

Effect of Parameters on Mechanical Properties of a Part Fabricated using Additive Manufacturing Processes

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Abstract:- In Additive manufacturing process part is built by adding layers of material instead of removing unwanted material as in other manufacturing processes. Mechanical properties of the parts made through additive manufacturing are very important for the functional use of the parts. The properties are greatly influenced by the various process parameters of the manufacturing process; therefore to get desire properties one should have proper control on these parameters. This paper summarizes the effect of process parameters on mechanical properties of parts built using different additive manufacturing processes.

Key words

Additive Manufacturing, Rapid Prototyping, Mechanical Properties, Process Parameters

Introduction

Each product that we use is made by some manufacturing process. With rapid growth in engineering a new group of manufacturing processes has been evolved, in which the part is made by adding layers instead of subtracting the unwanted material from a lump. In additive manufacturing processes the desired shape and size is obtained by deposition of layers contoured in x-y plane and the third dimension z results from single layers being stacked up on top of each other [1]. All additive manufacturing (AM) processes are also known by the names rapid prototyping (RP), additive fabrication, digital manufacturing, three dimensional printing, rapid manufacturing, solid freeform fabrication (SFF) and layered manufacturing. If this process occurs in the R&D stage, it is called rapid prototyping [2 cited by 3].

The mechanical properties of produced parts are important in the area of rapid prototyping, in that the prototype must have sufficient mechanical integrity and surface quality for handing and demonstration purposes. Mechanical properties become critically important in the area of rapid manufacturing where the stiffness, strength, and surface finish must be sufficient to meet in-service loading and operation requirements, and where they must be comparable to those produced using traditional manufacturing routes to make the RP based processes competitive [4].

Additive Manufacturing Processes

According to Kruth [5], the material accretion processes may be divided by the state of the prototype material before part formation.

1. Liquid-based processes
2. Powder-based processes
3. Solid-based processes

The liquid-based technologies may entail the solidification of a resin on contact with a laser, the solidification of an electro setting fluid, or the melting and subsequent solidification of the prototype material. The processes using powders compound them either with a laser or by the selective application of binding agents. Those processes which use solid sheets may be classified according to whether the sheets are bonded with a laser or with an adhesive. AM processes according to state of aggregation of their original material and is given in figure 1[1].

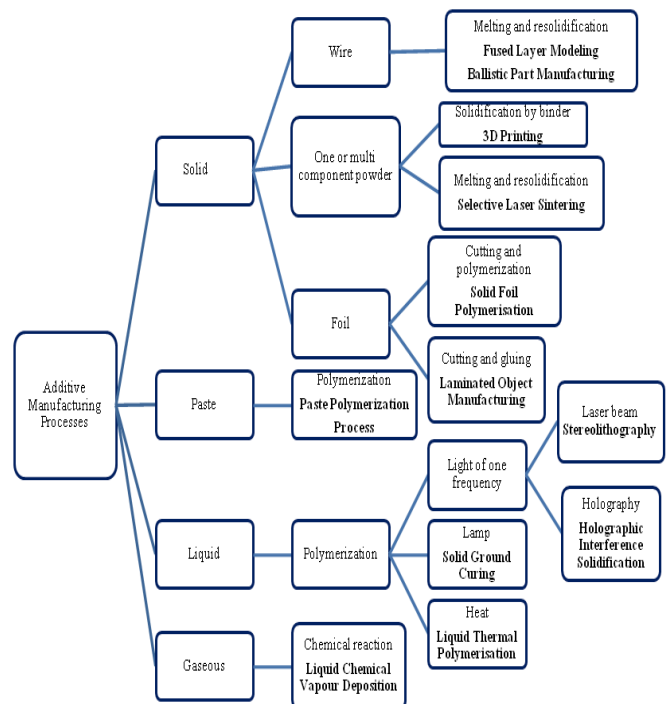


Fig. 1 Classification of AM Processes [1]

Mechanical Properties of AM Parts

The properties of AM parts are function of various process related parameters and can be significantly improved with proper adjustment. Since mechanical properties are important for functional parts, it is absolutely essential to study influence of various process parameters on mechanical properties so that improvement can be made through selection of best settings [6]. The various important process parameters influencing the mechanical properties of AM part are layer size, layer deposition angle, layer solidification mechanism, curing time, energy density, binding saturation, build direction, etc.

Using the fabricated samples by a Stratasys Fused Deposition Modeling (FDM) machine with different layer orientations viz 0°, 45/-45°, 45°, 90°, and 45/0° orientations as shown in fig. 2., It is investigated that the 0° orientation where layers were deposited along the length of the samples displayed superior strength and impact resistance over all the other orientations [7].

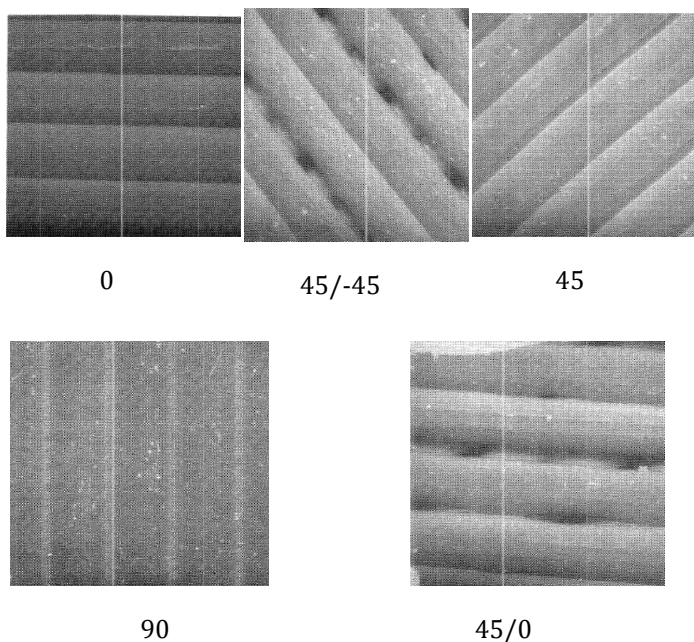


Fig. 2 Orientations for Model [7]

It has been shown that the addition of just a single layer of fibrous material, in a mat/veil form, in an acrylic-based photopolymer can increase significantly the elastic modulus and the mechanical strength of the SL built prototype, compared to its pure resin counterpart [8]. On the other hand, the mechanical properties did not improve significantly when thicker glass fiber mat reinforcements were introduced into an epoxy-based photopolymer. Both studied reinforced resin materials behaved under tensile loading linearly up to fracture, exhibiting lower elongation to fracture than their pure resin counterparts [9].

In SLS process energy density (ED) has major influence, compared to other process parameters, on the physical and mechanical properties of parts produced. It was observed that at lower ED levels the parts are porous, weak and anisotropic, but become more isotropic, solid and stronger as the ED level increases [4]. As a result, it is recommended that no parts should be built under an ED level of 0.012 J/mm².

The study made using CIBA TOOL 5530 in SL 5000 machine to analyze effect of three important parameters viz layer thickness, post-curing time and orientation on tensile, impact, flexural strength. It was shown that out of the three process parameters Layer thickness has the major contributing factor on 'part strength'. The optimal combinations of process parameters are 0.1mm layer thickness, 60 min post-curing time and vertical orientation for tensile, impact and flexural strengths of SL part [10].

Important investigations were made by 3D printing procedures on the ZPrinter 310 Plus and by the Polyjet procedure on the Objet Eden 330 machine. The materials used for the test specimens made on the Objet Eden 330 are VeroBlack, VeroBlue and FullCure 720, while the ZPrinter 310 Plus machine uses zp 102 powder, zb 56 binding agent and Loctite 406 and Loctite Hysol 9483 A&B reinforcing glue. The best mechanical properties belong to test specimens made of FullCure. For Vero material, the producer stipulates that VeroBlack has the highest flexural modulus, and still the analysis results show that it is the lowest one. In VeroBlue materials the producer's guaranteed values almost match the obtained ones. The worst mechanical properties are from the test specimens made of powder. However, their properties depend on the reinforcing agent which is added to powder or binding. Cyanoacrylate features better properties than epoxy resin [11].

As in additive manufacturing process the part is made in layers and number of layers in a part depends upon the layer thickness and part orientation. If number of layers is more, it will result in high temperature gradient towards the bottom of part. This will increase the diffusion between adjacent rasters and strength will improve [6]. But high temperature gradient is also responsible for distortion within the layers or between the layers. Moreover, increase in number of layers also increases the number of heating and cooling cycles and thus residual stress accumulation increases. This may results in distortion, interlayer cracking and part de-lamination or fabrication failure. Hence, strength will reduce. Small raster angles are not preferable as they will results in long rasters which will increase the stress accumulation along the direction of deposition resulting in more distortion and hence weak bonding. But small raster angle also means that rasters are inclined along the direction of loading and will offer more resistance thus strength will improve.

The layer orientations studied for FDM by Z510 machine were the crack arrestor, crack divider, and short transverse (fig. 3) with various combinations of the three, for a total of seven orientations. The mechanical strength was evaluated using tensile testing and three-point bend testing. The toughness was evaluated by Izod impact testing. The crack arrestor orientation was the strongest main orientation for the tensile and three-point bend test [12]. Weibull analysis was done on the Izod impact testing, due to high variation in the results for the crack arrestor and short transverse directions. It was found that the layer orientation and surface roughness played a significant role in the penetration of the coating and in the overall strength of the samples. 4

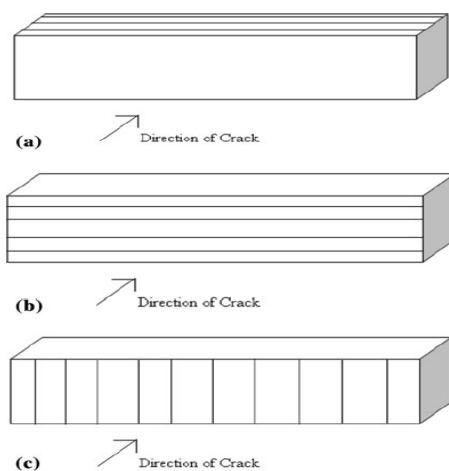


Fig. 3 Schematic diagram of the sample orientations [12] 7

Experimental study in 3D printing process shows that under the same layer thickness, increment of binder saturation level from 90% to 125% would result in an increase of tensile and flexural strengths of the specimens and decrease of dimensional accuracy and surface uniformity of specimens. On the other hand, under the same binder saturation conditions, increase in layer thickness from 0.087 to 0.1 mm would decrease tensile strength and increase flexural strength [13].

Conclusion

Additive manufacturing is very important process for producing functional parts by adding material. Mechanical properties of AM parts are affected by various process parameters, which are layer size, layer deposition angle, layer solidification mechanism, curing time, energy density, binding saturation, build direction. Using different AM technologies parts with desired mechanical properties can be produced by controlling the process parameters. 10

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International Journal of Advance Research and Innovative Ideas in Education Vol-2 Issue-5 (2016) 883-889.

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