Review on alternative approaches to fabricate the Copper based Electric Discharge Machining (EDM) electrodes

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Abstract. Electric discharge machining (EDM) process is the category of the non-traditional and non-contact machining processes which is widely used in the industries for machining of difficult to machine materials and mainly utilized for fabrication of dies and high precision equipments. Machining performance of the EDM is mainly affected by the physical properties of the electrode. The ideal electrode of the EDM should have high electrical and thermal conductivity, high specific heat, better machinability and high wear and erosion resistance etc. A single material cannot fulfil all these requirements. This paper presents the review of alternative approaches to fabricate the electric discharge machining electrodes by using different process.

1. Introduction
The continued development of modern structures needs materials able of combating increasing working temperatures, mechanical loads, mechanical distortions and chemical deterioration [1]. It is the need of industry to generate complex shapes of components with very tight tolerances and fine surface finish. These requirements are difficult to achieve with the conventional machining processes. To meet these requirements, non-conventional machining processes are used. The use of thermolectric energy has greatly helped in achieving an economic machining of extremely low machinability materials and jobs with complex geometries. There are many modern machining processes in which metal removal is based on thermal principles and Electrical Discharge Machining is one of them [2]. Out of the various advanced machining processes, EDM has been widely used to produce surgical components, dies and moulds and finishing parts for automotive and aerospace industry. Wire EDM and die sinking EDM are frequently used electric discharge machining techniques. EDM is used for the machining of complex shapes in hard materials and has wider applications in manufacturing of surgical parts, aero-space industry, automotive industry, forging and die industry etc.

Fig. 1 shows the schematic diagram of the die sinking EDM process. The EDM process can be divided into five phases. Phase 1. Electron emission, phase 2. Break down of dielectric fluid, phase 3. Plasma channel formation, Phase 4. Spark and crater formation, Phase 5. Collapse of plasma channel and flushing of debris.

Different materials like Copper (Cu), Graphite (C), Brass, Tungsten (W) and Steel are widely used as an electrode material for EDM. Copper has been the preferred tool material because of its good electrical and thermal conductivity which causes an efficient energy transfer to the work piece as well as the ease of availability and low cost [3-8]. However, in machining of difficult to machine materials, it has been observed that the copper tool disintegrates faster [9]. The problem of high electrode wear...
can be countered with the use of composite electrode in EDM process. Fabrication of electrode tip of metals of different significant mechanical properties can result in reduced electrode wear and improve surface texture of the electrode.

Different process can be used to fabricate the electrodes for the EDM like rapid prototyping, selective laser sintering, stereo-lithography, solid state sintering, microwave sintering, stir casting and powder metallurgy etc. This paper is reviewed comprehensively on the different methods adopted for the fabrication of electric discharge machining electrode/tool.

![Figure 1. Die sinking EDM process](image-url)

2. Review of different techniques for EDM electrode fabrication

Several efforts have been carried out by different researchers to improve the performance of the EDM electrode {higher material removal rate (MRR), lower tool wear rate (TWR) and lower surface roughness (SR)} by utilizing the different fabrication processes.

Durr et al. [10] used rapid prototyping technique to fabricate the electrode for the EDM applications. The electrode consisted of bronze, nickel and a few percent of copper phosphide powders were used and tool was built layer by layer. Process optimization made it clear that the porosity of the sintered electrodes directly controlled by the laser speed, laser power and sintering strategy. The electrodes were also infiltrated with silver containing brazing metal. These electrodes had achieved higher material removal rate and showed higher tool wear rates than conventional electrodes with higher surface roughness of the machined surface. This was due to the curling effect occurred during the process. Zhao et al. [11] reported the use of selective laser sintering (SLS) as useful method to fabricate EDM metal prototype. The density and other facets of the mechanical performance of an SLS metal prototype were improved by the metal infiltration. The metal prototype was dipped into a liquid infiltrant (copper used commonly) that rose into the open pores by the mode of capillary action. The results showed that the wear rate of the electrode was comparable to that of an ordinary electrode, and the surface roughness obtained was higher for the similar machining settings. This was due to the fact that the material spreads in the x-y direction during the process and it is difficult to control the directional properties in the z direction which limits the use of SLS technique for the fabrication of the EDM electrode. Dimla et al. [12] applied stereo-lithography and direct metal laser sintering for the coating of models to fabricate the tool for EDM process. The quantity of copper deposited on models by both methods created problems. The used processes were unable to deposit even layer of copper on the models and it varied from 50-1000 μm. These methods were not able to deposit required amount of copper, especially in the inner parts of the electrodes. The thickness of coating decreased from the outer surface to the inner walls and the tool electrodes were not found suitable for EDM. Hsu et al. [13] used rapid prototyping based on
electro less plating (nickel plating) and electroforming (copper) for the fabrication of electrode for EDM process. Process of this type reduced the manufacturing duration as well as curtailed the cost of electrode fabrication. The surface roughness was higher due to the curling effect which limits the use of the RP technique for EDM electrode fabrication. Equbal et al. [14] used FDM technique to fabricate the EDM tool. Acrylonitrile-butadiene-styrene (ABS) was used as the core material and outer shell was produced by copper coating. With FDM, it was found very difficult to maintain the sharp edges of tool as the curling was occurring. Although, the performance of tool fabricated with FDM process was comparable with solid copper tool but it was having lower dimensional accuracy. Blom et al. [15] employed electroforming and spray metal deposition methods to produce tool electrodes for EDM. The electrodes made from these non-conventional fabrication methods were compared with conventional solid tool electrodes. Machining time, material removal rate, tool wear rates and surface roughness at several standard machining settings were selected as responses. The solid tool performed better than electroformed tool in terms of MRR and TWR. This was due to the uneven thickness of the electrode shell walls and also the backing material was brooked which made the shell unusable.

Velmurugan et al. [16] worked on the Graphite based metal matrix composites (MMC). The composites were fabricated by the stir casting process and was further used as an EDM electrode for machining of the hybrid Al6061 MMC. Scanning electron microscope (SEM) was used to interpret the surface morphology of the fabricated electrode. Result reveals that MRR and TWR was increased with increment in the range of process parameters. The surface roughness of the electrode was also higher as compared to the solid Cu electrode. These trends were due to the non-homogeneous dispersion of the reinforcement material into the matrix element. Senthilkumar et al. [17] worked on the fabrication of Cu-B4C composite. Stir casting technique was used to fabricate the composite. The fabricated composite was used as an EDM tool. During the SEM study they found that the TWR was higher of the newly fabricated tool as compared to the Cu tool. This was due to the improper diffusion of the B4C reinforcement with the Cu particles. Pasha et al. [18] used stir casting method to fabricate the Cu-Al2O3 composite. Fabricated composite was used as an electrode for the EDM applications. Microstructural study reveals that the Cu-Al2O3 structure was not uniform and the low density particles were segregated and observed on the top surface. Further it was concluded that due to this nonhomogeneous dispersion, the TWR was relatively higher and also the SR of the machined part was relatively higher with the conventional Cu electrode.

Yin et al. [19] used microwave sintering technique to fabricate the Al2O3-Ti ceramic tool. The effect of the microwave sintering was observed on the mechanical and microstructural properties. Result shows that the variation in sintering temperature was affecting the properties of the tool while it was difficult to control the inert temperature of the microwave. Intrgranular structures were formed which leads to increment in the residual stresses of the tool which ultimately affects the life of the tool. Xu et al. [20] worked on the Cu-W alloy. Microwave sintering route was used for the fabrication purpose of the alloy. Increase in sintering temperature leads to increase in the density of the alloy while the increment was reduced at higher sintering temperatures. At moderate temperature of sintering (1200°C), better properties were obtained and after it, the increase in sintering temperature leads to decrease in the physical and mechanical properties of the alloy as it was difficult to control the inert temperature of the microwave. Somani et al. [21] has also concluded that the major difficulty with the microwave sintering is to control the inert temperature for the sintering process.

Samuel et al. [22] during the study used copper (Cu) powder with 99.7% purity as tool material and fabricated the tool using powder metallurgy (P/M) process (blending, compaction and sintering). Increase in conductivity was found with the increase in compacting pressure and sintering temperature. The electrode compacted at low pressure had low mechanical strength. High sintering temperature increased the bond strength and decreases erosion. Thus, the increase in compacting pressure and sintering temperature resulted in change in electrical, thermal, mechanical and microstructural properties resulting better performance. Mishra et al. [23] added carbon (0 to 10 %) and titanium carbide (0 to 10 %) in ZrB2 powder and studied the systematic sintering using powder metallurgy technique. The mixing
of carbon resulted in densification but further increase in carbon addition retarded the densification. Addition of TiC above 5% had adverse effect on sintering of ZrB₂. The inclusion of Carbon also helped to hinder the grain size and fine grained composite with high densification was obtained which is the advantage of the powder metallurgy route. Balasubramanian et al. [24] carried out EDM of EN8 and D3 steels using cast copper electrode and sintered powder metallurgy electrode. The sintered copper electrode showed higher MRR and low TWR as compared to casted copper electrode for both steels. This was due to the homogeneous dispersion of the particles and also due to the higher density of the electrode fabricated by the powder metallurgy route as compared to the electrode fabricated by the casting route. Ahmed [25] produced green P/M EDM tools with copper, titanium and boron carbide powders. These tools were utilized for the EDM of aluminium with the objective to change the surface characteristics. The performance of the tools was compared with the conventional Cu tool. Result reveals that the P/M tools have higher bonding strength and lower porosity. This was due to the volumetric heating during the sintering process which tends to increase the density of the sintered samples and makes it favourable for the EDMing conditions. Somani et al. [26] has worked on the Cu-SiC composite tool. The samples were prepared by the powder metallurgy route. During their study, they observed that the SiC particles were homogeneously dispersed with the Cu particles. Further it was concluded that volumetric heating during the sintering process leads to improve the physical, mechanical and metallurgical properties of the fabricated samples which makes the P/M route more attractive. Gautam et al. [27] also concluded that flexibility of the compositions and ease of manufacture leads to the P/M route advantageous over the other processes. Azarudeen et al. [28] worked on the Cu-TiC composite EDM electrode fabricated by the P/M route. They summarized that due to the volumetric heating and homogeneous dispersion of particles the performance of the EDM tool (higher MRR, lower TWR and SR) was improved.

From the literature review, it can be summarized that the EDM tools/electrodes fabricated by the P/M route showed improved and better results as compared to the electrodes fabricated by other processes like selective laser sintering, stereo-lithography, rapid prototyping, stir casting and microwave sintering. Ease of manufacture, volumetric heating and flexibility of composition are the major advantages of the P/M route, which gives it an edge over the other fabrication methods.

3. Conclusion

From the above study, it can be concluded that electric discharge machining process is suitable for machining hard materials with high dimensional accuracy. Copper is most regularly selected tool electrode by virtue of the quality of being stable under sparking condition. The Cu tool end gets flattened and deformed over a period of time which can be avoided if the electrode end is replaced with hard conducting materials like composites. These composite tool tips can have the desirable properties of different combined materials. These composite tool tips can be fabricated by solid phase sintering, rapid prototyping, selective laser sintering, stereo-lithography, stir casting, microwave sintering and powder metallurgy route etc. It has been found from the literature that the fabrication processes like stir casting doesn’t have the capacity of homogeneous dispersion of the particles; rapid prototyping technology having disadvantage of curling and shrinkage of parts, selective laser sintering and stereo-lithography has density variation in the final part. Control of inert sintering temperature is difficult in microwave heating which limits the use of this method. Powder metallurgy route doesn’t have these kinds of disadvantages and has advantage of volumetric heating during sintering due to which part comes out to be more densed and homogenous. From the literature it is quite evident that powder metallurgy is the preferable procedure followed by rapid prototyping and electroplating. Ease of fabrication, volumetric heating, flexibility of composition, wettability are the benefits of powder metallurgy thereby making it a suitable method for EDM electrode fabrication.
4. References

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