Investigation of Mechanical Properties of Copper Plated ABS Part with Different Layer Thickness

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Abstract

Fused deposition modelling (FDM) is most commonly used processes in additive manufacturing. FDM uses raw material in the form of wire filament and works on the principle of extrusion. Acrylonitrile butadiene styrene (ABS) is commonly used engineering plastic in FDM process for printing different parts for functional purpose or prototyping. As ABS is less expensive material among other plastic used in FDM process. The availability and cost of ABS highlights its more use in additive manufacturing. Mechanical properties of ABS can be enhanced by copper plating. Copper plating on ABS can provide good tensile strength and impact resistance to the ABS parts. . To optimize the printing parameters using taguchi's method, Minitab software is used to generate optimum number of combinations for printing of ABS parts. This work describes the detail study on investigating the physical and mechanical properties of ABS part without plated and copper plated ABS parts with different layer thickness 50µm, 200µm, 400µm and 600µm. Tensile strength, impact strength and hardness values for these different parts are found by various experimental tests. Focusing on the end results it was observed that after coating 600 micron layer of copper over 3D printed specimens, tensile strength is increased by 321.67% , whereas Mirco Hardeness by 139% and Impact strength is increased by 190% than existing properties of as printed specimens. It can be concluded that copper coating provides better option for improvement in mechanical properties of 3D printed parts without considerable variation in weight of parts or going for expensive metal printing process.

Keywords: FDM, ABS, Tensile strength,Impact strength, Hardness, Copper plating Introduction

I. **Introduction**

Our world is growing faster with sustainable development in the fields of science and technology. Use of renewable energy sources and reduction in the waste generation has given more importance in this century. Similarly the manufacturing industries are using advance technologies for betterment of effective conversion of conceptual designs of product to complete finished product. Additive manufacturing technology has provided a great advantage for attaining good accuracy and complexity of production. As Additive manufacturing finds it's applications in various fields like space, aerospace, defence, architectural, medical, artificial jewelleries, automotive and other prototyping activities. Additive manufacturing give additional advantage of no waste material generation. Fused deposition modelling (FDM) is one of the widely used processes in additive manufacturing. FDM uses raw material in the form of wire filament and works on the principle of extrusion. FDM allows using various engineering plastics like Acrylonitrile butadiene styrene (ABS), Acrylonitrile styrene acrylate (ASA), Polycarbonate (PC), Polyphenylsulfone (PPSF), Polyetherimide (ULTEM) and Nylon for building of prototypes. ABS is most commonly used thermoplastic polymer for FDM process as it has significant mechanical properties like impact resistance and toughness as well as less expensive compared to the other high performing plastics. Normally ABS parts perform better within a temperature range from −20 to 80 °C (−4 to 176 °F). Besides these ABS is chemical stable against the aqueous acids and alkalis. Many of FDM machines permit the adjustment of general process parameters, consist of temperature range of nozzle and build platform, the building speed, the layer thickness and rpm of the cooling fan. These parameters are generally set by the machine operator instead of product designer.

Jason T Cantrell et. al. [1] presented work on the characterization of 3D printed (using FDM Process) acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC) parts by adopting digital image correlation (DIC) method. Printed parts are built with different orientations and raster angles ([+45/-45], [+30/-60], [+15/-75], [0/90] in order to finding out the directional properties of materials. These parts are examined for the tensile and shear characteristics based on the parameters like Young's modulus, Poisson's ratio, tensile strength at yield, offset yield strength, elongation at break, tensile stress at break, and strain energy density. It was observed that build orientation and raster angles does not affect the young's modulus or poisons ratio in ABS specimens, Whereas in case of shear modulus & shear offset yield strength shown variation up to 33%. For PC parts it has shown anisotropic behaviour due to change in raster angles as it shown 20% variations in values of moduli and strengths.

K. Raja et. al. [2] made efforts for enhancing the corrosion resistance and hardness of the copper coated FDM printed 3D ABS parts. It consisting of controlling the coating layer thickness up to 50-54 micrometres which gives hardness value of 225 VHN. Similarly the effect corrosion on the parts is studied using the scanning electron microscope.

Azhar Euqbal at. al. [3] made an effort of copper coating of FDM printed ABS parts by the use of different acidic baths namely HF (hydrofluoric acid), H2SO4 (sulphuric acid), 5 wt% CuSO4 (copper sulphate) with 15 wt% of individual acids, H3PO4 (phosphoric acid) and CH3COOH (acetic acid).During the pre-stage of the coating process the parts were taken through use of two different etching agents chromic acid and solution mixture of sulphuric acid. Performances of different coating through these baths are examined by the electrical characteristics and use of scanning electron microscope (SEM) as well as energy dispersive X-ray spectrometry (EDS). It was observed that chromic acid etched samples revealed the better electrical performance when compared to other etched part in sulphuric acid.

S. Kannan et. al. [4] study show a significant work on the nickel and chrome plated 3D printed ABS parts (using FDM process) with different layer thickness of 60 µm, 70 µm and 80 µm respectively. These specimens were examined for the performance in impact resistance and hardness under these different electroplated layers of nickel and chrome. In order to evaluate the impact resistance of specimens drop test was conducted wherein the different drop weights of 0.89kg, 1.39Kg and 2.33Kg were used for drop test. It was observed that there was considerable increase in impact resistance with respective increase in coating layer thickness. Similarly these specimens were gone through Rockwell hardness test which shown improved values of hardness with respect to increase in the coating layer thickness.

S. Kannan et. al. [5] used FDM process for printing ABS specimens and these specimens were electroplated with copper having varying thickness of 60 µm, 70 µm and 80 µm. These samples were subjected to acid test and surface roughness measurements. Tensile strength of the specimen increased with increase in plating thickness as result there was comparable increase in the ductility of specimens with increasing plating thickness.

Jiushuai Xu et. al. [6] controlled the copper coating process and improved the adhesive strength of coating over the 3D printed ABS parts by using some modified substrates of ABS. These copper films for individual deposition rate and angles were examined by use of scanning electron microscopy (SEM) and X-ray diffraction (XRD).

H N Zhang et. al. [7] conducted similar experiment on the self-assembled film modified ABS resin treated with copper plating. Investigation is done to analyse the surface appearance, deposition rate and thickness of copper film over the ABS. It was observed that there was good adhesion between ABS resin and copper.

Anoop Kumar Sood et. al. [8] shows the influence of layer thickness, orientation, raster angle, raster width and air gap on tensile, flexural and impact strength of test specimen. This work has adopted the ANOVA method for analysis of variance in the parameters with respective the response surface plots. Accordingly the optimal parameter setting for respective response is obtained. It was observed that parts were having weak strength due to distortion between the layers.

Anoop Kumar Sood et. al. [9] studied the influence of important process parameters such as raster angle, layer thickness, part orientation and air gap on dimensional accuracy of fused deposition modelling (FDM) printed ABS P400 part. After printing of the part it is investigated that shrinkage occurs in part has dominance on length when compare with width of the part. Henceforth to find out the optimum parameter for eliminating the shrinkage defect, the parameters are optimized using the grey taguchi's method. Based on the nonlinear responses it is observed that artificial neural network is suitable for predicting such parameters.

Wang Gui-xiang [10] attempted the direct copper coating on ABS plastic. Study of the coating is conducted by atomic force microscopy (AFM), Ultraviolet- visible absorption spectrometry and X-ray fluorescence spectroscopy (XRF) methods. ABS substrate were etched by CrO3/H2SO4 solutions containing Pd2+ions, process is catalysed by Pd/Sn colloids solutions and accelerated in alkaline solutions containing copper ions. It was observed that etching reduces surface roughness and enhanced the colloid dispersivity. Also the size of copper particle affects the uniformity of the copper plating.

1. ABS Sample Printing

Some of the significant parameters that would affect the print quality and strength were taken into consideration based on the research. For generating the number of experiments according to the selected parameter and three variable taguchi's method play a vital role.

Table 01 Factors and variables under consideration

Sr. No	Factors	Variable I	Variable II	Variable III
1	Print strength	Hollow	Strong	Solid
2	Print Pattern	Cross	Diamond	Honeycomb
3	Print Fill Spacing (mm)	1	2	3
4	Top and Bottom Layers (No)	3	4	5

As this method is more suitable to optimize parameters namely printing strength, print pattern, print fill spacing and number of top as well as bottom layers in 3D printing of ABS parts as shown in above table 01.

Exp. No.	Setting Parameters				
	Print strength (Factor A)	Print Pattern (Factor B)	Print Fill Spacing (mm) (Factor C)	Top and Bottom Layers (No) (Factor D)	Cross Sectional view of the test samples
1	Hollow	Cross	1	3	
2	Hollow	Diamond	2	4	
3	Hollow	Honeycomb	3	5	
4	Strong	Cross	2	4	
5	Strong	Diamond	3	5	
6	Strong	Honeycomb	3	3	
7	Solid	Cross	3	5	
8	Solid	Diamond	1	3	
9	Solid	Honeycomb	2	4	

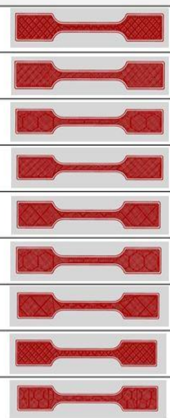

Fig. 01 Experiments generated by Taguchi's Method

To generate number of experiments by taguchi's method as shown in fig 01, Minitab software is used. After give the number of input parameters and number of variable it shows these experiments. In order to print with these different parameters on FDM it is required to set this parameter on the system software. Geometry of the specimens is different according to type of tests on the specimens to be conducted. Error percentage was reduced by adjusting the scale factor according so printing accuracy is good enough to compare the printed parts with the CAD geometry.

A. Measurement of Porosity

Porosity in FDM is defined as the inherent result of molten material being extruded and fused layer by layer. Fig.02 shows the internal pores between the layers seen on the microscope. Further to deal with mechanical or other physical properties it was necessary to determine the porosity of the printed samples of ABS. Porosity values estimated for the nine experiments and 3 specimen's i.e for all 27 ABS samples.

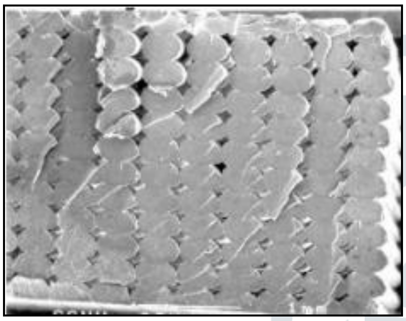

Fig.02 Internal pores between the layers actual image

Average values are normally varied from range 20%to 51% which depending upon the printing parameters. Experiment no 6 showed highest porosity percentage of 50.56% and fastest printing time while Experiment no 8 had the lowest porosity of 25.54% with maximum build time. The experiment No 6 showed maximum porosity as the factors influencing the print were the maximum print fill spacing of 3mm with the print pattern of honeycomb structure and with minimum no of top and bottom layers. While on the other hand, Experiment No 8 had minimum porosity as its print strength was set to solid, with minimum print fill spacing of 1mm and with a diamond print pattern.

B. Measurement of Roughness

Surface finish which also recognized as surface topography is generally consists of small local deviations of a surface from the perfectly flat ideal reference plane. Each manufacturing process produces a surface texture. If necessary, an additional post processing will be added to enhance the finish of the printed parts. Surface roughness termed as roughness, is a measure of finely spaced surface irregularities. FDM technology in RP process results in coarse surface finish. Measurement of surface finish is done in two different ways: contact and non-contact method.

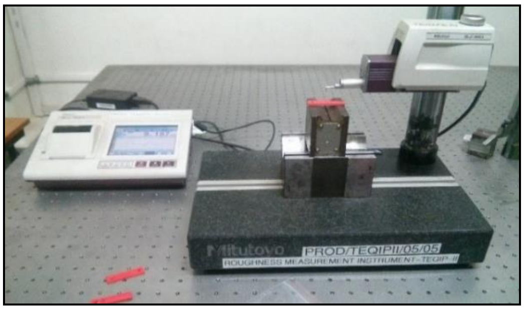

Fig. 02 Roughness measurement

Contact type surface measurement method uses a touch probe type surface roughness measuring machine as show in the above fig 02. Surface roughness (Ra) is described as the roughness average of a surfaces measured as microscopic peaks and valleys. Root Mean Square (RMS) of surfaces is measure of microscopic peaks and valleys.

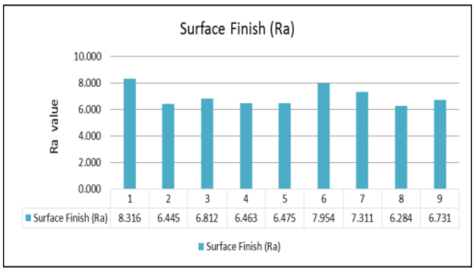

Fig. 03 Roughness values for experiments

It was observed that surface finish varied from 6.2 Ra to 8.3 Ra of the printed samples as shown in figure 03. Experiment 8 was influenced with a solid print pattern and minimum fill spacing of 1mm, hence it showed best surface finish among the other parameters. While experiment 1 has maximum roughness due to the hollow print strength and cross print pattern.

C. Measurement of Tensile strength

Mechanical Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. Plastic tensile dog-bone shaped specimens are made to ASTM test sample dimensions.

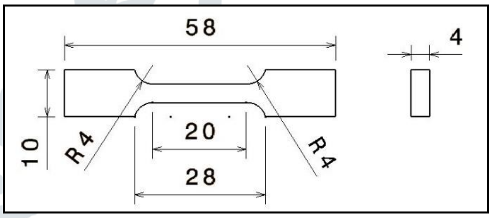

Fig. 04 Standard Dimension of Tensile test specimen

The tensile test was conducted in accordance with ASTM D638 standard of tensile testing for polymers. As per this standard, this test method can be used to test samples upto 14mm thickness. This data is especially useful for the qualitative characterization. The dimensions required for the part to be tested were derived from this standard as shown in figure 04 above.

Fig. 05 UTM setup for Tensile Test

This test was conducted with the help of UTM of 2-Ton capacity (Make: Universal) specifically designed for polymers. Setup is shown in the above figure 05. Whereas figure 06 below shown the break specimens after conducting the tensile test.

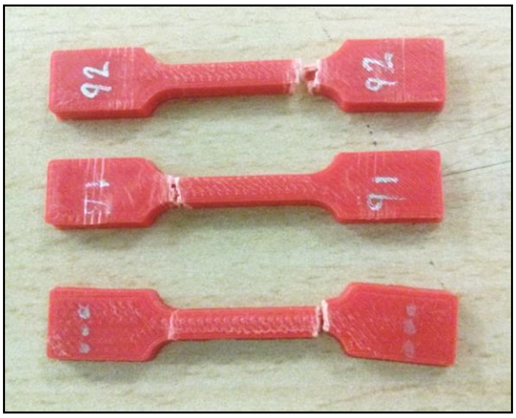

Fig. 06 ABS samples after tensile test.

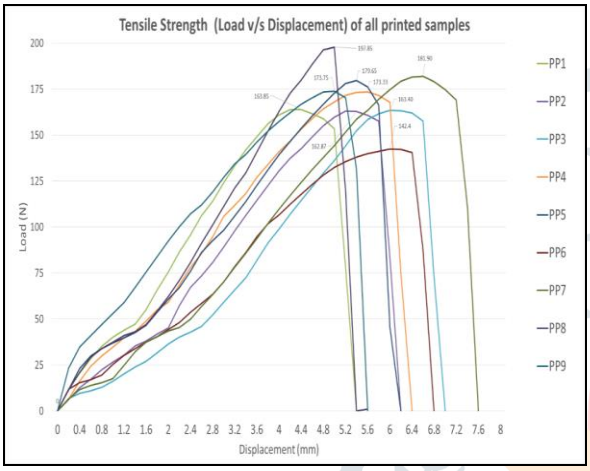

Fig. 07 Load Vs Displacement Curve for experiments.

It is observed form the figure 07 that the printing parameters used in Experiment No 8 showed maximum tensile strength of 12 MPa with an elongation of 22% while Experiment No 6 showed the least tensile strength of 9.38 MPa with elongation of 30%.

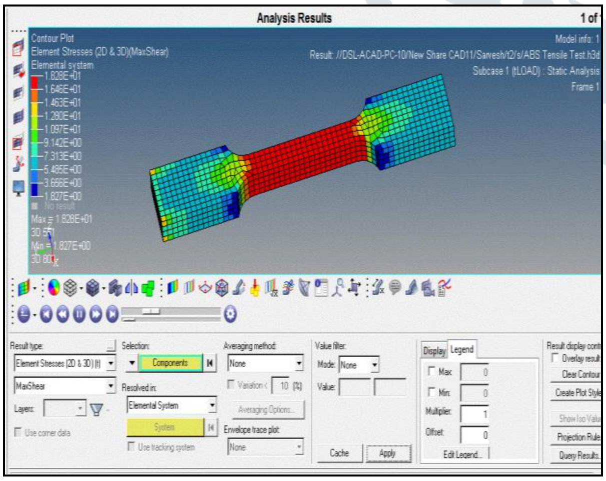

Fig. 08 FEA validation

FEA analysis was performed on the CAD model of the specimens. Experimental values from the tensile test are compared with the FEA values which showed less deviation among them.

D. Measurement of Impact resistance

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. Energy absorber is measured in terms of the materials notch toughness and behaves like a tool to study the temperature dependent ductile-brittle transition.

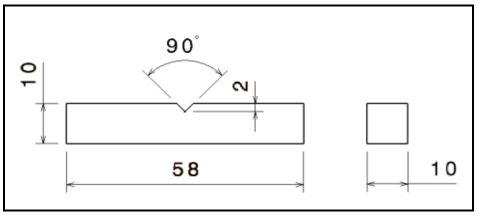

Fig. 09 Specimen dimension for Impact test

Specimens are printed as per the ASTM dimensions shown in figure 09 above in which notch of 90 degree is made at the middle part of the specimen.

Fig. 10 Impact test setup

The Charpy Impact test was performed in accordance with ASTM D256. The readings obtained were then compared with the reference value and the difference was calculated.

Fig. 11 Impact tested sample (partially broken)

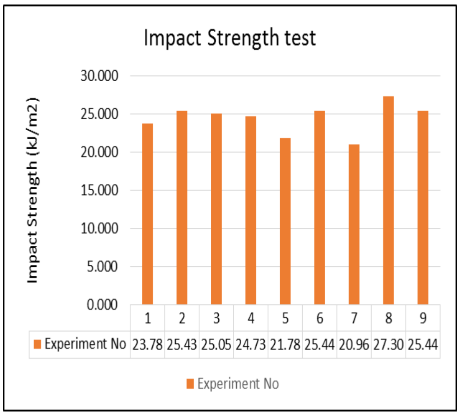

Fig. 12 Impact test results

From figure 11, it was observed that all the samples were partially broken. From figure 12, it shows that Experiment no 8 had the highest impact strength of 27.308 kJ/m2 while the experiment no 7 had minimum impact strength of 20.964 kJ/m2.

E. Metallization of ABS Parts:

Metallizing is the process of plating the surface of non-metallic components for purpose of protection, decoration or functional applications. Coating of ABS parts give improved mechanical properties. The ABS part fabricated through FDM is better than molded ABS parts, as the parts produced through FDM have a higher surface roughness, which is advantageous for depositing the catalysts on the part during the metallization process.

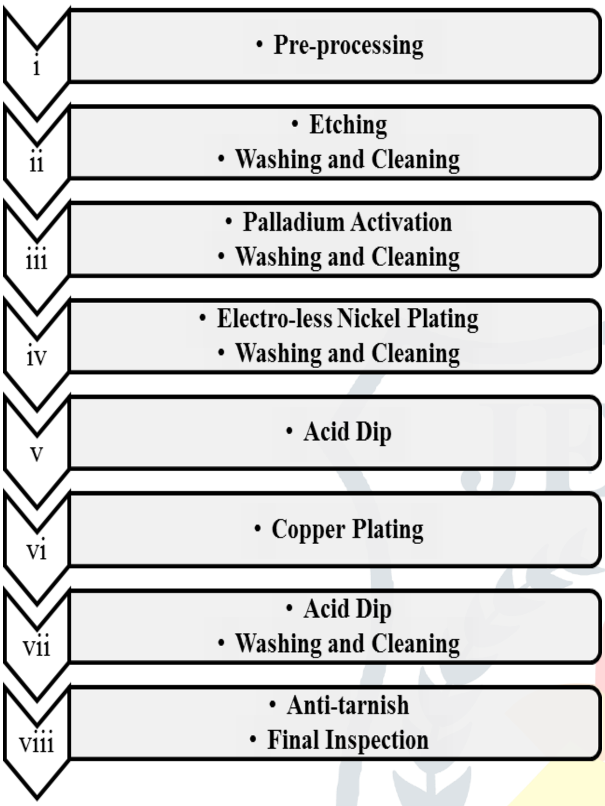

Fig. 13 Flow chart for copper plating process

Copper plating process was carried out following various step mentioned in above figure 13 which involves etching of specimens, washing and cleaning, palladium activation process, electro-less nickel plating , acid dip, later on copper plating then again acid dip and finally with anti-tarnishing.

Sr. No	Desired Thickness	Time	Current Density
1	50 microns	1 hrs. 48 mins	1.4 A/dm^2
2	200 microns	4 hrs. 50 mins	1.4 A/dm^2
3	400 microns	6 hrs. 40 mins	1.4 A/dm^2
4	600 microns	9 hrs. 15 mins	1.4 A/dm^2

Fig. 14 Copper plating of various layer thickness

As above figure 14 shows the different layer thickness of copper plating obtained using same current densities but requires different time span to obtain the desired thickness of layers on ABS parts. At first, all the FDM printed parts were copper electroplated with a film thickness of 50 microns. They were checked for the mechanical and physical properties. It was found out that the experiment no 8 was showing the best results. Hence it's decided further to print number of parts with the parameters used for experiment no 8 and coated these specific samples with 200, 400 and 600 microns to study the effect of plating thickness on the printing parameters.

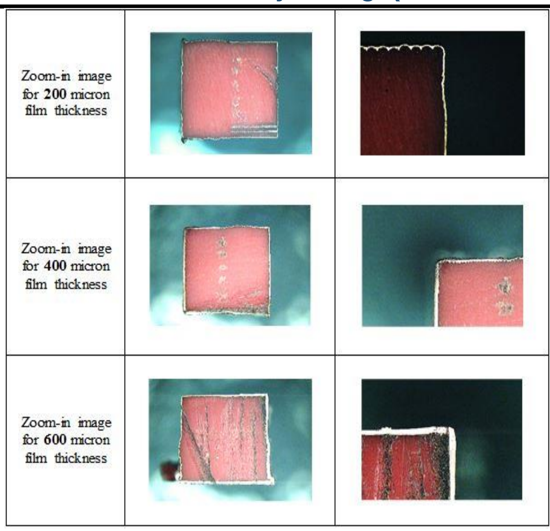

Fig.15 Layer thickness measurement actual images

The plated samples were examined for the plating thickness with the help of a digital microscope as shown in figure 15. The thickness before and after plating was noted and the difference was calculated to be the thickness of the plating on both the sides of the specimen. The results show that, porosity percentage did not have much impact on the film thickness deposition. During the plating process, if the sealing process of the part was carried out properly, there was no difference observed in plating thickness to be achieved. Hence sealing of the part becomes a critical operation while going for the electroplating copper process.

F. Measurement of Micro Hardness:

Micro hardness test are generally used to determine the hardness value of polymer and rubber used for different engineering applications. These test uses indenter to perform the operation of penetration on the test specimen surface and permissible deformations are measured on the setup. Using these values the hardness values are estimated of the test specimens. Micro hardness testing is a well-known non-destructive technique to obtain information on structural features and change in mechanical properties of pure polymers and polymer blends. This test requires an application of force with lesser amount compared with standard measurements. Indentations obtained on the specimen surface are very tiny hence microscopic measurements are used to determine deformations.

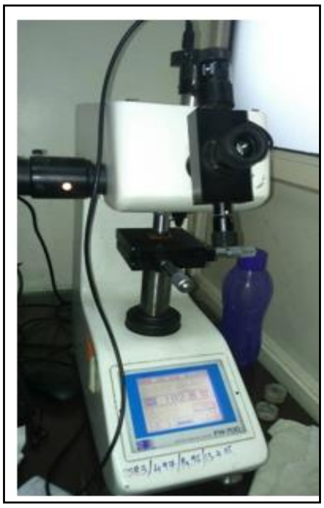

Fig. 16 Micro Hardness Measurement Test setup

Measurement of hardness is performed using the micro hardness test setup as shown in above figure 16. This uses small indenter for penetration and a microscopic digital instrument to measure the surface distortion.

G. Comparison of Parameters :

Comparison of tensile strengths for specimens:

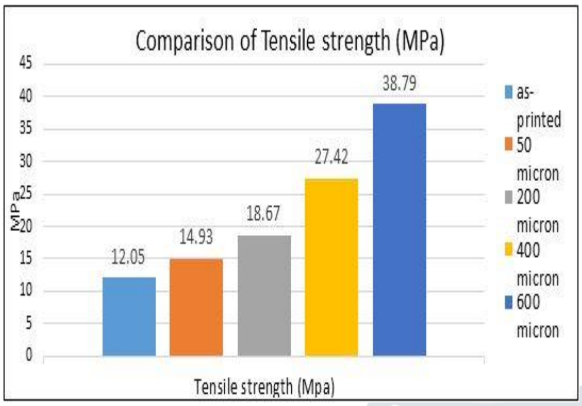

Fig. 17 Comparison of the tensile strength of as printed samples with different copper coated samples.

Fig 18 Sample before tensile test

Fig 19 Samples broke after tensile test

Comparison of impact strengths for specimens:

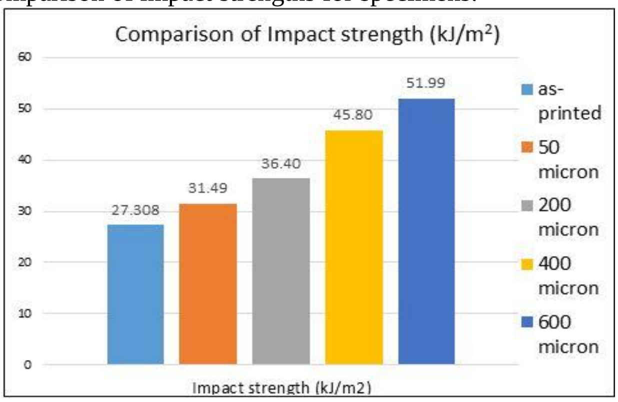

Fig 20 Comparison of impact strength for non-coated and coated ABS parts

Comparison of hardness

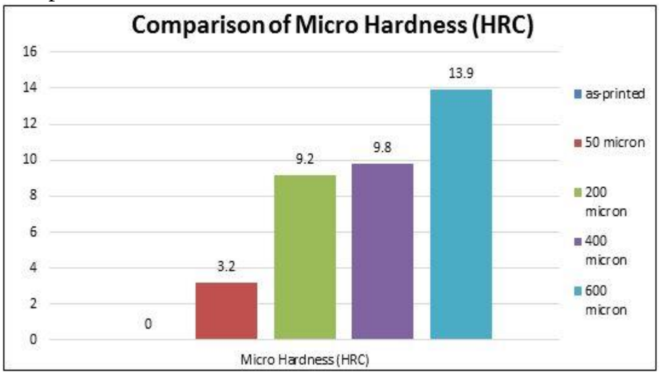

Fig 21 Comparison of Hardness for non-coated and coated ABS parts

Conclusion:

Focusing on the end results it was observed that after coating 600 micron layer of copper over 3D printed specimens, tensile strength is increased by 321.67% , whereas Mirco Hardeness by 139% and Impact strength is increased by 190% than existing properties of as printed specimens. It can be concluded that copper coating provides better option for improvement in mechanical properties of 3D printed parts without considerable variation in weight of parts or going for expensive metal printing process.

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References

[1] Jason T Cantrell, Sean Rohde, David Damiani, Rishi Gurnani, Luke DiSandro, Josh Anton, Andie Young, Alex Jerez, Douglas Steinbach, Calvin Kroese, Peter G Ifju, (2017) "Experimental characterization of the mechanical properties of 3DPrinted ABS and polycarbonate parts", Rapid Prototyping Journal, Vol. 23 Issue: 4, pp 01-20

[2] K.Raja, C.D. Naiju, S.Narayanan, P.A Jeeva, S.Karthikeyan, (2014) Metallization of ABS plastics prepared by FDM-RP process and evaluation of corrosion and hardness characteristics, International Journal of ChemTech Research Vol.6, No.14, pp 5490-5493.

[3] Azhar Equbal and Anoop kumar Sood, (2014) Metallization on FDM Parts Using the Chemical Deposition Technique, Coatings, Vol. 4, pp 574-586.

[4] S.Kannan , D.Senthilkumaran, (2014) Assessment of Mechanical Properties of Ni-coated ABS Plastics using FDM Process, International Journal of Mechanical & Mechatronics Engineering, Vol:14 No:03, pp30-35

[5] S.Kannan, D.Senthilkumaran, (2014) Investigating the Influence of Electroplating Layer Thickness on the Tensile Strength for Fused Deposition Processed ABS Thermoplastics, International Journal of Engineering and Technology, Vol 6, pp1047-1052.

[6] Jiushuai Xu , Ruibin Fan , Jiaolong Wang , Mengke Jia , Xuanrui Xiong and Fang Wang , (2014) Comparative Study of Electroless Copper Film on Different Self-Assembled Monolayers Modified ABS Substrate International Journal of Molecular Sciences, Vol. 15, pp6412-6422

[7] H N Zhang, J Wang, F F Sun, D Liu, H Y Wang and F Wang, (2014) Study of electroless copper plating on ABS resin surface modified by heterocyclic organosilane self-assembled film, Bull. Mater. Sci., Vol. 37, pp. 71–76.

[8] Anoop Kumar Sood , R.K. Ohdar , S.S. Mahapatra, (2010) Parametric appraisal of mechanical property of fused deposition modelling processed parts, Materials and Design, Vol. 31, pp287–295

[9] Anoop Kumar Sood a, R.K. Ohdar b, S.S. Mahapatra, (2009), Improving dimensional accuracy of Fused Deposition Modelling processed part using grey Taguchi method, Materials and Design, Vol. 30, pp4243–4252

[10] Wang Gui-xiang, Li Ning, Hu Hui-li, Yu Yuan-chun, (2006) Process of direct copper plating on ABS plastics, Applied Surface Science, Vol. 253, 480–484