Rapid prototyping Application in manufacturing of EDM Electrode

Azhar Equbal, Nitesh Kumar Dixit, Anoop Kumar Sood

Abstract— Electric discharge machining (EDM) is commonly used by toolmakers for complex injection moulds, punch dies and cavities made from hard to machine materials. Since conception EDM electrodes have been manufactured from solid conductive metals including copper and tungsten, and also using non-metals mainly graphite which are easy to machine. But the requirement of mold and die industries for quicker and flexible manufacturing method has prompted to apply rapid prototyping (RP) techniques in electrode preparation. In this regard present study will review the current research trend in this area. Various methods of producing electrodes through RP are classified and a large number of supplementary processes which integrated each route are reported.

Index Terms— Conductive; Electric discharge machining; Electroless; Electrode manufacturing; Metallization; Plating; Rapid prototyping.

1 Introduction

To remain competitive in the current industrial scenario it is necessary for any manufacturing unit to focus on the cost, quality and lead time. Various techniques and methods have been developed for achieving the same. Electrical discharge machining (EDM) is one of them. In EDM controlled metal removal is achieved by means of electric spark erosion. By applying a pulsating (ON/OFF) electrical discharges of high frequency current are produced repeatedly in series between tool and the work piece in the presence of dielectric fluid resulting erosion of tiny pieces of metal from the work piece [1]. The process machines electrically conductive hard material parts regardless of their geometry and has been widely used to produce dies and moulds and also for finishing parts for aerospace and automotive industry and surgical components [2]. During machining the shape of electrode is replicated in the work piece. As a result surface finish, dimensional accuracy and geometry of electrode, as well as material properties such as thermal conductivity and wear resistance affect EDM performance measures. If a very large or complicated cavity is to be produced, the above factors leads in the manufacturing of more than one separate electrode of a specific geometry which runs in required sequence for machining the same. These conditions results in the increase of cost and production time. For the reduction in tooling cost, product development time and increasing the productivity rapid prototyping (RP) technology were developed. Rapid prototyping (RP) encompass number of technologies like stereolithography (SLA), sequence for machining the same.

- *Azhar Equbal is currently pursuing Ph. D Degree program in Manufacturing Engineering in NIFFT, Ranchi, India, PH-9708570708. E-mail: azhr_eqbl06@yahoo.co.in.*
- *Nitesh kumar Dixit is currently pursuing Masters Degree program in Manufacturing Engineering in NIFFT, Ranchi, India,, PH-9313507926. E-mail: niteshkumardixit11@gmail.com*
- *Anoop kumar Sood is Assiatant Professor in Manufacturing Engineering in NIFFT, Ranchi, India, PH-916512292067. E-mail: anoopkumarsood@gmail.com*

These conditions results in the increase of cost and production time. For the reduction in tooling cost, product development time and increasing the productivity rapid prototyping (RP) technology were developed. Rapid prototyping (RP) encompass number of technologies like stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), and laminated object manufacturing (LOM) and produce physical part directly from a digital design depositing material layer by layer to generate shape of part. In doing the same, it bypasses the lengthy and costly traditional design and fabrication of moulds, jigs, fixtures and other tooling and process planning requirements prior to actual part fabrication. Many of these techniques are based on either the selective solidification of the liquid or the bonding of solid particles [3]. RP processes may benefit the EDM electrode manufacturing options by being able to provide higher quantities of electrodes of complex geometry with in less time and cost. Based on this present study is an attempt to understand the applicability of RP for EDM electrode manufacturing. Various methods of producing RP electrodes are classified and a large number of supplementary processes which integrated each route are reported. Emphasis is given on RP electrode variation used, and the performance achieved.

2 RP and its Constraints

Rapid prototyping (RP) emerged in 1987 and was first commercialized in 1988 with the introduction of a stereolithography (SLA) system by 3D Systems. RP processes belong to the additive (or generative) production processes. In all commercial RP processes, the part is fabricated by deposition of layers contoured in a (x-y) plane two dimensionally. The third dimension (z) results from single layers being stacked up on top of each other, but not as a continuous z-coordinate [4]. The starting point for any RP is 3-D (Three-dimensional) solid or surface CAD (computer aided design) of the object to be built, from which a data set describing that geometry must then be compiled. This data must be manipulated to generate the instructions required to control the process in the final stage of actually fabricating the component. The common process stages can be divided into two steps.

Step 1: In this step STL(sterelithography) file is generated by tessellating 3D model, tessellated model is sliced and the generated data is stored in standard formats that could be interpreted by RP machines. This information is used in step 2. At this stage choice of part orientation and slice thickness are the most important factor as part building time, surface quality, amount of support structures, cost etc. are influenced.

Step 2: In this step generation of physical model takes place. This step is different for different RP processes and depends on the basic deposition principle used in RP machine The software that operates RP systems generates laser-scanning paths (in processes like Stereolithography, Selective Laser Sintering etc.) or material deposition paths (in processes like Fused Deposition Modeling) from the slice information obtain in step 1. At this stage various process related information's like tolerance information (surface finish), material information, machine information (like laser spot diameter, cutting speed, temperature etc.) are important ('Wang et al (2000)," 5). Like other manufacturing process performance measures of RP techniques are dimensional accuracy, surface roughness, mechanical strength, build time, material properties and post processing. Factors affecting the final use of RP parts are depicted in Figure 1.

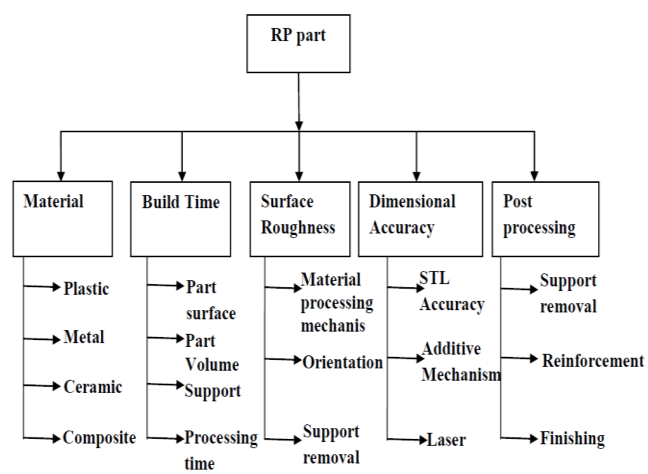

Fig. 1. Factors affecting RP part propertie

3 RP IN EDM ELECTRODE MANUFACTURING

For EDM is a process widely used in the machining of hardened material or even ultra hardened material to fabricate tools or moulds, is regarded as one of the main technologies in today's tooling field. Typically, in mould production, more than 25%, or even 40% of the machining lead-time is EDM. The major cost and time spent in EDM is the manufacturing of electrodes, which can take more than 50% of the total machining costs. Thus to minimize these RP is used as it has the potential to reduce lead-time and development costs through the rapid manufacturing of an electrode. For the complex cavity to be produced instead of using complicated electrode RP can aid by producing the same with numbers of small electrodes and also reduce the time and cost. It can produce electrodes of both conductive and non-conductive materials as discussed later.

4 ELECTRODES OF CONDUCTIVE MATERIALS

Present research in EDM electrode manufacturing using conductive materials mainly focuses on expanding the materials available and increasing the performances of RP techniques. Selective laser sintering (SLS) is most extensively researched in this respect. It uses metal compounds and binder powders for manufacturing of metal parts. It can be either direct metal laser sintering (DMLS) or indirect metal laser sintering (IMLS). IMLS uses a plastic binder material while DMLS uses a metal binder. Furthermore, DMLS is divided into solid state sintering (SSS) and liquid phase sintering (LPS). In DMLS prototypes and production tools are produced from metal powder without the use of polymer binder. The material can be sintered without pre-heating and negligible net shrinkage during the sintering process. Direct metal laser sintering to fabricate electrode was first researched by the "University of Cheminzed [6]". The shape of electrode was cylindrical and metal powder system consisted of Ni, bronze and few percent of copper phosphite. Thermal sintering occurs because copper phosphite interacts with bronze as low melting material. Optimization of process showed that laser power, laser speed, sintering strategy and hatched distance had the biggest impact on the porosity of sintered electrode. Thus for achieving the improve electrode performance the electrodes were infiltered by a silver containing brazing metal and also by tin containing plumb bob. The MRR achieved is 12.5mm^3/min and has higher tool wear. Finally it was concluded that the performance of electrodes as well as dimensional accuracy and surface roughness can be further improved. "Tay and Hyder [7] produce four types of electrode using DMLS. These electrode were solid copper electrode; copper electroplated electrode; an electroless copper plated electrode; and an untreated DMLS electrode. These electrodes were tested under various machining conditions. It was finally concluded untreated DMLS electrode can be considered for both semi roughing and roughing condition when minimal material is to be removed and electroless copper electrode can be used for moderate material removal and dimensional accuracy". Study performed by "Li et al. [8] on the effect of sintered copper based EDM electrodes has shown that electrodes having 15% TiC have the highest relative density, lowest electrical resistivity and good EDM performance. Due to problematic expansion of metal powders during IMLS the research mainly concentrated on the development of new materials with advance material properties". This leads to the research in the field of MMC till now. Researchers at the "University of Taxes [9] manufacture sintered EDM electrodes using MMC The feasibility of was investigated by the University of Texas and they achieved workpiece MRR of about 21 mm^3/min and tool wear ratio between 0.2 to 10%".

5 Electrodes of Non Conductive Materials

Electrode of non-conductive pattern is divided into two categories: positive metal coated parts (direct tooling) and negative metal coated parts (indirect tooling). The non-conductive part produced by RP is first metallized for converting it to conductive and the same can be then used as electrode. The various processes for metallization are electroless plating, electroforming, spray metal and electroplating etc. "Arthur et al. [10] uses copper electroplated SL electrode and concluded that metalized thickness of more than 180 µm is to be used for general applications". The failure associated because of heat distribution for above electrode was investigated by same researchers [11, 12]. They stated that due to different linear expansion between plastic core and metallized layer shear stress occur between their interfaces leading to electrode failure. Dimensional accuracy of copper shell of electroplated electrodes was investigated by "Gillot et al [13]. It was found that accuracy of electroplated electrode is a function of three factors: the accuracy of RP model, accuracy of primary metallization, and accuracy of copper shell thickness. They focused on accuracy of copper shell thickness and designed experiment to investigate the same. A CNC machine copper parts is used to avoid primary metallization. The shape of model was a pad which had two half cylinder and some other details. Finally it was found that because of lack of dimensional performances, electroplated electrodes were not satisfactory for industrial use". An attempt to improve efficiency of electroplated electrode was made using copper pyrophosphate electrolyte instead of acid copper [14]. A good pore closure properties were achieved but shear stress between interfaces increased due to high operating temperature resulting in distortion of shell. Back filled EDM electrodes from electroforming of a negative RP model was also produced. In this, a SL model of reverse form of the electrode was used. A convex dome shape of electrode was used. The eroded material was a tool steel and cut depth was 8.7 mm. After metallization a copper shaft was set into a back of the shell using epoxy adhesive. They machine it under different condition and found satisfactory performance. But they come across difficulties on separating the shell from epoxy negative body and the stair stepping phenomenon of SL models need to overcome, especially for electrodes having curved geometry, recess and details. "Yarlagadda et al. [15] adopted indirect tooling approach for producing EDM electrode. First, a Stereolithography pattern was fabricated and then used silicon RTV and vacuum casting to produce flexible silicon cavities followed by copper electroforming on the above cavities to produce a copper shell. The above shells were then preheated and backfilled with zinc to give the electrode the necessary mechanical strength. They concluded that feature distortions were created due to incomplete filling of the backing material as well as unequal shell thickness created during copper shell electroforming". "Soar et al. [16] uses a positive or negative SL pattern for spray metal deposition on it. After applying this in electroplating and electroforming process they found inferior characteristics of final electrode produced.

6 Problem and Challenges

RP process has their limitations in terms of fabricated part dimensional accuracy, surface roughness and mechanical strength. Together they will affect the final use of part for EDM electrode manufacturing. Moreover they have major limitation in terms of processable material, which is different from the electrode material. If RP process is making the electrode using conductive material there may be chance of internal porosity which will affect their EDM performance. For the case of non conductive material metallization is a major problem. In process of metallization it is necessary to obtain uniform coating and bonding between the plastic substrate and metallic film should be strong enough to operate in drastic EDM condition without failure. The various problems can also be due to shrinkage effect and stair-stepping which can be avoided using STL conversion or selecting the suitable part build parameters during part fabrication.

4 Conclusion

The increasing possibilities of rapid and effective methods of RP techniques for producing complex shaped parts in less time and low cost shows a high potential. The RP part used must have good dimensional accuracy and appropriate surface roughness for manufacturing the electrode which will provide the desired performance. For both direct and indirect approaches varieties of materials can be used. These materials can be either conductive or non-conductive. While using the conductive material for electrode the main problem is of porosity. This problem can be overcome to the great extent by using post infiltration using the appropriate filtrate material. If the non-conductor is used then the prime concern is to make it conductive via metallization. Although researches on development of RP electrode has been performed extensively but until now the desired level of performance has not been achieved which can replace conventional and costly CNC milling electrodes.

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