EDM TOOLING BY SOLID FREEFORM FABRICATION & ELECTROPLATING TECHNIQUES

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Abstract

The term "Rapid Tooling" refers to the rapid creation of tools in much the same way as Solid Freeform Fabrication (SFF) means the rapid creation of models. This revolutionary approach offers both designers and manufacturers attractive advantages in the form of time compression and cost reduction. Timesaving is of vital significance in the production of EDM electrodes for the fabrication of moulds and dies. The employment of SFF and electroplating for this purpose is described. The performances of these new type of electrodes were compared with those obtained conventionally in terms of dimensional tolerances, surface roughness and working time. The surfaces of both electrodes and workpieces were also examined by SEM microscope.

1. Introduction

Constant improvements in the performance of Solid Freeform Fabrication (SFF), also well known as Rapid Prototyping (RP) technologies [1,2,3] and both terms will be used in the paper, have greatly extended their market. This is particularly true with regard to Rapid Tooling (RT), the name given to the fabrication of tools used to make small runs of parts for construction of the prototypes of mass-produced objects. Both the technical and the commercial literature, in fact, show that other undeniably interesting applications are overshadowed by rapid tooling.

A sector of major importance that has so far received little attention is the fabrication of electrodischarge machining (EDM) electrodes, especially those employed in the manufacture of small and medium-sized dies and moulds. The application of RP techniques in the direct mould manufacture by metallisation [4] has some limits:

- it is fairly easy to use only for the production of simple plastic injection moulds and probably for sheet metal drawing dies;
- it can be employed to make simple dies without the moving parts needed to make the undercuts.

The fabrication of an EDM electrode by SFF, on the other hand, would be followed by unrestricted conventional manufacture of the die or mould. The economic aspects of this combination have still to be determined.

2. Production of EDM electrodes by Solid Freeform Fabrication

The RP model [5] itself could, in principle, be used as the electrode, or employed as a master for the creation of the final electrodes through further processes. The first alternative is unfeasible, since SFF techniques cannot be easily used for the direct production of metal objects, and even if the present limitations were overcome the metal structure would be unsuitable for an electrode. The second requires further operations, but results in good precision and an excellent finish.

Three methods can be used to obtain an electrode from a RP negative master:

- copper spraying: this has proved feasible in a number of tests. Its drawback is that electrode wear is considerable during machining due to the porosity of the copper;

- investment casting: this method has proved satisfactory in other applications. Electrodes made in this way, however, are unsuitable for EDM, since their structure results in marked granular corrosion and rapid deterioration;
- electroplating: the RP model is coated with a conductive lacquer and clad with a layer of copper in a galvanic bath. This method is inexpensive, since the forming operation is unmanned. In addition, the copper is very pure and dense. The long processing time required and some geometrical limits, however, are the drawbacks.

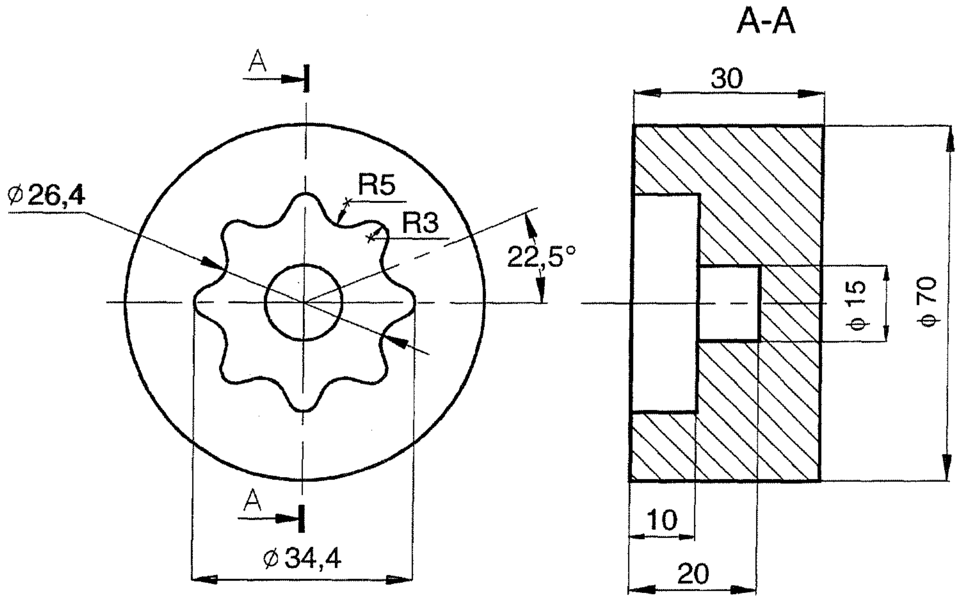

Figure 1: Negative master of the EDM electrode.

Electroplating offers the best trade-off between advantages and disadvantages. In the light of the current capacities of RP techniques [6,7] in terms of dimensional tolerance and surface finish, it may be supposed that the electrodes produced in this way will only be suitable for roughing operations.

2- <u>Experimental work</u>

The feasibility of constructing a electroplated EDM electrode was initially investigated with a part whose geometry was relatively complex (fig. 1), yet readily measurable with a co-ordinate measuring machine (CMM). Electroplating was carried out in an experimental cell (fig. 2) designed and built for the purpose at the University of Ancona. It has an acid bath and a soluble copper anode, and is equipped with:

- a temperature control system to keep the bath at 23°C, (range of recommended temp.: [20÷30]°C);
- a fumes exhaust system;
- a controlled voltage D.C. supply unit connected to a continuity set, since if copper were deposited chemically during a power failure it could prevent the build-up of the plating layer when the current comes on again.

The process parameter values have been chosen to maximise the growth rate of the layer once it is a few millimetres thick.

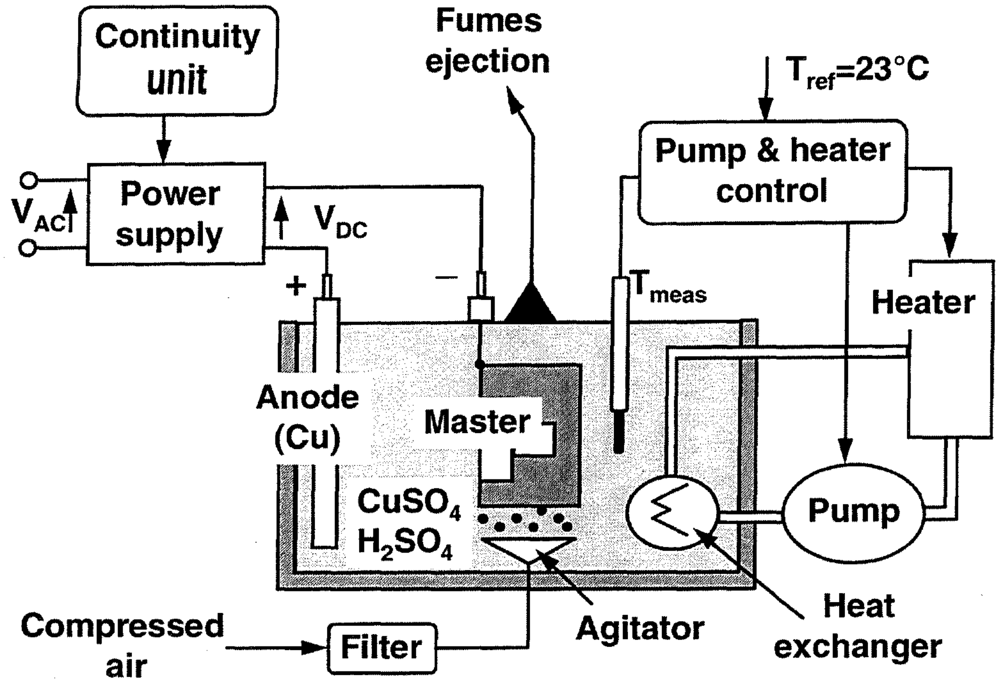

Figure 2: Sketch of the Cu electrodeposition cell.

The type of conductive paint applied on the surface of the negative master is one of the factors that determine the quality of the result, since it has a great influence on the rate of growth and the dimensional precision. Preliminary tests were run with copper and silver charged paints and with gold sputtering. A silver paint was chosen on the basis of four parameters: ease of application, covering power, growth rate and geometrical resolution. The master was built by stereolithography (SLA), as this widely used technique ensures good resolution and a good surface finish [7].

The first question to be settled was the dimensional stability of the master in the galvanic bath, since one of the main problems with polymers is their hygroscopic behaviour. The master was formed on a 3D System machine with the new CIBATOOL SL5170 epoxy resins. A wax master was also made with a Desktop NC manufacturing system.

Both masters were covered with an approx. 3 mm layer of copper. Insertion of a metal stem and filling of the shell with resin to stiffen the structure obtained by electroplating and lock the stem inside it completed construction of the electrode. The dimensional tolerance, the shape errors (flatness, roundness and cylindricity) and both horizontal (➔) and vertical (🡅) surface roughness of the two masters and electrodes were measured and the results are illustrated in Table I.

The precision of the two masters is much the same and the electrodes obtained from them are of practically the same quality. In view of this demonstration of the stability of the SLA and the fact that it showed no signs of alteration and could therefore be used again after removal of the copper shell, it was decided to make two more electrodes:

- one from the SLA master as before;
- the other by conventional milling with an NC machine tool.

Both electrodes were then used to make a cavity in a block of AISI 1040 carbon steel. The SLA master, copper electrode and workpiece are shown in fig.3.

Table I: Master and electrode dimension, shape and roughness measurements.

Element	Max n 90% [*]	Shape error (μm)			Ra (μm)	
		Flatness	Roundness	Cylindricity	→	↑
Wax master	299	9	15	29	4	5
Electrode	590	34	14	198	4	5
RP master	240	3	17	41	5.4	6.2
Electrode	204	16	14	26	5.4	6.2

[*] n: number of tolerance unit (5).

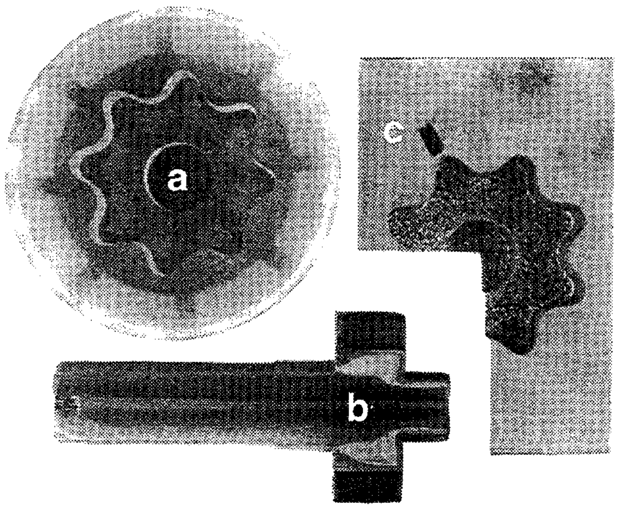

Figure 3: a) SLA master, b) Cu electrode, c) workpiece; both electrode and workpiece were sectioned to make SEM observations. On section of electrode is visible the deposed layer of copper.

The EDM parameter values were set for each test for evaluation of electrode performance. Dimension, shape and surface roughness measurements were taken from the masters, electrodes and workpieces. Both electrodes and the machined workpieces were also examined at SEM .

As can be seen in Table III, the dimension and shape tolerances of the two electrodes are of the same order of magnitude (see also fig. 4). There are two reasons for this: the conventional milled electrode was made to wide machining tolerances for roughing operations; the intrinsic difficulty of obtaining tighter tolerances when working on a malleable material such as electrolytic copper.

4. Results and discussion

4.1 Machining performance

EDM is very slow when compared with conventional material removal processes. As much material is possible is usually removed by conventional drilling and milling to save time and minimise electrode wear. This was not done in our study since the aim was to assess tool performance under the hardest conditions

A commercial EDM machine was used, with hydrocarbon as the dielectric. The test parameters were: voltage (V), the discharge time (t), and the efficiency ratio (t), defined as the ratio between t and the duration of the test sequence (discharge plus idle time). The test consisted of two stages: machining of the cylindrical part of the electrode only; machining of the whole electrode, including the part with the more complicated shape. The parameter values are set out in Table II. The electrode obtained from the SLA master used more current at the same voltage. Its removal rate (Vas), however, was faster than that of the conventional electrode.

Table II: EDM test parameter values.

	Conventional	SFF (SLA)
First stage		
t [ms]	300	300
V [V]	≅45	≅45
I [A]	7	14
t [t/p]	0.9	0.9
Vas [mm^3/min]	13	18
t [h]	2.2	1.6
Second stage		
t [ms]	750	750
V [V]	≅45	≅45
I [A]	18	20
t [t/p]	0.9	0.9
Vas [mm^3/min]	255	302
t[h]	3.9	3.3

4.2 Geometrical and roughness measurements

The geometrical and shape tolerances of the masters, electrodes and workpieces were determined with a CMM, which measures parts at all points with the same nominal dimensions. The surface roughness of the parts was evaluated with a Hommel T 1000 Stylus instrument using a sampling length of 4.8mm. As regard the dimensional error our evaluation model [7] introduces the number of tolerance unit (**n**) for 90% of the observations as the quality index, It is included in the third column of Table III and is also illustrated in fig.4. The shape errors (flatness, roughness and cylindricity) are listed in the forth, fifth, and sixth columns, and the roughness measurements in the seventh and eighth columns.

As can be seen, there are no significant differences in the maximum tolerance grade and the roughness measurements of the workpieces. The worse flatness and cylindricity of the part machined with the electrode derived from the SLA master can probably be attributed to the difficulty in its assembly.

It can therefore be asserted that the technology of galvanic deposition of copper in thickness on models constructed by SLA can be used with success for the production of EDM electrodes to be employed in roughing operations.

4.3 SEM observations

After machining the surfaces of both electrode, derived by SLA master and the workpiece were sectioned, cleaned ultrasonically and observed at SEM microscope.

Table III: Comparison of the results of the EDM electrode manufacturing methods.

Method	Element	Max n 90%	Shape error (mm)			Ra (μm)	
			Flatness	Roundness	Cylindricity	→	↑
Conventional	Electrode before machining	422	5	7	24	3.5	3.8
	Electrode after machining	456	8	7	16	4.1	4.4
	Workpiece	480	20	11	24	16	13
SFF (SLA)	RP model	240	3	17	41	5.4	6.2
	Electrode before machining	204	16	14	26	5.4	6.2
	Electrode after machining	220	6	16	25	6.6	7.1
	Workpiece	518	84	20	68	14	13

The shallow craters, roundish remolten parts and cracks (fig.5) reported for EDM of various types of steel [8] were observed on the workpiece.

In the horizontal zone of the hole, the globular parts are present in greater quantity with respect to the vertical surface (fig.6); this fact is imputable to the different efficiency of washing on the inside of the hole during the machining. A similar difference was noted on the electrode in the form of a greater iron contamination (see the arrows in fig.7) from the workpiece on the horizontal as opposed to the vertical part. Reciprocal tool-workpiece contamination has also been reported for EDM operations with conventional tools [8]. The outer white layer and the altered layer immediately below it are similar to those observed by other authors [9].

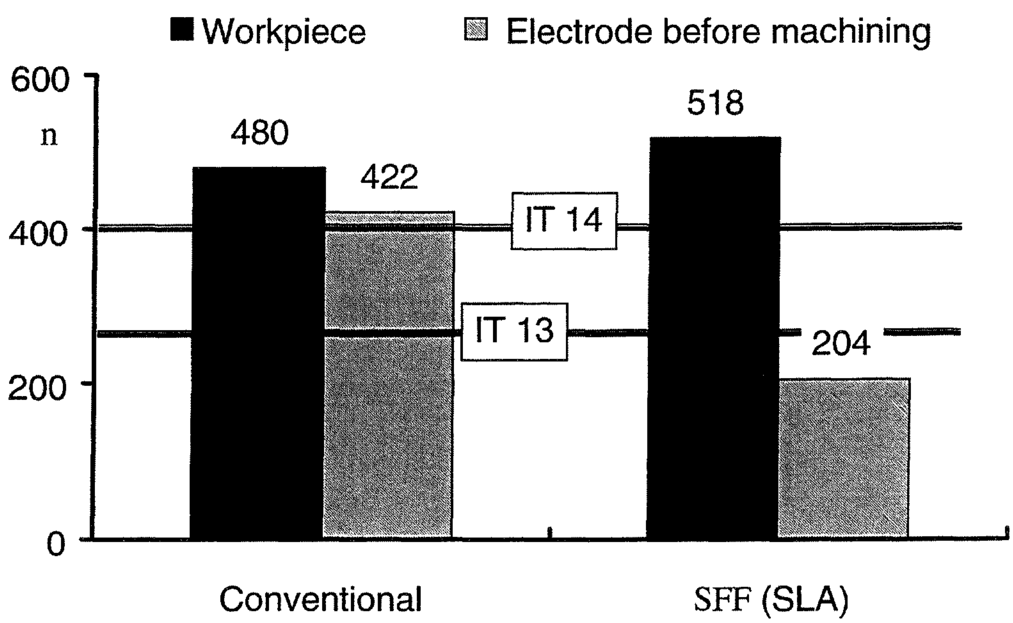

Figure 4: Comparison of both electrodes and workpieces in terms on number of tolerance unit for the 90% of observations.

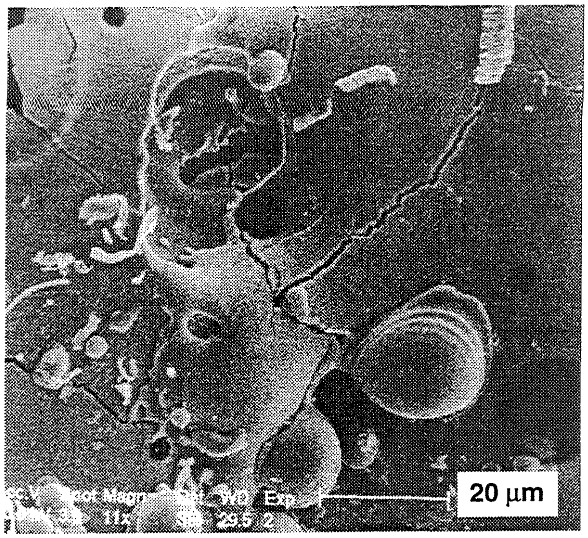

Figure 5: SEM image of the vertical surface of the hole

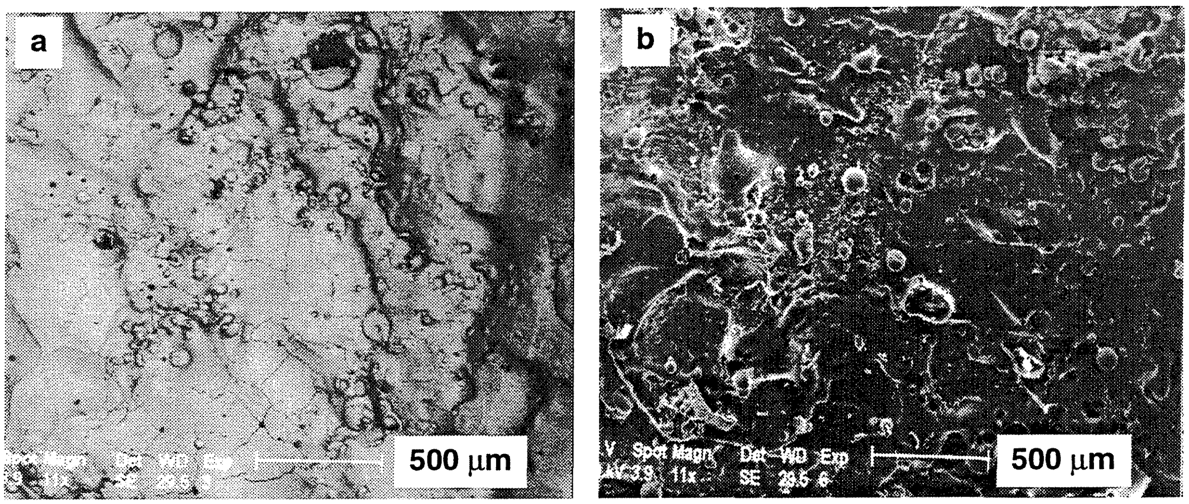

Figure 6: SEM image of the vertical (a) and horizontal (b) surface of the workpiece.

5. Conclusions

Four conclusions can be drawn from this study:

1. the method proposed gives electrolytic copper electrodes from SLA masters. Other SFF techniques can not be used, because they do not allow an acceptable surface finish to be obtained;
2. the dimensional precision of these electrodes is on a par with that of those produced conventionally for the same type of operations;
3. the deep thickness obtainable suggests that a 0.5 - 1 mm machining allowance can be provided for conventional finishing, which would mean that the method could equally be used to produce EDM electrodes for surface finishing operations;
4. the performance of these electrodes is decidedly superior to that of a tool obtained by mechanical machining from a bar nominally of the same material.

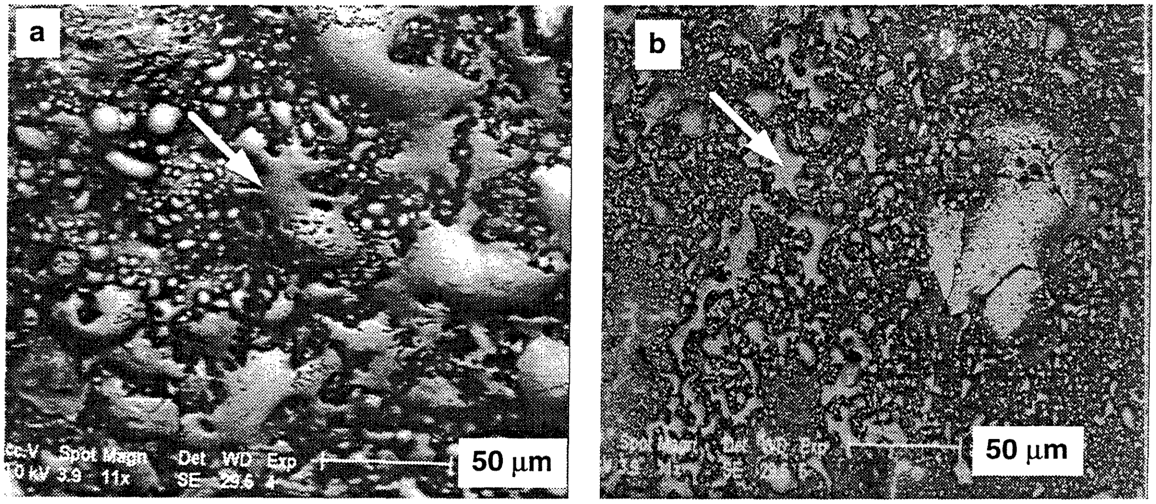

Figure 7: SEM image of the horizontal (a) and vertical (b) surfaces of the electrode.

No assessment can yet be made of the economic aspects of this method, since its feasibility requires further study.

Endurance tests are now in progress to determine the behaviour of the new electrodes over time, together with trials of the method in the fabrication of an injection mould. Their completion will allow initial conclusions to be drawn concerning the time and cost required for the production of an electrode of average complexity.

6. References

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7. Acknowledgements

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