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A Review on Effects of Post-Processing on Mechanical Properties of Additive Manufactured Part

Chetan D. Pethe¹, Rajendra S. Dalu²

¹M. Tech. (Production Engineering) Student, Government College of Engineering, Amravati, Maharashtra, India

²Principal, Government College of Engineering, Amravati, Maharashtra, India

Abstract: Additive manufacturing (AM) is the most advance manufacturing technique, where material is deposited in layer-by-layer manners to manufacture a three-dimensional part directly from a computer-aided design model. There are different additive manufacturing techniques available both metal and non-metal, about 60% of market share covered by a thermoplastic-based additive manufacturing, in that fused deposition modeling (FDM) is a most famous and flourishing technology. A biggest challenge for additive manufacturing parts (especially for parts made by FDM) in engineering applications is the weak inter-layer bonding. The weak of bonding between layers is usually results in poor mechanical properties. Researchers work continuously on the improvement of mechanical properties in three different stages additive manufacturing. First is pre-processing of AM material, second is in-process parameter, and third is post-processing of additive manufactured parts. This review paper discuss about different post-processing techniques of additive manufactured part. Also, discuss about the literature regarding effects post processing on mechanical properties of additive manufactured parts such as tensile, flexural, compressive and impact.

Keywords: Additive manufacturing, Post Processing, Mechanical Properties.

I. INTRODUCTION

Additive Manufacturing (AM) or else widely known as three-dimensional (3D) printing, is a manufacturing process that uses a computer aided design model to manufacture a part. As the technology has matured over the last 25 years and currently there are many different technologies available, however they all share one same basic characteristic; they all create a 3D object by adding material to the final-product layer by layer.

Today, Additive Manufacturing is used to make jigs and fixtures, casting patterns, tooling and an ever-increasing array of low volume, high value component parts. Additive Manufacturing provides manufacturers with practically endless flexibility, which is important towards business success in this competitive age.

Although additive Manufacturing seems to be a great option to overcome the imperfection possessed by conventional techniques, but the main weakness dealing with additive Manufacturing is that it is not possible to match the mechanical properties of conventional manufactured products due to the poor bond adhesion between layers. Also final mechanical properties of parts manufacture by means of the additive manufacturing are often uncertain, since they are influenced by a large amount of production parameters, which are really difficult to control in order to increase the strength and the stiffness of the parts. As a result, the practical application of components processed by the additive manufacturing is limited to low-loaded products and to those whose failures do not lead to severe effects.

AM is currently used in many applications. For instance, among other, AM is widely used in medical applications, aerospace, automotive industry, construction, cultural heritage and fashion. It is potential to expand its use in many other fields in the near future. Its ability to fabricate different-different products without high initial cost, its relatively high speed compared to other traditional processes and in this age industry needs mass customisation. This mass customisation is the strong point of this technology ideal for several fields and applications.

It has been observed that majority of the research work carried out is focused on the study of effect of the process parameter on mechanical properties of additive manufactured part. Less work has been reported on effect of post processing on mechanical properties. The main objective of the present study is to review the effect of post processing on mechanical properties, mainly tensile, compressive, flexural and impact of the additive manufactured parts.

II. MATERIALS AND METHODS

A. Raw Materials

Polymers are considered as the most commonly used materials in the AM industry due to their diversity and ease of adoption to different AM technique. Polymers for additive manufacturing are available in different the form such as filaments, reactive monomers, resin or powder. The capability of developing additive manufactured part of polymers and composites has been explored for several years in many industrial applications, such as the aerospace, automobile, toy fabrication and medical fields. Also, this process can be more cost-effective than other traditional manufacturing technique, such as moulding and extrusion for customised products. On the other hand, pure polymer products manufactured by AM are only often used for conceptual prototypes due to the inherent lack of mechanical properties and functionality. Fused Deposition Modeling (FDM) is most commonly used for the fabrication of polymer and thermoplastics with low melting points. On-going research aimed at resolving the inferior mechanical properties of additive manufactured polymers has been conducted, which led to the development of various methods and materials for manufacturing advanced polymer composites with better performance. However, eco-friendly polymeric materials with good physical properties are of major concern for additive manufacturing, such as ABS and PLA. ABS has good mechanical properties but emits unpleasant odour during processing whereas PLA is environmentally friendly but has poor mechanical properties.

B. Additive manufacturing

There are many different Additive manufacturing techniques. The best known techniques are: Selective Laser Sintering (SLS), Stereolithography (SLA), and Fused Deposition Modeling (FDM). The SLS technique functions by repeatedly feeding a layer of powder on a powder bed. The form of the product is created by putting the laser on a selection of the powder bed. SLA functions by curing resin using a UV-laser, creating a product layer after layer. FDM is the most popular contemporary technology to create products.

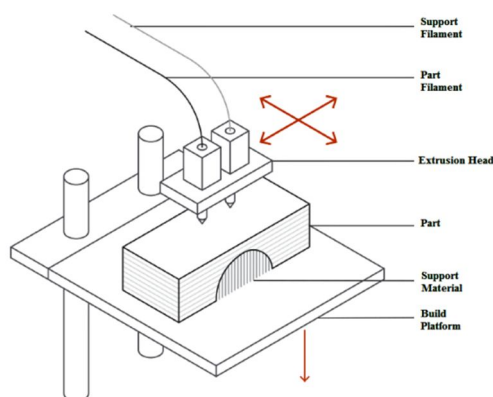


Figure 1: - Schematic of a typical additive manufacturing (FDM) Technique

Fused Deposition Modeling (FDM), or Fused Filament Fabrication (FFF), is an additive manufacturing process that belongs to the material extrusion family. And it was developed by Stratasys in 1992, is one of the most famous and flourishing Additive Manufacturing technique. In FDM, an object is built by selectively depositing melted material in a pre-determined path layer-by-layer, as shown in figure 1. The materials used are thermoplastic polymers and come in a filament form. FDM is the most widely used additive manufacturing technology: it represents the largest installed base of additive manufacturing technology globally and is often the first technology people are exposed to.

Here is how the FDM fabrication process works:

- 1) A spool of thermoplastic filament is first loaded into the printer. Once the nozzle has reached the desired temperature, the filament is fed to the extrusion head and in the nozzle where it melts.
- 2) The extrusion head is attached to a 3-axis system that allows it to move in the X, Y and Z directions. The melted material is extruded in thin strands and is deposited layer-by-layer in predetermined locations, where it cools and solidifies. Sometimes the cooling of the material is accelerated through the use of cooling fans attached on the extrusion head.
- 3) To fill an area, multiple passes are required. When a layer is finished, the build platform moves down and a new layer is deposited. This process is repeated until the part is complete.

C. Post Processing

Post-processing is applied to additive manufactured parts to improve the mechanical strength of materials. Poor layer bonding and layer delamination is the biggest challenge of additive manufactured parts. Thus post-processing to improve layers bonding is important. Meng Zhang et al. [14] demonstrated that microwave treatment on FDM printed ABS helps to fuse layers together, and therefore layer adhesion becomes stronger. Shaffer et al. [8] developed a method to improve the inter layer bonding between the layers by exposing 3D-printed co polymer blends, using radiation specific sensitizers, to ionizing radiation. In its website, 3D Hubs details several post-processing methods for FDM-printed parts, namely: Support Removal, Sanding, Cold welding, Gap filling, Polishing, Priming & painting, Vapour smoothing, Dipping, Epoxy coating, and Metal plating. David Impens, R. J. Urbanic [5] performed infiltration treatment on FDM manufactured samples. Branka Lozo et al. [9] also performed infiltration treatment on FDM. Guiwei Li et al. [6] applied ultrasonic strengthening treatment under static pressure on FDM manufactured samples. Radoslaw A. Wach et al. (2018) [11] performed thermal annealing on FDM samples. In thermal annealing sample were subjected to thermal treatment in the DSC furnace. S.Kannan et al. [13] studied the influence of electroplating on the impact property of ABS material developed by Fused Deposition Modeling (FDM).

III. LITERATURE REVIEW

Literature review provides effect of post processing parameter on additive manufactured. In this review paper selected research related to post processing and its effect on four different mechanical properties, i.e. tensile, compressive, flexural and impact properties. The effect of post processing on each properties explained brief below.

A. Tensile Properties

Tensile properties indicate how the material will react to forces being applied in tension. It is most important properties in case of engineering design. In the most of literature tensile strength of manufactured part tested. A tensile test is a fundamental mechanical test where a carefully prepared specimen as per different standard. Most of the literature follow ASTM standard for testing.

David Impens & R. J. Urbanic prepared tensile test specimens of ABS material with help of FDM technique. Then they performed infiltration post process treatment on those specimens. In that they submerge specimens in the infiltrate (polyurethane, cyanoacrylate, Epsom salt, and epoxy) for an allotted length of time, and allowed to fully cure. This process increased tensile strength over 50% than without infiltrated specimens [5].

Branka Lozo et al. fabricated standard sized samples for the tensile properties test on the Z Corporation/Contex Spectrum Z510/Cx machine. The parts were made with the Zp130 high performance composite material⁶ and Zb58 binder. Then samples were finished with the low viscosity epoxy, cyanoacrylate and polyurethane infiltrant. The epoxy infiltrated samples shows better tensile strength than cyanoacrylate agent, and polyurethane infiltrant. The epoxy infiltration agents improve tensile strength 5.23 times when compared to the non-post process sample measurement result [9].

Guiwei Li et al. used FDM technique for manufacturing of samples. The printing material was ABS and the support material was SR-30 soluble support. The printing layer thickness was 0.254 mm, the printing speed was 15 mm/s, and the interior of the sample was completely filled. Then ultrasonic strengthening operation performed under static pressure, the ultrasonic vibration system transfers ultrasonic vibration energy to the internal parts of the additive manufactured sample, and then transforms into the friction energy of the internal bond of the sample. The friction energy is transformed into heat energy and deformation energy in the process of ultrasonic strengthening, so as to realize fusion of broken raster. Ultrasonic strengthening after FDM 3D printing significantly improves the tensile mechanical properties by 11.3% of the sample and it broadens the potential applications for FDM 3D printing technology [6].

Meng Zhang et al. made specimens with help of fused deposition modeling (FDM) technique. For microwave irradiation effects, they embedded carbon nanotubes into acrylonitrile butadiene styrene (ABS) thermoplastics via a filament extrusion process. The vigorous response of carbon nanotubes to microwave irradiation, leading to the release of a large amount of heat, is used to melt the ABS thermoplastic matrix adjacent to carbon nanotubes within a very short time period. This treatment is found to enhance the inter-layer bonding without deformation the additive manufactured parts. Microwave irradiation resulted in over 30% increase in tensile strength over that without microwave irradiation [14].

Steven Shaffer et al. prepared samples as per ASTM D638 Type V of PLA material with the help of fdm technique. Each polymer sample was dosed with gamma radiation at varying temperatures 0°C, 20°C, 40°C and 60°C at a dose rate of 10.05 kGy per hour during irradiation. The samples irradiated at 60°C shows greater than 50% increase in tensile strength than not irradiated [8].

B. Flexural Properties

Flexural strength, also known as modulus of rupture or bend strength is a mechanical property for brittle material and is defined as a material's ability to resist deformation under load. With ever increasing demand for high quality and reliable components and materials, flexural tests have become an important test method in both the manufacturing process and research and development to define a material's ability to resist deformation under load. Hence following researcher work on the improvement of flexural strength of additive manufactured. Wenzheng Wu et al. manufactured flexural samples using FDM technique. The forming material was ABS material. They used a customized ultrasonic strengthening system to strengthen the additive manufactured samples. It was found that ultrasonic strengthening increased the bending strength of ABS samples by 10.8% [7].

Meng Zhang et al. manufactured specimens with help of fused deposition modeling (FDM) technique. For microwave irradiation effects, they embedded carbon nanotubes into acrylonitrile butadiene styrene (ABS) thermoplastics via a filament extrusion process. The vigorous response of carbon nanotubes to microwave irradiation, leading to the release of a large amount of heat, is used to melt the ABS thermoplastic matrix adjacent to carbon nanotubes within a very short time period. Microwave irradiation resulted in over 13.1% increase in flexural strength over that without microwave irradiation [14].

Radoslaw A. Wach et al. manufactured flexural test samples by fused deposition modeling (FDM). They performed thermal annealing on FDM samples to enhance flexural properties. In thermal annealing sample were subjected to thermal treatment in the DSC furnace. The temperature of annealing ranged from slightly above glass transition temperature, that is, 65°C, up to 95°C. The thermal annealing increase in the degree of crystallinity of FDM samples, results in improvement in flexural properties of the samples by 11–17% [11].

C. Compressive Properties

Compressive properties describe the behaviour of a specimen when it is subjected to a compressive loading at a relatively low and uniform rate of loading. In spite of numbers of applications of plastic products that are subjected to compressive loads, the compressive strength of plastics has limited design value. Compressive properties include compressive strength, yield stress, compressive strain, deformation beyond yield point, modulus of elasticity and slenderness ratio.

David Impens, R. J. Urbanic prepared tensile test specimens of ABS material with help of FDM technique. Then they performed infiltration post process treatment on those specimens. In that they submerge specimens in the infiltrate (polyurethane, cyanoacrylate, Epsom salt, and epoxy) for an allotted length of time, and allowed to fully cure. The infiltrated specimens resulted in increased in compressive strength over 70% that over non-infiltrated [5].

C.S. Lee et al. used FDM technique for manufacturing of samples and nano composite deposition treatment to improve compression strength. In that treatment, they deposited nano composite into 10–100µm thin layers to form a near-net-shape on every layer. Then net shape of the current layer was obtained by micro machining. By repeating the deposition and machining for each layer, final three-dimensional part with certain height. The FDM Nano composite deposition sample showed compressive strength of 23.6% higher than that of the non process specimen [10].

D. Impact Properties

Impact resistance is most important property for component designers to consider, and the most difficult to enumerate. Impact resistance of a material or a product is considered to be an important area for the product safety and accountability. Hence following researcher studied effect of post processing on impact strength. Branka Lozo et al. fabricated standard sized samples for the tensile properties test on the Z Corporation/Contex Spectrum Z510/Cx machine. The parts were made with the Zp130 high performance composite material and Zb58 binder. Then samples were finished with the low viscosity epoxy, cyanoacrylate and polyurethane infiltrant. The epoxy infiltration agents improve Impact strength 3.86 times when compared to the non-post process sample measurement result [9].

S.Kannan et al. studied the influence of electroplating on the impact property of ABS material developed by Fused Deposition Modeling (FDM). The impact test conducted on a specifically designed drop impact tester. The drop weight impact tests are carried on the normal and electroplated specimens (60 µm, 70 µm and 80 µm). 80 µm impact test specimens have shown an increase of 243%, followed by 70 µm specimens with an increase of 147 %. The 60 µm specimens have shown a decrease of 25% in strength. This indicates that the higher coating thickness has increased the impact resistance of FDM-ABS materials [13].

Claire Benwood et al. performed thermal annealing on FDM manufactured samples. Thermal annealing treatment enhanced the crystallinity by 37%, resulting in an increased in the impact strength increased by 80% than non-post process of FDM manufactured samples [12].

IV. CONCLUSIONS

From literature review it is understood that post processing treatment has a largely affect the mechanical properties of additive manufactured parts (especially for parts made by FDM). Observation made from literature review is as describe below

- A. Application of Infiltration, Ultrasonic strengthening, Microwave, Irradiation and ionizing radiation treatments improve the tensile strength of additive manufactured parts by 10% to 50%.
- B. Infiltration and Nano composite deposition treatments improve the compressive strength of additive manufactured parts by 23.6% and 70% respectively.
- C. Ultrasonic strengthening, Microwave irradiation and Thermal Annealing treatment improve the flexural strength of additive manufactured parts by 10% to 20%.
- D. Electroplating, Infiltration and Thermal Annealing improve the impact strength of additive manufactured parts by 80% to 200%.
- E. Post processing treatments improve inter layer bonding.

Finally from various research papers, it is concluded that post processing treatment overcome the weakness of additive manufactured parts. In this review paper, the main focus place on the technique which is used to improve mechanical properties of additive manufactured parts.

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