MECHANICAL PROPERTIES AND FREE VIBRATION ANALYSIS OF ELECTROPLATED ABS M30

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ABSTRACT

Improving the mechanical properties of additive manufacturing materials has led to an increase in the use of these materials in industry on an unprecedented scale. Acrylonitrile butadiene styrene M30 (ABS M30) samples were fabricated by the Fused Decomposition manufacturing (FDM) process and then pre-coated with a thin layer of Cr and Cu through the physical vapor deposition (PVD) process. Finally, the samples were electroplated with copper of various thicknesses and an outer nickel layer. Tensile test results showed that with increasing coating thickness, modulus of elasticity, ultimate tensile strength and flexibility increased. The maximum UTS for coated specimens were approximately three times that of uncoated specimens. SEM images of the fracture surface of the specimens after tensile testing showed a decrease in the thickness of the coating due to the plastic deformation of these layers. Lateral vibration of ABS M30 specimens was studied by experimental work and COMSOL program. The effect of coating thickness on the first and second frequencies of the ABS M30 coated sample was not significant compared to its effect on UTS.

KEYWORDS: Fused Deposition Manufacturing, ABS M30, Physical Vapor Deposition, Electroplating, Comsol & Lateral Vibration

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1. INTRODUCTION

Additive manufacturing (AM) is a collection technique used to manufacture parts from computer aided design model. AM produces specialty parts with complex shape at low cost from different materials.[1,2] Fused deposition modeling (FDM) is widely accepted additive manufacturing technique due to use economical machines and variety of materials. The FDM technique uses a heating chamber to melt polymer material that is forced into a heated nozzle as thermoplastic filament. The filament materials are deposited through the nozzle to form successive layers and build a 3D part according to computer aided design model.[3-5]

Mechanical properties of the FDM printed products are important to meet the part quality. Mechanical properties of materials for component formed by FDM should be taken into consideration to create an array structures of desired properties.[6,7,8] Recently many studies were conducted [9-14] in the area of dynamic mechanical properties of FDM printed products for various industries such as aerospace and automotive. Evaluating the dynamic response of FDM parts play important role in understanding the response of the produced parts for long-term applications. Dynamic and vibration analyses are important for the studies of the FDM parts are subjected to dynamic conditions in order to avoid premature failure. Many investigations have already done on ABS and ULTEM materials.

One of the most limitation of fused deposition modeling 3-D printing is the strength characteristics of the FDM products which usually worse in comparison with injection moulding product. In recent years researchers have

attempted [15-20] to improve mechanical properties of manufactured parts such as stiffness, strength, tensile elasticity, and energy absorption. The researchers investigated the effect of process parameter and different type of fillers on the mechanical properties of the FDM products.

Meanwhile, other researchers tried [21-23] to use post processes in order to improve material properties of the FDM parts. Electroplating procedure is one of the post processing used to improve properties of FDM printed products such as stiffness, strength and toughness. FDM parts need to initial plating in order to conductive for electroplating process.

This study presents the effect of the electroplating layer thickness on the vibration response of FDM parts made ABS M30, ULTEM 1010, and ULTEM 9085 materials.

2. FINITE ELEMENT MODELLING

The COMSOL finite element program was used for free vibration of the FDM beams. For this purpose, a beam with dimension of 300×20×5mm were first created. A volume with total surface area of 0.0152m² and center of mass (0.15,0.01,0.0025) for beam model was obtained. The beam was discretized into 8268 elements and 41415 number of degree of freedom as shown in Fig. (1). Cantilever boundary conditions can also be modeled by constraining all degrees of freedoms of the nodes located on the left end of the beam. The material properties for different coated FDM materials were obtained from Experimental works.

Figure 1: The Finite Model of a Beam in COMSOL.

3. EXPERIMENTAL PROCEDURE

The selected material was ABS-M30 provided from 3D-Fabrica company (Turkey). All specimens for tensile and vibration tests are fabricated using fused decomposition manufacturing process (FDM). The number of tensile test specimens was fifty samples in x and y-directions which were made according to ASTM D638 type v. The average number of replicate was considered for each condition was five which gave an acceptable repeatability for each tensile result. The sample for vibration tests was a bar with length =300mm, width=20mm and thickness=5mm. Twenty samples were made from ABS M30 material in x and y directions for vibration test. The samples divided to five groups for coating process as shown in

Table (1). The coating process was performed in two steps. The first step was sputtering physical vapor deposition which applied to pre-coated samples with a thin layer of metals (Cr 30nm and Cu 200nm). All samples pre-coating was performed by FHR Centrotherm Group (Germany). The second stage of coating was electroplating done by Galvano form Company (Germany). All samples electroplated to different layer thickness of Cu and an outer layer of Ni according to Table (1). The tensile properties of all samples were determined using “Karmmrath & Weiss, Dortmund” testing machine with a capacity of 10 KN at the university of Freiberg, Germany. Also, Field emission gun-SEM used to investigate final coating in Freiberg University. The samples were coated with a thin layer of carbon and tested under acceleration voltage of 20 KV. The experimental work of determining natural frequencies performed on the cantilever beam samples which impact hammer type 8206 B&K used to excite printed beams. Module type 3560 B&K with pulse program used to analyze the transmitted data from accelerometer type 4507 B&K mounted on the excited beam. The all vibration tests performed in Salahadd in University (Iraq).

Table 1: Sample Sets for Coating Process

Thickness of Coating (μm)		No of Specimens		
Cu Layer	Ni Layer	x-Direction	y-Direction	z-Direction
0	0	5	5	5
100	2	5	5	0
150	2	5	5	0
200	2	5	5	0
250	2	5	5	0

4. RESULTS AND DISCUSSIONS

Figure (2) shows the ultimate tensile strength measured for specimens with different thickness coating. The thicker coated had higher value of UTS. The samples which manufactured in x-direction show higher UTS than samples in y-direction. The maximum UTS obtained for the 250 μm Copper coating was approximately three times that of the UTS of uncoated samples. These results lead to the fact that the electroplating process with a pre-coated layer of PVD process can give high strength to ABS M30 plastic.

Figure 2: Ultimate Tensile Strength of Samples with Different Coating Thickness.

The tensile test of specimens made in z-direction was performed for coated samples. The results in z-direction

indicated a UTS of 16.3 MPa which was very low compared to the x and y-directions. Manufacturing in z-direction was also very time consuming and costly. For these reasons, the effects of the coating on the Z direction have not been studied.

Figure (3) shows the effect of coating thickness on the value modulus of elasticity. Higher thickness samples show higher value of the Young's modulus. The results of stress-strain diagram of a sample with and without coating in x and y-direction is illustrated in figure (4) - (6).

Figure 3: Modulus of Elasticity for Samples with Different Coating Thickness.

Figure 4: a. Strain-Stress Diagram for Uncoated Samples Made in x-Direction.

Figure 4:b. Strain-Stress Diagram for un-Coated Samples Made in y-Direction.

Figure 5: Strain-Stress Diagram for Coated Samples Made in x-Direction.

Figure 6: Strain-Stress Diagram for Coated Samples Made in y-Direction.

The results showed that with increasing the thickness of the coating, the ductility increases and gave more strain. This leads to a higher modulus of elasticity in the higher coating thickness.

The SEM images of the specimens after tensile test are shown in the figure (7).

Figure 7: a. SEM Image of the ABS M30 Coated with 100 μm Cu and 2 μm Ni.

Figure 7: b. SEM Image of the ABS M30 Coated with 150 μm Cu and 2 μm Ni.

Figure 7: c. SEM Image of the ABS M30 Coated with 200 μm Cu and 2 μm Ni.

Figure 7: d. SEM Image of the ABS M30 Coated with 250 μm Cu and 2 μm Ni.

It is difficult to separate the Ni layer from the Cu layer, but the Cu layer can be easily distinguished from the plastic material. The thickness of the copper and nickel coating appears to have decreased due to the plastic deformation.

Table (2) shows the Young's modulus and Poisson's ratio obtained from the tensile test and used to find the natural frequencies of different samples in the COMSOL program. The Poisson ratio was obtained from the relationship between lateral and longitudinal pressure from the results of the tensile test.

Table 2: Modulus of Elasticity and Poisson's Ratio for Different Samples

Thickness of Cu Coating (μm)	E-x Direction (MPa)	E-y Direction (MPa)	ν -x Direction	ν -y Direction
100	2498	2421	0.43	0.422
150	2814	2782	0.481	0.473
200	3682	3467	0.554	0.547
250	4159	3983	0.57	0.573

Uncoated beam samples in x and y directions were tested for validation of the COMSOL program. The results of the vibration test for the uncoated specimen made in the x direction are shown in figure (8).

Figure 8: a. Experimental Result for First Lateral Frequency**Figure 8: b. Experimental Result for Second Lateral Frequency**

Figure 8-a Experimental result for first lateral frequency Figure 8-b Experimental result for second lateral frequency

The first and second lateral frequencies obtained from Figure (8) for the tested samples were 11 and 75 Hz.

Figure (9) shows the deformation shapes of the cantilever beam for the first and second lateral frequencies.

Figure 9: a. Deflected Shape for First Lateral Frequency.**Figure 9: b. Deflected Shape for Second Lateral Frequency.**

The results of COMSOL program for the first and second lateral frequencies were 11.96 and 74.87. Comparison of the results of the experimental and COMSOL program showed a good agreement. The results were obtained for the samples made in the y direction in the same way as the x direction. The test results were 12 Hz and 78 Hz for the first and second lateral frequencies, respectively. These results also showed good agreement with the results of COMSOL program

which were 12.1 Hz and 80 Hz. Table (3) shows the first and second lateral frequencies for the different samples obtained from the COMSOL program.

Table 3: First and Second Lateral Frequencies from COMSOL Program

Thickness of Cu coating (μm)	f1-x direction (Hz)	f1-y direction (Hz)	f2-x direction (Hz)	f2-y direction (Hz)
100	11.86	11.8	79.75	73.91
150	11.67	11.85	74.27	74.18
200	12.77	12.39	80	77.62
250	12.64	12.64	79.04	79.04

The results of the first and second lateral frequencies showed that the effect of coating on natural frequency was low compared to the effect on UTS and strain of ABS M30 materials.

5. CONCLUSIONS

Tensile results for ABS M30 uncoated specimens showed that the strength and strain of specimens made in the z direction were much lower compared to the x and y directions. Therefore, the coating process in ABS M30 samples, which were made in x and y directions using FDM process, was done in two stages, PVD and electroplating. Coating on the samples increased the Young's modulus, ultimate tensile strength and ductility. The maximum UTS was obtained for coating samples with a thickness of 250 μm copper and a thickness of 2 μm nickel, which was approximately three times the UTS of uncoated samples. SEM images of the fracture surface of the specimens after tensile testing showed a decrease in the thickness of the coating due to the plastic deformation of these layers. The Poisson ratio was obtained from the lateral and longitudinal strains in the tensile test. Young modulus and Poisson ratio data were used in the COMSOL program to find the lateral frequencies of different coated samples. Good agreement has been reached by comparing the results of lateral vibrations from the experimental test and COMSOL program. The effect of coating thickness on the first and second lateral frequencies was not significant compared to its effect on mechanical properties.

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