© 2018 IJSRST | Volume 4 | Issue 2 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Electroforming Defects During Metal Deposition on Plastic Substrate Produced by Additive Manufacturing

Gurpreet Singh Phull*[1], Sanjeev Kumar[2], Ravinderjit Singh Walia[3]

[1]PhD Research Scholar, Department of Production and Industrial Engineering PEC University of Technology, Chandigarh, India

[2]Professor, Department of Mechanical Engineering PEC University of Technology, Chandigarh, India

[3]Professor,Department of Mechanical Engineering Delhi Technological University, Delhi, India

ABSTRACT

Additive manufacturing is evolving as an important process in the product and tooling development as direct or indirect process in the recent decade. The hybrid processes are being experimented by using additive manufacturing for the development of a component, assembly, EDM electrode, inserts or moulds etc. The investigated work in this paper highlights the possible manufacturing defects surfaced during metal deposition on fused deposition produced modelling. The study is the compilation of the observations during the experimentation of deposition of nickel and copper on the plastic substrate for process parameters of electroforming. The challenges of the depositions are categorized in two parts (i) Problems due to the Process (ii) Problems due to the Design. The main process parameter influenced the quality of the deposition found are activation of the nonconductive plastic, current density, solution concentration and agitation of the bath. The design of the components to be plated requires special attention about sharp corners, edges, hidden area and vertical walls.

Keywords: Electroforming; Fused Deposition Modeling; Additive Manufacturing; Nickle Plating

I. INTRODUCTION

Electroplating is the process of deposition of thin metal coating on various materials. Since the invention of the electroplating in 1805 by the Italian inventor Luigi V. Brugnatelli and commercialization during 1840s, it has evolved as a mature technology and widely being used in various products. Other important uses of electroplating is called electroforming, which is the deposition of thick layer on the substrate of more than 300 microns to 400 microns. Electroforming is deposition of metal on to a master of substantial thickness, so as to extract the shell after removal of the master. The shell produced must be of desired shape, surface finish and accurate dimensions so as to be used for producing the replicas of the master (Ron P). The electroforming has wide acceptance and usage as an additive manufacturing process for making molds, mandrels or components.

Electroforming of the ABS components produced by Fused Deposition Modeling (FDM) for the use in rapid tooling is one of the areas of interest in recent years. The tools produced by this method can be used for injection molding, sheet metal dies or investment casting molds (Sadegh et al., 2009). Rennie et al. (2001) used electroforming of Rapid Prototyping (RP) mandrels for producing electric discharge machining electrodes in fairly reasonable timescales. Hsu et al. (2008) used stereolithography to produce gypsum powder electrode and electrode-less plating with electroforming to produce EDM electrodes. Jetley et al.

(2006) presented a study to make injection molding insert using a low melting point metal casting alloy. A small insert of simple geometry was made by casting a tin-bismuth alloy over a plastic core. The insert was then used in injection molding process. Monzon et al. (2006) analyzed electroforming as a procedure to make cores for plastics injection molds. Shells were obtained from models manufactured through rapid prototyping using the FDM system. The main objective was to analyze the mechanical features of electroformed nickel shells, studying different aspects related to their metallographic structure, hardness, internal stresses and possible failures, by relating these features to the parameters of production of the shells with electroforming equipment. Finally a core was tested in an injection mold.

II. BACKGROUND

2.1 Electroforming

There are different ways to define electroforming, but ASTM B 832-93 describes it simply and concisely as follows: "Electroforming is the production or reproduction of articles by electrodeposition upon a mandrel or mould that is subsequently separated from the deposit." In the electroforming the main part is electrolytic cell in which current is passes through a bath containing electrolyte, the anode and the cathode. The deposition of a metallic coating onto an object is achieved by putting a negative charge on the object to be coated and immersing it into a solution containing a salt of the metal to be deposited. The metallic ions of the salt carry a positive charge and are thus attracted to the object. When they reach the negatively charged object, it provides electrons to reduce positively charged ions to metallic form (Helen H. L, 2006)

The deposition rate for electroforming process is controlled by current density, voltage, and electrolytic concentration of the electrolyte. The properties such as hardness, ductility, strength and internal stress can be varied significantly by changing electrolyte composition and operating condition.

B. Stein (1996) discussed about the nature of the stresses induced during the electroforming process, with an elaboration about measuring and controlling the stresses within the process window. It was emphasized to create a bath stress profile and process window for the better stress control. McGeough et al. (2001) described the process principles and mechanisms of electroforming, outlining its advantages and limitations. The review work established that electroforming can be successfully done with metals such as copper, nickel, and iron with thickness up to 16 mm. Xiang el al. (2006) suggested a process for direct electroplating on ABS plastics. They referred that although electroless copper plating on nonconductive plastics is very effective and economical method, but it is not environment friendly. The deposition rate presented in the study was 0.07 mm/s. The deposits were uniform and their difference of thickness was less than 0.1 micron meter. Hsu et al. (2008) performed electroless plating on the 3DP produced gypsum powdered electrode prototype. The electroless nickel plating was followed by electroforming of copper of up to 1mm thickness. The surface to be electroplated were made rough using corrosive compound of potassium dichromate, sulfuric acid and water. The optimization also done for the corrosion time, which was 3 minute in this study.

III. METHODS

3.1 Electroforming process

The setup for electroforming is made up of stainless steel tank with provisions for agitation of the salt solution and mounting of the electrodes and the samples to be plated. The main setup remains same whether the substrate is of plastic or metallic nature. The nonconductive materials are required to be made conductive before final deposition. Two options are primarily used to make the surface of a nonconductive material to conductive surface, (i) the use of chemicals to activate the surface through electroless plating and (ii) application of the conductive paint on the surface using a spray gun or brush. Once the components are made conductive after that the process of the electroforming remains almost similar for both metallic and nonmetallic surfaces.

The parameters affecting the nickel deposition based on their influence as referred by the various literatures, are pH level, current density, concentration of the solution and temperature. The setting s used in this experiments are taken as per the studies conducted by the author and published (Gurpreet et al., 2017) . The response parameters such as deposition thickness, deposition rate or surface roughness have a contribution from each control factors like voltage, temperature, time, pH level, solution concentrations or current density. These optimum parameters obtained in the experiments is represented in Table 1 for copper electroforming and Table 2 for nickel electroforming.

Table 1. Optimum Settings for Copper Electroforming

Process arameter	Level of Factor	Response Parameter	Best Value Attained	Significant
Voltage	4 V	Deposition	0.18 mm/hr	Yes
CSS Conc.	200 g/L			Yes
Time	8 Hrs			No
Voltage	2V	Surface Roughness	1.81 μm	No
CSS Conc.	190 g/L			Yes
Time	6 Hrs			No

Table 2. Optimum Settings for Nickel Electroforming

Process Parameter	Level of Factor	Response Parameter	Best Value Attained	Significant
pH	4 pH	Deposition	0.086 mm/hr	Yes
Temperature	50 ^{0}C			No
Nickel Sulphate Conc.	270 g/L			No
Nickel Chloride Conc.	64.5 g/L			No
Current Density	6 A/dm^2			Yes
pH	4 pH	Surface Roughness	0.57 μm	Yes
Temperature	50 ^{0}C			No
Nickel Sulphate Conc.	300 g/L			No
Nickel Chloride Conc.	90 g/L			No
Current Density	1 A/dm^2			Yes

During the experimentation various process settings were tested for the above parameters to achieve the best parameters for the good quality product. The non-desired results obtained during these experimentation are discussed in the next section in detail

IV. CHALLENGED OF THE PROCESS

The challenges which have surfaced for during the deposition of the metal were found to be both due to the process and design.

4.1 Problems due to the Process

The process problem which affected the final electrode position can be due to the FDM process, activation process or electroforming control parameters. The following points are the compilation of few such observations. The poor quality of FDM product due to process parameters or poor machine leads to the porosity in the components, which create the problem during the activation process particularly for electroless nickel plating. This results uneven covering on the surface and some part of it remains without plating. Figure 1 shows the improper plating on the poor quality FDM part

Figure 1. Poor Quality FDM Part with Improper Deposition

Error in cleaning and pre-processing before activation leads to the conductivity problems, sometimes partial part is conductive and in some cases the whole part is not activated for plating.

Figure 2. Uncover Area due to Poor Conductivity

Figure 2 shows the part which remained non-conductive on some portion due to pre-processing. The higher rate of currents leads to the burning of the plating Figure 3.

Figure 3. Burnt Samples Due to High Current Density during Nickel Deposition

Due to poor activation the adhesion of the deposition with the substrate surface is not proper and the deposition start to peel off. Figure 4 shows such component.

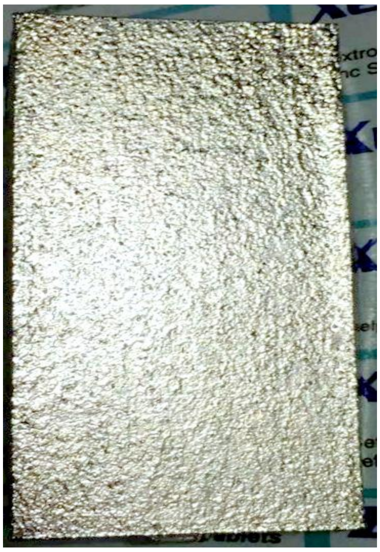

Figure 4. Sample with Poor Adhesion

The poor agitation also leads to the drops in the efficiency of the plating bath after some time, hence slow down the rate of reaction. The formation of the lumps is another area of concerns owing to the different current density zones. The figure 5 shows a component with the lumps formed at some high current density zones.

4.2 Problems due to the Design

As such there is no constraint of fabricating any part using additive manufacturing, but the designing of the part to be done taking in to consideration the limitation of the electrodeposition process. Following discussion highlights a few of the observation found during the process. The sharp corners or edges to be avoided, as sharp corners depleted the plating and sharp edges increase the sensitivity of the part as high current density point. Figure 6 (a) and (b) show the components having the flaws in the electrodeposition.

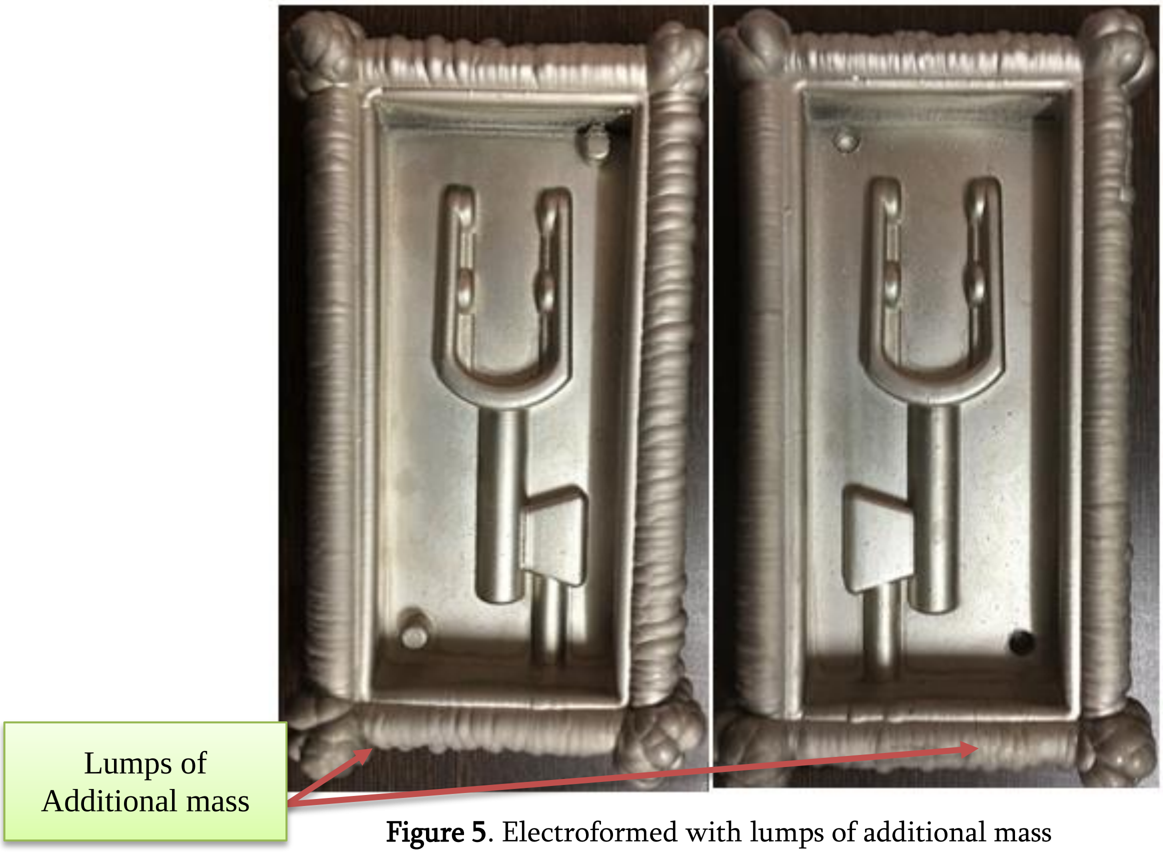

Figure 5. Electroformed with lumps of additional mass

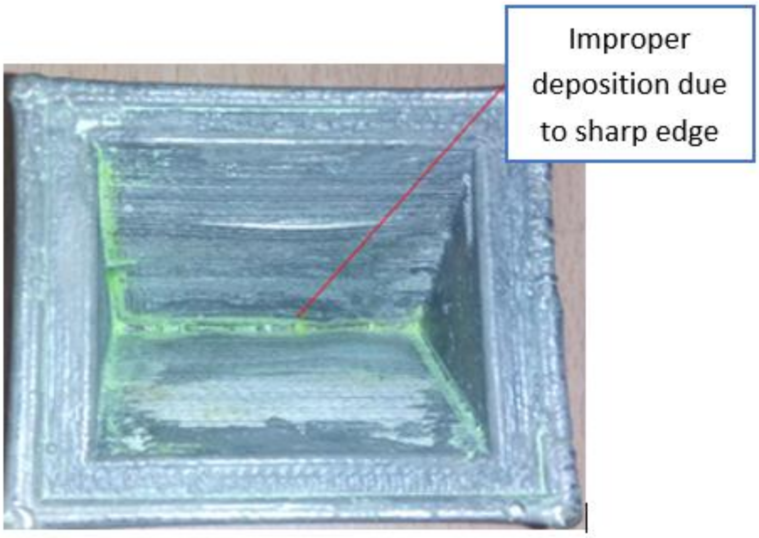

Figure 6 (a). Poor Deposition due to the Sharp Corner

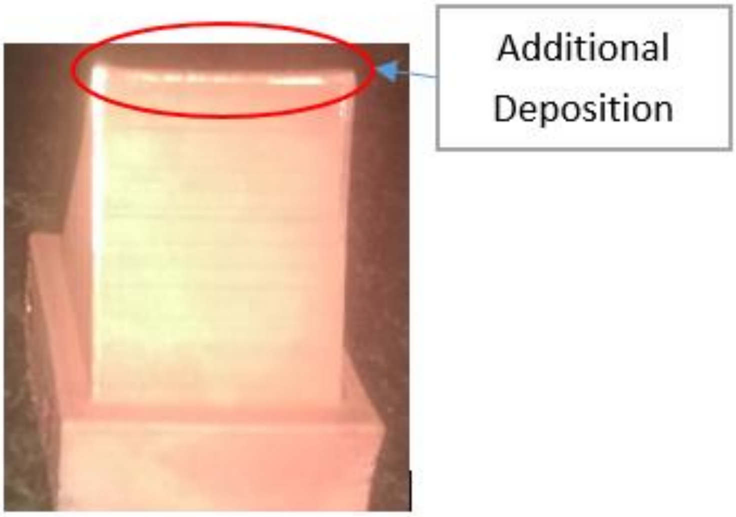

Figure 6 (b). Excessive Deposition due to the Sharp Edge as High Current Density Area

The area to be plated has to be exposed as an open surface to the solution, the plating in the undercover portions of the part does not yield sound results. Figure shows the component with improper plating at the hidden surfaces.

Figure 7. Poor Deposition on the Hidden Surfaces

Vertical walls to the solution also not result in the proper plating, some draft angle will help in improving the quality of the plating. Figure 8 represents the point made in this discussion.

Figure 8. Poor Deposition on the Vertical Surfaces

4.3 Microstructure Analysis

In order to analyze any flaw or critical observation at micro level the SEM image of the microstructure of the deposited copper was obtained. The observation clearly suggest as depicted in Figure 9, the grain size changes as the deposition thickness increases. The variation in the grain size is owing to the change in the thermal conductivity of the metal as its growth increases, resulting in to better heat dissipation. So the variation in the grain structure can be minimized with better heat dissipation arrangments.

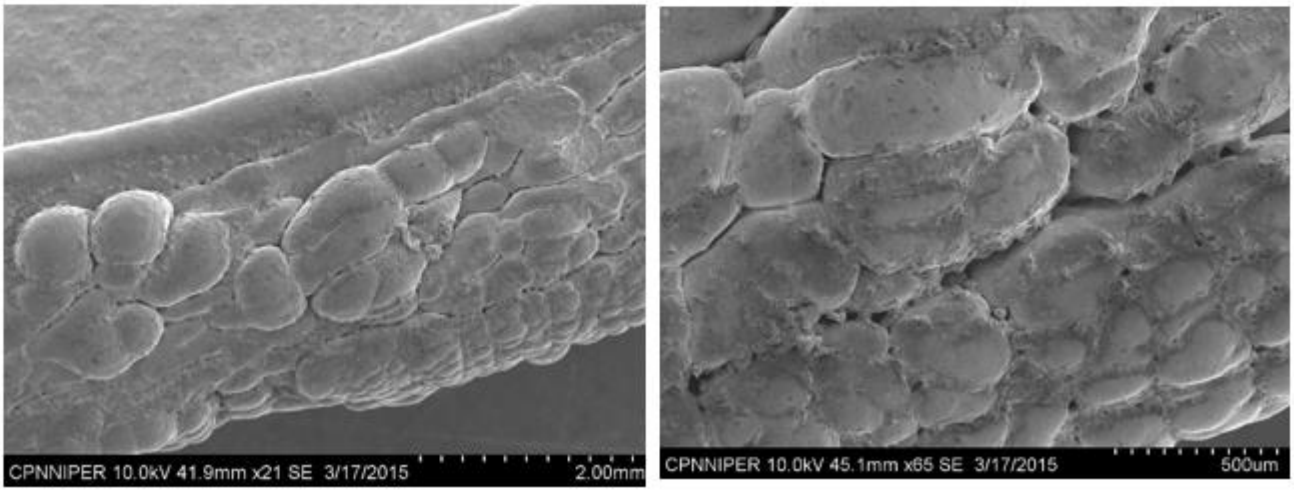

Figure 9. Microstructure of deposited metal

V. CONCLUSIONS

In this study the experiment was conducted by considering variable parameters namely pH, solution concentration, temperature and current density. The objective was to find the deposition rate and surface roughness to study the effects of the variable parameters on these characteristics, but during the process some critical observations came to the surface which should be taken care to avoid the production of bad quality noncompliance product. The following conclusions are drawn:

- ✓ The pre plating surface preparation treatment has to be done with utmost care to avoid any nonconductive zone generation.
- ✓ Temperature has least contribution for the metal deposition rate and surface finish.

- ✓ The ph value is the major contributor to improve the surface finish in comparison to current density and temperature.
- ✓ Higher current rates and lower boric acid shows the burning of the deposit.
- ✓ It was observed that after some time, the deposition of material does not remain uniform throughout the surface being plated due to the formation of high and low current density zones, hence retarding the overall thickness deposition rate on the complete profile.
- ✓ The initial plating of copper also affects nickel electroforming process. Higher copper plating coverage, better will be nickel electroforming. When copper plating was done after applying the conductive paint on ABS components, the coating was not good at the sharp edges. This problem may be circumvented by providing rounds or fillets at the corners during the design stage.
- ✓ The proper bath agitation system ensures the mixing of the solution and dissipation of the heat for better surface finish and uniform grain size.

VI. REFERENCES

[1]. B. Stein, 1996. A Practical Guide to Understanding, Measuring and controlling stress in Electroformed Metals. AESF Electroforming Symposium, Las Vegas.

[2]. Galantucci L.M., Lavecchia F., Percoco G., 2009. Experimental study aiming to enhance the surface finish of fused deposition modeled parts. CIRP Annals - Manufacturing Technology, 58, 189–192.

[3]. Garga Ashu, Bhattacharya Anirban & Batish Ajay, 2016. On Surface Finish and Dimensional Accuracy of FDM Parts after Cold Vapor Treatment. Materials and Manufacturing Processes, 31,522-529.

[4]. Gurpreet Singh Phull, Sanjeev Kumar & Ravinderjit Singh Walia, 2017. Nickel Deposition Optimization on Plastic Substrate Produced by Additive Manufacturing. International Journal of Manufacturing Science and Engineering, 8(2), 119-125.

[5]. Hsu C. Y., Chen D. Y., Lai M. Y. , Tzou G. J., 2008. EDM electrode manufacturing using RP combining electro less plating with electroforming. Int J Adv Manuf Technol. 38, 915–924.

[6]. Helen H. L, 2006. Electroplating. Encyclopedia of Chemical Processing DOI: 10.1081/E-ECHP-120007747, Taylor & Francis.

[7]. Jetley S and Daniel K. L, 2006. A Rapid Tooling Technique Using a Low Melting Point Metal Alloy for Plastic Injection Molding. Journal of Industrial Technology, 22, 3.

[8]. Kurth J.P, M.C.Leu and T nakagawa, 1998. Progress in additive Manufacturing and rapid prototyping. Keynote paper, Annals of the CIRP, 47,525-540.

[9]. McGeough J.A., Leu M.C., Rajurkar K.P., De Siliva A.K.M. and Liu Q., 2001. Electroforming Process and Application to Micro/Macro Manufacturing. CIRP Annals - Manufacturing Technology,50,499-514.

[10]. Monzon M D., Marrero M. D, A. Nizardo B, Pedro M. H, Cardenes J. F, 2006. A technical note on the characterization of electroformed nickel shells for their application to injection molds. Journal of Materials Processing Technology, 176, 273-277.

[11]. Prasad K.D.V Yarlagadda, Ismet P. Ilyas, Periklis Christodoulou, 2001. Development of rapid tooling for sheet metal drawing using nickel electroforming and stereo lithography process. Journal of Materials Processing Technology, 111, 286-294.

[12]. Prasad K.D.V. Yarlagadda, Periklis Christodoulou, Vijay S. Subramanian, 1999. Feasibilities studies on the production of electro

discharge machining electrodes with rapid prototyping and the electroforming process. Journal of Materials Processing Technology, 89-90,231-237.

[13]. Rennie A. E.W., Bocking C. E., Bennett G. R., 2001. Electroforming of rapid prototyping mandrels for electro-discharge machining electrodes. Journal of Materials Processing Technology.110, 186-196.

[14]. Ron P. Electroforming-a unique metal fabrication process. Nickel Development Institute Technical Series N 10 084.

[15]. Sadegh R, Rezaei M R, Akbari J, 2009. Design and Manufacturing of a wax injection tool for investment casting using rapid tooling. Tsinghua Science and technology,14, 108-115.

[16]. Sood A.K., Odhar R.K., Mahapatra S.S., 2009. Improving dimensional accuracy of fused deposition modelling processed part using grey Taguchi method. Materials and design, 30, 4243-4252.

[17]. S.Watson,Reprinted from transaction of the institute of Metal Finishing,NiDi Publication no.14005.

[18]. Stratasys inc, Fused deposision modeling for fast, safe plastic models, 12 th Annual conference on computer graphics, Chicago, April 1991, pp326-332.

[19]. Vidhata Mehta et al, Qualitative comparison of activation of ABS plastic component for Electroplating, International Journal of Science, Technology & Management, Volume No 04, Special Issue No. 01, March 2015 ISSN (online): 2394-1537.

[20]. J.A. Mc Geough, “Electroforming Process and Application to Micro/Macro Manufacturing”, School of Mechanical Engineering, Edinburgh, UK.

[21]. Xiang Gui Wang, Ning Li, Hui-Li Hu and Chun yuan Yu, 2006. Process of direct copper plating on ABS plastics. Applied Surface science, 253, 480-484.