A Review on Copper and its alloys used as electrode in EDM

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Abstract: In 21st century, the demand of HSTR (High Strength Temperature Resistant) material is steadily increasing due to its numerous industrial applications. These materials are machined efficiently by Electro discharge machining (EDM) process. EDM process largely depends upon the electrode used, as different electrode material will have different properties and these properties affect the performance of the EDM process. Thus the selection of proper electrode material plays a very important role in EDM process. Different electrodes frequently used are Copper, Brass, Graphite, Copper Tungsten etc. In the present paper a detail study has been done over different copper and copper based electrodes used in EDM process.

1. Introduction

Electro Discharge Machining (EDM) is an electro-thermal non-conventional machining process for conductive material, where electrical energy is used to generate spark and material removal mainly occurs due to thermal energy of the spark [1]. The molten material is flushed from the crater cavity by dielectric fluid in form of dirt and debris and the replica of the electrode is transferred to the work material [2]. machining of ceramics, super alloys, composites can easily be accomplished with ease using EDM process [3]. By using this process any kind of intricate shape can be made irrespective of hardness and strength of the material. EDM process has been accepted and is widely employed as a standard process to manufacture mould and dies of aerospace, automotive, marine, nuclear, surgical and petroleum components. Peak current, pulse on time, pulse off time and voltage are the primary input parameters whereas Material Removal Rate (MRR), Tool Wear Rate (TWR), Surface roughness (SR), Surface quality (SQ) and Dimensional accuracy (DA) are the output parameters[4]. TWR is one of the most significant response parameter in EDM. So selection of proper tool material in EDM process is a major challenge for the researchers.Fig.1 shows the schematic diagram of the EDM process.

Fig. 1. Schematic Diagram of EDM process [5]
EDM process largely depends upon the electrode used, as different electrode material will have different properties and these properties affect the performance of the process differently. Thus the selection of proper electrode material plays a very important role in EDM process. An ideal electrode must have high MRR, low TWR and should provide better surface finish. The basic and the most important properties of electrode material are high melting point, high electrical conductivity, high thermal conductivity, high density, easy manufacturability and low cost [6]. Electrodes that are generally used in EDM process are copper, graphite, copper tungsten, silver tungsten, tungsten carbide, brass. Fig.2. shows the tool wear in x and y direction. Various researchers have investigated the effect of the machining parameters on MRR, TWR, SR in EDM process using different electrode materials. Generally copper and its alloys are widely used as an electrode due to its high conductivity and low cost. From the literature survey it is observed that none of the author has done the detail study on copper and its alloys used as electrode. In the present research a thorough study has been done over copper and copper based electrodes used in EDM process.

Fig.2 Tool wear in x and y direction [7]

2. Classification of electrodes
Electrodes are classified into Metals, Non-Metals and Composites [8].

2.1 Metals

2.1.1 Copper
When it comes to high surface finish Copper electrode is generally used. This tool is easy to machine and fabricate. It can produce mirror-like surface finish but is only useful in small cavities where it is difficult to polish. It is not recommended for high accuracy and detailing [9].

2.1.2 Copper tungsten
As copper and tungsten are not mutually soluble, thus it is a sintered electrode in which copper infiltrates the tungsten powder. It has high heat resistance, high electrical and thermal conductivity, low thermal expansion, shows good wear rate, produce excellent surface finish generally at high discharge current and is not recommended for large areas [10].

2.1.3 Brass
Brass is a metallic alloy of copper and zinc. By varying the proportions of zinc and copper different types of brass alloys can be created having different mechanical and electrical properties. Its electrical conductivity is 20%-40% of pure copper and shows comparatively high surface roughness as compared to other metals thus is not recommended for high accuracy work. It is often used for drilling small holes and cannot be used for machining hard materials [10].
2.1.4 Aluminium
Aluminium is highly conductive, inexpensive and easy to machine metal. But the problem with these electrode is surface oxidation. Electrical conductivity of aluminium is only 60% of that of copper. Aluminium has very less TWR but provides very high value of SR [11].

2.2 Non-metals

2.2.1. Graphite
It is most widely used electrode material and is best non-metal material used as electrode. It is cheap and is easily available and is highly stable. It is very brittle thus cannot be used for making small electrodes. It is therefore used for making large cavities. Graphite however has a property of arcing so to prevent that anti arcing devices are incorporated in set up.

2.3 Composite

2.3.1. Copper infiltrated graphite
It has properties of both copper and graphite and shows better rigidity and increased electrical conductivity. Limitation of using copper graphite electrode is its high wear rate at corners and its high cost. It yields good surface finish and allows stable machining under unfavourable conditions.

3. Copper and its Alloys

3.1 Copper
Ohdar et al. [8] utilised copper as a tool while machining mild steel by considering peak current, pulse on time, pulse off time and flushing pressure as input parameters and accomplished study with the result that for high value of MRR, pulse on time is the most significant factor and for low TWR, peak current is the most significant factor. At peak current 12amp, flushing pressure 0.3 kg/cm², pulse on time 15μs and pulse off time 3μs MRR becomes very high and at peak current 14amp, flushing pressure 0.3 kg/cm², pulse on time 5μs and pulse off time 7μs TWR reduces significantly. MRR and TWR decrease whereas SR value increases with the increase in pulse duration. Tool diameter also has an effect on MRR, TWR and SR value. Increase in tool diameter increases the MRR, TWR and SR value. The dielectric pressure also has a little effect i.e. with the increase in dielectric pressure, MRR increases but TWR and SR value reduces [12]. Ahmad et al. [13] explained the relation of material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) with peak current and pulse duration.

![Fig.3. Effect of peak current and pulse duration on MRR [13]](image-url)
In their study they also discussed that for high MRR peak current is the most important parameter while for TWR pulse duration is the most important parameter but at very high peak current value, TWR is adversely affected. In order to achieve good surface finish lowest peak current and the lowest pulse duration is suggested by them. They achieved lowest SR value at (a) Ip=20A, ton=200µs and highest SR value at (b) Ip=40A, ton=400µs. For MRR, pulse on time followed by pulse off time is the most significant factor and for TWR, peak current is the most significant factor. Some researchers stated peak current as the most significant factor for MRR and some stated pulse time as the most significant factor, on the other hand for TWR some stated peak current and some pulse duration as the most significant factor. Pulse current, Pulse duration and pulse voltage has 42.42%, 11.13% and 44.17% contribution respectively in affecting the surface roughness of the material in EDM process [14].
MRR, TWR and SR increases continuously with the increase in peak current but with the increase in pulse on time MRR, TWR increases and SR decreases. They also stated the optimal conditions for high MRR and low TWR while machining titanium super alloy using copper tool. At peak current 15Amp, Pulse on time 20 µsec, pulse off time 50 µsec they obtained high MRR and at peak current 9 Amp, Pulse on time 50 µsec, pulse off time 50 µsec respectively they obtained low TWR[15]. Balasubramanian [16] accomplished study using cast and sintered copper electrodes and examined that, for cast electrode MRR is high (72.4 mm3/min) and TWR value is low (12.73mm3/min) in comparison to Sintered electrode. Furthermore the SR value for Sintered electrode is marginally less as compared to Cast electrode.

3.2. Copper Tungsten
Marafona et al.[17] proposed a new method which is known as two-stage EDM method and concluded that a black layer surface is produced on the tool due to the burning of hydrocarbons(Dielectric) which inhibits tool wear. According to this methodology a lower current intensity in the first stage to form carbon inhibitor layer i.e. a current intensity of 18.3 A and pulse duration of 420 µs. In second stage higher current intensity along with long pulse duration i.e. 37.1 A with a pulse duration of 560 µs will improve MRR while reducing TWR. They also explained the relation between MRR and TWR for traditional and new method as shown in fig.6. TWR decreases, with the increase in peak current till 18A and then TWR increases. The minimum TWR is found in the range of peak current 10-23A for all pulse duration. As pulse off time increases, TWR decreases and the combination of short pulse interval and small ampere yields the maximum TWR. Optimum values for low TWR are 12 A peak current, 10 µs pulse duration and 280 µs pulse off time [18]. Halkaci et al. [19] discussed the relation between surface roughness with power and time given by \( Ra = A x^B \) where x is spark time or power, A and B are constants. Lee et al.[20] expressed relation of MRR and TWR with voltage and current through graphs explaining that with the increase in voltage MRR decreases while TWR increases but with the increase in peak current both MRR and TWR increases.

Fig.6. Material removal rate as a function of tool wear ratio for traditional and new methods [17]
Fig. 7. Effect of voltage and current on MRR and TWR [20].

Fig. 8. Comparison of copper and copper tungsten electrode in terms of relative wear and machining time [21].
On comparing copper and copper tungsten electrode it was seen that copper electrode shows more TWR in comparison to copper tungsten electrode but the machining time for copper tungsten electrode is much higher than that of copper electrode. For increasing value of pulse current MRR for copper electrode is more than that of copper-tungsten electrode.

### 3.3. Brass

MMR and TWR increases with the increase in pulse current due to higher energy density during EDM process and MRR increases with the increase in pulse off time but it decreases with the increase in pulse on time in case of brass electrode [23]. Comparative study of brass and copper electrode reveals that brass electrode has higher TWR and lower value of MRR because of its lower thermal conductivity, high electrical resistance and low melting point. Copper electrode greatly improves the performance characteristics as compared to brass electrode for same set of control parameters in EDM process [24]. They also revealed that Dielectric pressure and pulse current are the most significant factors affecting the EDM process in case of brass electrode. Fig.10. shows the comparison between copper and brass electrode in terms of MRR and TWR.
4. Comparison of Copper and its alloys in terms of MRR and TWR

4.1. MRR vs. Discharge Current

![Graph showing MRR vs. Discharge Current for Copper, Copper Tungsten, and Brass electrodes.]

4.2. TWR vs. Discharge Current

![Graph showing TWR vs. Discharge Current for Copper, Copper Tungsten, and Brass electrodes.]

Conclusion
Copper-tungsten offers comparatively low TWR for the tested materials whereas the performance of copper electrode is high. In case of copper electrode and brass electrode surface roughness is comparatively high at higher values of pulse current. Copper-tungsten electrode yields good surface finish for the work material at high discharge current. Copper-tungsten offers good dimensional accuracy and low diametric overcut at high values of pulse current. Copper-tungsten is preferred for low electrode wear, good surface finish and good dimensional accuracy. TWR increases with the increase in current and voltage. TWR of brass electrode is more than that of copper electrode. This is due to the fact that thermal conductivity and melting point of copper is higher as compared to that of brass. TWR of copper electrode is more than that of copper tungsten electrode. Thus Brass electrode has the highest TWR followed by copper electrode and then copper tungsten electrode. MRR increases with the increase in peak current for all electrode material. MRR of copper electrode is higher than that of copper tungsten electrode and MRR of brass electrode is higher as compared to copper electrode. Thus copper tungsten has the highest MRR in comparison to brass and copper electrode.

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