RELATIONSHIPS BETWEEN WALL THICKNESS AND EROSION DEPTH OF THIN WALLED ELECTROFORMED EDM ELECTRODES PRODUCED FROM RP MODELS

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Abstract

Metal filled thin walled electroformed EDM electrodes, fabricated using RP models, have been shown to be an effective route to producing die sink electrodes. However, due to the nature of electroforming, there are certain limits to the maximum depth of erosion of cavities that can be achieved, this being related to the electrode wall thickness. This initial study examines the relationship between the electrode wall thickness and depth of erosion.

Introduction

Electroforming is a method of producing a solid freeform object by the process of thick electroplating. It has been used in the toolmaking industry for many years, largely as tool insert shells for low-pressure injection moulding [1]. Some workers have examined the use of electroforming as a means of producing die sink Electro-discharge machine (EDM) electrodes, (e.g. [2]). However, these electroforms were several millimetres thick and took many days to produce. From previous work [3] [4] [5], it has been found that there are limitations to the use of *thin walled* (~ 1 mm) electroforms that were used as EDM electrodes. A major factor in this is the edge weakness problem associated with electroforming, in that, material is not deposited evenly in sharp corners or recesses. This leads to early wear and failure of the electrode during the EDM process, the resultant being lost time, money, materials and resources.

This paper describes a preliminary investigation into the relationship between electroform thickness and the depth of erosion into a tool steel blank. It attempts to identify the most influential factors pertaining to the failure of thin walled electroformed EDM electrodes. This work is part of a larger programme to develop a system of rapid EDM electrode production with the ultimate aim of having the capability to produce an injection mould tool in around 24 hours.

Preparation of the Master Patterns

For the purposes of this paper, dedicated electroforms were produced using 3D Systems ThermoJet master patterns or mandrels (Figure 1) with simple square internal features. Two types of model were designed, each having the same x and y dimensions but different cavity depths; 15 mm for the S series and 7 mm for the T series. By electroforming onto such a pattern, the resultant structure comprised of an electrode having three square section blocks that could be used to erode cavities of the same shape as the original master model.

The production of the master patterns was conducted on the ThermoJet due to its quicker build time capabilities in comparison to that of other rapid prototyping methods. Typically, six of these models could be manufactured simultaneously in around three hours. However, the accuracy of the master patterns were not as great as those produced on, for example, an SLA 250/50. Figure 4 shows the dimensional difference in the ThermoJet master patterns (produced using ThermoJet 88 thermopolymer wax) compared to the original CAD dimensions. The values shown in Figure 4 correspond to the data measurement points shown in Figure 5. As dimensions A and B were not being measured from this stage onwards (due to the insertion of a copper frame), its excessive inaccuracy was disregarded, and only dimensions C-K were subsequently noted. The majority of RP systems are accurate to ± 0.15mm, making the results for many of the parts out of tolerance.

Figure 1. Wax master pattern built on 3D Systems ThermoJet

Figure 2. Machined copper frame for EDM tool holder attachment

Figure 3. Sprayed master pattern with copper frame inserted and tape masking

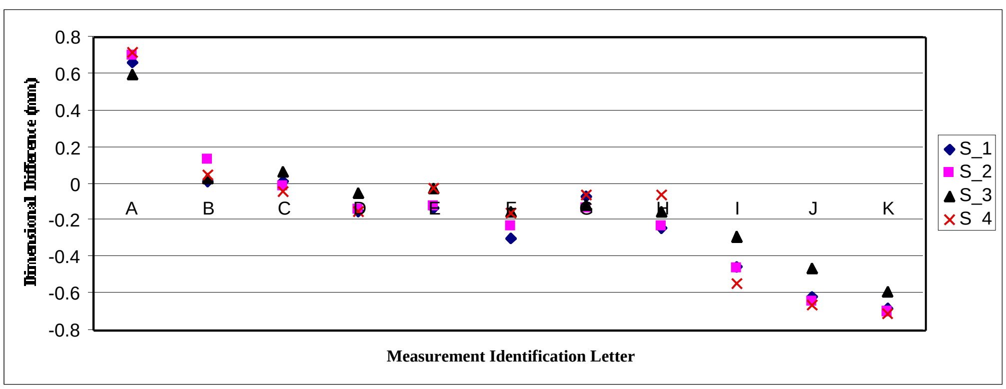

Figure 4. Dimensional difference of four ThermoJet 88 models in comparison to original CAD data, S series only

It should also be noted at this point that dimensions I, J and K are all *z* measurements, making the *z* accuracy well out of tolerance. This has been the form for the majority of models created on this particular system. The ThermoJet system does allow correction for build tolerances but these were not used during this programme of work.

After masking the external regions with a polyurethane sheet, the working area of the wax pattern was sprayed with a high silver content conductive paint. A machined copper frame (Figure 2) for attachment to the EDM tool holder was placed within the internal boundary of the master. Connection cables were screwed into it to make electrical connection to the plating circuit. A covering of tape over the copper plate (Figure 3) was then applied to prevent any unintended growth or overlapping on the copper frame during the electrodeposition stage.

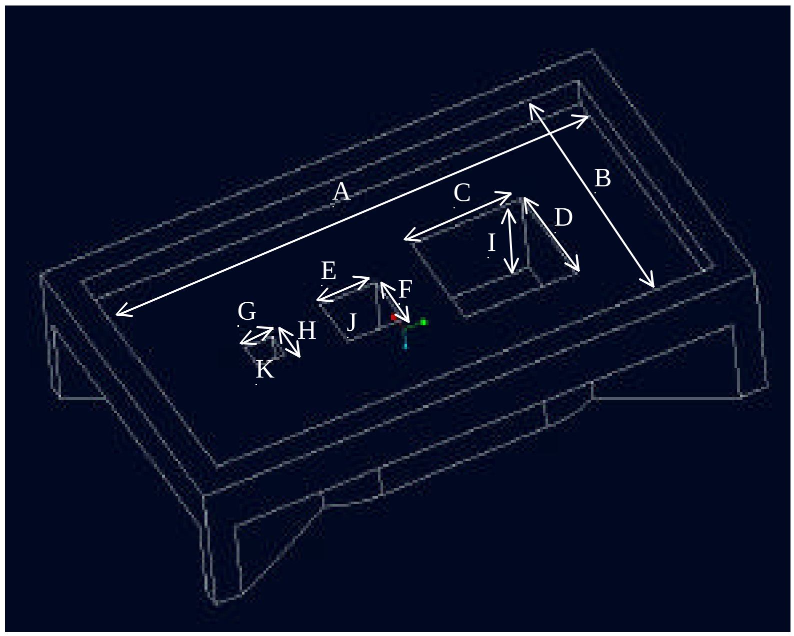

Figure 5. Data measurement points on model

The Electroforming Process

Once prepared, the models were placed in a copper electroforming bath. Electroforming was carried out in the following copper electroplating solution:

Copper sulphate $5H_2O$	75 g/l
Sulphuric acid	100 ml/l
Chloride	60 mg/l
Addition agent	12 ml/l (replenished with 5 mls/10amp hours plating)
Temperature	25 - 30^{o}C
Current density	15 mA/cm^2

The addition agent was used to maintain a fine crystal structure of the deposit and to ensure that the internal stress was maintained at close to zero. Significant internal stress may lead to distortion of the electroform, especially those with thin walls. The plating thickness was controlled by varying the time of deposition corresponding to an *average* plating thickness as shown in Figure 6. It should be noted that the local thickness of deposit at any one point is dependant on the geometry of the part; recessed regions in the mandrel will attract less deposit whilst prominent regions will attract more. A current density of 15 mA/cm^2 was preferred due to the relatively uniform distribution of copper achievable at low current densities. Current densities higher than 20mA/cm^2 tend to give more uneven and sometimes nodular growth. Electrolyte agitation was provided by directing the outlet of the filter pump towards the growing electroforms.

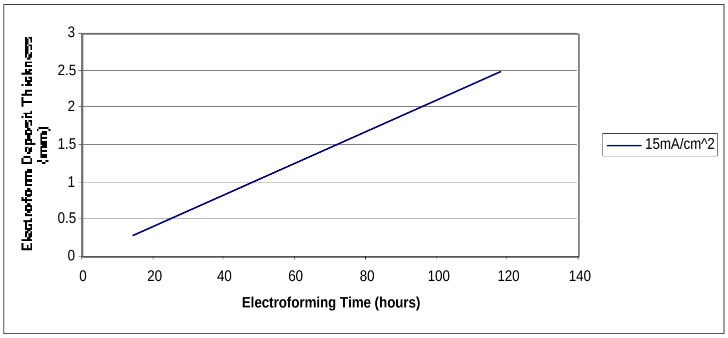

Figure 6. Electroform average thickness plotted against electroforming time.

Figure 7. Section showing typical edge weakness

However, even under these deposition conditions, dist uniform, being lower in the recesses than elsewhere. A phenomenon known as edge and corner weakness may often be seen in the corners and edges of these internal recesses (Figure 7). This results from the reduction in electrical field strength in such areas with coverage being achieved by the merging of the plating on the adjacent sides. As corners and edges undergo the greatest wear during the EDM process, this edge weakness is the primary cause of failure of electroformed electrodes.

Electrode Filling

After electroforming the shells onto the models, the ThermoJet master was melted, leaving the freestanding shell. The electroform become attached to the copper frame as the deposit grows across the interface between the metallised face of the model and the frame. The thickness of the working face of each cavity was measured using a micrometer.

Earlier trials [3] showed that by using the electroformed shell alone as an EDM electrode, early failure occurred. This led to the concept of filling the cavity of the shell with a low melting point metal, tin-bismuth eutectic (M.P. 137^{o}C). By doing this, the working life of the electrode may be increased significantly. Filling was carried out by applying an activated flux (Bakers Fluid No. 3) and heating the shell to around 150^{o}C prior to pouring the molten alloy at a temperature of 200^{o}C. This ensured that the alloy "wetted" the copper and formed a metallurgical joint. Figures 8 and 9 show the finished electrodes of both designs.

Electrodischarge machining conditions

The completed electrode was then mounted onto a System 3R tool holder for use on a Charmilles Roboform 31 EDM machine. The frame allowed for accurate positioning of the electrodes and acted as an internal datum for machining. However, for this part of the work, which specifically related to electrode wear, the EDM machine was set to sink the electrode only.

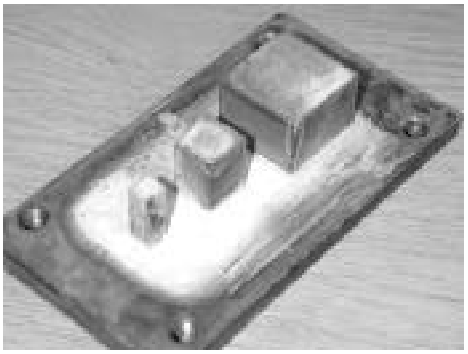

Figure 8. Final electroform – deep cavity S series, showing the three sizes of blocks

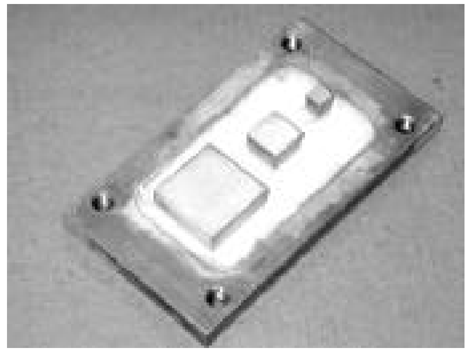

Figure 9. Final electroform – T series with shallow cavity

Peak currents of 12 amps were used. Both lateral and vertical flushing was used during the erosion process.

Results

During the erosion process, the electrodes were examined in situ every 15 minutes. The depth at which a corner or edge failed was recorded but erosion was continued until all three blocks had failed. It was noted that once an edge or corner failed, the horizontal face of the block would start to curl away from the electrode and the low melting point metal would rapidly melt and vaporise as erosion continued. Vertical faces were not affected in this way and remained undistorted. Where the alloy was exposed, nearly all of the erosion took place on the alloy and not in the steel.

After all block sections had failed or until the pre-set depth of erosion had been reached, the electrodes were metallurgically microsectioned to examine both the copper distribution and deposit structure. Previous work [3] [4] had shown that wear of the tool faces was low, of the order of 1%. This meant that the error of measurement of the microsections would not be markedly affected as normal measurement errors in microsections are of the order of 2 - 5%. Figure 10 shows the positions at which measurements were made. Table 1 shows the results of those measurements. Where the electroformed shell had been destroyed during the EDM process, not measurable (n/m) has been indicated.

The eroded cavities were additionally used to identify the actual point of failure. As virtually no erosion of the steel takes place where the low melting point alloy is exposed, the actual depth of failure can be directly measured.

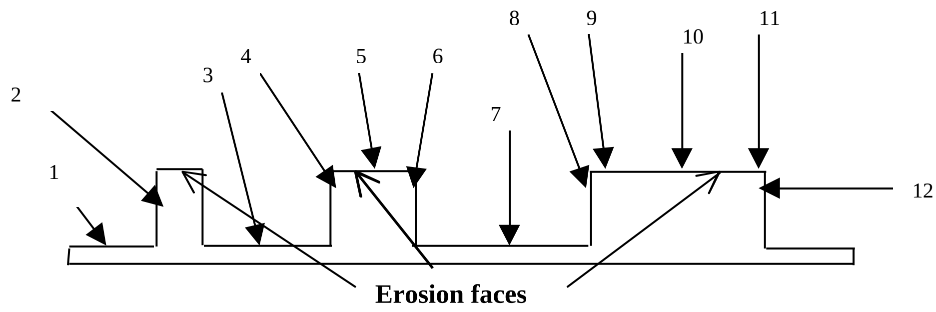

Figure 10. Positions of microsection measurement of electroform wall thickness

	S1	S2	S5	S3	S4	T6	T1	T2	T3
Position									
1	0.5	0.76	0.81	1.38	0.72	0.42	0.75	0.9	0.97
2	n/m	0.05	0.13	0.18	0.1	0.11	n/m	0.25	0.34
3	0.7	0.79	0.9	1.78	0.54	0.77	1.2	1.44	2.07
4	0.14	0.1	0.21	0.22	0.09	0.25	0.54	0.45	0.4
5	n/m	0.1	n/m	0.17	n/m	0.24	N/m	0.49	0.63
6	0.11	0.11	0.19	0.25	0.14	0.18	N/m	0.3	0.38
7	0.76	1.31	n/m	1.96	1.5	0.69	1.25	1.44	1.86
8	0.19	0.25	0.35	0.4	0.35	0.31	0.41	0.76	0.8
9	n/m	0.2	0.27	0.32	0.28	0.3	0.46	0.74	0.79
10	0.25	0.33	0.35	0.4	0.39	0.46	0.48	0.69	0.97
11	n/m	0.24	0.25	0.35	0.26	0.3	0.4	0.45	0.57
12	0.17	0.22	0.25	0.36	0.29	0.31	0.34	0.44	0.74
Average Thickness	0.8	1.16	1.4	1.67	1.16	0.5	0.75	1.0	1.27
Plating time (hours)	39	60	72	86	60	24	36	48	61
Notes					Repeat of S2				

Table 1. Thickness of shell measured at positions shown in Figure 10. Average thickness is calculated from Faradays Laws. All measurements in mm.

Figure 11 shows a graph of the thickness of the erosion faces (points 5 and 10) and base (point 7) for both the S and T series of electrodes. It can be seen that there is a linear relationship although the S series electrodes have a steeper slope compared to the equivalent T series due to the former having a higher aspect ratio cavity than the latter.

Table 2 shows the erosion depths achieved for each of the electrodes in terms of the small, medium and large blocks. From this data, it was possible to compare the erosion depth achieved against both the thickness of the erosion face and the time required to make the electroform as seen in Figures 12 and 13. From this data, it can be seen that in most cases, a minimum erosion face thickness in the region of 0.6 mm is required to erode at least 6mm of tool steel. With the geometry's used in the tests, this equates to between 40 and 80 hours plating time. Even then, small deep cavities would not be able to erode to any significant depth.

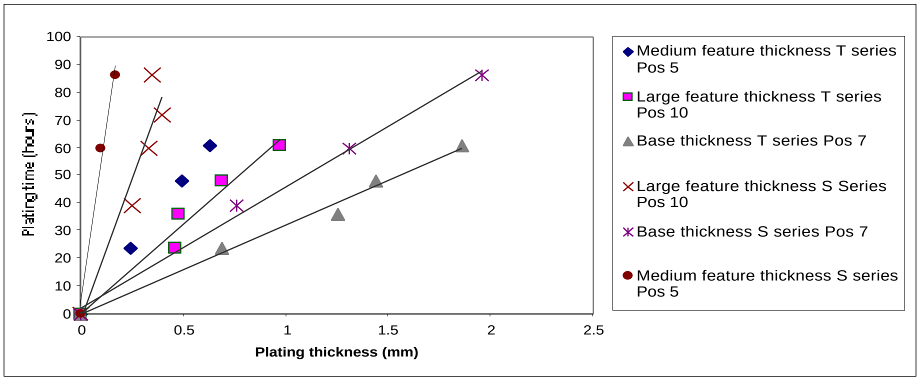

Figure 11. Measured plating thickness of large and medium erosion faces plotted against the plating time.

	S1	S2	S5	S3	S4	T6	T1	T2	T3
Erosion Depth (meas.)									
Large cavity	0.64	0.32	4.22	12.35	1.82	0.68	4.03	5.59	6.3
Medium cavity	0.15	0.4	0.76	8.55	0.62	0.38	1.51	5.6	6.3
Small cavity	0	0.04	0.13	0.61	0.13	0.08	0.24	2.61	defect
Erosion Depth (Observed)									
Large cavity	1.2	1	4.85	12.6	2.1	0.845	3.39	3.3	6.3
Medium cavity	0.7	0.5	1.12	4.6	0.8	0.845	1.47	3.37	6.3
Small cavity	0.5	< 0.5	0.75	0.8	< 0.5	0.4	0.65	1.3	defect

Table 2. Erosion depths of cavities produced from both S and T series electrodes. Shaded regions indicate full depth eroded with no failure of the electroformed shell.

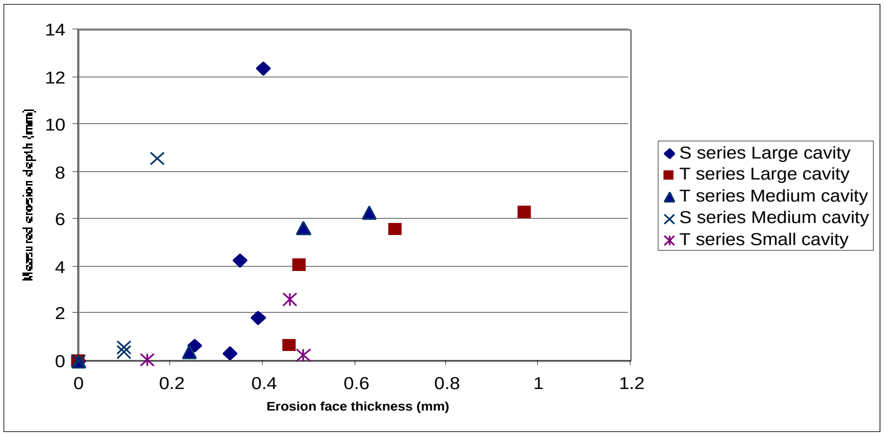

Figure 12. Erosion face thickness plotted against measured erosion depth. Insufficient data was available to plot the S series small cavity results.

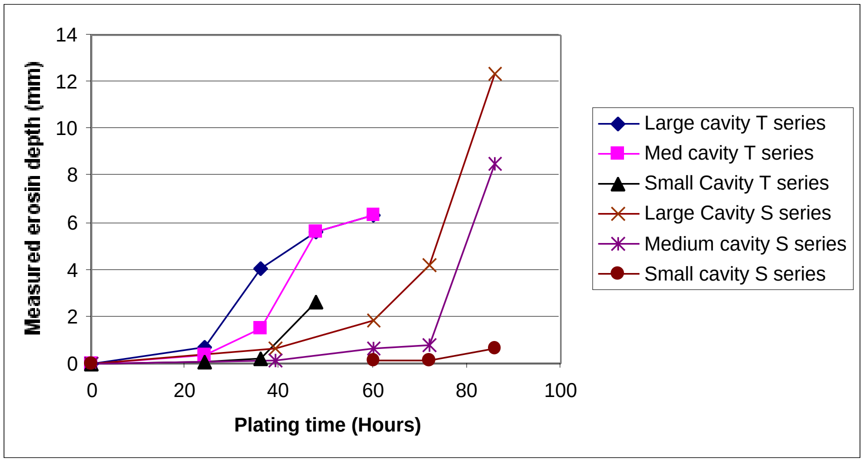

Figure 13. Plating time plotted against measured erosion depth.

Discussion

It has been shown that it is possible to use filled thin walled electroforms as EDM electrodes. The depth of erosion that can be achieved is related to the wall thickness of the leading faces adjacent to the primary sparking corners and edges of the electrode. A minimum face thickness of 0.6 mm would appear to be a critical minimum thickness to achieve an erosion depth of more than 6 mm. From the data presented, narrow internal cavities are not plated to this critical thickness within reasonable timescales. It should be noted that the current density used in this work was quite low at 15 mA/cm^2. Under appropriate conditions of agitation, current densities of up to or over 60 mA/cm^2 may be used. This would suggest that it should be possible to obtain the critical minimum thickness in a period of around 25 hours even in high aspect ratio cavities. Unfortunately, increasing the current density has the effect of reducing the metal distribution. Therefore, it would be necessary to introduce methods of improving the metal distribution. This aspect will be investigated further.

One great advantage in the use of electroforms in this application is that although a single electrode may only be able to erode say 6 mm of tool steel, the electroforming process is such that several electroforms may be grown concurrently. This means that deeper cavities can be eroded using sequential electroformed electrodes, much in the same way as roughing and finishing electrodes are used today. The speed of the ThermoJet modeller combined with a high speed electroforming process has the potential to radically decrease both the time taken to produce injection mould tools as well as the cost.

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