Literature review of Electrodes used in EDM

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Abstract**:** EDM electrode materials need to have properties that easily allow charge and yet resist the erosion that the EDM process encourages and stimulates in the metals it machines. This paper is literature review of EDM electrodes for various work piece materials and find out the limitations of existing research. Developments in the field of materials lead to new electrode materials for EDM process. It is desired that the tool or electrode should have minimum tool wear rate (TWR) and maximum material removal rate (MRR)The review shows that recent trends in electrodes are composite electrodes like Copper-Manganese, ZrB2–Cu composite, Cu-W electrode, copper-graphite, Cr/Cu-based composite electrodes, metal-matrix materials Mo–CuNi, TiB2–CuNi, and ZrB2–CuNi, Al–Cu–Si–TiC composites. There is a scope to develop new composite materials for electrodes which will give better performance.

***IndexTerms* - EDM, TWR,MRR,Composites**

I.INTRODUCTION:

EDM electrodes consist of highly conductive and/or arc erosion-resistant materials such as graphite or copper. EDM is an acronym for electrical discharge machining, a process that uses a controlled electrical spark to erode metal. EDM electrodes include components made from brass, copper and copper alloys, graphite, molybdenum, silver, and tungsten. Electrical discharge machining (EDM) makes it possible to work with metal for which traditional machining techniques are ineffective. It only works (except by specific design) with materials that are electrically conductive. Using recurring electric discharge, it is possible to cut small, odd-shaped angles and detailed contours or cavities in hardened steel as well as exotic metals such as titanium and carbide.EDM electrode materials need to have properties that easily allow charge and yet resist the erosion that the EDM process encourages and stimulates in the metals it machines. Alloys have properties which provide different advantages based on the needs of the application.

Brass is an alloy of copper and zinc. Brass materials are used to form EDM wire and small tubular electrodes. Brass does not resist wear as well as copper or tungsten, but is much easier to machine and can be die-cast or extruded for specialized applications. EDM wire does not need to provide wear or arc erosion resistance since new wire is fed continuously during the EDM wiring cutting process.

Copper and copper alloys have better EDM wear resistance than brass, but are more difficult to machine than either brass or graphite. It is also more expensive than graphite. Copper is, however, a common base material because it is highly conductive and strong. It is useful in the EDM machining of tungsten carbide, or in applications requiring a fine finish.

Copper tungsten materials are composites of tungsten and copper. They are produced using powder metallurgy processes. Copper tungsten is very expensive compared to other electrode materials, but is useful for making deep slots under poor flushing conditions and in the EDM machining of tungsten carbide. Copper tungsten materials are also used in resistance welding electrodes and some circuit breaker applications.

Graphite provides a cleaning action at low speeds. Carbon graphite was one of the first brush material grades developed and is found in many older motors and generators. It has an amorphous structure.

Molybdenum is used for making EDM wire. It is the wire of choice for small slot work and for applications requiring exceptionally small corner radii. Molybdenum exhibits high tensile strength and good conductivity, making it ideal where small diameter wire is needed for demanding applications.

Silver tungsten material is tungsten carbide particles dispersed in a matrix of silver. Silver offers high electrical conductivity and tungsten provides excellent erosion resistance and good anti-welding characteristics in high-power applications. This composite is thus the perfect choice for EDM electrode applications where maximizing conductivity is crucial.

Tellurium copper is useful in EDM machining applications requiring a fine finish. Tellurium copper has a machinability that is similar to brass and better than pure copper.

II.LITERATURE REVIEW

Singh et al. (2004) worked to find out the most suitable electrode material for the electrical discharge machining of hardened En-31 tool steel because heat treated steel is hard to machining with traditional process. Different electrode materials used are copper, copper tungsten, brass and aluminum. With increasing the discharge current, Cu and Aluminum shows best MRR. With increase in discharge current MRR increases because spark discharged energy increases which cause the large impulsive force in spark gap. Cu and Cu-W shows less wear. Aluminium and brass shows more wear with increase in discharge current. Aluminium and copper shows high MRR and also large craters. So it shows poor surface finish.

Goyal (2014) conducted experiments using composite material electrodes on Die steel EN-31. Powder metallurgy technique has been applied to fabricate the composite electrodes with different ratio of Copper- Manganese powders. It was observed that copper-manganese (weight ratio: 70-30) composite electrode shows better results than Copper-Manganese (weight ratio: 80-20) electrodes for material removal rate (MRR) while machining the work piece. The highest value of material removal rate (MRR) achieved with copper-Manganese (70:30) is 48.46% higher than copper-Manganese (80:20) under the same machining conditions.

A.K. Khanra(2007) the EDM performance ofZrB2–Cu composite (prepared through liquid phase sintering)tool on mild steel has been carried out at different process parameters. The performance of composite tool is compared with the Cu tool. The phase changes in tool and work piece material during the EDM are also observed. The ZrB2–40 wt.% Cu composite tool shows higher MRRwith decrease TRR over pure Cu tool. The average surface roughness of tool surfaces and diametric overcut produced on the work piece are found to be more for ZrB2–40 wt.% Cu composite tool than Cu tool.

H.C. Tsaiet al. (2003) this paper proposes a new method of blending the copper powders contained resin with chromium powders to form tool electrodes. Such electrodes are made at low pressure (20 MPa) and temperature (200 °C) in a hot mounting machine. The results showed that using such electrodes facilitated the formation of a modified surface layer on the work piece after EDM, with remarkable corrosion resistant properties. The optimal mixing ratio, appropriate pressure, and proper machining parameters (such as polarity, peak current, and pulse duration) were used to investigate the effect of the material removal rate (MRR), electrode wear rate (EWR), surface roughness, and thickness of the recast layer on the usability of these electrodes. According to the experimental results, a mixing ratio of Cu–0wt%Cr and a sinter pressure of 20 MPa obtained an excellent MRR. Moreover, this work also reveals that the composite electrodes obtained a higher MRR than Cu metal electrodes; the recast layer was thinner and fewer cracks were present on the machined surface. Furthermore, the Cr elements in the composite electrode migrated to the work piece, resulting in good corrosion resistance of the machined surface after EDM.

Mona A. Younis,et al. (2015) in theirstudy, the effect of electrode material was studied to avoid resulting residual stresses, the surface roughness and cracks resulted during Electrical Discharge Machining (EDM). Two types of EDM electrode materials were chosen, Dura graphite 11 and Poco graphite EDMC-3. Two grades of tool steels are chosen as test materials, DIN 1.2080 and DIN 1.2379. Different machining methods were chosen ‘‘rough, medium, and soft’’, it was found that the Dura graphite 11 exhibits more surface cracks upon DIN 1.2379, less micro-cracks appeared on the surface than on DIN 1.2080 while the higher surface roughness appeared in DIN 1.2080 using Dura Graphite 11 electrode, also Residual stresses were studied upon the surface and it was found that POCO Graphite EDMC-3 electrode results higher residual stresses compared with Dura Graphite 11 electrode. Also Soft EDM machining exhibits higher residual stresses as a result of higher pulse on duration time.

Haron et al. (2008) investigated the effect of copper and graphite electrode with different diameters for machining of XW 42 tool steel and to select optimum material. High tool wear is main problem in EDM which result in inaccurate dimension. So research was done to select the optimum material combination and electrode material. Different diameters used for electrode in mm are 10, 15, 20 and different current intensity used in ampere is 3A and 6A. Dielectric used is kerosene. The mass lost from electrode and work material is weighed by digital weighing scale. Copper and graphite used have melting point 1083◦C and 455 ◦C. EWR of Cuelectrodesare lower than graphite electrode. Cu has higher melting point and wear resistance, for copper electrode EWR decreases with increasing size of electrode. Material removal rate is more at high current for both electrodes. MRR decreases with increasing size of electrode for copper, while for graphite 15 mm diameter electrode shows highest MRR. They found that found that the bigger electrode diameter will lose more heat when machining, because this heat will be transferred to electric fluid. The temperature of electric fluid will increase close to the melting point of the material. Copper is suitable as electrode material for machining of XW42 tool steel because it shows higher MRR and lower EWR than graphite electrode.

Wong et al. (2001) investigated the effect of TiC in Cu-W electrode on electrical discharge machiningof tool steel ASSAB 705 work piece. If copper content increases, wear resistance decreases because low melting point of copper. If tungsten content is more then it increases porosity because of insolubility between copper and tungsten. TiC is used in it because it is high refractory material with high melting point and high thermal shock and abrasion resistance. Ni is also added because of its good solubility with copper and tungsten at liquid phase. Composition used in this work is Ni- 3.50 %, Cu- 25%, W + TiC- 75%. There are six batches electrode which has different composition of W and TiC. Percentages of Tic in six batches of are5,10,15,20,30,60 and percentages of W are 95,90,85,80,70,40 which called A1, A2, A3, A4 A5 and A6respectively. Electrical resistivity of electrode of 15% TiC is less because at that higher relative density and lower porosity. So it gives higher MRR and lower EWR. At 15% TiC, relative density is high, so porosity is lower decreases the electrical resistance and create strong bonding between particles. So, it shows high MRRand

Table 2.1: Summery of Electrodes used in EDM

Author	**Work piece material**	**Tool material**	**Findings**
Wong et al. (2001)	tool steel ASSAB 705	TiC in Cu-W electrode	15% TiC in Cu-W gives

			higher MRR and lower EWR
H.C. Tsai(2003)	AISI1045 medium carbon steel	Cr/Cu-based composite electrodes	Cu–0wt%Cr and a sinter pressure of 20 MPa obtained an excellent MRR
Singh et al. (2004)	hardened En-31 tool steel	Copper, copper tungsten, brass and aluminum.	Aluminum and copper shows high MRR
Thirupathi(2007)	Enconel	Cu-W Tool	Cu-w(70%-30%) gives less TWR
Haron et al. (2008)	XW 42 tool steel	copper and graphite	copper has higher MRR and lower EWR
A.A. Khan(2008)	Aluminum and M.S	copper and brass	brass electrodes gives high MRR
T. A. El-Taweel(2009)	CK45 steel	Al–Cu–Si–TiC Composite	more sensitive to peak current and pulse on time
P. Janmanee(2010)	Tungsten carbide (WC-Co)	Graphite (Poco EDM-3), copper-graphite (Poco EDM-C3) and Cu-tungsten (solid)	Poco EDM-3 gives higher Material Removal Rate (MRR)
ParveenGoyal(2013)	Die steel EN-31	Copper- Manganese composites	The highest value of (MRR) achieved with Cu-Manganese (70:30)
A.K. Khanra(2014)	Mild steel	ZrB2–Cu composite	ZrB2–40 wt.% Cu composite tool shows higher MRR with decrease TRR
Priyaranjan Sharma 2014)	AISI 329 Stainless steel	Copper and Brass rotary tubular	Maximum MRR and less EWR for Cu electrode
Nibu Mathew(2014)	H11 chromium hot work tool steel	powder metallurgy copper tungsten (75% Cu and 25%W)cu electrode 99%Cu).	powder metallurgy tool electrode (CuW) gives better TWR
Tiago Czelusniak(2014)		metal-matrix materials Mo–CuNi, TiB2–CuNi, and ZrB2–CuNi	
C. MathalaiSundaram(2014)	OHNS steel	copper powder with titanium carbide (TiC) and Tungsten carbide (WC)	Experiments proposed
MonaA. Younis(2015)	high carbon, high chromium alloy tool steel	Dura graphite and Poco graphite	POCO Graphite EDMC-3 electrode results higher residual stresses compared with Dura Graphite 11 electrode
Suhardjono(2016)	hardened tool steel SKD11	cooper, aluminum, steel, brass, stainless steel, bronze and graphite	graphite & brass electrodes for roughing , stainless steel electrode is for finishing process

low EWR. At higher TiC percentage, increasing porosity made weak bonding between particles and hence particles drop out during machining which makes the spark scattered and reduces the strength of spark, which also increases surface roughness.

Suhardjono(2016) experimented an EDM machining process uses a different type of electrode material such as cooper, aluminum, steel, brass, stainless steel, bronze and graphite to machine a work piece of hardened tool steel SKD11. Parameters being analyzed in this research are not only the surface quality but also the material removal rate (MRR), the tool wear rate (TWR), the wear ratio (WR) which is defined as MRR/TWR. The result of the research shows that using different electrode material gives the surface roughness differences less than 3 µm e.g. for pulse current Ip=20A and Ignition voltage Uz=150V using the steel electrode and stainless steel electrode gives maximum Ra 9.63 µm and minimum Ra 6.90 µm respectively or between ISO N9 and N10.In the point of view of quantitative performance, the graphite and brass give the two highest MRR that is almost two times higher than the mild steel and stainless steel electrode. However the brass electrode has a tool wear rate 7.8 times higher than the steel electrode or 5.5 times higher than stainless steel electrode. Therefore it has the lowest wear ratio and even less than 1.0 for Ip=45A. The highest wear ratio is shown by stainless steel electrode with WR=5.23 and the lowest one is by brass electrode with WR=0.9. So, it means the brass electrode is eroded faster than the work piece. In conclusion the application of the graphite and brass electrodes are normally used for roughing and stainless steel electrode is for finishing process.

P. Janmaneeand A.Muttamara (2010) studied the performance of different electrode materials on tungsten carbide work piece with EDM process. The electrode materials were graphite (Poco EDM-3), copper-graphite (Poco EDM-C3) and copper-tungsten (solid).The important parameters were discharge current, on time, off time, open-circuit voltage and electrode polarity. Awork piece material was a tungsten carbide (W 90-Co10). The results show that the electrode negative polarity performs very well;Poco EDM-3 gives higher Material Removal Rate (MRR). Both powder electrode (EDM-3 and EDM-C3) give the better MRR and EWR more than solid electrode.The Surface Roughness (SR) of copper-tungsten gives the best when current peak intensity not over 20 amperes.

Pay Jun Liewet.al (2017) In this paper, new carbon nanofiber (CNF) reinforced copper (Cu) composite electrodes were fabricated via powder metallurgy (PM) process for electrical discharge machining (EDM) applications. The concentrations of CNF in the composite electrode were varied and the properties of Cu-CNF composite electrodes such as relative density, porosity, hardness and electrical conductivity were determined and compared with that of pure Cu electrode. The Cu and CNF powders were mixed using high-energy planetary ball mill, followed by cold compaction process and sintering operation. The results indicated that high concentration of CNF in composite electrodes decreased the relative density and hardness of the electrode. However, the porosity and electrical conductivity of Cu-CNF composite electrodes increased with the increasing of CNF concentration. These findings provide possibility of using Cu-CNF for high EDM machining efficiency particularly on low conductivity ceramic materials.

A.A. Khan(2008)An analysis has been done to evaluate the electrode wear along the cross-section of an electrode compared to the same along its length during EDM of aluminum and mild steel using copper and brass electrodes. In an overall performance comparison of copper and brass electrodes, we found that electrode wear increases with an increase in both current and voltage, but wear along the cross-section of the electrode is more compared to the same along its length. This is due to easier heat transfer along the length compared to the same along the cross section of the electrode. It was also found that the wear ratio increases with an increase in current. That means, though a higher current causes more removal of work material and the electrode, comparatively more material is removed from the electrode. The highest wear ratio was found during machining of steel using a brass electrode. The low thermal conductivity of brass electrodes causes less heat loss, and its low melting point results in fast melting of the electrode material. At the same time, low thermal conductivity of steel results in poor heat absorption, and its high melting temperature causes poor removal of work material. These factors result in the highest wear ratio during machining of steel using a brass electrode. The highest material removal rate was observed during machining of aluminum using brass electrodes. Comparatively low thermal conductivity of brass as an electrode material does not allow the absorption of much heat energy, and most of the heat is utilized in the removal of material from aluminum work piece at a low melting point. But during machining of steel using copper electrodes, a comparatively smaller quantity of heat is absorbed by the work material due to its low thermal conductivity. As a result material removal rate becomes very low. The current work focused on the investigation of appropriate materials that fulfills EDM and SLS process demands. Three new materials composed of Mo–CuNi, TiB2–CuNi,and ZrB2–CuNi were developed and characterized. Electrodes SLS conditions were manufactured through a systematic methodology. EDM experiments using different discharge energies were carried out, and the performance evaluated in terms of material removal rate and volumetric relative wear. The results showed that the powder systems composed of Mo–CuNi, TiB2–CuNi, and ZrB2–CuNi revealed to be successfully processed by SLS, and the EDM experiments demonstrated that the new composite electrodes are promising materials.

C.MathalaiSundaram(2014**)**focus on fabrication of metal matrix composite (MMC) electrode by mixing copper powder with titanium carbide (TiC) and Tungsten carbide (WC) powder through powder metallurgy process, Copper powder is the major amount of mixing proportion with TiC and WC.However, this paper focus on the early stage of the project where powder metallurgy route was used to determine suitable mixing time, compaction pressure and sintering and compacting process in producingEDM electrode. The newly prepared composite electrodes in different composition are tested in EDM for OHNS steel.

III.CONCLUSION:

EDM is useful for machining advanced materials likehigh carbon, high chromium alloy tool steel, hardened tool steel, hardened tool steel SKD11, alloys which are difficult to machine with conventional machining processes. In thispaper, the literature review shows that different authors conducted experiments in the field of electrical discharge machining using different electrodes. Many researchers worked on the improving performance of EDM by using different electrode materials suchas cooper, aluminum, steel, brass, stainless steel, bronze and graphite. Some researchers also used composite electrodes likeCopper- Manganese composites, Cu-Cr,ZrB2-Cu,copper powder with titanium carbide (TiC) and Tungsten carbide (WC) etc. The performance of EDM process is largely dependent on electrodematerial and the ideal electrode shows highest MRR and lowest tool wear.There is a scope to develop new composite materials for electrodes which will give better performance for machining hardened materialsused in manufacturing dies, automotive parts, surgical and aerospace components.

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