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Problems and Challenges in EDM Electrode Fabrication Using RP: A Critical Review

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Abstract: The principle of Electro-Discharge Machining (EDM) electrode manufacture using rapid prototyped models has been investigated and presented by the many authors. Applying a thin coating of copper to prototyped parts by electroplating has provided direct method from model to tool. A number of factors have putting forward limitations to the application of these electrodes. This paper outlines and proposes the number of factors/reasons affecting the quality and performance of these electrodes. Premature failure of RP electrodes is attributed to a number of wear and failure mechanisms which are investigated at University of Texas and also at the University of Nottingham. The paper is linked with the theoretical work in this regard.

Key words: Electrical discharge machining (EDM) Rapid tooling · Rapid prototyping · Coating

INTRODUCTION

To remain more competitive in present market condition reduction of product development cycle time is of prime concern. Hence, attention has shifted from traditional methods of manufacturing to rapid manufacturing [1-5]. Rapid prototyping (RP) has provided a route to faster product modelling. RP was first commercialized in 1988 with the introduction of stereolithography (SLA) by 3D system. RP belongs to additive or generative production processes. In all commercial RP processes the part is fabricated by layer wise deposition procedure. The layers are stacked one upon other giving the height to the part [6]. It has got the potential of building parts of any complex shape without any extra cost because of absence of tooling [2-3]. Rapid technology not only allows the production of models and prototypes for visualization purposes but also of functional parts. A new group of RP application thus comes into picture that covers the production of prototype and production tooling. These new applications are known as Rapid tooling (RT). Rapid tooling is related with fast tooling production using prototypes made by RP. The integration of RP with established tooling techniques is essential to the continued expansion of the RP application base. This paper focuses on the manufacture of production tooling for EDM using RP models. The use of thin copper coated models as EDM electrodes and the associated problems are discussed. The potential for application of RP to EDM electrode production has been discussed in previous publication by the authors [7-10] and it is sufficient to provide only a broad outline here. Till now the techniques of stereolithography (SLA) and selective laser sintering (SLS) has only been applied in this regard.

The increase in demand for small tools for plastics and rubber component production over the last 20 years is likely to continue. This has applied pressure on tooling manufacturers to reduce lead times and costs. EDM is a process widely used in the manufacture of the mould cavities for plastics and rubber. Typically, the EDM cycle for mould and die production in the tool room can account for about 25% - 40% of the total lead-time. A major cost and time element in the EDM cycle is related to the electrodes production, which can account for over 50% of the total machining costs [11]. The application of RP to electrode manufacture could provide an opportunity to move from product verification to tooling with significant reductions in time and cost. A number of possible routes to RP electrodes have been proposed [9] and classified as 'direct' or 'indirect'. Direct production is the use of RP models as electrodes, while indirect routes use RP cavities

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(or masters) as an intermediate step to electrode manufacture.

The various techniques applied to the transformation of RP models to electrodes have not provided a realistic alternative to conventionally machined electrodes till date. The number of works carried out in this field by the various researchers has only concluded that the electrodes manufactured by this method are mostly suitable for finishing or semi-finishing operation. However, for roughing application still the researches are in progress. The functions of roughing and finishing electrodes for EDM die sinking are fundamentally different. The roughing electrode is an approximation of the geometry required in the cavity, with respect to size and detail. The primary function of this electrode is the bulk removal of material from the workpiece. However, the closer this electrode is to the profile of the required cavity the less work is needed to be done by the finishing electrode. The function of the finishing electrode is to provide a cleaning cut which generates the final profile and detail of the tool cavity. To satisfy their specific functions the roughing and finishing electrodes are manufactured to different specifications. The finishing electrode is not used to remove substantial volumes of workpiece material but must maintain its geometry through low tool wear.

The surface finish of the electrode must be as smooth as possible to reduce the necessity for post processing of the tool surface. Literature suggested that the SL electrodes are currently unsuitable for mass material removal where high amperage applied during EDM generates high surface temperatures at the electrode which cannot be dissipated effectively through the SL substrate. This results in premature failure of the electrode. An appropriate thickness for the copper coating has been determined, which will sustain EDM finishing cuts using an optimized machine set-up [10]. The methodology for producing SL coated finishing electrodes is detailed in earlier work and it is appropriate to provide only a summary of the processing steps here:-

- Production of SL model in SL5170 epoxy resin, using ACESTM build @ 0.15 mm layers.
- Application of high conductivity silver paint (10 µm thicknesses).
- Electro deposition of copper from acid copper sulphate bath solution (175 µm thickness).

Copper coated RP Models

Sizing of RP models-Offsetting: Electrodeposition of copper onto model manufactured by RP processes causes oversizing, which can compromise geometric accuracy of required part. Therefore it is necessary to determine the proposed thickness of deposition and undersize the RP model accordingly. Electro deposition generates a non-uniform coating. The non-uniformity of the coating varies especially for deep cavities and sharply projected regions. This variability can be controlled to a degree but it is impossible to completely eradicate the problem. The requirement for a mean copper deposit of 175 µm has been determined through experimental work done previously by the researchers to achieve EDM performance. The external surfaces of the CAD and RP model must have a negative offset applied to accept this deposit.

Controlling Copper Deposition: The performance of plated EDM electrodes manufactured using RP techniques (which mainly include SLA and SLS) is dependent on the accuracy and quality of the applied plating. The uniformity of electrodeposits over the surface of a plated model will depend on the nature the current density varies from point to point over the surface. The type of solution and operating variables also contribute to variability. Control of plating determines the accuracy of the electrode and its EDM performance. The factors affecting current distribution and MTP are; Geometry, Electrical, chance factors. Geometric considerations relate to the size as well as the shape of the model. Electrical/Electrochemical control concerns the state of the electrolyte and the model. Chance factors are somewhat more difficult to control relating to the condition of the surface of the model, the necessity for pre-treatment and variability during the plating process.

Quality of Coating: Simple models prepared using different RP techniques have shown good electrical performances but problems of uniform distribution of material are still present. Due to more and more effort, work is now progressing to more complex surface profiles requiring measures to be taken for quality copper deposition thoroughly. A number of techniques are currently commercially used to improve metal distribution on the model during plating:

- Screens - Screens are physical shielding elements which are used for blind areas of the model thereby reducing copper deposition in those areas.
- Robbers - These are additional conductive elements, suitably placed adjacent to region of the electrode attracting a greater thickness, that "rob" a greater

proportion of the current and minimise thickness variations.

- Conforming anodes - Instead of using a simple geometry anode (source) a unit conforming to the profile of the model can be produced. This can be expensive and is unlikely to be practical.
- Bi-polar electrodes - These are conducting elements that do not comprise part of the electrical circuit but when suitably placed in recesses or cavities where deposit thicknesses will be low, generate additional plating fields in these regions thereby improving the metal distribution.

These techniques are further enhanced by considering size and position of the model relative to the anode and the size and shape of the plating bath, which all affect the polarisation field.

Periodic reverse and pulsing are methods of varying the deposition rate to prevent preferential build up. Periodic reverse allows for the removal of excess deposits, while pulsing can generate a better quality of deposit through on-off current switching. Further information on current and metal distribution can be found in the literature but a good introduction will be found in reference [12]. To overcome problems associated with material deposition the above techniques are being considered for plating complex models.

Electrode Wear and Failure: Electrode wear is the volumetric calculation of material removed from the electrode relative to material removed from the work piece. It is also called as tool wear ratio (TWR).

$$\text{Tool wear ratio (\%)} = V_{electrode}/V_{work} \quad (1)$$

An understanding of different features on an electrode which are subjected to a greater intensity of wear is of fundamental importance to their accuracy and performance. It is important to provide a controlled deposit of copper allowing for sacrificial wear. The thickness of coating had no apparent influence on the volumetric wear of the electrodes. Arthur *et al*. concluded that for erosion of a 4mm cavity the average TWR was calculated as 0.6% [13]. They also investigated that the performance of solid copper under identical EDM conditions was 0.5%. Electrode failure can be due to electrode wear or catastrophic failure. Wear failure describes the loss of geometry of the electrode due to sacrificial material removal. A shallow cut does not introduce substantial wear at the electrode and therefore wear is not likely to cause failure, unless the copper coating layer is very thin.

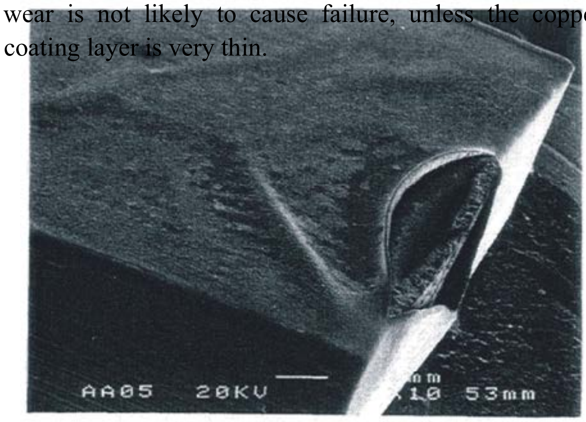

Fig. 1: Edge failure of a coated SL electrode

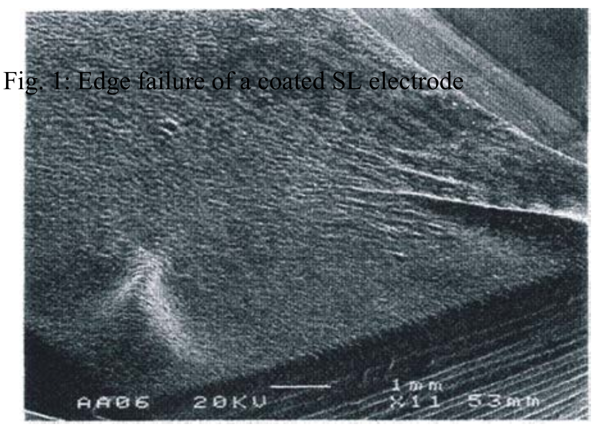

Fig. 2: Delamination of a copper coated SL electrode

Catastrophic failure of electrodes manifests itself in a number of ways. All damaged electrodes appear to have failed due to overheating. Failure can be classified by the apparent damage.

- Edge failure - The external edge or corner of an electrode receives a high concentration of spark discharges during EDM causing overheating and results in the copper layer splitting
- Delamination - Delamination is the rippling of the copper layer from parent material substrate. Differential thermal expansion of electrode material and copper and the lack of bonding between materials is the most likely cause of this failure.
- Rupture - The use of high current in EDM is the primary factor leading to rupture, causing a spark discharge of an intensity too great for the copper layer to sustain. The excessive heat generated at the

discharge explodes the coating where the thermal energy cannot be dissipated efficiently. The inability of the thin copper coating to transmit the spark

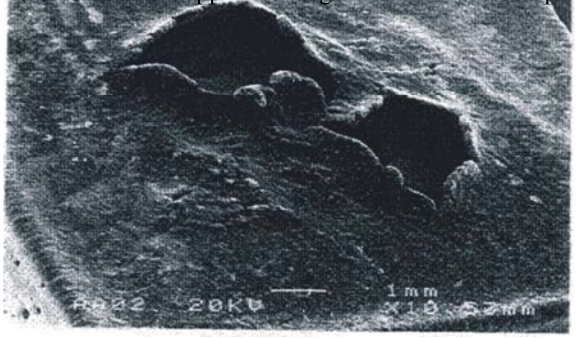

Fig. 3: Rupture of a coated SL electrode

Fig. 4: Figure showing peppering defect

energy is and will probably remain the single biggest obstacle to high material removal with these electrodes.

- Peppering - This is believed to be caused by inclusions or contamination of the copper deposit. The defect appears as multiple penetrations of the copper layer (Figure 4).
- Distortion - The build up of excessive thermal energy in the electrode during machining softens the material. Once this begins to occur there is little support afforded to the copper veneer and over a short time the composite electrode distorts.

Heat Dissipation

At the Electrode: The ability of an RP coated electrode (particularly SLA) to absorb or dissipate energy during EDM is directly related to thickness of the conductive coating. The rate of theoretical energy absorption *(*Watts) increases with greater copper thickness. The actual thermal conditions at the electrode coating during EDM are investigated. Arthur *et al*. [13] proposed that using

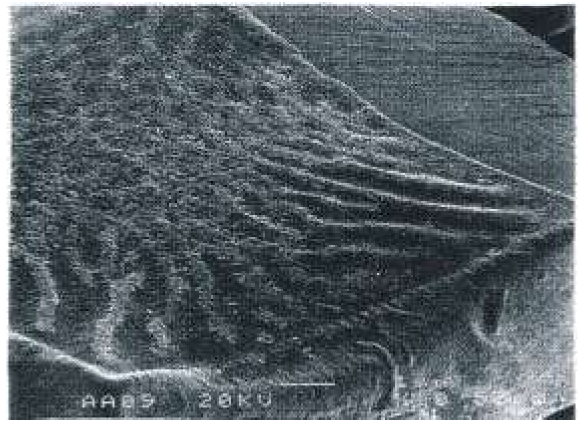

Fig. 5: Distortion of an electrode

thermal labels the electrode temperatures during EDM do not exceed 100°C, applying an optimized machining set-up.

In the Dielectric: The dielectric used in EDM is multi-functional. Its primary function is clearing of the spark gap and suppressing the spark by forming an enclosed channel between electrode and workpiece which collapses as the spark is absorbed. The secondary function is the dissipation of thermal energy from the machined surface. The dielectric acts as a heat sink for both the electrode and workpiece, transferring high heat intensity from the spark gap to the dielectric. The dielectric flow is used to best effect by incorporating direct flushing at the spark gap during electrode 'off times. This is referred to as pulse flushing from a point source. In this way the debris can be ejected and heat removed in the most efficient manner.

At the Tool/work Piece: The heat generated at the tool surface is dissipated both into its body and into the dielectric. The work piece is generally metallic and solid, fixed to the EDM machining table. This system ensures efficient thermal conduction, provided sufficient dielectric flow and low ambient tank temperature are maintained. Using electroplated RP electrodes the material removal rate (MRR) is low and therefore the heat emissions do cause excessive temperature gradients. Temperatures measured during EDM at the work piece do not differ substantially from the dielectric.

Enhancing Electrode Performance: The quality and physical properties of the electrode must be matched effectively with the applied machining conditions. Application of the electrodes demands a detailed understanding of the EDM factors which influence its performance.

Controlling Copper Quality and Distribution

Deposit Quality: One of the routes to catastrophic failure of the electrode results from defects within the copper coating. Electrodeposits have a different microstructure to bulk metals due to the nature of the deposition process. In the case of the acid copper electrolyte, in order to produce smooth deposits, certain organic additives are introduced to the electrolyte that modifies the grain structure. If the deposition process is not adequately controlled in terms of electrolyte composition, contamination and deposition conditions, then the structure of the deposit will become variable. It is therefore very important that a very tight control of the plating electrolyte and its conditions of use is maintained. Organic additives are decomposed during the plating process and can form compounds that interfere with the growth of the deposit, leading to the development of high internal stress or other forms of deposit degradation. Organic contaminants may be removed using activated carbon. Finally, to ensure a consistent deposit, chemical analysis of the electrolyte components carried out on a regular basis, combined with appropriate deposit testing is essential.

Deposit Distribution: The distribution of metal over a complex geometry is dependent on many factors as mentioned. It is possible to prepare an acid copper electrolyte to exhibit an improved distribution, other formulations of copper electrolytes are available that offer a significant improvement. These electrolytes are based on copper compounds in the form of chemical complexes. Besides improved distribution, these electrolytes produce finer grained equiaxed deposits and should reduce the tendency to pore continuity. By using these electrolytes in conjunction with the physical methods of improving metal distribution, the difficulty of obtaining a uniform deposit can be minimised.

Controlling the EDM Process: Efficiency of EDM with the RP fabricated electrode can be sought through optimization of MRR. The LI8 test array prescribed by Taguchi [14] provided a suitable structure for examination of seven adjustable EDM parameters at three levels. The relationships between the various adjustable EDM parameters are complex, however the use of fractional factorial experiment (FFE's) as outlined above has determined a start point from which improvement in coating techniques should offer potential for improvements in both machining efficiency (MRR) and electrode wear. Improving the quality and distribution of the copper deposit is likely to yield greater resilience against electrode failure, providing an opportunity for enhanced EDM performance.

CONCLUSION

The potential for application of copper coated RP models is currently limited by a number of factors. The efficiency of the RP electrodes depends on the quality of the electrodeposited copper coating and the EDM machine set-up. Optimization of both areas is necessary for good performance. The inefficient heat/energy dissipation from the front face of the electrode during EDM causes catastrophic failure. The factors contributing to failure are being investigated. A thermal model is to be developed, providing a means of predicting electrode behaviour. The reason for failure of electrode and also the factors controlling the electrode performance is discussed. Further work should provide an opportunity for greater machining efficiency.

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