868
20	12	10	10	35	6	0.157	1.938
21	12	10	13	40	9	0.178	4.297
22	12	20	7	35	6	0.094	-2.499
23	12	20	10	40	9	0.111	0.086
24	**12**	**20**	**13**	**30**	**12**	**0.132**	**5.249**
25	12	30	7	40	9	0.132	-6.936
26	12	30	10	30	12	0.149	1.138
27	12	30	13	35	6	0.170	2.144

Fig.2 shows the main factor effects on MRR. Pulse on-time has highest influence on the process performance followed by spindle speed, percentage of cobalt and wire feed rate.

Fig.3 reveals the higher material removal rate is obtained when pulse on-time at higher level, spindle speed at lower level, cobalt percentage at higher level, pulse off-time at lower level and wire feed at lower level.

Fig. 2 Mean effect plot of MRR

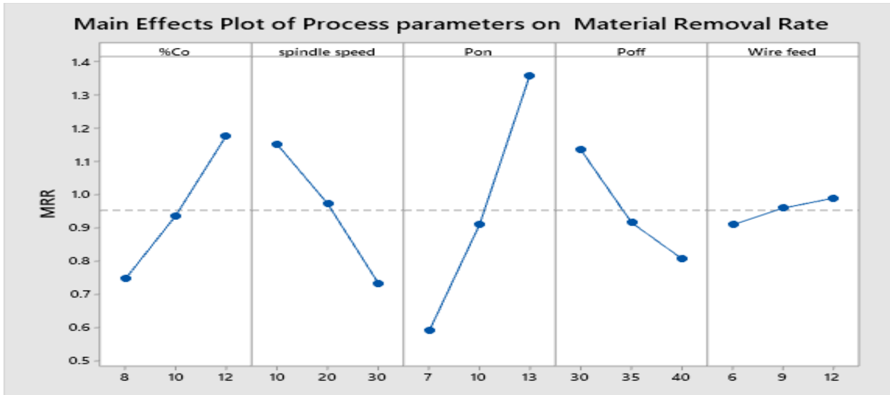

Fig. 3 Mean effect plot of S/N ratio of MRR

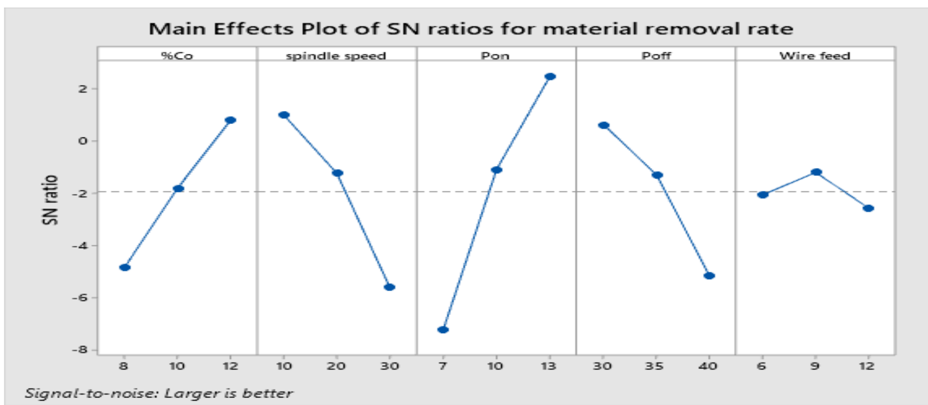

Table 4: ANOVA table for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
%Co	2	0.83580	0.41790	11144.00	0.000
spindle speed	2	0.79920	0.39960	10656.00	0.000
Pon	2	2.69340	1.34670	35912.00	0.000
Poff	2	0.50820	0.25410	6776.00	0.000
Wire feed	2	0.02940	0.01470	392.00	0.000
Error	16	0.00060	0.00004		
Total	26	4.86660			
Model Summary					
S		0.0061237			
R-sq		99.99%			
R-sq(adj)		99.98%			
R-sq(pred)		99.96%			

Formation of empirical model of MRR

The empirical formula of MRR is based on linear regression analysis using Minitab 19 software. MRR is formulated with five independent variables such as %Co, spindle speed, pulse on-time, pulse off-time, and wire feed.

$$MRR = 0.050 + 0.10750\ \%Co - 0.02100\ \text{spindle speed} + 0.12833\ Pon - 0.03300\ Poff + 0.01333\ \text{Wire feed} \quad (4)$$

Regression coefficient values of the MRR are evaluated for the model and tabulated in Table 5. Form the table 5, the values of S stand for the residual standard deviation of coefficient is very small, thus have higher accuracy. Moreover, P values of %Co, spindle speed, pulse on-time, pulse off-time and wire feed are lower than 0.005 that means all the parameters are more significant on the model. R^2 and R^2 (adj) values are found as 99.99% and 99.98% respectively. It signified the model is within the acceptable range.

Table 5: Regression coefficients of MRR

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.050	0.119	0.42	0.678	
%Co	0.10750	0.00597	18.01	0.000	1.00
Spindle Speed	-0.02100	0.00119	-17.59	0.000	1.00
Pon	0.12833	0.00398	32.26	0.000	1.00
Poff	-0.03300	0.00239	-13.82	0.000	1.00
Wfeed	0.01333	0.00398	3.35	0.003	1.00

4 Conclusions

MRR of Wire-EDT has been discussed with Taguchi L_{27} OA. The following valuable outcomes are found from the experiments.

1 Pulse on-time has highest percentage of contribution of 55.35% followed by percentage of Cobalt present in the tungsten carbide 17%, spindle rotational speed 16% and pulse off-time 10%.

2 Wire feed has less percentage of contribution on MRR with a value 0.6%

3 The empirical formula of MRR is formulated based on regression analysis. The empirical model has less value of the residual standard deviation and within the acceptable range.

4 Through Taguchi's S/N ratio analysis, higher S/N ratio is 5.259. which gives the best optimal combination of parameter settings for getting higher material removal rate at the given experimental domain.The best optimal combination of parameters arepercentage of cobalt is 12%, spindle speed is 20 rpm, pulse on-time is 13 µs, pulse off-time is 30 µs and wire feed is 12 m/min.

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