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Investigation of mechanical behaviour and surface roughness properties on electroplated FDM ABS parts

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Abstract:- **Additive Manufacturing is a professional production technique which builds up complex shaped parts layer by layer, as opposed to subtractive manufacturing methodologies by using the .stl file as input. The mechanical strength of polymer-based additive manufacturing components is not sufficient to meet the demands of functional end tooling operations. Surface roughness also should be improved for its effective implementation in various applications. Many research methodologies were proposed to improve the mechanical strength and surface properties of additive manufacturing components but post-processing characterization is a kind of method which is highly concentrated in recent years by various organizations. A pilot study was conducted among the available techniques like D.C sputtering, electroforming and electroplating by using specimens which were fabricated in different orientations and it was found that the electroplating process provided good adherence of coating material over substrate when comparing to other two processes. In this study fused deposition modelling technique was used to fabricate acrylonitrile butadiene styrene parts in 0,30,45,60 and 90-degree orientations and these parts were electroplated with copper by using sulphuric acid as electrolyte. The tensile and flexural tests were carried out over electroplated and non-electroplated specimens to analyze the effect of different orientations on the anisotropic behaviour of parts. Surface roughness test was also carried out over electroplated and non-electroplated specimens by using portable surface roughness tester to analyze the effect of different orientation over surface roughness properties. The results indicated that there is a significant amount of improvement in surface roughness properties and mechanical properties of electroplated specimens when comparing to non-electroplated specimens that show a possibility for utilizing this methodology in end tooling applications.**

Keywords- Acrylonitrile Butadiene Styrene, Additive manufacturing, Copper, Electroplating.

I. INTRODUCTION

1.1 Additive manufacturing

Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing. Additive Manufacturing builds up components layer by layer using materials which are available in fine powder form, liquid form, and filament form in different additive manufacturing process. A range of different metals, plastics and composite materials may be used (Sathishkumar et.al 2016). The strengths of Additive Manufacturing lie in those areas where conventional manufacturing reaches its limitations.

1.2 Electroplating

Electroplating is the process of plating one metal onto another by hydrolysis, most commonly for decorative purposes or to prevent corrosion of a metal. To perform electroplating over plastics first, the surface of the plastic is etched away using an oxidizing solution. Because the surface becomes extremely susceptible to hydrogen bonding because of the oxidizing solution, typically increases during coating application. Coating occurs when the plastic component (post-etching) is immersed in a solution containing metallic (nickel or copper) ions, which then bond to the plastic surface as a metallic coating. In order for electroplating (or electrolytic plating) to be successful, the plastic surface must first be rendered conductive, which can be achieved through basic electroplating inks. Once the plastic surface is conductive, the substrate is immersed in a solution. In the solution are metallic salts, connected to a positive source of current (cathode). An anodic (negatively charged) conductor is also placed in the bath, which creates an electrical circuit in conjunction with the positively charged salts. The metallic salts are electrically attracted to the substrate, where they create a metallic coat. As this process happens, the anodic conductor typically made of the same type of metal as the

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metallic salts, dissolves into the solution and replaces the source of metallic salts, which is depleted during deposition.

2. LITERATURE SURVEY

2.1 Need of additive manufacturing in tooling

Additive manufacturing in tooling is highly preferred than conventional tooling methods like CNC machining in terms of speed, difficulty and quality (Joanna noble et al 2014). Experimentations are performed for development of additive manufacturing tooling for sand casting, investment casting and plastic moulding applications (Ingole et al 2009). Ismail Durgun et al (2015) investigate the usage of fused deposition modeling (FDM)-based sheet metal tooling for small lot productions as a real case. Wohler's report (2016) lists the various fields of additive manufacturing in industrial applications like Functional parts (28.1%), Tooling components (4.8%), Patterns for metal castings (10.8%), Patterns for prototype tooling (11.3%), Form fits and assembly (17.5%), Visual aids (10.4%), Presentation models (9.5%) and education/research (6.4%) and others (1.3%).

2.2 Electroplating of plastic components

Properties such easy formability, light weight and corrosion resistance provides natural advantage to plastic over metal. However, there are many areas in which due to decorative or technological considerations, metallic properties are required or demanded (Kuzmik et al.1990). Metallization is a process in which a non-conductive material, such as plastic, is made conductive by providing a conductive layer on it. With metallization, the physical and mechanical properties of plastics, such as reflectivity, heat resistance, strength, etc., can be improved or may be changed as desired and the advantages of both metal and plastic in combination has been increased (Mittal 2001). Skelly (2008) stated that metallized plastic got widespread applications in fields like oil & gas, automotive industry, electronic industry and others. Domenech et al. (2003) suggested that plastics such as Polysulfone, Polypropylene, Teflon and Acrylonitrile-butadiene-styrene (ABS) etc. can be metalized with different metals. Radulescu et al. (2002) proposed that metals like copper (Cu), zinc (Zn), nickel (Ni), chromium (Cr) etc. metallized by using variety of processes like brushing a metal paint, spray metal technique, sputtering, electroless plating, electroplating, vacuum metallization etc. Having excellent electrical conductivity and being relatively inexpensive, Cu has been widely studied for metallization, and a variety of plastics have been plated.

3. METHODOLOGY

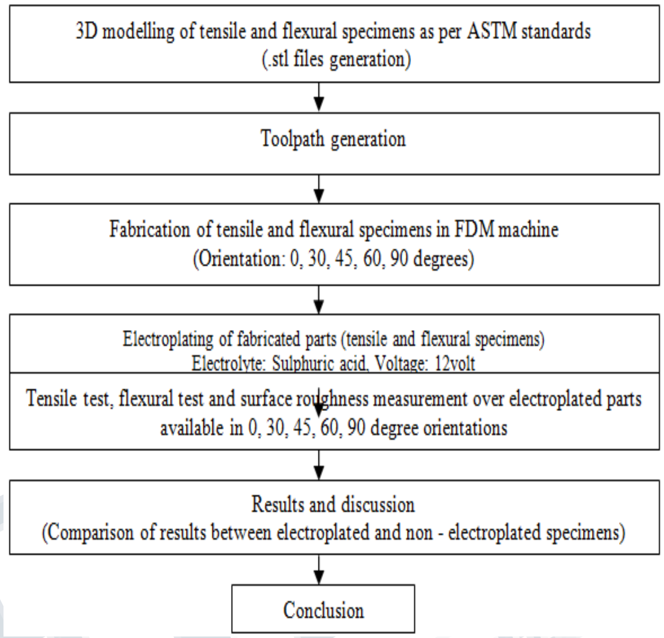

Figure 1 Methodology

4. EXPERIMENTATION

4.1 3D modeling

The 3D models of tensile and flexural test specimens were modeled by using solid works software as per ASTM D638 and ASTM D690 standards respectively. The .stl (standard triangulation language) files of tensile and flexural test were created and checked from errors like data redundancy, overlapping of facets etc.. The figure 2 shows the 3D model and ASTM standard of tensile test specimen. The figure 3 shows the 3D model and ASTM standard of flexural test specimen.

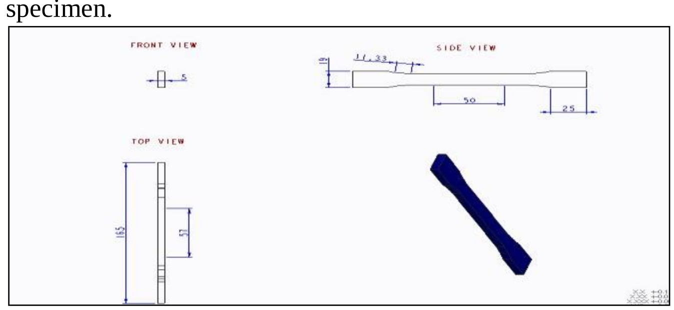

Figure 2 ASTM D638 standard and 3D model of tensile test specimen.

ISSN (Online) 2456-1290

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Vol 2, Issue 11,November 2017

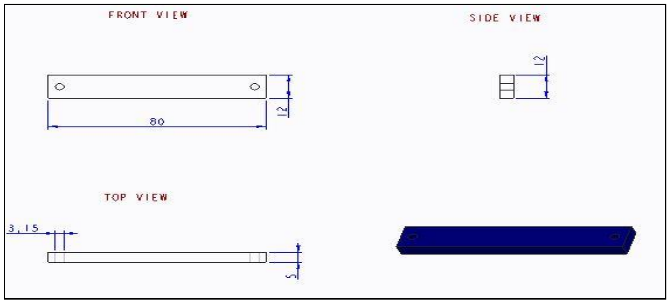

Figure 3 ASTM D638 standard and 3D model of flexural test specimen.

4.2 Fabrication

The Fabrication of tensile and flexural test specimens was carried out in Stratasys U print SE machine in five different orientations (0, 30, 45, 60 and 90 degrees).The figure 4 shows the different orientations of specimens in FDM machine. All specimens were printed in zigzag toolpath. The fabrication was carried out by using ABS like material. The figure 5 shows the fabricated specimens in FDM machine. After fabrication the post processing operations like removal of support structure was performed and the specimens were cleaned. The specifications of FDM machine and ABS material is shown in Table1 and Table 2 as follows.

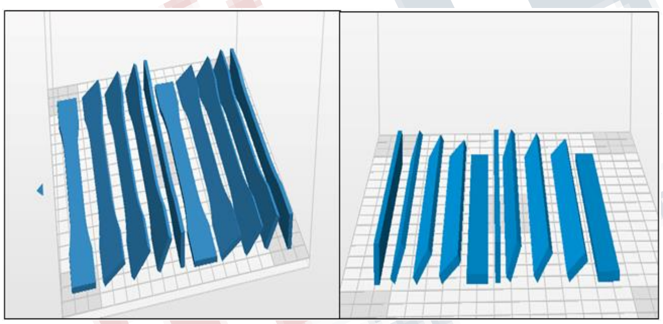

Figure 4 0,30,45,60 and 90 degree orientations in FDM machine

Table 1 Specifications of Stratasys U print SE FDM machine

Model material	ABS plus
Support material	SR 30 soluble
Build size (mm)	203 × 152 × 152
Layer thickness (mm)	0.254
Power (VA)	100-127

Table 2 Specifications of ABS like material

Commercial name in FDM	ABS plus
Glass Transition Temperature (Tg)	108°C
Coefficient of Thermal Expansion	8.82x10-05 mm/mm/°C
Heat Deflection (HDT) @ 66 psi	96°C
Formula	$(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$

Figure 5 0,30,45,60 and 90 degree fabricated specimens in FDM machine

4.3 Electroplating

After fabrication of tensile and flexural specimens the specimens were cleaned and prepared for electroplating process. Since the process of electroplating involves the usage of electric current, thermoplastic based tensile and flexural specimens were converted into conductive one by coating with copper conductive ink. The copper conductive ink coated specimens were then attached to cathode and source copper material was attached to anode in electrolytic bath respectively. Sulphuric acid (H2SO4) was chosen as electrolyte because of its well-known electrical conductivity and with this comes a better throwing power. Throwing power is the ability of the electrolyte to get uniform depositions in areas with different current densities. It was also observed the addition of more sulfuric acid provided better throwing power. Initially the pilot experiments were conducted based on theoretical calculations to choose the appropriate current and time. Based on pilot experiment results it was observed that maximum current of 4.5 amperes/sq. inch provides better adherence and those pilot specimens tested for exceeding this value resulted in melting and collapsing of specimens. The increasing voltage in electroplating will increase thickness of coating so here in this study voltage was taken as a constant value of 12 Volt to perform the electroplating of specimens which printed in different orientations. The electroplating time of each specimen was 10 minutes and the corresponding thickness of coating obtained was 2.5 mm. The figure 6 shows the steps followed in electroplating of specimens.

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Vol 2, Issue 11,November 2017

Figure 6 A. Painting conductive copper ink over plastic specimen
B. Tensile and flexural specimens before electroplating
C. Electroplating setup
D. Specimens taken out from electrolytic bath
E, F. Copper Electroplated specimens (2.5mm thickness)

4.4 Tensile and Flexural testing

The copper electroplated and non – electroplated specimens which fabricated in five different orientations were tested to find tensile and flexural strength as per standards ASTM D638 and ASTM D690 respectively. Both tensile and flexural tests were performed at room temperature. The outlay of tensile and flexural test is shown in figure 7

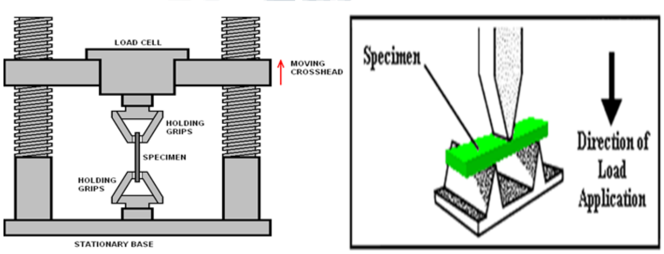

Figure 7 Tensile and Flexural test setup

4.5 Surface Roughness Measurement

The surface roughness of electroplated and non – electroplated specimens were measured by using portable surface roughness tester and its surface texture was closely observed by using as shown in figure 8 as follows

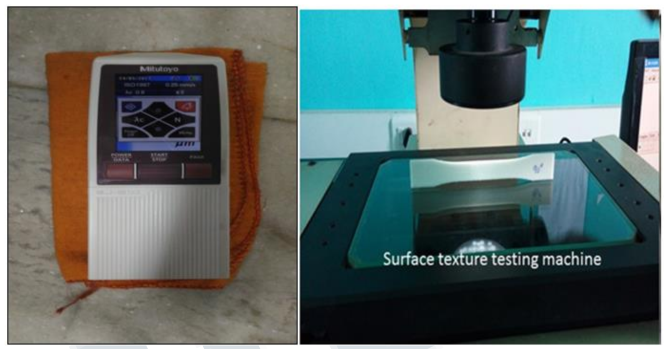

Figure 8 Surface roughness Profilometer and Video measuring machine

5. RESULTS AND DISCUSSION

5.1 Tensile test

The tensile test results of electroplated and non – electroplated specimens in different orientation is shown in table 3 given below

Table 3 Tensile test results

S.no	Orientation (Degree)	Ultimate tensile strength (Mpa)		Utimate tensile load (KN)	
		Non -Electroplated	Electroplated	Non -Electroplated	Electroplated
1	0	32	39	1.52	1.94
2	30	28	26	1.36	1.31
3	45	25	27	1.29	1.48
4	60	26	28	1.35	1.41
5	90	17	20	0.79	0.93

From the above results it is evident that the ultimate tensile strength and ultimate tensile load of copper electroplated specimens are improved significantly in all orientations except for 30 degree orientation. It was analyzed and found that in 30 degree build direction the electroplating of copper not influenced its mechanical properties because of its weaker anisotropic behaviour in this particular orientation which influences the easy breakaway of elastomers irrespective of its thickness. A comparison graph of ultimate tensile strength and ultimate tensile load between non – electroplated and electroplated specimen is shown in figure 9 .Comparing to non – electroplated specimens the tensile

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Vol 2, Issue 11,November 2017

strength and tensile load of electroplated specimens are improved as follows

•In 0 degree orientation the ultimate tensile strength and ultimate tensile load is improved for 17.9% and 21.649% respectively.

•In 30 degree orientation the ultimate tensile strength and ultimate tensile load is reduced for 7.142% and 3.676% respectively.

•In 45 degree orientation the ultimate tensile strength and ultimate tensile load is improved for 7.407% and 12.83% respectively.

•In 60 degree orientation the ultimate tensile strength and ultimate tensile load is improved for 7.142% and 4.25% respectively.

•In 90 degree orientation the ultimate tensile strength and ultimate tensile load is improved for 15% and 15.05% respectively.

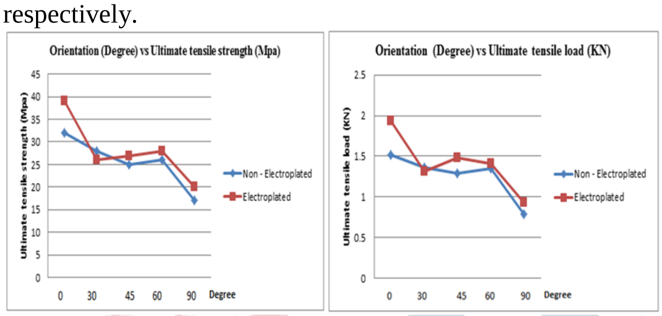

Figure 9 Comparison of ultimate tensile strength and ultimate tensile load vs orientation

5.2 Flexural test

The flexural test results of electroplated and non – electroplated specimens in different orientation is shown in table 4 given below

Table 4 Flexural test results

S.no	Orientation (Degree)	Ultimate flexural strength (Mpa)	
		Non -Electroplated	Electroplated
1	0	57.78	112.17
2	30	52.31	56.45
3	45	44.58	48.08
4	60	48.08	102.32
5	90	34.33	36.32

From the above results it is evident that the ultimate flexural strength of copper electroplated specimens are increased significantly in all five orientations when comparing to non – electroplated specimens. A comparison graph of ultimate flexural strength between non – electroplated and electroplated specimen is shown in figure 10. Comparing to non – electroplated specimens the ultimate flexural strength of electroplated specimens are improved as follows

•In 0 degree orientation the ultimate flexural strength is improved for 48.48%.

•In 30 degree orientation the ultimate flexural strength is improved for 7.33%.

•In 45 degree orientation the ultimate flexural strength is improved for 7.729%.

•In 60 degree orientation the ultimate flexural strength is improved for 53.01%.

•In 90 degree orientation the ultimate flexural strength is improved for 5.479%.

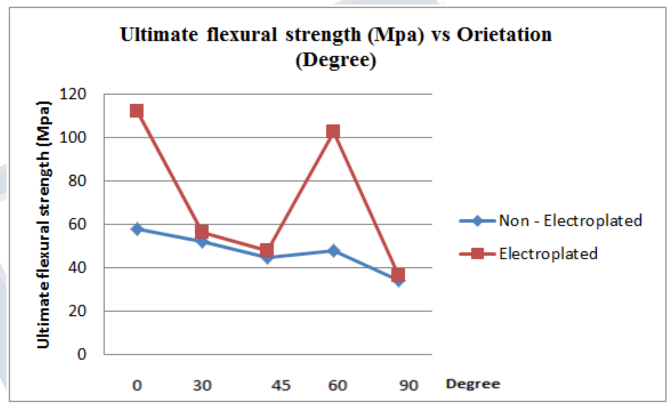

Figure 10 Comparison of ultimate flexural strength vs orientation

5.3 Surface roughness test

The surface roughness test results of electroplated and non – electroplated specimens in different orientation is shown in table 5 given below

Table 5 Surface roughness test results

S.no	Orientation (Degree)	Tensile test specimen surface roughness (µm)		Flexural test specimen surface Roughness (µm)	
		Non -Electroplated	Electroplated	Non -Electroplated	Electroplated
1	0	20.278	2.696	19.804	2.739
2	30	20.649	4.887	21.823	5.321
3	45	22.790	7.612	23.201	9.105
4	60	29.414	11.964	27.228	7.506
5	90	30.876	7.245	30.063	8.856

From the above results it is evident that the surface roughness of copper electroplated specimens were reduced to a greater amount when comparing to non – electroplated specimens which lacks in better surface finish. A comparison graph showing surface roughness values between non – electroplated and electroplated specimens are shown in figure

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Vol 2, Issue 11,November 2017

11. Comparing to non – electroplated specimens the average surface roughness value of electroplated specimens are reduced as follows
•In 0 degree orientation the average surface roughness value is reduced about 86.70%.
•In 30 degree orientation the average surface roughness value is reduced about 76.33%.
•In 45 degree orientation the average surface roughness value is reduced about 66.59%.
•In 60 degree orientation the average surface roughness value is reduced about 59.32%.
•In 90 degree orientation the average surface roughness value is reduced about 76.53%.
The throwing power of copper in the electroplated bath is high and accurate which resulted in uniform plating in all directions, also resulted in good surface finish comparing to non – electroplated specimens.

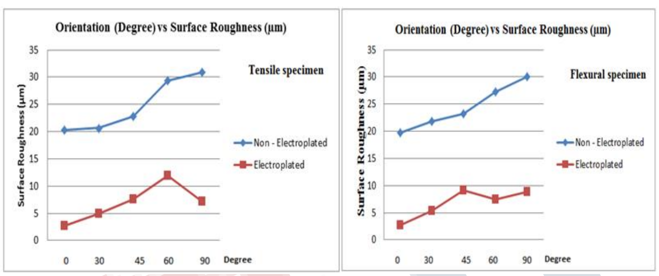

Figure 11 Comparison of surface roughness vs orientation

6. CONCLUSION

From the above results the following points are concluded from this study.
•The electroplating of copper over 3d printed specimens in five different orientations improved its mechanical properties (tensile, flexural) and surface texture properties significantly which provides a confident to use copper electroplated additive manufactured components in direct end tooling applications effectively.

•Among the five different build orientations tested in this study it was observed that 0 degree orientation (flat orientation) provided better tensile strength and higher tensile load bearing capacity than other orientations followed 90 degree.

• Similarly for the flexural strength among the five different orientations tested in this study 60 degree orientation provided very good flexural properties when compared to other orientations.

•The surface finish of 3d printed components are highly demanded when it is utilized for end tooling applications , it is observed in this study electroplating provides better surface finish comparing to other post processing techniques like electroless plating etc… because of its inherent throwing capacity provided by electric current.

•Among the five different orientations better surface finish was observed for o degree orientation when comparing to other orientations because of its non-complex tool path followed at the time of fabrication in FDM machine.

•The material consumption and Build time is very less for 0 degree orientation when comparing to other orientations because of its less support structure requirement.

•The specimens tested at 0 degree orientation showed better anisotropic properties and surface texture properties when comparing to other orientations which may be highly considered for future applications in 3d printing technology.

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