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Analysis and Experimental Study of Electrical Discharge Face Grinding on Tungsten Copper Alloy

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Abstract

Electro-discharge face grinding (EDFG) process has been utilized for machining of flat surfaces of materials that are difficult- to-machined by creating spark between face of disc shape rotating tool electrode and workpiece. The rotation of non-abrasive disc shape wheel electrode about vertical axis (a new feature of face grinding) enhances the material removal rate (MRR) and average surface roughness (ASR) in view of compelling flushing of working gap. This paper presents the effect of input process parameters of EDFG, such as discharge current, pulse on-time and off-time, and wheel speed on MRR and ASR during machining of tungsten copper alloy workpieces. The settings of machining parameters were determined by using Taguchi's robust design approach. The machining parameters were optimized with multi response characteristics of material removal rate (MRR) and average surface roughness (ASR). Multi response signal-to-noise (MSNR) ratio was applied to measure the performance characteristics deviating from the actual value. Analysis of variance (ANOVA) was employed to identify the level of importance of the machining parameters on the multiple performance characteristics considered. Finally, experimental confirmation was carried out to identify the effectiveness of this proposed method.

Keywords: Average surface roughness; Electrical discharge face grinding; Material removal rate.

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1. INTRODUCTION

Technologically feasible materials which have improved thermal, chemical, and mechanical properties such as strength, heat resistance, wear resistance, and erosion resistance are best suited efficient machining process [1]. At Present scenario the manufacturing industries are facing challenges from machining of technologically improved demanding materials (tough super alloys, ceramics and composites) with complex design requirements (high precision, complex shapes, and high surface quality) at reduced machining costs. To meet these challenges with conventional machining processes are still more difficult for sufficiently hard materials. Hence, advanced machining processes have been developed for machining of technologically improved materials. At present, many of the advanced machining processes are being widely prevalent in industries to achieving the desire quality [2]. Each of these advanced machining processes has their own potential and limitations. Electro-discharge machining (EDM) is one of most widely used thermal erosion based advanced machining processes which has been utilized for process optimization. EDM has two electrodes (tool electrode and workpiece electrode) separated by small gap (5–200 µm) which is called as inter electrode gap (IEG). The dielectric fluid acts as an insulator between the tool electrode and workpiece electrode. Dielectric fluid has ability to discharge heat due to convection. As machining proceeds, the concentration of particles in the gap increases rapidly. Wear debris is flushed out from the sparking area by dielectric. Insufficient flushing results in the stagnation of the dielectric, build-up of machining residue in the gap, short circuits, arcs, and low material removal rate (MRR), and culminate in the stalling of the machining process.

EDM has been found to machine features in five different ways such as Sinking-EDM, Drilling-EDM, Cutting-EDM, Milling-EDM, and Grinding-EDM. These are shown in Fig. 1.

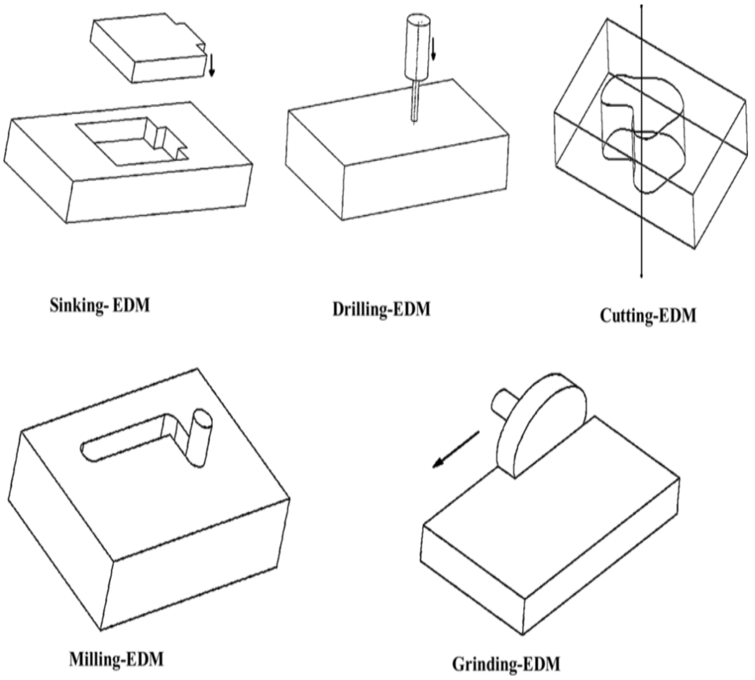

Fig 1.-Types of EDM operations [3]

Grinding-EDM which is also called Electro-discharge grinding (EDG) works on the same principle as EDM. EDG involves an electrically conductive nonabrasive disk shape rotating tool electrode. The advantage of using rotating tool electrode is that the electrode wear can be effectively distributed to the surface of the tool electrode. EDG can be operated in three different

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configurations, (1) electro-discharge surface grinding (EDSG), (2) electro-discharge cut-off grinding (EDCG), (3) Electro-discharge face grinding (EDFG). In this paper EDFG is studied.

In EDFG, an electrically conductive disc shape nonabrasive rotating tool electrode is used. Here the tool electrode rotates about vertical spindle axis. A part of the grinding wheel and workpiece both are immersed in the dielectric, and are connected to pulsed DC supply. The rotating motion of the wheel ensures the effective flow of dielectric in the IEG, and hence flushing of the dielectric can be eliminated. Mechanism of material removal is exactly same as in EDM, except that rotary motion of the tool (i.e., wheel) helps in effective ejection of the molten material. Contrary to conventional face grinding, in EDFG there is no direct physical contact (except during short circuit, if any) between the tool and the workpiece, hence, fragile and thin sectioned specimens can be easily machined. In EDFG, the material removal takes place due to melting and/or vaporization without any shearing action. Substantial research has been made in the past few years over experimental study of EDM using an electrically conductive rotary tool electrode.

Several authors used rotary EDM along with different flushing techniques, on different materials, and studied their effect on material removal, electrode wear, and surface roughness (SR). Singh et al. [4] investigated the effect of various parameters affecting electro discharge face grinding of WC-CO composite. Taguchi methodology and grey relational analysis were used to determine optimum machining parameters. Input parameters considered were wheel speed, current, pulse on time and duty factor whereas output factors were MRR, WWR and ASR. Conclusions drawn from their study was that MRR increase with increase in current, wheel speed and decrease with increase in pulse on time. WWR and ASR increase with wheel speed and current. Wheel speed was observed to be most significant factor affecting electro discharge diamond face grinding (EDDFG). Singh et al. [5] proposed a grey based Taguchi method to optimize the machining parameters of new developed EDDFG process with multiple quality characteristics. Experiments were conducted on cylindrical high speed steel workpiece of diameter 25mm for 60 minutes. The effect of wheel rpm, current, pulse on time and duty factor were observed on material removal rate (MRR), wheel wear rate (WRR) and average surface roughness (R_a). It was observed that the MRR increase with increasing wheel RPM, current and pulse on-time, while it decreases with an increase in duty factor. The most significant factor affecting the EDDFG robustness was identified as pulse on-time and duty factor. Singh et al. [6] adopted a hybrid machining process comprising diamond grinding and electro discharge grinding. They used Taguchi methodology and response surface methodology for optimization of EDDFG process. Experiments were performed on high speed steel workpiece with spark erosion oil as dielectric liquid. A conclusion made from their paper was that various factors affecting EDDFG are wheel speed, duty factor, square effect, current etc. Parameters kept under consideration as output parameters were MRR, ASR and WWR. The optimum value of MRR, WWR and ASR obtained from multi-objective optimization using TM only are 1.8254 mm^3/min, 0.005223 g/min and 3.312 μm, respectively while using the hybrid approach these values are 1.9457 mm^3/min, 0.001266 g/min and 2.91 μm, respectively. Singh et al. [7] reported modelling and optimization of electro discharge diamond face grinding of cemented carbide-cobalt composite. He adopted Taguchi methodology as well as response surface methodology to investigate the factors affecting MRR, WWR and ASR and concluded that pulse on time, square effect of duty factor and wheel speed are major factors affecting EMDFG. The optimum value of MRR, WWR and ASR obtained from multi-objective optimization using TM only are 0.3945 mm^3/ min, 0.008104 g/ min and 3.11 μm, respectively, while using the hybrid approach these values are 0.7982 mm^3/ min, 0.006122 g/min and 2.78 μm, respectively. Shrivastava et al. [8] studied modelling and optimization of electric discharge diamond face grinding. Process performance of copper-iron-graphite metal matrix composite are studied by analyzing MRR and SR. Input parameters taken were peak current, pulse on time, pulse off time and grit size. They identified that peak current and grit size of diamond are significant factors for MRR while peak current and pulse on time are significant factors for SR. Optimization results showed improvements of 95 and 29 % in MRR and SR, respectively. Yadav et al. [9] investigated multi objective optimization of process parameters in electro discharge diamond face grinding based on ANN-NSGA-II hybrid technique. High speed steel cylindrical workpiece of diameter 25mm was kept under consideration. In their research they proposed that combination of high wheel speed, moderate pulse current, high pulse on time and moderate duty factor are suitable for higher MRR whereas combination of moderate wheel speed, low pulse current, high pulse on time and high duty factor of process parameter are suitable for better surface finish. Yadav et al. [10] used response surface methodology and genetic algorithm for optimization of electro discharge diamond face grinding of tungsten carbide-cobalt composite. Input parameters considered for their research were wheel speed, pulse current, pulse on time and duty factor whereas output parameters took under consideration were MRR and ASR. Conclusion drawn from their work was that a suitable combination of input parameters and optimal parameters settings provides higher material removal rate and average surface roughness. Yadav et al. [11] applied non-dominated sorting genetic algorithm for multi-objective optimization of electric discharge diamond face grinding process on cylindrical high speed workpiece of 25 mm diameter. In their study they considered pulse current, pulse on time and duty factor as input parameters and studied their effect on MRR and surface finish. They proposed that optimal solution provides many combination of lower surface roughness with varying MRR, which facilitates selecting a better combination of process parameters as per product or design requirement. Yadav et al. [12] describes modelling and optimization of slotted-electrical discharge diamond face grinding process by machining Aluminium-silicon carbide-graphite composite and by applying soft computing techniques namely artificial neural network (ANN) and non-dominated sorting genetic algorithm-II (NSGA-II). Input parameters taken were pulse current, pulse on tie, pulse off time, grit number and wheel RPM whereas material removal rate (MRR) and average surface roughness (Ra) were considered as output parameters. Their results showed a good agreement with experimental data with absolute percentage error of 4.28 % and 5.09 % for MRR and R_a respectively.

Based on the above literature survey, it has been found that use of rotating tool electrode in EDM improves MRR due to improved flushing action and sparking efficiency. It has also been found that the electrode wear rate increases with increasing wheel speed. Many researchers have concentrated their experimental investigations on EDDFG. Few literature has been found regarding experimental study of EDM in face grinding mode. The present research work is an attempt in this direction. The purpose of this research is to study the effect of input process parameters of EDFG, such as discharge current, pulse on-time and off-time, and wheel speed on MRR and ASR during machining of tungsten copper alloy workpieces. The settings of machining parameters were determined by using Taguchi's robust design approach. The machining parameters were optimized with multi response characteristics of material removal rate (MRR) and average surface roughness (ASR). Multi response signal-to-noise (MSNR) ratio was applied to measure the performance characteristics deviating from the actual value. Analysis of variance (ANOVA) was employed to identify the level of importance of the machining parameters on the multiple performance characteristics considered.

2. EXPERIMENTAL PROCEDURE AND OPERATING PARAMETERS

Experiments were conducted on a Press-Mach Spark Generator Machine Tool, Model A25 with a self-designed grinding attachment in face grinding mode. A photograph of the setup is shown in Fig. 2. The setup consists of an electrically conductive rotating nonabrasive grinding wheel (copper), motor, shaft, V-belt, and bearing mounted on the ram of the machine to rotate the nonabrasive grinding wheel about an axis perpendicular to the machine table. While machining, the rotating wheel is fed downwards under servo control for material removal in the face configuration. The nonabrasive grinding wheel and the work surface are physically separated by a gap, the magnitude of which depends on the local breakdown strength of the dielectric for a particular gap voltage setting. The workpiece is thus simultaneously subject to heating, melting & vaporizing due to electrical sparks occurring between the electrically conductive rotating nonabrasive grinding wheel and the workpiece.

Figure 2. - EDFG setup assembled on EDM machine

Table 1: Machining parameters and their levels used in the experiment for tungsten copper alloy

Parameters	Symbol	**Level**		
		1	**2**	**3**
Current (A)	I	3	5	7
Pulse on time (µs)	Ton	100	150	200
Pulse off time (µs)	Toff	50	75	100
Wheel Speed (RPM)	S	725	825	925

The input process parameters (or control factors) taken are wheel speed, current, pulse on time, and pulse off time. The output parameters analyzed are MRR and ASR. Experiments were performed on a 20 mm-diameter cylindrical workpiece made of tungsten copper alloy. Machining parameters and their levels used in the experiment for tungsten copper alloy are shown in Table 1.

The spark erosion oil was used as dielectric liquid. Each workpiece was machined for 15 min before measuring output parameters. Performing an experiment more than once, that is, replicating the experiment, can often reduce the effects of variability on experimental results. It has been reported in the literature [13] that a single set of experiments will not give any indication of variability. Variability of experimental results can be precisely captured by increasing the number of repetitions of each set of experiments by simultaneously experimental cost will increase. A minimum of two repetitions is required to avoid variability in experimental results. Three repetitions are appropriate from both points of view; that is, capturing the variability and avoiding the unnecessary increase in experimental cost. Hence, it was decided to select the trials in random order and to complete three repetitions in each set of experiments. The amount of material removal after 15 min was obtained by finding the weight difference before and after machining using a precision electronic digital weight balance with 0.1mg resolution. The MRR is calculated using the following formula:

$$\mathrm{MRR} = \frac{(W_i - W_f) \times 1000}{\rho \times t}\ \mathrm{mm}^3/\mathrm{min}$$

Where, W_i is initial weight of workpiece in g (before machining), W_f is final weight of workpiece in g (after machining), t is machining time in minutes, and is density of workpiece in g/cm^3. ASR was measured using Digital Portable Surface Roughness Tester. The workpiece clamped within the device.

3. TAGUCHI METHOD FOR PARAMETER DESIGN

The Taguchi method of robust parameter design is an off-line statistical quality control technique in which the level of controllable factors or input process parameters is so chosen to nullify the variation in responses due to uncontrollable or noise factors such as humidity, vibration, and environmental temperature. In the Taguchi method the experiments are performed as per standard OAs [13, 14].The experimental values of quality characteristics are used to compute the quality loss values for each quality characteristic in all experimental runs. Depending upon the nature of quality characteristics, the quality loss function can be of several types. In the present case maximizing the MRR and minimizing ASR are desired; therefore, the quality loss function in the *i* th trial (l_i) for higher-the-better case and smaller-the-better case will be used [13, 14].

4. RESULTS AND DISCUSSION

The experimental values of response MRR, and ASR are shown in Table 2. The variation of MRR and ASR with experiment number is shown in Fig. 3 and 4. The quality loss values for quality characteristics MRR and ASR in each experimental run are calculated. The quality loss, normalized quality loss, total normalized quality loss, and MSNR values have been computed. These values are shown in Table 3. In calculating total normalized quality loss, three different weights, that is, w1= 0.7and w2= 0.3, for MRR and ASR, have been assigned assuming different importance of the quality characteristics.

Table 2. - Experimental observations for tungsten copper alloy using L_9 OA.

S. No.	I (A)	Ton(µs)	Toff (µs)	S (RPM)	MRR (g/min)	ASR (µm)
1	3	100	50	725	0.00140	2.31
2	3	150	75	825	0.00186	1.87
3	3	200	100	925	0.00280	2.25
4	5	100	75	925	0.00194	2.56
5	5	150	100	725	0.00253	2.07
6	5	200	50	825	0.00300	2.30
7	7	100	100	825	0.00477	2.73
8	7	150	50	925	0.00520	2.99
9	7	200	75	725	0.00383	2.65

Table 3. - Quality loss values and multiple S/N ratio (MSNR) for tungsten copper alloy

Experiment No.	Quality Loss:		Normalized quality Loss		Total Normalize quality Loss	MSNR
	MRR	ASR	MRR	ASR		
1.	-57.0774	-7.27224	1	0.7644	0.9293	0.3184
2.	-54.6097	-5.43683	0.956	0.5714	0.8411	0.7515
3.						
4.	-51.0568	-7.04365	0.894	0.7403	0.8482	0.7150
5.	-54.2440	-8.16480	0.950	0.8582	0.9226	0.3499
6.	-51.9376	-6.31941	0.909	0.6642	0.8361	0.7774
7.	-50.4576	-7.23456	0.884	0.7602	0.8468	0.7222
8.	-46.4296	-8.72325	0.813	0.9169	0.8444	0.7345
9.	-45.6799	-9.51342	0.800	1	0.8602	0.6540
10	48.3360	-8.46492	0.846	0.8897	0.8596	0.6570

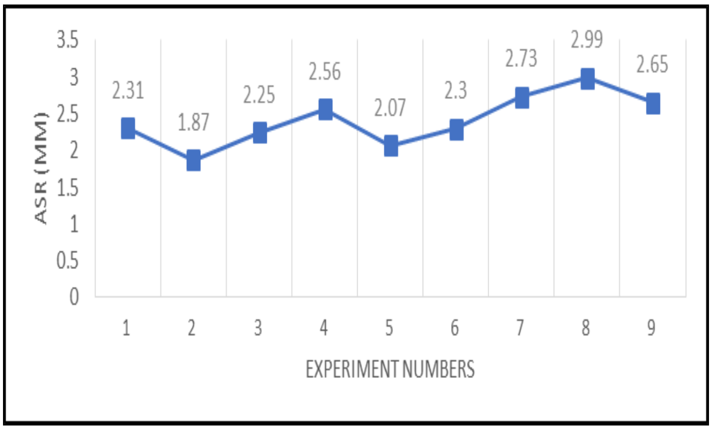

Figure 3.-Variation of ASR with experiment number

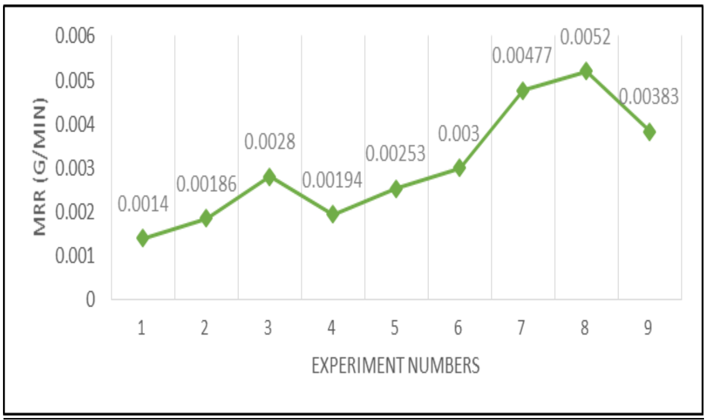

Figure 4.-Variation of MRR with experiment number

The effect of different control factors on multiple quality characteristics MRR and ASR is shown in factor response (Table 4). The optimum levels of different control factors for MRR and ASR obtained are Current at level 3 (7A), Pulse on time at level 1 (100 µs), pulse off time at level 2 (75 µs), and Wheel speed at level 1 (725 RPM). The ranking shown in the table shows the relative contribution of the factors on multiple quality characteristics. The graphical representation of factor effect on multiple quality characteristics (MRR and ASR) at different levels is shown in Fig. 5.

Table 4.-Effect of factor level on multiple S/N ratio (MSNR).

Level	I (A)	Ton (µs)	Toff (µs)	S (RPM)
1	0.3184	0.7644^a	0.5360	0.7248^a
2	0.6055	0.7186	0.7430^a	0.5636
3	0.7447^a	0.4676	0.6036	0.5974
Maximum -Minimum	0.4263	0.2968	0.2070	0.1611
Rank	1	2	3	4

^{a} Optimum Level

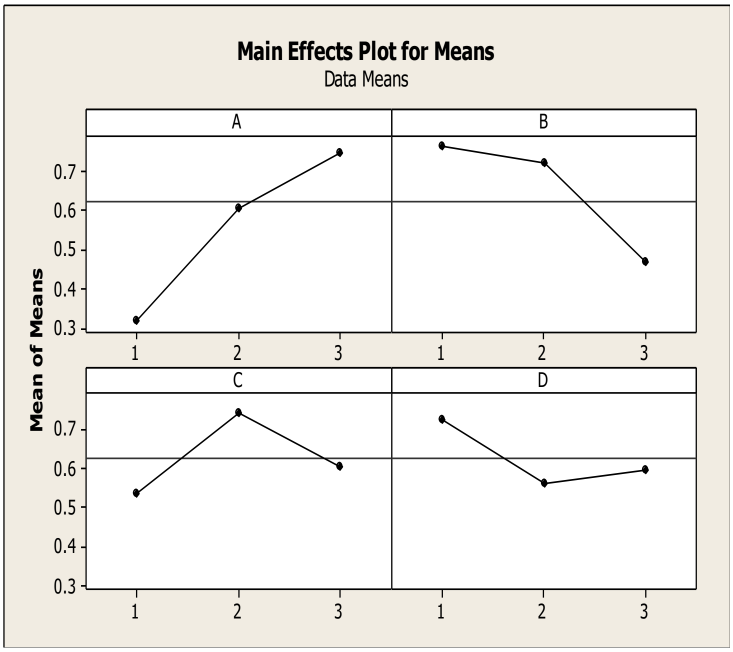

Figure 5. - Effect of factor levels on multiple S/N ratio

Conducting a verification experiment is a crucial final step of a robust parameter design. Its purpose is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. The confirmation experiment is performed by conducting a test with optimal levels of the control factors calculated previously. The predicted value of MSNR obtained and that from confirmation tests are shown in Table 5. The improvement in multiple S/N ratio at the optimum levels of process parameters is found to be 0.4951dB.The values of MRR (g/min), and ASR (µm) at optimum levels of process parameters are 0.3945 and 3.11, respectively, against the initial parameter settings of 0.05193 and 3.07. Hence, a considerable improvement in MRR but deterioration in ASR has also been observed.

Table 5.-Results of confirmation experiment at optimum parameter level.

		Optimal EDDFG machining parameters	
	Initial parameter setting	Prediction	Experiment
Level	I1Ton1Toff1S1	I3Ton1Toff2S1	I3Ton1Toff2S1
MRR (g/min)	0.00140	—	0.00634
ASR (µm)	2.31	—	2.11
MSNR (dB)	0.3184	0.9296	0.8135

Improvement of MSNR = 0.4951dB.

5. CONCLUSIONS

The multi-objective optimization of MRR and ASR using a Taguchi quality loss function has been done for the EDFG process of tungsten copper alloy workpiece. The following conclusions can be drawn on the basis of results obtained:

1. The optimum levels of input process parameters for simultaneous optimization of output parameters MRR and ASR during machining of tungsten copper alloy has been determined as wheel speed at 725 RPM, current at 7 A, pulse on time at 100 µs, and pulse off time at 75 µs.

2. The MRR was found to increase up to 0.00634 g/min and ASR was found to reduce up to 2.11 µm against the initial value of MRR and ASR as 0.00140 g/min, and 2.31 µm, respectively.

3. The multiple S/N ratio at any condition has been improved by 0.4951dB.

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