IMPROVEMENT OF EDM MACHINING PERFORMANCE BY BRASS COATED COPPER ELECTRODE

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ABSTRACT: *The Electrical Discharge Machining (EDM) surface depends on the properties of the work piece and electrode material. Many electrodes are readily available on the market, in which the copper is cheapest one among the other electrodes. The performance of metal electrodes is enhanced through coating technology and with different manufacturing processes like casting and powder metallurgy. In these, coating processes are simple, less time-consuming, and lower cost compared to others. The coating powder material is selected based on the properties of the base electrode material. Brass powder is selected for coating on the copper electrode, which has more hardness value and is also one of the electrode materials. By developing an electrode, machining performance has to be improved in order to increase the production rate. The production rate is measured in terms of Metal Removal Rate (MRR) and tool cost in terms of Tool Wear Rate (TWR). The quality of components is desired by surface roughness (SR), dimension (Depth), and Micro Hardness (MH). The main objective of this work is to improve the selected output responses of EDM machining PH15-5 stainless steel material with brass coated copper electrode by controlling various process parameters such as voltage (V), current (Amp), Pulse on duration (µs), Pulse off period (µs), Fluid pressure (Kg/cm2) and shape of tool. Well-designed experiments were conducted using an L27 orthogonal array according to the Taguchi method. The signal to noise ratio (S/N) associated with measured values was plotted, and factors affecting response factors have been obtained. The output of the experiments on a brass coated copper electrode was inferred and compared with a copper electrode. Machining performance has been improved slightly and the desired quality of the machined surface feature was obtained while using the brass coated copper electrode.*

KEY WORDS: *EDM, Electrode Material, Coated electrode, Brass coated copper, PH 15-5 Stainless steel*

1 INTRODUCTION

Electrical Discharge Machining (EDM) is one of the widely used techniques in Non-Traditional Machining (NTM), especially for finishing operations of high-precision components that are not possible through conventional material removal processes [1]. This leads to EDM being used in various applications, such as the aerospace, nuclear, power plant, chemical, and medical industries [2]. Stainless steel (SS) alloys are also used in similar applications due to their high strength and toughness. The material of Precipitation-Hardening (PH) 15–5 martensitic stainless steel faces issues in machining operations that are performed by a conventional method. PH15-5 is one of the precipitation-hardening stainless steel materials that contains high chromium and nickel alloying elements [8]. The corrosive resistance and high strength of this material property lead to many applications, such as actuator parts for modern fighter aircraft, high-pressure valves, turbine blades, fittings, gears, high strength shafts, and fasteners [6]. Therefore, it requires the EDM type of NTM process to obtain the desired quality of components. Ahmet Hascalık & Ulac Caydas. [2] performed EDM of Ti–6Al–4V by selecting various materials as electrodes, namely graphite, electrolytic copper, and aluminium. The graphite electrode favorably improved the MRR, electrode wear rate, and crack density, with a medium surface finish. Surface roughness and material removal rate at different levels of peak current are considered to examine the capability of machining titanium alloy using tungsten and copper (normal and cryogenically treated) electrodes in the EDM process. The result shows that cryogenically treated copper is superior to a normal electrode. The micro hardness of the machined surface increases by adding the particles to TiC precipitation [16]. Aluminium boron composite material was fabricated and machined in the EDM process by Paras Kumar & Ravi Parkash [5] with different electrode materials like En19, copper, and graphite. It was concluded that the highest MRR and lowest surface roughness obtained by graphite electrodes, as well as a low electrode wear rate, exist when using copper electrodes. Dewangan et al. [9] analyzed surface integrity characteristics like white layer (WLT), surface cracks (SC), and surface roughness (SR), which had an impact on machined surfaces by different tool materials (copper, brass, and graphite). After the analysis, it was concluded that brass was found to be superior among the copper and graphite electrode tools. Amorim et al. [18] utilized the graphite electrode for investigating the performance of Ti-6Al-4V by the EDM process. The fitness of the sample was evaluated by SEM images, x-ray diffraction, and measuring micro hardness. The best result of MRR, SR, and volumetric relative wear was obtained when 10 µm particle size and negative polarity of the graphite electrode was involved in the process. The presence of titanium carbide on a machined surface was identified by XRD diffraction

An experiment carried out on EDM machining of different work piece materials by Mona Younis A et al. [17] using different electrode tools such as copper, Dura graph 11, Dura graph 13, and copper-infiltrated graphite. Machining with EDM reported a surface destruction like crack due to the white layer formation. Mona Younis A. [17] revealed that the surface defect was minimized by using different electrode materials and reducing the thickness of the white layer, which causes the defect on the surface. Gopalakannan & Senthilvelan [3] conducted an experiment on EDM process, which discovered that the performance of EDM increased by graphite electrode Smooth surface with good dimensional accuracy was obtained by using the copper tungsten electrode on machining the stainless steel. Similar output values were reported using both the copper and graphite electrodes, but the tool wear rate in the copper-tungsten tool was considerably lower.

The effects of the ceramic-coated copper electrode on the machining of Titanium grade 5 alloy were investigated by Prasanna, J and S. Rajamanickam [4] on TWR and overcut. The coated electrode reduced both the output of TWR and overcut by 92 % and 62.5 %, respectively. D. L. Panchal et al. [11] compared copper tools, TiAl-coated copper tools, and TiN-coated copper tools for machining HCHCr die steel. The tin-coated tool gave the highest output for MRR and EWR when compared to the other three tools. In today's manufacturing scenario, competitive industries play a vital role in changing the shape and quality of components. To achieve the desired productivity and features, the shape and flexibility of the electrodes are considered as most important. MRR, SR and dimensional accuracy are considered as important response factors that significantly affect the tool geometry (Pellicer et al. [7]). The surface integrity of the EDM machined surfaces is influenced by the electrode material. The desired characteristics of the surfaces cannot be achieved by the readily available electrode material at maximum process performance. Copper is one of the reasonably economical electrode materials, among others such as tungsten and copper tungsten. At the same time, copper is not suitable for getting the highest MRR. Many researchers use various electrode materials in EDM, resulting in neither increased MRR nor smooth SR. Many factors, such as high hardness and dimensional accuracy, are also heavily influenced by electrode materials. In this regard, the coated electrodes performed well, according to the literature. Hence, new developments in electrode materials have to be initiated.

2 EXPERIMENTAL WORK

In this research work, EDM Die sinking machine is utilized, and the parameters such as current (I), voltage, pulse-on, pulse-off, and pressure were varied through the control panel and the details are given in the Table 1.1. Ph15-5 stainless steel material is machined with a hole of 10 mm diameter and 3 mm depth for obtaining accurate data for measuring the depth of the hole. Copper and brass-coated copper electrodes were chosen for conducting the experiment in three different shapes, namely; (i) circular (10mm diameter), (ii) square (10 mm on each side), and (iii) triangle (10 mm on each side) as shown in Figure 1.1. Brass powder is coated with 5µ thickness on each shaped copper electrode by electroplating process. Electroplating is coating a metal by electric circuit and metal is to be immersed in an electrolyte which contains salt solution of metal. In brass coating, copper plated is made as cathode of an electrolytic cell, the anode is brass metal, and the electrolyte solution is a cyano-alkaline baths (copper 65% and zinc 35% cyanide). The level of input parameters can be changed using the control panel, and it was selected based on the pilot experiment by varying one factor at a time. The range of voltage and pressure were selected based on the availability in the machine, and the shape of the tool was identified from the literature review. The following input parameters were identified from the pilot study and the values are as follows; Current (5.5 to12.5 voltage), Voltage (30 to 40 volts), pulse on time (6 to 10 micro seconds) and pulse off time (4 to 6 micro seconds).

Table 1 Machining parameters and their level

Input Parameters	Symbol	Level 1	Level 2	Level 3
Voltage (V)	A	1	2	3
Current (A)	B	1	2	3
Pulse ON time(Ton) µs	C	1	2	3
Pulse OFF time(Toff) µs	D	1	2	3
Shape	E	Circle	Square	Triangle
Pressure Kg/cm2	F	1	2	3

The input-output parameters [15] were related to exploring every possible circumstance in a research experiment known as Design of Experiments (DoE). DoE was initially introduced to the agricultural application industry and established further for different applications. Among different DoE, the Taguchi technique is one of the most commonly used DoE to conduct experiments at the least cost by means of orthogonal arrays [14]. In this work, 27 number of experiment conducted based on orthogonal array.

After conducting an experiment, it determines the deviation between the experiment and the desired value in the form of loss function through signal to noise ratio (S/N) [15]. This loss provides a deviation in the target or quality for the manufacturer. At the target value, the private and social loss is found to be zero and this loss increases gradually to the specifications indicated in the product as there exists a deviation from the target value. Generally, lower-the-better (minimum TWR and SR), higher-the-better (maximum MRR and MH), and nominal-the-better (depth) are considered respectively as given in Equation (1 to 3) [14] to find three quality characteristics used for calculating the S/N ratio. The aim of the present research work is to obtain an accurate depth, maximum MRR and MH, and minimum TWR and SR. The quality characteristics are predicted from the following Equations (1 to 3) [14].

$$\eta = S/N = -10\log\left[\frac{1}{n}\sum_{i}^{n} y_i^2\right] \quad (1)$$

$$\eta = S/N = -10\log\left[\frac{1}{n}\sum_{i}^{n} \frac{1}{y_i^2}\right] \quad (2)$$

$$\eta = S/N = 10\log\left[\frac{1}{n}\sum_{i}^{n} \frac{y_i^2}{s^2}\right] \quad (3)$$

Where, yi = Measured data at the ith experiment
n = number of observation in the experiment
s = variance in the observed data(y)

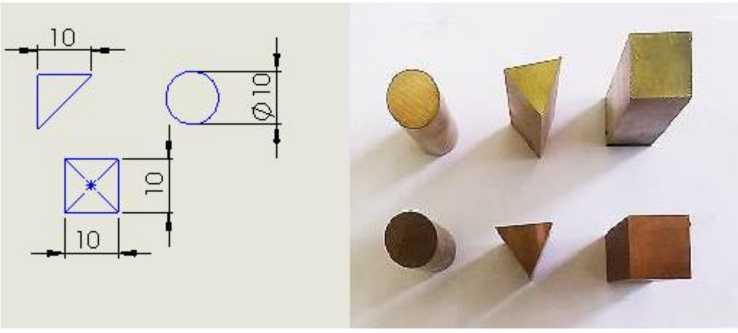


Fig. 1 Cross section of the Electrodes

3 RESULT AND DISCUSSION

Copper and brass-coated copper electrode were compared with various charts between 27 experiments and corresponding response factors such as metal removal rate, tool wear rate, surface roughness, depth, and micro hardness. The bar and radar charts have been used for comparison of brass-coated copper with copper electrodes. The brass-coated copper tool resulted in higher MRR as shown in Figures 2

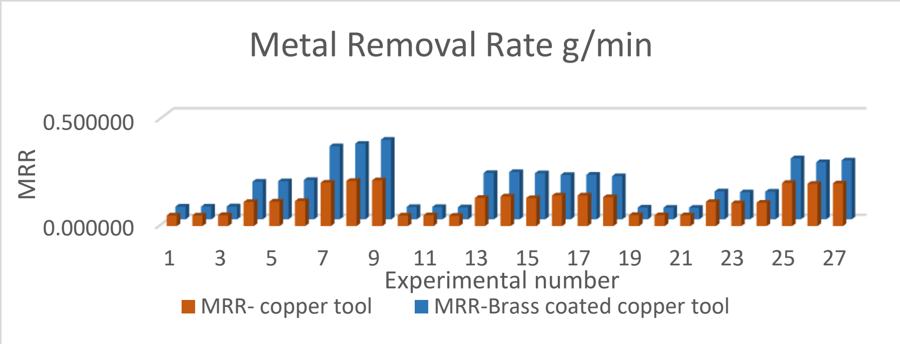


Fig. 2 Comparison of coated and non-coated electrode for Metal Removal Rate

In all 27 experiments, MRR is higher in a brass-coated copper tool than a copper tool, and TWR is considerably lower in a non-coated copper tool and it is shown in figure 3. The fact that brass powder has a lower thermal conductivity than copper leads it to concentrate more heat on the work piece surface. Thus increasing the metal removal rate and noticeably decreasing the tool wear rate. Brass combined with copper increases the stability of the electrode tool, which reduces tool wear. The coated electrode draws the highest MRR among 27 experiments at the highest current and pulse on time duration. The thermal energy created by the plasma arc required for material removal is highest at the third level of current.

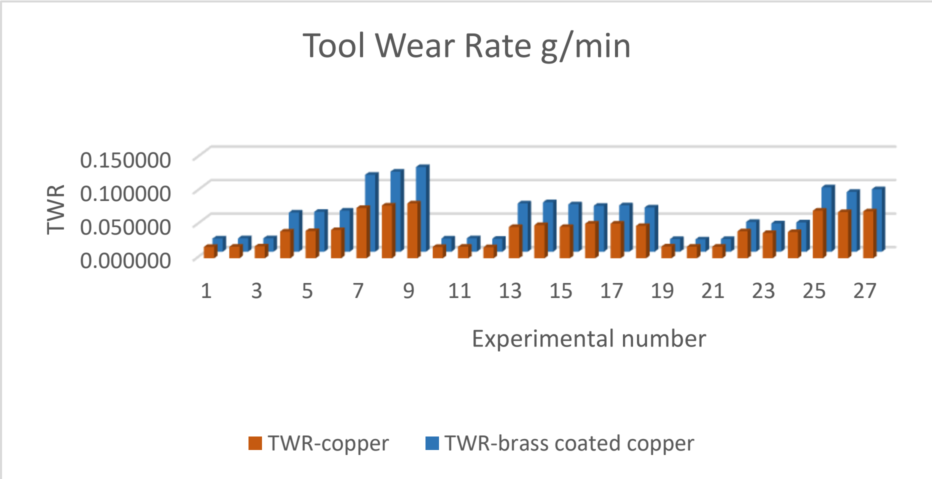


Fig. 3 Comparison of coated and non-coated electrode for Tool Wear Rate

Tool wear rate is very low at the lowest level of current, pulse on time, and high at pulse off time due to the lower energy level of the plasma channel. The pressure of the fluid increases the loss of material from both the tool and the work piece. Figure 4, 5, and 6 compare the experimental results of both electrodes for surface roughness, depth, and micro hardness, respectively. The brass coated copper electrode produced a low surface roughness, which was comparatively equal for both electrodes. The machined surface hardness increased at some point in an experiment while using a brass-coated copper tool and decreased as the current increased. The brass powder initially increases the amount of material removed from a work piece. Once a copper surface exists, that decreases the rate of melting and allows time for removing melted materials from the machined zone. Thus, it reduces the adhesion of melted materials to the machined surface. It gives a good surface finish and the highest surface hardness level. The accuracy of the depth in all experiment closes to 5 mm as the desired value in brass coated electrode, and it increases in the positive direction as current and voltage increased.

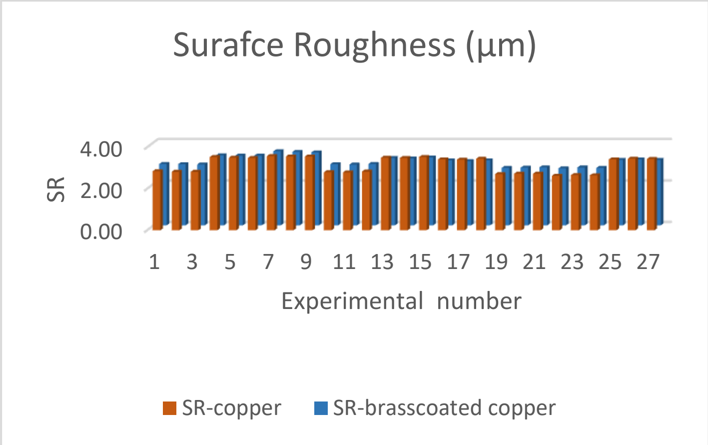


Fig. 4 comparison of coated and non-coated electrode for Surface Roughness

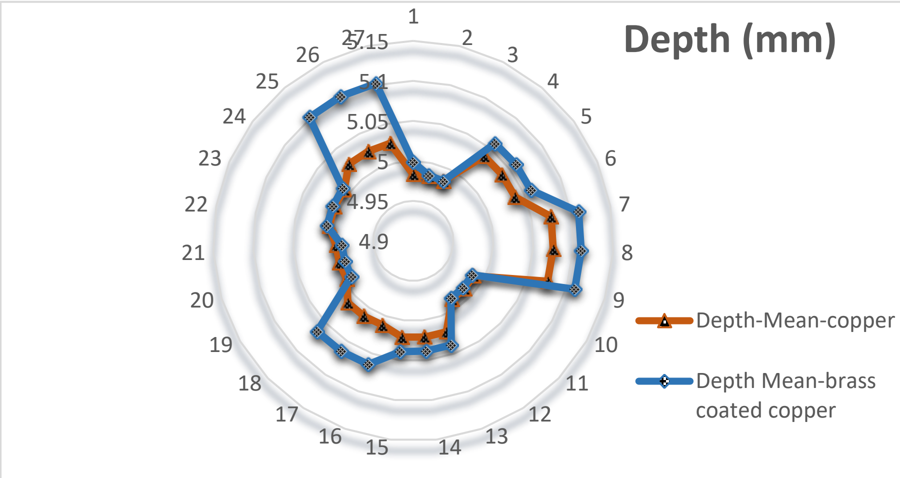


Fig. 5 comparison of coated and non-coated electrode for Depth

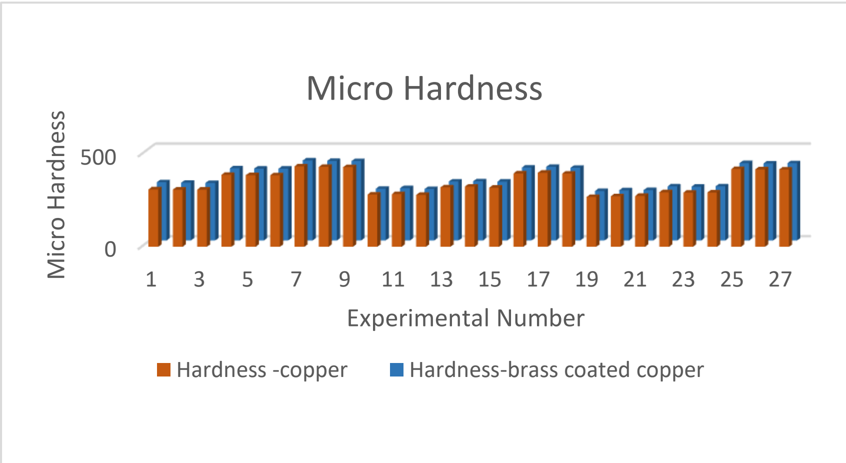


Fig. 6 comparison of coated and non-coated electrode for Micro Hardness

A comparison of the average S/N ratio in Figure 7 revealed that, the metal removal rate and micro hardness were higher in brass coated copper electrodes. Low surface roughness and depth values are obtained by brass-coated copper electrodes. But the tool wear rate is considerably higher in brass coated copper electrode. MRR, TWR, SR, and micro hardness values are obtained nearly equal with all geometry shape of coated and uncoated electrode Depth has been slightly impacted by tool geometry, which provides multiple depth sizes in the same hole. The circular geometry electrode is capable of generating depths that are of same size when compared to electrode with triangular and square shapes.

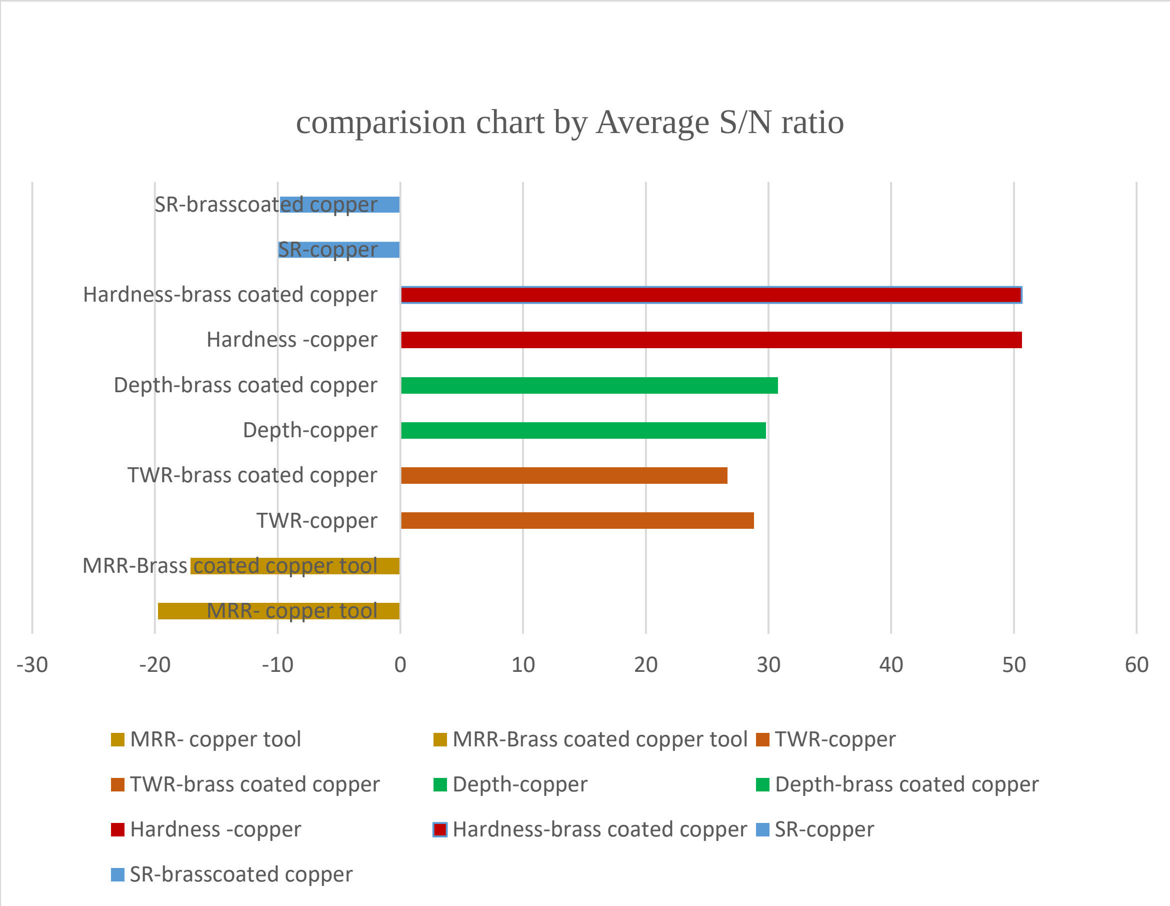
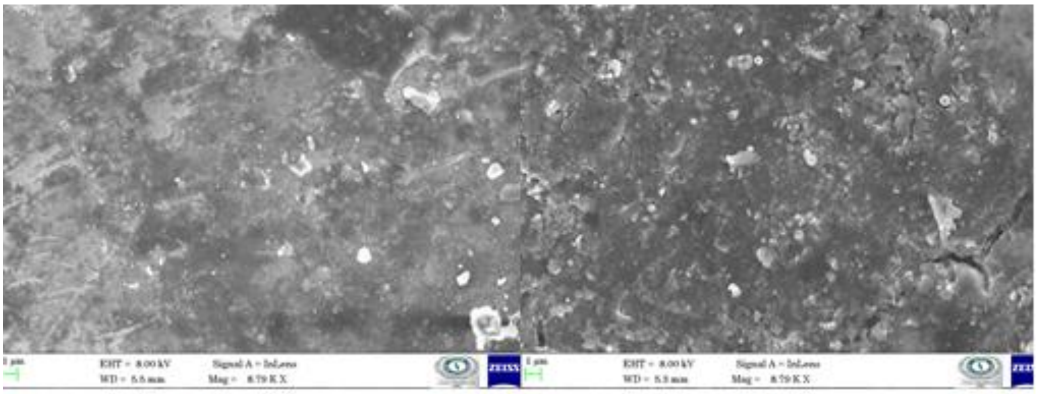


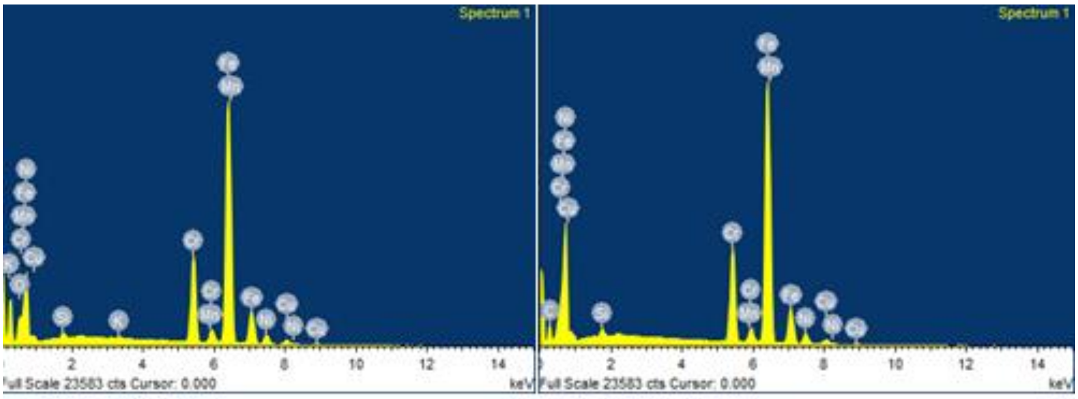
Fig. 7 Comparison chart between brasses coated copper and copper electrode by average S/N ratio

SEM image of the EDM machined surfaces. Figures 8 (a), (b) show the micrographs of the machined surface with a brass-coated copper electrode and a copper electrode respectively, for magnifications of 8000 X. The image revealed that the melted portion present on the surface was machined with a copper electrode, which leads to uneven surfaces. The higher thermal conductivity of the copper electrode increases the intensity of the discharge current and the amount of molten material suspended over the machined surface. Shallow craters are formed in the surfaces, and the material gets re-solidified as a recast layer, which is present on the machined surface as white layers. EDM surfaces are affected by irregular blending structure and cracks. The surface machined with a brass-coated copper tool was smoother as compared to the surface machined by a copper tool. It is because the melting point of brass powder is high enough to breakdown the dielectric fluid, and time is given for taking away the eroded material. A machined surface with a brass coated copper electrode exhibits small cracks and minimal white layers compared to the copper electrode. Fundamental elements on machined surfaces are predicted by EDAX as shown in Fig 9 (a), (b). The carbon element slightly increased 10% as shown in spectra of machined surfaces with the copper electrode. The presence of carbon reduces energy spark on machined surfaces when it is produced again and again. This discharge energy is concentrated at the same location, oxygen element identified in spectra of machined surfaces with brass coated copper electrode.



(a) (b)

Fig. 8 (a) SEM image of machined surface with brass coated electrode (b) SEM image of machined surface copper tool electrode



(a) (b)

Fig. 9 (a) SEM image of machined surface electrode **Fig.9 (b) SEM image of machined surface with brass coated copper tool electrode**

4 CONCLUSION

Experimentation of current research work investigated the machining of PH15-5 stainless steel material in EDM machining process. Copper and brass-coated copper electrodes have been used for conducting an experiment for 5 mm depth at different profile geometry. The developed brass coated copper tool performed well in achieving the highest metal removal rate, depth accuracy, and micro hardness. It also enhances the surface finish of the EDM machined surface of precipitated hardened stainless steel (PH15-5). The following inferences were found after the experiment and investigation of the EDM process with coated and non- coated copper electrodes.

- The metal removal rate of EDM by the brass coated copper electrode significantly increased compared to the non-coated copper electrode.
- The brass coated copper electrode gives a smooth surface finish and good surface integrity to the machined surfaces.Micro hardness of the surface increased marginally by the brass coated copper electrode.
- Accuracy of the hole reached close to the desired value of 5 mm depth using the coated electrode.
- Tool wear rate is slightly high in the case of a brass coated copper electrode but it will not affect the surface characteristics.
- The electrode material is highly influenced by the thermal energy created through current in obtaining the highest MRR, MH, and lowest TWR and SR

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