Investigating the Influence of Electroplating Layer Thickness on the Tensile Strength for Fused Deposition Processed ABS Thermoplastics

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Abstract- Fused Deposition Modeling (FDM) is a kind of Rapid prototyping (RP) technique, which allows direct transformation of CAD files into physical models. This paper attempts to identify and study the influence of electroplating layer thickness on the mechanical strength of Acrylonitrile butadiene styrene (ABS) samples developed from the FDM process. The study is conducted on the tensile test samples of ABS, built on Stratasys FDM vantage SE machine, and tested under IS specified test conditions. The electroplated samples were also subjected to acetic acid tests and surface roughness measurements to check for proper adhesion of plating. The electroplating thickness adopted was 60, 70 and 80 µm. The electroplated tensile samples indicated an increase in the tensile strength with the corresponding increase in the plating thickness. 60 µm sample exhibited lower ductility and 70, 80 µm samples exhibited enhanced ductility.

Keywords-ABS, FDM, Electroplating, CAD, RP.

I. INTRODUCTION

There are many feasible methods are available to produce thermoplastics products today. Every viable method has some pros and cons. It is the part design, shape and size of the product which decides an appropriate process for fabrication. Thermoplastics are commonly processed by the Injection molding (IM) technique [1], but the main disadvantage with IM technique is the cost and time involved in processing a product. Therefore, RP process can be viewed as an alternate replacement for IM. RP process has the capacity to fabricate even parts that are more complex having imaginable geometry in a short duration [2]-[4]. There are different RP processes available now a day of which FDM method has the capability to produce tough parts that are ideal for functional usage [5].

One of the main limitations of RP parts is the limited strength characteristics of RP materials which in turn limits their scope of application in many areas of engineering. To overcome these limitations, aerospace industries have adopted electroplating procedures for creating mock-ups of modules to obtain stiffness and durability of RP models [6]. Thulasi Durai et al. [7] reported that, a few fabrications efforts involving the use of the RP technique of selective laser sintering (SLS) for the development of air frame and wing structures used by scientists from National Aeronautics Limited (NAL), Bengaluru, India. Similarly, Chandrasekhar et al. [8] reported that, the scientists from Gas Turbine Research Establishment (GTRE), Bengaluru, India, were using of stereolithography (SL) and laser engineered net shaping to facilitate flow-visualization and blade refurbishment tasks. The method of electroplating has been used by automobile industries in early 1960’s to replace some metal parts with plastics in automobiles for weight reduction, weather proofing and aesthetics. Later, this method was expanded in domestic applications like fabricating, wash taps for basins, bath showers, toilet showers, etc. Off late, researchers are concentrating on developing metal-polymers combination materials to develop functional prototypes. M.V.Kulkarni et al. [1] has confirmed that, with electroplating on IM materials, the strength of the plastics increases considerably. The present study is an effort to record the results of the tensile tests conducted on the electroplated FDM-ABS samples by varying coating thicknesses.

II. FUSED DEPOSITION MODELLING OF ABS PROTOTYPES

Fused deposition modeling of RP refers to an additive manufacturing technology commonly employed for modeling, prototyping, and manufacturing applications. The technique utilized by FDM is based on the rapid solidification of the molten laminate material delivered through an extrusion head. The semi-fluid thermoplastic material is deposited into thin layers, building the model upwards off a fixtureless base as shown in Fig. 1.

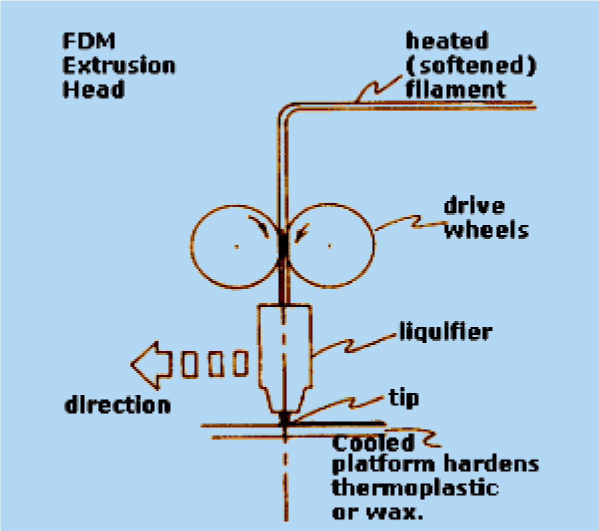


Fig. 1. Fused Deposition Modeling [9]

The developed FDM-ABS samples have been shown in Fig. 2. It is essential to maintain the thermoplastic material temperature and is therefore maintained just below the solidification temperature to ensure proper adhesion between the layers. A precision volumetric pump is used to control the material passing through the extrusion orifice. The models are fabricated upon a platform which is lowered between layers, to make room for the next layer. Layer thickness is adjusted between 0.178 mm and 0.356mm. Layer thickness is controlled by varying the speed of the extrusion head with the maximum speed being limited as 380 mm/sec. The width of the extrusion or layer road width is varied between 0.250 mm and 0.965 mm. An advantage of the FDM process is that the material delivery process can be done on-demand and does not require a large initial pool of expensive material. Any material exhibiting thermoplastics behavior is a likely candidate for the process [10] and in this study, tensile prototypes are made of ABS.

Fig. 2. Developed FDM-ABS Tensile Samples

III. ELECTROPLATING OF FDM PROTOTYPES

Deposition of thin metal foils over the FDM prototypes through custom developed plating procedure is one of the important aspects in the present study. The entire plating cycle involves sequential application of surface preparation of FDM coupons, electroless deposition and electrolytic plating processes [11]. As the upward surfaces of prototypes display glossy surface finish, adhesion between electrodeposited metallic layer and the prototype surface tends to be poor [10]. Typically chemical or physical treatments are used to roughen the prototype surface and ensure adhesion [12]. M V Kulkarni et al. [13] have made an extensive study on electroplating of ABS plastics and according to them, EP processes involve a series of steps like electroless procedures (surface preparation, etching, surface activation, electroless copper) followed by electroplating procedures (acid copper, acid Nickel and chrome flash).

The present study employs chemical processes as it has innate ability to provide superior adhesion. After the surface processing, the prototypes are subjected to plating. For electro plating of FDM coupons, conductivity is introduced into surface through series of procedures involving acidic treatment, surface activation and treatment with electroless copper solution [Fig. 3 (a) – (d)]. Fig. 3(a) and (b) represent the surface activation technique and Fig. 3(d) represent electroless treatment. Through electroless copper, a thin metal foil of 1-2 µm thickness is deposited on FDM part and the surface is rendered conductive. During the electro deposition process, a copper metal foil of 5 µm is deposited in an electrolytic bath maintained at elevated temperature Fig. 3(e). Wetting agent is used to mitigate the risk of pitting and inhibitor is used to reduce the grain size of the deposit. Fig. 3 (f) shows the plated FDM-ABS test samples. Plating experiments are repeated and the thickness of the deposited layer is varied in 60 – 80 µm range. Tensile strengths of the coated specimens are experimentally evaluated and results are presented in Fig 4.

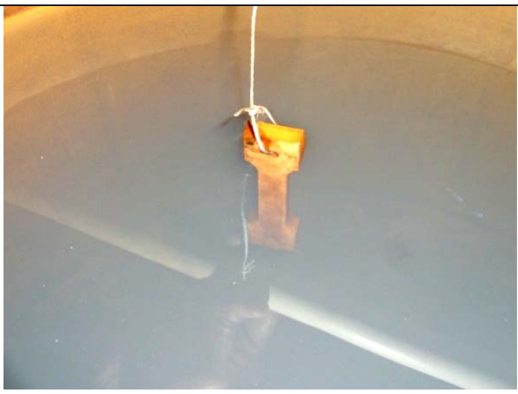
IV. EXPERIMENTAL RESULTS ON TENSILE STRESS MEASUREMENT

All the FDM-ABS Tensile samples are fabricated as per ASTM E837 (equivalent IS standard IS: 3073-1967, RA-2006) standards. This Standard is normally followed to determine the residual stresses of the material. Residual stresses are those stresses that can act in the absence of external loads. Typically, it is believed that all the fabrication and heat treatment processes introduce residual stresses in the manufactured components [10]. Initially, before taking up electroless plating procedure it becomes mandatory to test the samples for glacial acetic acid tests. The test is conducted as per ASTM D1939 standard. During the test the immersion of samples in glacial acetic acid exposes the presence of any residual stresses in the samples by showing a crack. If the samples show any signs of crack then it would be subjected to residual stress measurements study and in the present study the samples did not show any signs of residual stresses.

The samples are therefore subjected to next process of testing and are checked for the surface roughness. The measurements are done as per IS: 3073-1967, RA-2006. The purpose of carrying roughness measurements are to check for the proper adhesion of electroplated layers between the surface and layers. The results of the study have been shown in Table 1. The results indicate that with increase in plating thickness roughness decreases. Similarly, the UTS values of FDM-ABS electroplated samples have been increased. The tensile testing is conducted as per the relevant IS 1608- 2005 standards. The results of the tests indicate that samples have shown improved UTS vales. The increase in UTS values have also been noted for stereolithography based samples by Chandrasekhar et al. [10] and by N. Saleh et al. [6]. The results corresponding to all the layer thicknesses are graphically shown in Figure 4.

(a) Etched FDM-ABS Sample

(b) Tin chloride Activated Sample



(c) Silver Nitrate Activated Sample

(d) Electroless Copper sulphate treatment

(e) Copper electro deposited FDM-ABS sample	(f) Nickel electro deposited FDM-ABS sample

Fig. 3. Electroplating of FDM – ABS Tensile Samples.

TABLE I
Surface Roughness, Plating Thickness and UTS Values of FDM-ABS Samples

Sample Code	Ra, µm	Plating Thickness, µm	UTS, MPa
A	3.3	---	10
B	2.2	60	11.39
C	1.43	70	13.27
D	0.7	80	14.93

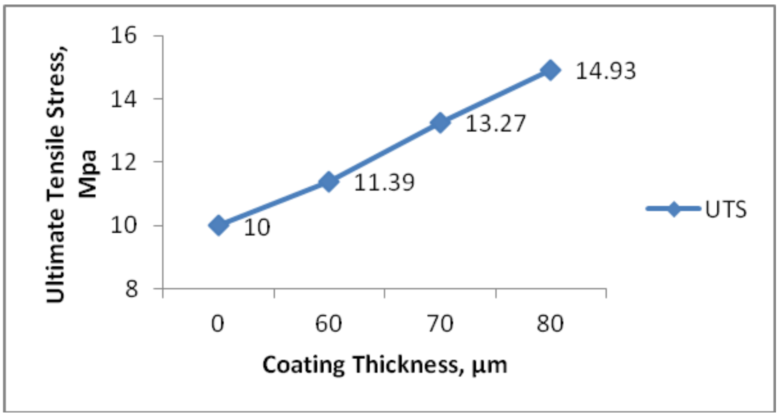


Fig. 4. UTS vs Coating Thickness for FDM-ABS Electroplated Samples

N.Saleh et al. [6] describes that the increase in tensile strength is due to the reason that metal-coated SL polymer has the properties of a bonded composite material. The hard and stiff metal coating, firmly anchored in the SL material, confers new mechanical properties on the material that differ from those of the individual components. The reasons as quoted by N. Saleh et al. [6] holds true in our study also. From the Fig. 4, it is also understood that there is only a marginal increase in tensile strength for plated samples in the range of 0 – 60 µm. Fig. 5 indicates that electroplated FDM-ABS samples exhibit a brittle mode of fracture. It has been observed that layers have broken without any signs of elongation as seen from Fig. 5.

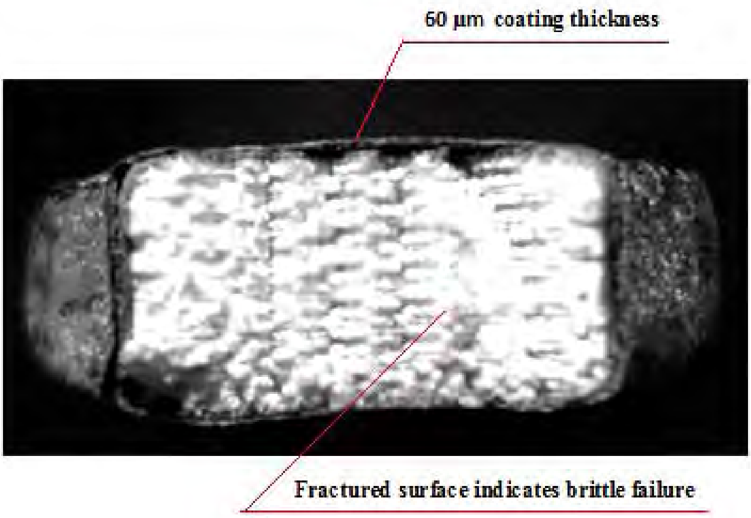


Fig. 5. Enlarged View of Fractured Surface of Tensile Sample.

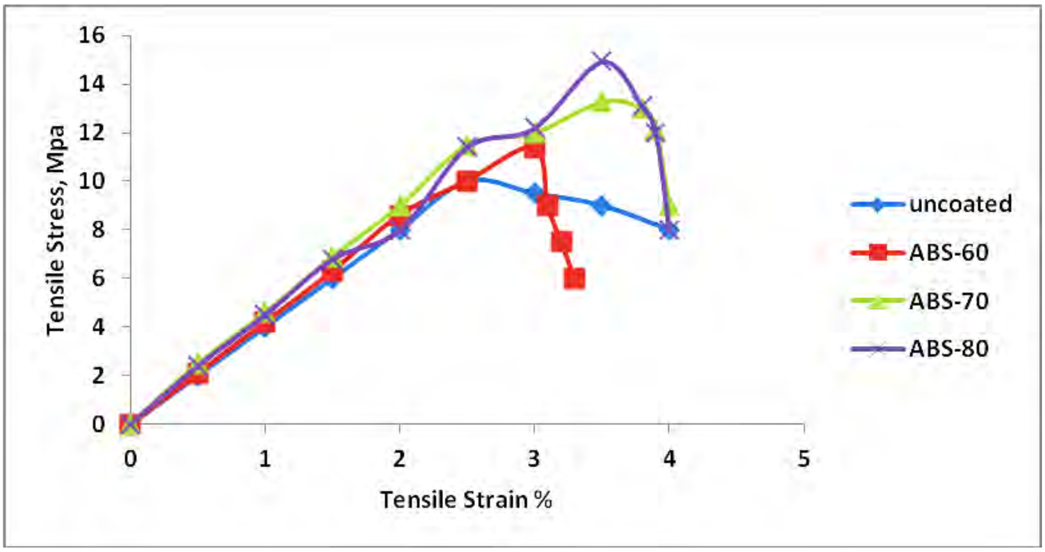


Fig. 6. Tensile Stress vs Tensile Strain for Coated and Uncoated FDM-ABS Samples

Fig. 6 gives the tensile stress–strain curves of FDM samples with and without electroplating respectively. Compared with the 60 µm FDM sample, the 70 µm and 80 µm electroplated FDM samples tested in tensile conditions shows a more pronounced increase in UTS with increasing strain. The coating of a thin layer of nickel has changed the tensile characteristics of the FDM materials. Furthermore, a fracture is observed at a 4 percent tensile strain for the uncoated, 70 µm and 80 µm FDM-ABS samples. It is also interesting to note that 60 µm sample exhibits lesser strain in comparison to uncoated, 70 µm, and 80 µm samples. The possible reduction of this is due to lesser thickness of plating (60 µm) that causes the easy breaking with lesser elongation and finally culminates with brittle fracture. At higher thicknesses the plating gains the ductility and further helps in undergoing more strain. This indicates that the samples with higher coating thickness have higher modulus of elasticity.

V. CONCLUSIONS

Rapid prototyping techniques of fused deposition modeling are successfully applied for quick realization of FDM samples from the CAD designs. Deposition of thin metallic foil over the surface of ABS infuses composite like characteristic into FDM prototypes and may lead into the development of high strength-to-weight characteristic in functional prototypes. Based on the experimental evaluation of tensile stresses it is concluded that FDM samples need to be built with higher levels of layer thickness in FDM process. Reinforcement effect in case of thin section prototypes is less pronounced and finally ends up in brittle failure. But with the increase in thickness the prototypes may acquire the properties of ductile materials. Also, it can be seen that 60, 70, and 80 µm samples have increased their strength by 13.9%, 32.7%, and 49.3% respectively in comparison with the uncoated sample. The surface roughness values have also considerably shown lesser roughness with the increase in coating thickness.

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