Research Article

Effect of a Rapid Tooling Technique in a 3D Printed Part for Developing an EDM Electrode

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The role of rapid tooling (RT) in additive manufacturing (AM) seems essential in improving and spreading out the vista of manufacturing proficiency. In this article, attempts were made to discover the feasibility and the accomplishments of the RT electrode in the field of electro-discharge machining (EDM). Fused deposition modeling (FDM) is one of the AM processes adopted to fabricate the EDM electrode prototype by coating with copper. The copper is deposited on FDM-built ABS plastic component for about 1 mm through thick electroplating. The copper-coated FDM (CCF) and solid copper (SC) electrodes are used to conduct experiments on a die-sinking EDM machine using tool alloy steel as a workpiece. The CCF polymer electrode can be efficiently used in EDM operations as the build time of any complex shape was substantially reduced. However, the material removal rate (MRR) is far less than that of the SC electrode. It is recommended that the CCF electrode is used for semifinishing and finishing operations in which MRR happens to be less. However, CCF can get spoiled as high temperatures are generated on the machining tool, and the plastic core hardly sustains such high temperatures.

1. Introduction

To meet the day-to-day needs of evolving products rising from customers and contenders became difficult for current technology's manufacturing process. Industrial technology development helps in meeting the demands in a stipulated time and cost to a great extent. However, the manufacturing planning requires a tool/die of specific applications either for a mini or large size of a production batch that regulates the product finishing. Production expenses of a product are mainly assessed from the tooling expenses, not by machining expense [1]. Current progress like 3D printing (AM) for developing the model and rapid tooling (RT) for producing tools using modern techniques mainly fits to minimize the tool producing time and, accordingly, production time to achieve a competitive advantage. The subtraction production approach utilizes various processes to remove the excess unwanted substance from the unfinished workpiece. The modern machining methods like electrochemical machining (ECM), abrasive jet machining (AJM), ultrasonic machining (USM), and electro-discharge machining (EDM) were commonly utilized for machining intricate shapes and cavities/-

holes which are hard to machine substances. For a specific part/model requirement, factors like the raw substance, process applications, and the postprocessing conditions are affected.

The five steps of AM include preparing a CAD model, STL version, dividing and program writing, selecting AM type, and postprocessing requirements. They are moderately responsible for the process outputs and properties, dimensional correctness, surface condition, mechanical durability, building time, etc. The model is enhanced notably with the precise setting of several process variables. AM generates more important resolutions quicker and depends on the accumulated layers, substances, composites, and curing methods [2].

Crump et al. successfully developed FDM first time in 1989, and Stratasys Inc. launched the first industrial FDM group equipment in 1990. FDM creates a component by deposition of molten thermoplastic substances on a supported plane or earlier developed component by getting glued to an adjacent substance, and cooling in air yields a final desired product. The FDM typically uses wires of a thermoplastic substance like ABS plastic, wax, and nylon. The

FDM-produced product's output quality depends on the raster's angle, thickness, width, nozzle, chamber temperatures, and feed rate. During the FDM product fabrication, molecules uniting in the deposition path are induced by raster inclinations [3]. The volumetric reduction makes an inadequate layer bonding and higher porosity as it remains in the semimolten state during the setting stage. Simulation of the FDM solidification process by applying finite element analysis (FEA) remarked that the concentrated residual stresses distorted the part's base surface [4]. The part inclination influenced building time, component strength, surface texture, and dimensional exactness such that the tensile strength consistently decreased with an increase in inclination as void formation takes place. Adhesive capacity and bond strength of two adjoining fibers were affected by the casing temperature [5]. The mechanical durability of the component improves with the improvement of the microstructure. The variation in filament temperature during the laying process leads to dimensional inexactness due to deformation. Thus, it is indispensable to comprehend the FDM's drawbacks before suggesting it for the RT application.

Various operations like contouring, deep channeling, pocket forming, and planetary machining operations can be accomplished using the die-sinking EDM [6]. Computer numerical-regulated EDM is the most advanced method to increase precision, performance, and productivity [7]. EDM parameters include electrode discharge current (enhancing the sparks and their pulse duration), dielectric solution and jet pressure, tool type and geometry, and workpiece substance [8]. Multicriteria decision-making to develop surface performance measurement in the EDM process using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has been utilized. Minimum levels of average white layer thickness and surface roughness at maximum compressive residual stress are obtained while machining AISI 304 stainless steel showed the most influent parameter which was current for plasma formation [9]. Taguchi-Grey analysis-based criteria decision-making was applied to evaluate quality characteristics (like recast layer thickness, wire wear ratio, and microhardness) of the wire EDM process. The wire electrode selection factor that helps in generating spark energy was the most influent actor on the quality characteristics [10]. The variables principally changing the EDM performance measures are MRR (mm^3/min), TWR, the percentage ratio of volume of electrode to volume of workpiece material, and the surface roughness (SR) of the corroded cavity represented by an arithmetic average roughness (Ra). The process variables along with the electrode geometry, the tool, and the workpiece material properties like thermal/electrical conductivity and the wear resistance, govern the EDM outputs profoundly [11]. Studying the trials' results on rectangular tungsten-copper electrodes during machining of D2 steel showed the carbon, Fe, and chromium deposition on the electrode surface. MRR was maximized by settling the current and pulse duration and controlling the carbon layer deposition [12].

The RT is a continuous form of the AM model changed into a tool directly from the CAD illustrations instantly to meet the immediate requirement. RT are classified into direct

and indirect tooling and patterns for casting. The FDM-produced electrodes undergo a few postprocessing for various EDM applications (roughing, semifinishing, and finishing). The postprocessing stages differ for the AM-fabricated electrodes as the different electrical and mechanical properties (nonconductive, conductive, and pattern for casting) [13]. Therefore, the AM nonconductive prototype surface is to pass through an intermediate process of metallization to make the working surface electrically conductive with a suitable metal coating [14]. The simple flat shape of plastic (epoxy) model metalized EDM electrodes machined a 4 mm deep cut on the tool steel without electrode failure. This method can be applied in semirough or finishing cut operations [15]. It is concluded that the failure occurs at the epoxy-metal interface because the variations in linear thermal expansion lead to raised shear stresses on the copper shell [16]. The nonuniform deposited copper (Cu) thickness of the electroplated AM electrodes is one of these processes' main drawback. The CAD models for a tool incorporate various topologies of geometry like deep slots which create problems during milling along with surfaces at various angles. Such geometries are easy to produce using direct rapid RT processes. Without an enough amount of Cu layer, the electrodes will just burn out immediately when erosion begins making them unsuitable for EDM due to variations in coating thickness which resulted in poor surface finish and/or dimensional inaccuracies [17]. As a result of the comparison, it has been seen that the electroplated electrode has a greater density and is more robust than metal spray coating [18]. Electroplating by electroforming reproduces the mandrel's form precisely without shrinking and distortion, resulting in similar metal forming processes (casting, stamping, or drawing) [19]. Investigations on the usage of quick EDM electrodes produced from most suitable two different methods of RT processes used in the finishing of laser-sintered tools (Cu coating of stereolithography models and direct metal laser-sintered (bronze) models) were performed. The Cu quantity deposited on both electrodes proved challenging as the electroplating process was not able to deposit enough Cu in their inner cavities with very gradual reduction in Cu layer thickness from the outside. Virtually, there is no deposition in the inner walls and bottom face. Consequently, the electrodes were not suitable for the EDM process [20].

After a significant survey of different fields of AM and RT, it has been noticed that very few research studies were implemented on developing 3D printed plastic into an EDM electrode using the rapid tooling technique. Copper can be deposited on 3D printed polymer material using electroplating onto it to a proper thickness. The present work is devoted to the copper-coated 3D printed polymer electrode model's experimental investigations and compared with a solid copper electrode while electro-discharge machining of tool alloy steel.

2. Methods and Materials

2.1. Changing of a 3D Printed Polymer into a Rapid Tool Conductive Electrode. It describes the fabrication of the 3D printed ABS plastic electrodes using the FDM process and different processes to metalize the plastic electrode and test

FIGURE 1: Schematic of electrode fabrication processes.

TABLE 1: EDM test run parameters.

Parameters	Range	Parameters	Range
Density of Cu, ρ_{Cu}	7725 kg/m ³	Density of tool alloy steel, ρ_s	9860 kg/m ³
Open-circuit voltage	60 V	Duty factor	60%
Current	6 A	Pulse-on time	200 microseconds

samples (Figure 1). Then, it is converted into an EDM electrode using the metallization of 3D printed plastic surfaces. The metallization process deposits metal onto the plastic surfaces. Three-stage processes were to be implemented for the plastic/polymer material to change into electro-conductive surfaces and improve the thickness to a higher level by the electroplating process. The 3D printed polymer electrode surfaces were coated with conductive silver paint for about 6 to 8 μm thick and allowed to dry. Secondly, chemical annealing is carried out to reduce colloidal silver containing settled silver particles. They are to be cautiously filtered at above atmospheric pressure with the help of 0.2 μm sized filter mesh and retained in a sealed container for utilization. Obtained condensed silver colloidal dispersion is applied in the thin layer on the plastic surfaces and dried. Repeating this coating multiple times yields better results.

It was kept in an oven at 90°C for about half an hour to make these fine pure silver layers of 1 to 3 μm adhere to the plastic surface. Finally, the electroless plating of the Al scattered coating layer in the form of Al scattered paste is applied on the 3D printed polymer electrode samples' surfaces. Dried for 24 hours, forms, about 10 μm thick, are mildly scrubbed to polish the surfaces with higher graded sandpaper. Then,

cleaning was performed by rinsing in purified water and then drying out at 50°C for 60 minutes. Then, prototypes are immersed in the electroless plating copper bath solution for about 4 hours. After rinsing with distilled water, the dried surface acts to be electrically conductive. All the electrodes and FDM models are be electroplated for many hours to increase the copper deposition thickness in the plating bath solution for about 24 hours for each sample.

By maintaining the average rate of deposition with a current density and room temperature without additives and continuous filtration of the solution and by stopping the process after few hours for a while and measuring thickness attained and knowing the rate of deposition, we increase thickness by increasing time of deposition as at this rate, it acts like a steady state. The maximum time of electroplating elapsed for the electrode is about 210 hours to obtain a thickness of 1 mm at the rate of 110 $\mu\text{m}/24$ hours. A scanning electron microscope (SEM) was used in determining the thickness as they give direct evidence [19].

2.2. Experimental Methodology. The cavity-type EDM trials were made in machining a hardened tool alloy steel work-piece. A workpiece sample of 75 mm diameter and 5 mm

TABLE 2: MRR, TWR, and SR results of 3D printed (RT) and solid copper (SC) electrodes at $\tau = 70\%$.

Current I (Amp.)	At $T_{on} = 50$ microseconds						At $T_{on} = 100$ microseconds						At $T_{on} = 150$ microseconds					
	MRR SC	MRR RT	TWR SC	TWR RT	SR SC	SR RT	MRR SC	MRR RT	TWR SC	TWR RT	SR SC	SR RT	MRR SC	MRR RT	TWR SC	TWR RT	SR SC	SR RT
2	1.865	1.775	0.037	0.016	3.521	4.421	2.020	1.990	0.043	0.015	3.237	4.137	1.925	1.895	0.053	0.014	3.894	4.794
2.15	1.923	1.841	0.039	0.018	3.600	4.500	2.058	2.032	0.045	0.017	3.302	4.202	1.942	1.913	0.055	0.016	3.943	4.843
2.3	1.987	1.913	0.041	0.019	3.687	4.587	2.101	2.080	0.047	0.019	3.374	4.274	1.965	1.937	0.057	0.018	4.001	4.901
2.45	2.056	1.992	0.044	0.021	3.782	4.682	2.150	2.135	0.049	0.020	3.454	4.354	1.993	1.968	0.060	0.020	4.066	4.966
2.6	2.132	2.078	0.046	0.022	3.885	4.785	2.204	2.197	0.052	0.022	3.542	4.442	2.027	2.006	0.062	0.021	4.139	5.039
2.75	2.212	2.170	0.049	0.024	3.995	4.895	2.264	2.265	0.054	0.023	3.638	4.538	2.066	2.050	0.065	0.023	4.220	5.120
2.9	2.299	2.269	0.051	0.025	4.113	5.013	2.330	2.340	0.057	0.025	3.741	4.641	2.111	2.101	0.067	0.025	4.308	5.208
3	2.359	2.339	0.053	0.026	4.197	5.097	2.377	2.394	0.059	0.026	3.814	4.714	2.144	2.139	0.069	0.026	4.372	5.272
3.15	2.455	2.449	0.056	0.027	4.328	5.228	2.452	2.480	0.061	0.028	3.930	4.830	2.199	2.201	0.072	0.028	4.473	5.373
3.3	2.556	2.566	0.059	0.029	4.466	5.366	2.533	2.573	0.064	0.029	4.054	4.954	2.259	2.270	0.075	0.030	4.582	5.482
3.45	2.663	2.689	0.062	0.030	4.613	5.513	2.619	2.672	0.068	0.031	4.186	5.086	2.325	2.345	0.078	0.031	4.699	5.599
3.6	2.776	2.819	0.065	0.031	4.767	5.667	2.711	2.778	0.071	0.032	4.325	5.225	2.396	2.427	0.081	0.033	4.823	5.723
3.75	2.894	2.956	0.069	0.032	4.929	5.829	2.809	2.891	0.074	0.034	4.473	5.373	2.473	2.516	0.085	0.035	4.956	5.856
3.9	3.018	3.100	0.072	0.034	5.099	5.999	2.912	3.011	0.078	0.035	4.627	5.527	2.556	2.612	0.088	0.036	5.096	5.996
4	3.104	3.199	0.075	0.035	5.217	6.117	2.984	3.094	0.080	0.036	4.735	5.635	2.614	2.679	0.091	0.037	5.194	6.094

Current I (Amp.)	At $\tau = 70\%$						At $\tau = 75\%$						At $\tau = 80\%$					
	MRR		TWR		SR		MRR		TWR		SR		MRR		TWR		SR	
	SC	RT	SC	RT	SC	RT	SC	RT	SC	RT	SC	RT	SC	RT	SC	RT	SC	RT
2	1.925	1.895	0.053	0.014	3.894	4.794	1.865	1.785	0.055	0.014	3.478	4.378	1.825	1.800	0.063	0.018	3.204	4.104
2.15	1.942	1.913	0.055	0.016	3.943	4.843	1.908	1.828	0.057	0.015	3.544	4.444	1.894	1.868	0.065	0.020	3.286	4.186
2.3	1.965	1.937	0.057	0.018	4.001	4.901	1.956	1.877	0.060	0.017	3.617	4.517	1.968	1.943	0.067	0.022	3.376	4.276
2.45	1.993	1.968	0.060	0.020	4.066	4.966	2.010	1.934	0.062	0.019	3.699	4.599	2.048	2.024	0.070	0.023	3.473	4.373
2.6	2.027	2.006	0.062	0.021	4.139	5.039	2.070	1.996	0.064	0.021	3.788	4.688	2.134	2.112	0.072	0.025	3.579	4.479
2.75	2.066	2.050	0.065	0.023	4.220	5.120	2.135	2.066	0.067	0.022	3.885	4.785	2.225	2.207	0.075	0.026	3.692	4.592
2.9	2.111	2.101	0.067	0.025	4.308	5.208	2.206	2.142	0.069	0.024	3.989	4.889	2.322	2.308	0.077	0.028	3.812	4.712
3	2.144	2.139	0.069	0.026	4.372	5.272	2.256	2.196	0.071	0.025	4.063	4.963	2.389	2.379	0.079	0.029	3.897	4.797
3.15	2.199	2.201	0.072	0.028	4.473	5.373	2.337	2.284	0.074	0.027	4.181	5.081	2.495	2.492	0.082	0.030	4.031	4.931
3.3	2.259	2.270	0.075	0.030	4.582	5.482	2.423	2.378	0.077	0.028	4.306	5.206	2.607	2.611	0.085	0.032	4.172	5.072
3.45	2.325	2.345	0.078	0.031	4.699	5.599	2.514	2.478	0.080	0.030	4.439	5.339	2.725	2.736	0.088	0.033	4.321	5.221
3.6	2.396	2.427	0.081	0.033	4.823	5.723	2.612	2.585	0.083	0.031	4.580	5.480	2.848	2.868	0.091	0.035	4.478	5.378
3.75	2.473	2.516	0.085	0.035	4.956	5.856	2.715	2.699	0.087	0.033	4.728	5.628	2.977	3.007	0.095	0.036	4.643	5.543
3.9	2.556	2.612	0.088	0.036	5.096	5.996	2.823	2.820	0.090	0.034	4.884	5.784	3.111	3.153	0.098	0.038	4.815	5.715
4	2.614	2.679	0.091	0.037	5.194	6.094	2.899	2.904	0.093	0.035	4.993	5.893	3.204	3.254	0.101	0.038	4.934	5.834

FIGURE 2: MRR vs. discharge current for two types of electrode at $\tau = 70\%$. FIGURE 3: TWR vs. discharge current for two types of electrode at $\tau = 70\%$.

thick tool steel was prepared, making the surfaces grounded and cleaned. The EDM uses electrode made of thick electroplated 3D printed polymer RT (ECRT). After confirming the possibility of yielding good results, the set of trials of thick copper ECRT electrode were performed at a standard set of parameters, as provided in Table 1. The material removing rate (MRR), tool wearing out rate (TWR), and the surface roughness parameter R_a (SR) are calculated using trial results by substituting into their mathematical equations (1) to (2). SR parameter R_a (in μm) was measured at different locations

using a profilometer for a cut-off length of 0.8 mm, and average values are tabulated in Tables 2–4. Similar trials are performed with a solid copper electrode having the same dimensions. The experimental results obtained by the RT and copper electrodes are compared for the same input parameters and workpiece. To compare the performances of the RT and SC tools, three influencing factors of EDM processes, namely, discharge current (DC), pulse-on time (T_{on}), and duty factor (τ) on MRR, TWR, and SR are investigated at an open-circuit voltage (V) of 40 and the flushing pressure of

FIGURE 4: SR vs. discharge current for two types of electrode at $\tau = 70\%$. FIGURE 5: MRR vs. discharge current for two types of electrodes at $T_{on} = 50$ microseconds.

0.035 MPa. EDM operations of 10 minutes each were conducted for both electrodes, and results are tabulated in Tables 2–4 for varying DC from 2 to 4 A and altering T_{on} and τ (refer to equation (1)) for both electrodes [19].

$$\% \tau = \frac{T_{on} * 100}{T_{on} + T_{off}}, \quad (1)$$

$$TWR = \frac{W_{loss\ tool} * 10^6}{T_m * \rho_c} \text{ (mm}^3/\text{min)}, \quad (2)$$

where T_m is the machining time (around 1 hour) and ρ_c and ρ_s are the density of copper and workpiece (kg/m^3). $W_{loss\ tool} / W_{loss\ steel} = (\text{weight}_{\text{before machining}} - \text{weight}_{\text{after machining}})$ is the weight loss of an electrode and a workpiece, respectively.

$$MRR = \frac{W_{loss\ steel} * 10^6}{T_m * \rho_s} \text{ (mm}^3/\text{min)}. \quad (3)$$

It produces a columnar structure with the chemical annealing using its silver dispersed solution rather than with

FIGURE 6: MRR vs. discharge current for two types of electrodes at $T_{on} = 150$ microseconds.

FIGURE 7: SR vs. discharge current for two types of electrodes at $T_{on} = 50$ microseconds.

silver paint, which is more suitable for thick electroplating. Hence, the electrode is subjected to copper electroplating for about 200 hours on the sample coated with silver dispersed solution (produced by chemical annealing). Thickness of copper attained is around 1 mm.

3. Results and Discussions

EDM machining was performed on tool steel by varying inputs like DC, T_{on} , and τ on performance characteristics like MRR, TWR, and SR using a 3D printed polymer

copper-coated electrode and traditional solid copper electrode which are tabulated.

The combined effect of varying DC and pulse-on time on three outputs is plotted in the graphs (Figures 2–4) of the SC and the Cu-coated FDM RT electrodes. Generally, all the figures show each of the three outputs considered in this MRR, TWR, and SR for both the electrodes with varying C. When the DC is increased, the spark energy also increases, which produces an additional heat resulting in a large particle size of metal removed from the work surfaces, damaging the quality of the machining surface.

FIGURE 8: SR vs. discharge current for two types of electrodes at $T_{on} = 150$ microseconds.

FIGURE 9: TWR vs. discharge current for two types of electrodes at $T_{on} = 50$ microseconds.

Figures 2, 5, and 6 show the plots on the material removal rate (MRR) where it increases with the increasing DC for all values of T_{on} and % duty factor τ (tau), because by increasing DC, it directly affects the output energy, which causes an increase in the crater dimension resulting in increased MRR, while considering the combined τ with DC, it is noted that the higher τ value influences more MRR than the T_{on} . However, a slight variation of MRR is found while comparing the two electrodes concerning DC, T_{on} , and τ . Figures 2, 5, and 6 show that MRR was monotonically increasing with

the increase in DC for SC and RT electrodes. It is also seen that an increase in T_{on} causes a very little increase in MRR. Conversely, MRR decreases when T_{on} is very low. An increase in T_{on} instigates increased MRR due to the heat flux, conducted into the workpiece, for more time in the form of plasma conduit. But the application of continuous heat flux was done for a more extended period by increasing T_{on} , and the pressure inside the plasma channel decreases. As a result, MRR also decreases due to the unaffected molten volume of metal. Similarly, it is seen that the combined effect of

FIGURE 10: TWR vs. discharge current for two types of electrodes at $T_{on} = 150$ microseconds.

DC and τ for MRR showed that MRR increased with an increase in DC, but little influenced by τ . When τ increases, the spark intensity between the gaps increases, raising the temperature influence on the increase in MRR.

Figures 4, 7, and 8 show the influence of DC variation on SR obtained by two electrodes along with T_{on} and τ parameters. Figure 7 shows that the combined influence of τ and the DC on "SR" of RT electrode (rapid tool) is minor. But as the T_{on} increases along with τ (it affects a little), the increase in " T_{on} " is more dominant on SR. The SR is less for medium values of both τ and T_{on} , which is preferred. Because low " T_{on} " value allows significantly less time to produce the spark, this generates nonuniform spark distribution on the machined surfaces. Thus, the metal removal process is arbitrarily affected due to less T_{on} , which gradually increases by increasing " T_{on} " to produce a uniform distribution of the spark over the machining surface. Further increased value allows more spark time that increases the MRR, causing little rise on the increased SR from the lowest value. The SR is worst with a lower value than the higher value of T_{on} . Figures 4, 7, and 8 show that the surface's quality decreases with the increase in DC for both SC and copper-coated EDM RT electrodes [21].

Figures 3, 9, and 10 show variation of TWR of two electrodes (SC and RT) for combined DC variation with T_{on} and τ . It is seen that TWR increases with the rise in discharge current for both the electrodes. The TWR of the solid Cu electrode is much greater than that of RT. The plot also shows that TWR increases with a rise in T_{on} as it speeds up removing material from spark generation and increases heat flux, which in turn helps wear out of a tool. Conversely, the impact of τ (duty factor) was observed that TWR responds very slowly with an increase in duty factor. TWR plays a very crucial character/factor in the EDM process for controlling the machining cost.

4. Conclusion

The article's objective is to bring a comparison on the performance of a rapid tool 3D printed polymer coated with copper with the traditional solid copper EDM electrodes in terms of MRR, TWR, and SR. Various conclusive remarks can be drawn from the results.

- (1) It is possible to produce an RT electrode of a 3D printed polymer for any intricate design/shape components. The 3D printed model polymer substance surface has been metalized with Cu to the desired thickness to convert their surfaces into conductive electrode surfaces by electroplating without extra preparations
- (2) The acid Cu electroplating process has been used to obtain the desired coating thickness of 1 mm on the 3D printed polymer EDM electrode surfaces, making it practicable in EDM applications
- (3) The two electrodes' performances are studied during the machining of tool alloy steel (hardened steel) showing that RT electrodes performed effectively with low TWR
- (4) From test results, it is revealed that the MRR remained almost nearer for both the tools
- (5) RT electrode can be mathematically modeled and conditionally metalized again for reutilizing to reduce the electroplating duration and material's and the tool's cost
- (6) RT EDM electrode saves more tool substance by metallic coating to form the required cavity in the EDM method

- (7) The impact of DC, T_{on} , and τ on SR, TWR, and MRR is studied in combination by varying each factor to a different level. DC and T_{on} have shown a substantial role in controlling the machining characteristics, whereas τ showed the least impact in both electrodes and workpiece

In the future, further studies' goal should be to perform machining on diversified materials and various additives in bath solution for obtaining improvement of the desired tool material characteristics like hardness, surface quality, and deposited thickness. The intricate-shaped RT electrode utilizes very low amount of depositing metal than a SC electrode for sustaining producing cost as well as time, depositing substance, and expanding its general approval factor. EDM electrodes made by the FDM technique should be designed with an advanced method such that it reduces both the electroplating time and depositing metal coating thickness relatively. Multiple thin plated electrodes can be used to save plating time. Multiple sequential progressive electrodes may be found to have suitable and feasible complicated shapes.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors have no conflicts of interest.

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