IMPROVEMENT IN PROPERTIES OF CHROMIUM COATED ABS PARTS

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ABSTRACT

Fused Deposition Modelling (FDM) creates parts with complex designs by extruding layers of polymers, such as acrylonitrile butadiene styrene (ABS) one on top of another. All parts printed using FDM have presented with a rough surface. There are numerous parameters that influence the thermo-mechanical properties of the FDM parts and further study is needed to fully comprehend their inter relationship. Most studies agree on the fact that coating will improve its mechanical properties. However, very few standards have been established. An attempt has been made to coat ABS parts with a chromium based paint in order to determine the significance of the coating. Tests conducted on the coated parts have shown an increase in hardness and impact strength while the surface roughness has reduced.

KEYWORDS: Rapid Tooling, Fused Deposition Modelling, Additive Manufacturing, Surface Roughness, Thermo Mechanical Properties & Chromium Coating

Received: Jun 08, 2020; **Accepted:** Jun 28, 2020; **Published:** Sep 15, 2020; **Paper Id.:** IJMPERDJUN20201253

1. INTRODUCTION

Started during the early 1980s, Rapid prototyping (RP), also called Additive Manufacturing (AM), is a set of processes used to fabricate components directly with the aid of computer-aided design software(CAD). [1]

Additive Manufacturing (AM) is the fabrication of three dimensional physical models by the application of material in successive layers. The models created from AM can range from form-fit prototypes to fully functional test mules and products. The AM processes are used because of their quick turnover time compared to conventional techniques of manufacturing. Their applications range from everyday products like bookmarks to medical implants and aerospace components.

The growth of AM is at such a pace that the creative progress of 3D printing towards design & manufacture of products will constantly produce a variety of new avenues with far reaching capabilities. [1]

These systems are categorised on the basis of build material being used, namely, Liquid, Solid & Powder. The two most commonly used systems are Stereolithography, in which a photosensitive polymer stored in a large vat is cured using lasers to obtain the finished article and Fused Deposition Modelling, where thermoplastic filaments are extruded from a heated tip to create the product one layer at a time. [2]

2. FUSED DEPOSITION MODELLING (FDM)

In FDM, the raw material in the form of filaments is fed through rollers and a heating element so that it melts and the melt is extruded out of nozzles. The first layer adheres to the build platform and all successive layers adhere to the previous ones after which the layer cools and hardens. The motion of the extrusion head, which creates they layers of plastics, is restricted to the XY plane. The build platform will move down by a distance equal to the thickness of

each layer so that the newer layers can be deposited.

An FDM part is akin to a laminate composite, with layers stacked vertically, in its structure and does exhibit similar behaviour in terms of directional properties. The thermo-mechanical properties of the components are not only dependent on varied characteristics of the material used in the filament but also the direction of the build. [3]

2.1. Acrylonitrile Butadiene Styrene (ABS)

FDM is used to fabricate Acrylonitrile Butadiene Styrene (ABS) parts of the highest quality. ABS is a common polymer that allows the user to execute functional tests on trial parts. ABS is an engineering plastic that has butadiene, a monomer for synthetic rubber, distributed uniformly over a matrix of acrylonitrile-styrene. [4]

It retains excellent toughness, easy processing ability, chemical resistance, good dimensional stability and is inexpensive. However, it suffers from intrinsic limitations in terms of mechanical strength.

Furthermore, it is easily fretted and non-conducting. Fretting as per the ASM is the wear experienced by two materials which are in contact at an inter-laminar level and subject to loads & vibrations. Apart from ABS, polycarbonate, PC-ABS thermoplastic, ABS plus thermoplastic, PC-ISO thermoplastic, ABS-M30 thermoplastic, ULTEM 9085, PPSF/PPSU thermoplastic and ABS M30i thermoplastic are also used. [5]

2.2. Rapid Tooling

Rapid Tooling (RT) is a subset of AM, which has a significant impact on the product design & manufacturing process mostly in the plastic processing industry. The cost effective & time efficient nature of AM has proved to be a boon to the tooling industry as it has helped ensure the transfer of technology in the polymer industry. The process of creating tooling straight from CAD models, without intermediate steps is regarded as a significant step in reducing cost & time to market in new product development. It also indicates a substantial shift in the tooling industry. [1]

Vacuum, sand & investment casting along with injection moulding are now commercially using Rapid Casting (RC) through FDM as a means of creating tooling. RP is also now an aid to engineering design, planning, analysis, tooling and manufacturing through the printing of silicone rubber patterns and moulds. [1]

2.3. Characteristics of Finished Parts

The advantage of FDM is the increased freedom of design given to the engineers, as the movement of the extrusion head is controlled using ISO codes similar to CNC codes which have been used for decades. This increased accessibility pushes the capabilities FDM to many new fields of technology [6]

The principle of the FDM process involving three steps, namely, Preprocessing, Production & Post processing.

- Preprocessing: This involves the use of a software tool to slice the 3D .stl (Standard Tessellation Language) file into layers of uniform thickness.
- Production: The extrusion head moves through the build volume and deposits the polymer. If supports are required, the support nozzle, which is part of the extrusion head, deposits an easily breakable or water soluble material on to the build platform.
- Post processing: The operator either removes the support or dissolves it in water with or without a catalyst. [7]

- FDM can print components with plastics that have properties similar to a moulded component. Control over these properties is particularly essential to create products that can be used as prototypes for functional tests. [8]
- Strength – Parts made with ABS have strengths that are 85% of moulded part made with ABS.
- Restricted accuracy – Filament shape (diameter of 1.27 mm) of the material deposition inherently reduces the accuracy of the component built. Some of the newer machines have attempted to overcome these issues through an increased control of the machine parameters.
- Ease of material change – The material used to create the model is supplied in the form of a spool of filament. The machines can also keep track of the amount of material used in every process. These two factors make very easy to have adequate material for printing and reduces the time for material change drastically.
- Surface Roughness – The biggest disadvantage of FDM is the poor surface finish of the printed parts. Roughness is influenced by different parameters viz. part build orientation, layer thickness and raster angle. [9]

Some research has shown that the reduction in layer thickness increases the tensile strength, however, it is more expensive as more material is needed for manufacturing the components.

The orientation of the part being built plays a significant role as noted from the results of a Canadian research group. It was observed that maximum tensile strength is obtained for part orientation laid out to coincide with the direction of tensile loading. [10]

Essentially, many reviews have shown that there are numerous variables that affect the mechanical strength and surface characteristics of the FDM parts and further study is needed to provide greater clarity in the matter. [11]

3. TESTING OF PRINTED PARTS

3.1: Sample Preparation

The first step in creating a procedure to improve the surface characteristics & properties of a 3D printed ABS part is to prepare samples for testing. It starts with a 3D model which is converted into STL (Standard Triangulation Language) file format in the CAD software. This format represents a 3D surface as an assembly of planar triangles. The file is imported into a pre-processing software. The pre-processing software calculates sections and slices the part design into number of horizontal layers, determines the amount of build and support material required for the part and orientation of the part on worktable. On the basis of part geometry and position, the support structure is created as needed.

The tool path or part printing instructions are generated by software. The FDM nozzle head follows the instructions from the software while printing the parts. All the samples are printed in accordance with the tests that need to be performed.

Shore D Hardness test for plastics requires the samples to be printed as per ASTM D2240 (length of 25.4 mm, width of 12.7 mm & thickness of 6.4 mm)

Izod Impact test for plastics requires the samples to be printed as per ASTM D256 (length of 63mm, width of 12.7 mm, thickness of 3 mm & depth after the notch of 10.16 mm). The notch is created using a notch cutter after printing. Samples for the evaluation of surface roughness can be printed using either of the above standards.

All ABS specimens were printed using Statasys uPrint SE_{plus}. All samples were printed along x-direction. Statasys

uPrint SE_{plus} is set to print the samples at a temperature of 300 °C, 0.254 mm layer thickness and 45°/-45° raster angle. In order to vary parameters during pre-processing, an open source software is used. The temperature is changed to 280°C and 290°C and layer thickness is increased to 0.330 mm with the help of the software. The samples were printed along required orientation in different sets for various tests.

3.2: Coating of FDM Parts

In order to change the surface properties, the functional coating may be applied on the substrate of the material. The coating material is either used to improve the inherent property of the substrate or provide a characteristic that the substrate never had.

In this study, a chromium based paint is used to spray on to the substrate of ABS parts because:

- It is tough & can be applied on a non-conductive material like ABS without any preparatory treatment.
- It is versatile because it can be coated on surfaces like wood & glass.
- It is eco-friendly as it contains fewer toxins and is often water based

Coating Procedure

- **Step 1:** The painting process starts with removing dirt with a clean cotton cloth by wiping the surface.
- **Step 2:** Once the area is dry and clean, a polyurethane primer is applied on the surface with the help of a spray gun without making the layer too thick and allowed it to dry for some time.
- **Step 3:** After the part has dried, a putty (a powdered material applied to smoothen the base) is applied on the layer of primer. It is then allowed to dry for one hour.
- **Step 4:** Next step is to spray another layer of primer, before which sanding is done slowly to further avoid the peaks and valleys obtained after the putty is dried. Another layer of primer is sprayed to get a very bright surface finish and allow it to dry for another half an hour. All the above steps are done in room temperature and there is no requirement to change the temperature.
- **Step 5:** The part is then sprayed Krylon Premium Chrome paint. Spraying is done with the help of spray gun which is held 10 inches away from the surface of the part being sprayed. Once the coating is complete, the painted part is kept for 24 hours in an oven maintaining a temperature of 50 °C.

Figure 1: Uniform Chromium Coating on FDM 3D Printed Part.

The figure 1 shows FDM parts with a uniform coating of chromium required for testing and comparison. The thickness obtained is around 0.25 mm. Different sets of samples with different parameters were coated to test for strength and to study the surface properties. Figure 2 shows the set of samples coated to test and compare it with uncoated samples.

Figure 2: Different set of Samples Coated with Chromium Paint.

3.3: Impact Tests

The impact testing of ABS parts was conducted on Izod Impact testing machine by engaging a specimen mounted vertically. The material is subjected to a load from a weighted pendulum hammer striking the notch

Figure 3: Breaking of Specimen after the Application of the Impact Load.

Impact energy was determined and the results are conveyed in terms of energy absorbed per unit of thickness at the notch or Impact strength of unit J/m. Figure 3 shows the broken specimen after the application of load from the weighted pendulum hammer.

Apparatus used: Testing Machine: International Equipment, Impact Energy of 0 to 25 joules, and Range of scales: 0 to 5.42 J, 150° Release angle of pendulum, Hammer: R2 (Hard chrome plate).

The printed parts were tested for Impact Strength as per ASTM D256 under different conditions of temperature, layer thickness and coating. The results obtained are shown in tables 1 & 2

Table 1: Impact Test Results for Uncoated Samples

Sl No.	Temp. (°C)	Layer Thickness(mm)	Impact Energy (J)	Angle	Impact Strength (J/m)
1	300	0.254	0.35	138	116.6
2	300	0.330	0.32	139	106.6
3	290	0.330	0.3	142	100
4	280	0.330	0.22	143	73.3

Table 2: Impact Test Results for Coated Samples

Sl No.	Temp. (°C)	Layer thickness(mm)	Impact Energy (J)	Angle	Impact Strength (J/m)
1	300	0.254	0.4	137	133.3
2	300	0.330	0.4	137	133.3
3	290	0.330	0.22	143	73.3
4	280	0.330	0.20	145	66.6

The bar chart in figure 4 provides a comparison in terms of impact strength for different test samples. The highest Impact strength (133.3 J/m) is obtained in components printed at 300°C, with 0.254 mm layer thickness and with a coating of chromium.

3.4: Hardness Tests

Figure 4: Chart Showing Values of Hardness Under Various Conditions of Temperature, Layer Thickness and Coating.

The most common measuring test for hardness of plastic is Shore (Durometer) test. The preferred hardness test method is the Shore Hardness which uses either Shore A or Shore D scale for elastometers or rubbers and softer plastics like vinyls, fluropolymers and polyolefins. Shore D & A scales are used for harder & softer plastics respectively.^[12]

Figure 5 shows the instrument measuring the hardness of the coated specimen. Apparatus: Testing Machine: Durometer, Spring Power: 4450 cN, Indenter: Truncated cone 30°, Measuring Distance: 3 mm, Measuring Range: 0 to 100. The printed parts were tested for hardness as per ASTM D2240 under different conditions of temperature, layer thickness and coating.

The results obtained are shown in tables 3 and 4.

Table 3: Hardness Test Values for Uncoated Samples

Sl No.	Temp. (°C)	Layer Thickness(mm)	Trials					Average
			1	2	3	4	5	
1	300	0.254	69	70	70	70	70	69.6
2	300	0.330	66	65	63	68	67	65.8
3	290	0.330	65	62	61	62	64	62.8
4	280	0.330	58	63	59	61	57	59.6

Table 4: Hardness Test Values for Coated Samples

Sl No.	Temp. (°C)	Layer Thickness(mm)	Trials					Average
			1	2	3	4	5	
1	300	0.254	73	71	69	71	72	71.2
2	300	0.330	70	68	71	68	70	69.4
3	290	0.330	67	69	68	66	69	67.8
4	280	0.330	59	64	65	64	65	63.4

The chart in figure 6 shows that the highest hardness (71.2) is obtained in components printed at 300°C, with 0.254 mm layer thickness and with a coating of chromium.

Figure 5: Measuring the Hardness of the Coated Specimen. **Figure 6: Chart Showing Values of Impact Strength under Various Conditions of Temperature, Layer thickness and Coating.**

3.5: Measurement of Roughness

The roughness is measured with the instrument called Metrix Microsurf Surface roughness tester. It is a portable device which measures the surface roughness very quickly, and gives the values in terms of average and depth. It consists of a probe which contacts the surface of the part and communicates with a computer as shown in the figure 7.

Apparatus: Testing Machine: Mertix Microsurf (Portable surface roughness tester), Stylus tip: Diamond 900/5 μmR , Measuring range: 0.25, 0.5, 0.75 mm/s, 1 mm/s (returning), Power supply: 230 volts single phase 50Hz AC, Evaluation parameters: R_a , R_c , R_y , R_z , R_t , R_{max} , R_p , R_v , RSM

Figure 7: Measuring the Roughness of the Uncoated Specimen.

The results obtained are shown in tables 5 and 6

Table 5: Roughness Values for Uncoated Samples

SI No.	Temp. ($^{\circ}\text{C}$)	Layer Thickness(mm)	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
1	300	0.254	0.491	1.39	0.489	1.404
2	300	0.330	0.506	1.432	0.503	1.446
3	290	0.330	0.518	1.467	0.513	1.481
4	280	0.330	0.531	1.501	0.526	1.516

Table 6: Roughness Values for Coated Samples

SI No.	Temp. ($^{\circ}\text{C}$)	Layer Thickness(mm)	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
1	300	0.254	0.247	0.7	0.245	0.706
2	300	0.330	0.258	0.731	0.255	0.739
3	290	0.330	0.345	0.975	0.342	0.985
4	280	0.330	0.375	1.061	0.373	1.072

The lowest value for surface roughness, 0.247 μm , is obtained in components printed at 300 $^{\circ}\text{C}$, with 0.254 mm layer thickness and with a coating of chromium. The bar chart in figure 8 provides a comparison between the roughness values at different condition.

Figure 8: Chart Showing Values of Roughness under Various Conditions of Temperature, Layer Thickness and Coating.

4. CONCLUSIONS

This study provides an insight into the impact of build parameters on the mechanical properties & surface characteristics of ABS parts printed using FDM additive manufacturing technology. The optimum blend of parameters that exhibit an improvement in surface quality have been determined.

The tests for hardness & impact strength and measurement of surface roughness have revealed that build temperature, layer thickness and secondary surface treatment has influenced the performance of the printed ABS parts. Build temperature directly correlates to the impact strength of the part. The hardness value decreases as the temperature decreases irrespective of the layer thickness but increases with the introduction of surface coating. When the samples are coated, the R_a reduces to 50% compared to the uncoated parts. The surface roughness is better if the layer thickness 0.254 mm compared to that of 0.330 mm.

It is evident that at a build temperature of 300°C, with a layer thickness of 0.254 mm will provide the best possible output from pre-processing conditions. Across the board, the components have performed better when they have been coated with the chromium based paint indicating that it may be essential for rapid tooling applications

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