Chapter 5
Machining Performance of Cobalt-Chromium and β-Type Titanium Biomedical Alloy

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1 Introduction

Today, non-traditional machining approaches confirm their emergence in the fabrication sector by processing of extremely hard and intricate-shaped metals and alloys [1, 2]. Contemporary manufacturers employ a variety of sophisticated machining techniques, including electric discharge machining, water jet machining laser beam machining and electrochemical machining [3]. Among the various other established machining processes, electric discharge machining (EDM) is a fabrication method that is extremely well known. This approach of fabricating has a significant effect on the surface characteristics as well as the development of extensive subsurface layers with altered chemical composition and morphology [4]. EDM, also referred to as thermo-electric processing, involves regulated, high-energy electrical discharges which are aimed at the surface of the substrate from the tool. A particular amount of material is removed from the surface of a substrate as a consequence of the plenty of electric discharges, thereby which raise temperatures of the intended zone [5, 6]. The fabrication of various materials and alloys depends greatly on the EDM process factors such as pulse time, current, dielectric medium, voltage, type of electrode, and polarity (positive or negative).

For surface customization of AISI D2 tool steel, Guu et al. [7] contemplated using this thermoelectric technique. They stated that the toughness and the thickness of the recast layer could be improved by boosting the amount of spark discharge energy at the workpiece from the tool electrode. The current was found to be an essential variable for material removal rate (MRR) and surface roughness when EN31 tool steel was being machined by Das et al. [8] The MRR is primarily impacted by the amplification of current intensity combined with pulse-on time. An identical outcome was

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observed by Sharif et al. [9], who identified rising current as a crucial factor affecting all of the output results of the EDMed 316L workpiece. Similarly, Mahajan et al. [10, 11] investigated the ED machining performance two different alloys such as Co–Cr and duplex stainless steel and reported that machining parameters especially current highly influenced the material removal rate of alloys. The present work devoted to the machining of cobalt-chromium and titanium using electric discharge machining. The machining performance of two biomedical alloys, i.e., Co–Cr and Ti β-type is compared, and their results are assessed in terms of material removal rate and surface integrity.

2 Materials and Methods

In order to perform the studies, rectangular blocks with the dimensions 75 mm × 40 mm × 5 mm was purchased from Metline Industries in Mumbai, India for the tests. Table 1 show the characteristics of the workpiece alloy. Utilizing the Minitab-17 statistical analysis program, the experimental layout was created using Taguchi's L9 orthogonal array. Table 2 lists the experimentally selected values for the input machining variables, including electrode, discharge current, pulse-on time, and pulse-off time. The tests were performed on a die-sinker type EDM machine (model S645 CMAX, maker OSCARMAX, Taiwan), with negative polarity settings and an identified processing time of 20 min for each run. A dielectric medium was utilized, which was deionized water.

Each experiment was run thrice on three distinct plates of alloys. The experimental L9 orthogonal array is shown in Table 3 along with their variable configurations. During the experiment, the settings for the spark gap voltage (60 V), the dielectric medium (deionized water), and the flow pressure (0.5 kgf/cm^2) remained constant. By employing an electronic weighing balance (made citizen, model CY220), via

Table 1 Properties of workpiece alloys

Properties	Units	Co–Cr	Ti-β type
Chemical composition	N.A	Cr: 28.5%, Mo: 6%, Si: 0.7%, Mn: 0.5%, Ni: 0.25%, C: 0.22%, Fe: 0.2%, P: 0.02%, Ti: 0.01% and Co: remainder	Nb: 32.74%, Zr: 7.6%, V: 1.72%, Al: 0.5%, Fe: 0.25%, Cr: 0.22%, Mo: 0.22%, Cu: 0.03%, Mn: 0.02% and Ti: remainder
Workpiece size	mm	75 × 40 × 5	
Density	g/cm^3	10	5.06
Melting range	°C	1330 °C	1573–1690
Thermal conductivity	W/mK	9.4	6.28
Specific capacity	J/kg-K	390	525

Table 2 Experimental parameters and their levels

Input parameter	Units	Level 1	Level 2	Level 3
Electrode	N.A	Graphite	Tungsten	Tungsten-Copper
Discharge current	Ampere	10	16	25
Pulse-on time	μ-seconds	60	150	200
Pulse-off time	μ-seconds	60	150	200

Table 3 Taguchi array based on the parametric combinations of input parameters

Exp. trial	Level of input variable				Actual value of input variable			
	Current	Pulse-on	Pulse-off	Electrode	Current	Pulse-on	Pulse-off	Electrode
1	1	1	1	1	10	60	60	Gr
2	1	2	2	2	10	150	150	W
3	1	3	3	3	10	200	200	W–Cu
4	2	1	2	3	16	60	150	W–Cu
5	2	2	3	1	16	150	200	Gr
6	2	3	1	2	16	200	60	W
7	3	1	3	2	25	60	200	W
8	3	2	1	3	25	150	60	W–Cu
9	3	3	2	1	25	200	150	Gr

display readings with a maximum of three decimal places, the starting and final weights were calculated for every run in order to determine the MRR. Figure 1 shows the experimental setup of the study. Furthermore, the removal of material on the processed surface was computed using Eq. 1.

$$\text{MRR}\,(\text{mm}^3/\text{min}) = \frac{1000\ \times\ \text{mass loss of workpiece}\,(\text{g})}{\text{workpiece density}\left(\frac{\text{g}}{\text{mm}^3}\right)\ \times\ \text{machining time}} \tag{1}$$

3 Result and Discussion

The current research computes the EDM performance for the machining of two different alloys, namely cobalt-chromium and β type titanium alloy. Three attempts were carried out for both alloys and a mean value was considered to evaluate the output responses. The outcome value of each trial for Co–Cr and Ti alloys, illustrated in Table 4.

The MRR outcomes revealed that the substrate treated according to trial 8 amongst all machined titanium substrates exhibits predominant MRR (34.86 mm^3/min). Similarly, for Co–Cr alloy, also the trial 8 was considered as the highest material removal rate (23.37 mm^3/min). Therefore, the alloy specimen machined, according to trial 8,

Fig. 1 Schematic view of electrical discharge machining with dielectric flushing arrangement [12]

Table 4 Output responses for EDMed Co–Cr alloy

Exp. trial	Output response value for MRR (mm^3/min.)							
	Co–Cr alloy			Mean MRR	Titanium alloy			Mean MRR
	Rep 1	Rep 2	Rep 3		Rep 1	Rep 2	Rep 3	
1	3.49	3.42	3.47	3.46	4.87	4.14	4.66	4.56
2	3.69	3.93	3.74	3.79	5.22	4.82	4.71	4.92
3	4.08	4.23	3.61	3.97	5.43	4.95	5.22	5.20
4	13.59	13.14	13.21	13.31	21.67	19.32	20.41	20.47
5	8.86	7.29	8.02	8.06	14.55	13.71	14.17	14.14
6	10.82	11.68	10.91	11.14	18.63	18.86	17.19	18.23
7	17.46	17.08	17.31	17.28	32.43	30.88	30.64	31.32
8	23.77	22.93	23.41	23.37	36.21	34.52	33.85	34.86
9	14.07	15.11	14.12	14.43	19.52	20.64	19.03	19.73

Rep Repetition

exhibits highest metal removal rate (MRR) in both alloys. At the same machining parameters, titanium alloy showed the highest metal removal rate, with an improvement of about 1.5 times greater than the Co–Cr alloy. The results also confirmed that machining at high discharge energy i.e., 16A peak current; 150 ms/60 ms pulse on/off time put significant affect on machining. It was due to the fact that the melting and evaporation of the workpiece significantly depend on discharge energy generated during the cycle. It can also be seen that the tendency of the metal removal rate for both of the alloys are same. However, the trial machined on titanium alloy showed comparatively higher highest metal removal rate except for sample 2, which was treated at low discharge energy (5 A peak current; 150 ms/150 ms pulse on/off time) among all trials. In other words, we can say that discharge energy significantly affects the material removal rate.

It can also be seen that substrates machined with Copper-tungsten (W–Cu) electrode showed comparatively higher metal removal rate than other electrodes. Thus, the Copper-tungsten (W–Cu) electrode contributed significantly to attaining the enhanced machinability. This is due to fact that copper-tungsten material has superior bulk hardening properties as compared to graphite [13]. Thus, the material removal rate was considerably higher when copper-tungsten (W–Cu) electrode was used in machining even the discharge energy was less as compared to graphite tool machined trials.

Figure 2a, b represents the surface morphology of highest material removal rate substrate (trial 8) and least material removal rate substrate (trial 1) of titanium alloy respectively. The surface roughness of highest material removal rate substrate (trial 8) was significantly higher than least material removal rate substrate (trial 1). Figure 2a represents the morphology of trial 8 surface that demonstrates pores surface at the nano-scale level (Ra = 2.46 μm; Rz = 8.7 μm). Also, the trial 8 exhibits some surface irregularities like uneven residues of molten metal and ridges of redeposit material. This is due to fact that there is a resistance in the transmission of heat and fumes due to large motel pool formed on the machining surface. This process was occured at higher peak current and large pulse on time where a large amount of discharge energies was produced. Thus, the large sized voids are shaped resulting in the formation of the non-uniform surface with higher surface irregularities [14–16]. The trial 1 surface showed the superior surface morphology (Ra = 0.17 μm; Rz = 1.3 μm) and good surface finish (Fig. 2b). Unlike, no porous structure was seen in trial 1 or at low metal removal rate substrate. Therefore, the low metal removal rate machining generates a wide range of uniformly patterned surfaces that exhibits efficient surface integrity as compare to high metal removal rate machining.

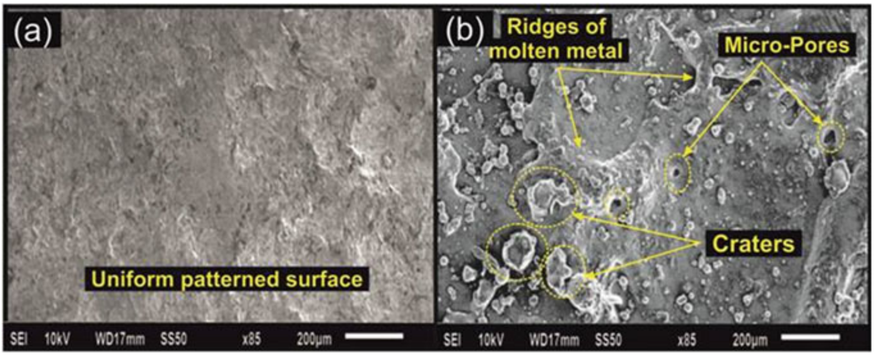

Fig. 2 FE-SEM images illustrate the surface morphology of Trial 8 and Trial 1 of titanium alloy respectively

4 Conclusions

Machining was successfully performed on the Co–Cr alloy and Ti alloy substrates by using the EDM process with the aim to figure out the machinability of alloys. The results of the material removal rate calculations confirmed that titanium alloy substrate exhibited a 1.5 times more MRR as compared with the Co–Cr alloy substrate. A 16 A peak current at a 150 ms pulse on time and a 60 ms pulse off time with a tungsten-copper (W–Cu) electrode is the best parametric set for machining. The surface morphological analysis confirmed that the low metal removal rate machining generates superior surfaces integrity as compare to high metal removal rate machining.

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