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Effect of Different Electrode Materials on the Performance of EDM: A Review

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***Abstract*:**

The cutting and machining of metals with high impact resistance, hardness and toughness are a challenge nowadays. The machining of these materials by conventional techniques and non-conventional machining processes are analyzed by most of the researchers. Electrical discharge machining (EDM) is a non-traditional controlled spark generation machining process used to machine hard, tough and impact resistance alloy materials. This article gives intense literature of recent various methodologies used to improve the performance of die sinking EDM and Wire EDM process with more specifically to cladding/ coating technology on tool/wire electrode. This study presents a methodology to select process parameters like current, voltage, pulse on time, pulse off time, magnetic field effect, dielectric pressure, coating materials, etc. with respect to output responses, namely Tool wear rate, Material removal rate, Surface roughness, crater morphology, crack density, dimensional accuracy etc.This paper also highlights different tool electrode material, wire electrode material, various coating materials and their respective dimensions, design of experiment (DOE) and optimization methods.

Keywords: EDM, cladding electrodes, DOE, Optimization, coatings

1. Introduction:

Electrical Discharge Machining (EDM) is a type of non-conventional machining process which is employed to machine conductive materials irrespective of their hardness, toughness, shape, size. Similarly, Wire EDM is a thermo-electrical process in which the melting and vaporization of microscopic particles of material take place due to the series of sparks between the workpiece and the wire which carries an electrical charge. Wire electrodes of various materials have been introduced to help the user needs through maximum productivity and quantity by selecting the best suitable wire. EDM has wide applications namely in coinage die making, prototype production, small hole drilling, closed loop manufacturing, metal disintegration machining, etc. Here there is no direct contact in between the tool and the workpiece. The main advantage of EDM is it can machine complex and hard materials which is difficult to machine with conventional machine tools [1-2]. The working principle of Die Sinking EDM and Wire EDM is explained in Fig 1. And Fig.2 respectively.

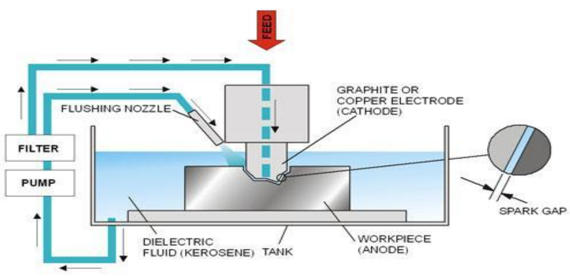

Fig1.Schematic of Die Sinking EDM [3].

The working principle of EDM depends on thermoelectric energy which is created in between the workpiece and the electrode when an electric current is made to pass through both the workpiece and the electrode which is submerged in dielectric fluid. The workpiece and the electrode are maintained with a gap called 'spark gap' in order to make it suitable for sparking. The heat of each electrical spark is estimated about 15000-21000 degree Fahrenheit erodes some material that is vaporized and melted from the workpiece. These particles are further flushed by the dielectric present [1].

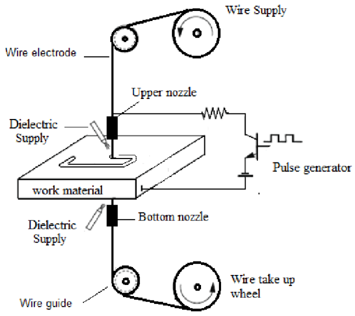

Fig 2. Schematic of Wire EDM Process [4].

Wire EDM shown in the above figure uses the same principle to machine parts with an excellent surface finish and no burrs irrespective of the size of the cut. Generally, a brass or copper wire is used and deionized water which acts as a dielectric medium is used to cool the workpiece continuously and flush the machining area. When the voltage between the two electrodes i.e. the electrode and the workpiece exceeds a certain limit, the intensity of electric field between them becomes greater than the strength of dielectric, which breaks down and allows the electric current to flow and machine the component. This phenomenon is known as the breakdown of a capacitor (breakdown voltage) [2,5].

3. Literature Review:

Saroj Kumar Padhi, S.S. Mahappatra and Harish Chandra Das used an electrode of acrylonitrile butadiene sterane (ABS) plastic with electroplating of 1000 microns of copper on it. After experimentation, it was concluded that coated electrode wear is comparatively less than copper electrode and both electrodes have nearly same MRR. In the case of the RT (copper electroplated plastic tool), the deposited metal was in the purest form of copper, carries more current to discharge, enhances MRR comparing to a solid copper tool. It was seen that RT electrode machined surface had more surface finish than copper electrode due to the surface quality of RT electrode [6].

A comparative study of Cu-W with other electrodes such as copper, graphite, Ag-W revealed that Cu-W has highest MRR, low TWR, less microcrack density. The SR was observed to be high as compared to Ag-W electrode. Also Cu-W (25-75%) powder metallurgy electrode gave a good multi-objective performance in comparison with conventional copper electrode [7, 8, 9, 10]. Subramanian Gopalakannan and Thiagarajan Senthilvelan performed an experimental investigation to study the effect of pulsed current on MRR, TWR, SR and diametrical overcut for 316-L and 17-4 PH with the different electrode materials such as copper tungsten, copper and graphite electrodes which revealed that copper electrode gave more MRR and copper tungsten electrode yields lower tool wear rate, smooth surface finish, low diametrical overcut and good dimensional accuracy [11].

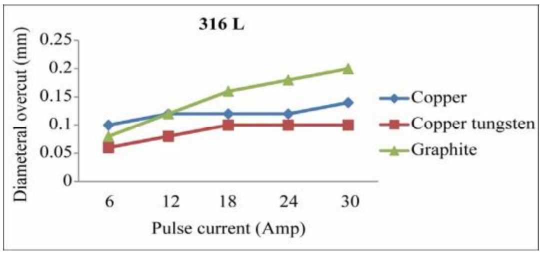

Fig 3. Effect of pulse current on diametrical overcut 316 L [11].

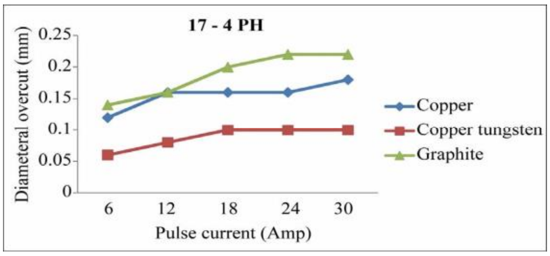

Fig. 4 Effect of pulse current on diametrical overcut 17-4 PH [11].

Arvind Kumar Tiwari and Jasvir Singh determined the optimal cutting condition of the EDM process of various workpiece material using various composition of Cu-W electrode. The optimization of the key cutting factors such as voltage, discharge current, pulse on time, duty cycle, spark gap and flushing pressure was done [12].

Y.Liu et.al. used multi-material electrode such as iron and copper, copper and copper tungsten, brass and copper which were used to machine die steel workpiece material. In single pulse discharge process, the breakdown probability is approximately the same for all electrode materials. Under continues discharge process the local discharge breakdown occurs due to the heating effect of previous discharge which increases the temperature of tool material and therefore increases breakdown probability [13].

The role of copper and Copper Nanotubes was analyzed by S.S.Shirguppikar et.al. using Taguchi Method which concluded that the significant parameters were current and pulse on time for MRR In case of non-coated tools whereas the significant parameter for the coated tool was current. The high electrical conductivity of the tool leads to sparking during machining and increased the depth of drill with coated CNT [14]. The dispersion of CNTs in the copper matrix improved wear properties of electrodes by applying ultrasonic vibrations during plating. The mean wear rate of Cu based CNTs was approximately half of the copper electrode under the same machining conditions [15].

The performance of zinc coated brass and brass electrode in the EDM of Inconel-718 revealed that coated electrode had a good surface finish and high MRR. MRR was increased with the pulse on time, wire feed rate and the decrease in pulse off time. Wire material and flushing pressure also had a significant effect on MRR [16, 17]. Jatinder Kapoor, Jaimal Singh Khamba and Sehjipal Singh studied the performance of zinc coated copper wire, brass wire and copper-zinc coating on steel wire by considering process parameters namely peak current and pulse on time. After the study, it was concluded that the use of composite wire enhanced the cutting speed. SEM examination of the workpiece gave the results that smooth surface was obtained with the brass wire whereas composite wire gave rough surface [18].

The different electrode tool materials like copper chromium, brass, copper were used in the machining of workpiece. It was further concluded that Cu-Cr had better depth of cut than brass electrode and also had less tool wear rate. Brass had better overcut than Cu-Cr at 12A and also had better hardness. A sintering pressure of 30 or 20 MPa gave high MRR during the fabrication of composite electrodes as compared to 10 MPa. The surface finish is found to be poor when the composite electrode is used. Further, the resistance of the workpiece material to corrosion was imprzioved by using such composite electrodes [19, 20, 21].

Silver coated copper tool electrodes were used in the machining process which resulted in more MRR, low TWR, better surface finish and good dimensional accuracy than the copper electrode. In the machining of Ti-6Al-4V alloy, the silver and zinc coating on copper electrode proved to improve MRR by 58.177% as compared to copper electrode but the TWR was found to higher. For the machining of Inconel 800, it was found that silver coated tool gave minimum tool wear rate at low pulse on time, low pulse off time and low peak current settings. Maximum MRR obtained was 0.74133 g/min. The tool wear obtained was in the range of 0.004g/min to 0.007g/min [22, 23, 24]

Copper coated aluminum electrodes were used to assess the machining of 38X2H2MA Steel by T. R. Ablyaz, E. S. Shlykov and S. S. Kremlev. This electrode was compared with aluminum and copper electrode to analyze their tool wear rate. Hence, it was concluded that the tool wear rate of copper coated aluminum was found to be minimum than copper electrode and aluminum electrode had the greatest tool wear that is 0.7mm [25].

S Rajamanicham et.al. analyzed the effect of Al_2O_3 coated copper electrode on the machining of Inconel 825 and compared it with the machining done by the copper electrode. The optimum combination of process parameters that are voltage, current, pulse on time and pulse off time helped to conclude that coating helped to reduce the tool wear rate but it also decreased the material removal rate. It was keenly seen that by using Al_2O_3 coated electrode there was 83.88% of saving in TWR but MRR was reduced to 51.20% [26].

Copper electrode with a coating of ZrB_2 (copper zirconium diboride) performed well in the machining of NAK 80 workpiece material. As copper has a considerably low melting point as compared to ZrB_2 particles so most of the heat generated was due to copper than ZrB_2 during discharging and hence decreased erosion of ZrB_2 particles. The results, therefore pure copper had less corrosion resistance than coating electrodes. Greater MRR, average SR, diametrical overcut with less TWR than conventional Cu electrode was obtained. Performance such as spark resistance was improved compared to the conventionally electroformed copper electrode and also proved to be suitable for finish machining [27, 28, 29]

K. Suzuki et.al compared the performance of copper and copper tungsten electrodes with electrically conductive CVD diamond electrode. The investigations concluded that for EDM area more than $0.5mm^2$ EC-CVD diamond shows zero wear and considerably minimum wear for an area less than $0.25mm^2$ at reversed polarity. Tungsten carbide is machined with very low tool wear as the temperature rise due to single spark is significantly low which is proved by thermal FEM analysis [30].

The adaptive neuro-fussy interference system (ANFIS) to predict the white layer thickness using Cu-Zn electrode. Based on the ANFIS model minimum white layer thickness was obtained at lowest levels of peak current, pulse on time and high level of pulse off time [31].

The machining of Inconel-718 was performed with the help of copper tungsten electrode with high pulse on time and peak current. It was recommended that the optimal machining condition could be performed by a combination of high peak current (40A) and pulse on time (400μs) for high MRR, SR and low TWR It was suggested to use positive polarity to achieve maximum MRR, low TWR and negative polarity for maximum SR [32, 33].

Shantisagar Biradar, Deepak Panchal and Vaibhav Gosavi machined high carbon high chromium die steel (HCHCr) using titanium nitrate coated copper electrode. After the analysis done by Grey Relational Analysis, it was concluded that maximum MRR and minimum TWR is obtained at a current of 10A, 45V, and pulse on time of 200 μs [34].

J. Jeykrishnan et.al found out the optimal machining parameters of EDM was obtained to improve the process response using nickel coated copper electrode in the machining of Inconel 825 alloy. The ANOVA table gave the percentage of pulse on time, current, pulse off time to get better surface finish which was 82.31%, 13.51%, 0.89%, respectively [35].

A detailed investigation was done on material deposition rate (MDR) and tool wear rate (TWR) during the surface modification of aluminum workpiece by TiC/Cu green compact tool electrode. MDR and TWR increased with an increase in electrode composition, pulse on time and current and decreased with an increased compaction pressure. The process was made faster by adding the copper powder in electrode material [36].

The effect of content of SiC particles, ultrasonic power on surface morphology, and EDM wear rate of fabricated Cu-SiC composite electrode was taken under consideration and it was found that an ultrasound power of 50 W generated a high SiC content of 16.5% in the electrodeposited which was high with uniform distribution and the composite had low erosion rate [37].

Kulwinder Singh and Dinesh Kumar made an attempt to study the influence of cryogenic treatment on powder metallurgy copper tungsten electrode at different machining parameters like duty cycle, gap voltage, peak current and polarity during EDM of H11 tool steel. After comparing cryogenically treated copper tungsten with copper tungsten electrode it was concluded that MRR increased with an increase in peak current, a decrease in duty cycle and gap voltage. Cryogenically cooled copper tungsten electrode proved to be feasible for the EDM of H-11 die tool steel at straight polarity [38].

A new EDM electrode composed of Mo and pre-alloyed CuNi was investigated which resulted in a much better performance in comparison with SLS copper powder electrodes and was inferior to the solid copper electrodes [39]

Orhan Gülcan et.al studied the effect of Cu-Cr and Cu-Mo powder metal (PM) tool electrodes in the machining of SAE 1040 steel workpiece. The Mo-based PM electrodes yields higher MRR than Cr-based electrodes due to higher electrical and thermal conductivity. Mo-based electrodes results in lower TWR due to its high melting point [40].

The effect of an increase in pulse current on MRR, TWR, SR of alloy steels i.e. EN31, EN8 using copper, brass and chromium copper electrode after detailed analysis of various performance parameters concluded that chromium copper had highest MRR. Copper had highest SR then followed by chromium copper and brass. Copper and chromium copper had low TWR as compared to brass. [41].

Kishor H. Watane and Mangesh Gudadhe deposited titanium carbide and copper composite on a mild steel substrate. The green compact with low compaction pressure gives a higher amount of coating over the surface. With the increase of titanium percentage, the deposition rate increases when other parameters are kept constant [42].

The modification of the surface of high carbon steel EN 31 with the help of copper- chromium- nickel tool electrode resulted in the formation of an alloyed layer with 23%, 38.7%, 23% increase in chromium, nickel and carbon respectively. XRD result revealed the presence of chromium carbide (Cr_3C_2) which is an intermetallic compound of chromium, iron and nickel (FeCrNi) in addition to cementite (Fe_3C) phase in the alloyed layer. The surface machined using optimal set of parameters was observed to have no micro-crack [43].

The effect of electrode cooling during the EDM of Ti-6Al-4V was analysis which resulted that 27% reduction in EW was obtained with electrodes cooled by liquid nitrogen as compared to electrode of same material without cooling The use of nitrogen assisted EDM leads to the increase in more than 62% in MRR and reduction in TWR due to the reduced temperature of electrode [44, 45].

Some investigations in the EDM of hardened tool steel using aluminum, copper tungsten, copper and brass electrodes were carried out. Investigations indicated that increased pulse current resulted increase in output parameters of EDM. Copper and aluminum electrodes offered high MRR. It was observed that copper is comparatively better electrode as it gives good surface finish, low diametrical overcut, less TWR and high MRR [46].

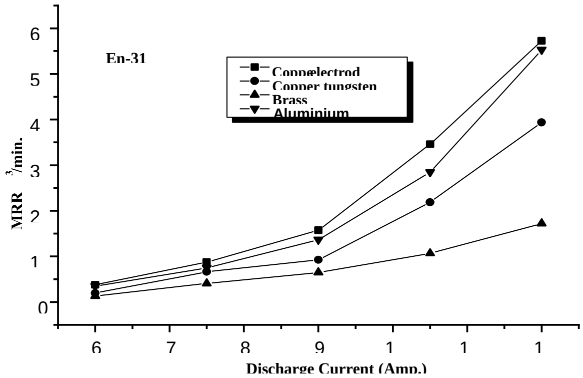

Fig 5. Effect of discharge current on MRR for Cu, Cu-W, Brass, Al [46]

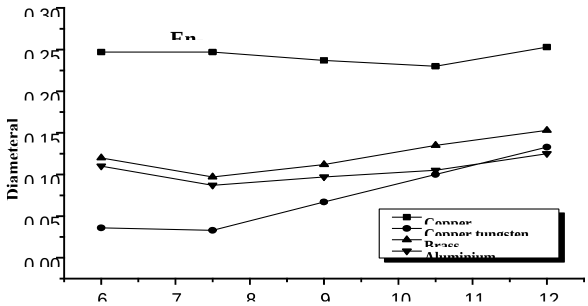

Fig 6. Effect of discharge current on diametrical overcut for Cu, Cu-W, Brass, Al [46].

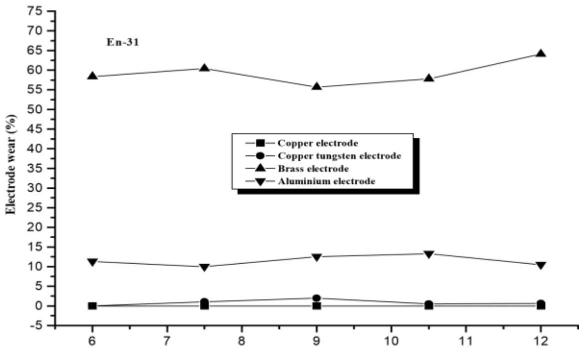

Fig 7. Effect of discharge current on SR for Cu, Cu-W, Brass, Al [46]s.

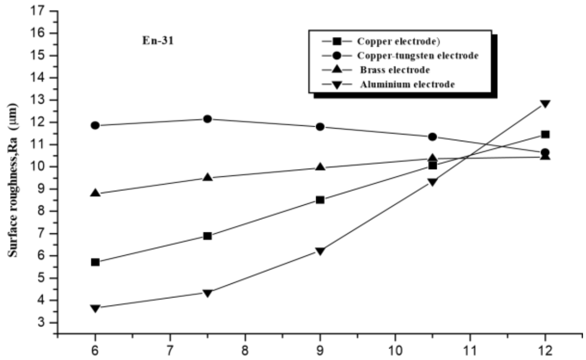

Fig 8. Effect of discharge current on EW for Cu, Cu-W, Brass, Al [46].

4. Comparative Study Based On Literature Review:

According to the above review, a comparative study was made between non-coated and coated electrodes. The coated electrodes proved to be economical and had high conductivity which resulted in better surface roughness, high metal removal rate (MRR), material deposition rate (MDR) and reduced tool wear rate (TWR), least overcut and crack density.

The following Table 1 shows the different electrodes with base metal and its coating from year 2004 to 2018. It is seen that a lot of research has been done taking copper as a base metal and applying various coatings on it.

Table 1. Results of the different electrodes

Sr. No.	**Year**	**Base metal**	**Coating**
1.	2004	Copper	Tungsten
2.	2005	Copper	ZrB_2 particles
3.	2005	Electrically conductive CVD diamond	-
4.	2008	Copper	-
5.	2012	Copper	Silver
6.	2013	Copper	Zinc
7.	2013	ABS(acryloni trile butadiene sterane)	Copper
8.	2013	Steel	Copper, Zinc

9.	2013	Copper	Titanium carbide
10.	2015	Copper	Chromium, Nickel
11.	2016	Brass	Zinc
12.	2016	Copper	Titanium nitrite
13.	2016	Copper	Nickel
14.	2016	Copper	Sic
15.	2016	Copper	Molybdenu m
16.	2017	Copper	Zinc, silver
17.	2017	Aluminum	Copper
18.	2018	Copper	Al_2O_3

5. Conclusion:

This paper helped to focus on recent technologies in wire electrodes of wire EDM and die sinking EDM from the use of copper electrodes to brass electrodes and then to the latest coated electrodes. This review contributes the objectives to enhance the material removal rate, surface roughness and to reduce the tool wear rate by the use of various coatings on an electrode. This paper reviews the past research work done on the various coating electrodes to increase the life of the electrode and improve the performance of the EDM process.

Acknowledgments:

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