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3D-Printing in Additive Manufacturing

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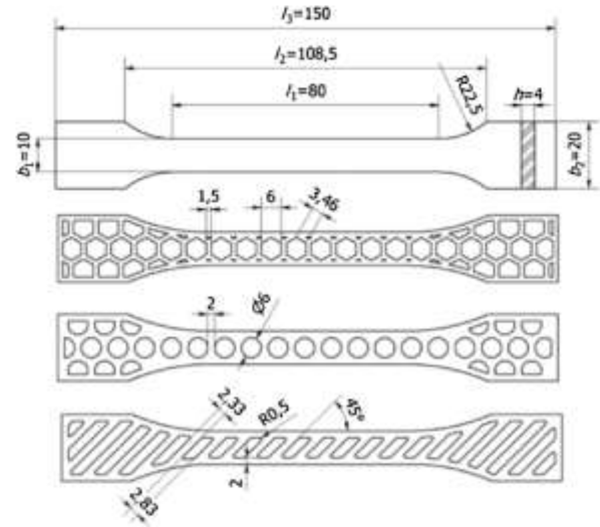
Abstract:- *3D printing, more formally known as Additive Manufacturing (AM), is already being adopted for rapid prototyping and soon rapid manufacturing. The commonly-used ASTM and ISO mechanical test standards which have been used by various research groups to test the strength of the 3D-printed parts have been reported. Also, a summary of an exhaustive amount of literature regarding the mechanical properties of 3D-printed parts is included, specifically, properties under different loading types such as tensile, bending, compressive, fatigue, impact and others. Properties at low temperatures have also been discussed. Further, the effects of fillers as well as post-processing on the mechanical properties have also been discussed. Lastly, several important questions to consider in the standardization of mechanical test methods have been raised.*

Keywords: Additive manufacturing, 3D printing, Mechanical properties,,, and standards Polymer, Polymer nano composites, Post-processing

1. INTRODUCTION

Additive Manufacturing (AM), 3D printing, has been drawing increasing interest from industry, as well as the research and academic communities. Recently, cheaper and faster AM techniques have been developed which can produce high print qualities. Also, polymer materials for 3D printing are now being produced with a wider range of properties. These advancements continuously change how the products are designed and manufactured and how they are being used by consumers. Innovators and inventors can now easily produce prototypes of their ideas as 3D printing greatly simplifies prototype production. The design and fabrication processes have actually been reduced from weeks to a few hours essentially allowing to innovate on the fly. AM could minimize production costs and improve the overall efficiency in the manufacturing sector AM is now being seriously considered to produce materials for several applications, namely, construction , apparel , dentistry ,medicine , electronics ,automotive , robots , military , oceanography , aerospace , and others. Just recently, a3D-printed satellite launching device won the design competition sponsored by Mouser Electronics. For practical applications, the 3D-printed parts should with-stand various amounts of mechanical and environmental stresses during its use. It is important to know the required strengths for each application under various loading conditions, and at the very least, the physical properties of 3D-printed parts should be similar to those manufactured by traditional methods, such as injection molding. To limit the scope, this paper is focused only on mechanical characterization of polymer materials. Generally, plastics have lower strength than metals but they have lower density and higher strain failure. In some cases, plastics will have higher strength per unit weight than metals. Therefore, considering its lower cost and manufacturability with complex designs, plastics could have more advantages in many applications. It is thus not surprising that in a recent survey, polymers account for more than half of the parts currently produced by AM.



2. OVERVIEW OF ADDITIVE MANUFACTURING

Additive Manufacturing (AM) has been defined as the process of joining materials to make parts from a 3-dimensional model data one layer at a time. Fig. 3 shows the general additive manufacturing process flow. As opposed to milling or cutting a part from a block of material, AM builds up the part, usually layer upon layer, using powders or liquid. In the case of polymers, filaments are also widely being used. Other terms synonymously used to AM are as follows: 3D printing, direct digital manufacturing, freeform fabrication, rapid prototyping, additive fabrication, additive layer manufacturing. There are several diverse processes used for AM. Based on the standard, AM processes have been classified into seven categories: material extrusion, vat photo polymerization, powder bed fusion, binder jetting, sheet lamination, material jetting and directed energy deposition Usually, 3D printer manufacturers provide their own software to slice the model in the STL file into individual layers. The sliced file will then be sent to the Additive Manufacturing device, printer. The printer will then print one layer (2D) on top of the other, and thereby forming three-dimensional object in the process. After forming the

3D-object, it may need some post-processing depending on the desired property. Post-processing may include curing annealing, painting or others.

3. REVIEW OF ADDITIVE MANUFACTURING METHODS FOR POLYMERS

(1)Fused deposition modeling (FDM)

Scott Crump, the co-founder of Stratasys, patented the Fused Deposition Modeling (FDM) in. FDM-based 3D print-ers are presently the most popular consumer-level 3D printers for printing polymer composites that is based on extrusion additive manufacturing (AM) systems. Extrusion-based AM generally follows the printing principle of extruding a material and depositing onto a platform creating a two-dimensional layer on top of another resulting to a tangible three-dimensional object. Among other extrusion-based techniques, FDM is a material-melting technique which uses a spool of thermoplastic filament such as PC, ABS and PLA with varying diameters to be melted and extruded through a heated nozzle. Recently, thermoplastics with higher melting temperatures such as PEEK can already be used as materials for desktop 3D printing.

(2) Stereo lithography (SLA)

This was one of the earliest AM techniques developed. The basic concept of stereo lithography (SLA) is to print using a photo curable resin, typically epoxy or acrylic, by exposing it to ultraviolet (UV) light of specific wavelength so the exposed 2D-patterned resin layers become solid through a process called photo polymerization.

(3)Digital light processing (DLP)

Digital Light Processing (DLP) is another vat polymerization technique quite similar to SLA, except that instead of using scanning laser beam to solidify a layer of resin, a digital mask is projected to create the pattern. Technically, DLP can print an object with lesser time compared to SLA since each layer is exposed entirely all at once by the projected pattern rather than meticulously scanned by a laser. This is advantageous when simultaneously printing multiple large compact objects with less detail.

(4)Selective layer sintering (SLS)

Selective Laser Sintering (SLS) is a type of Powder Bed Fusion(PBF) wherein a bed of powder polymer, resin or metal is targeted partially (sintering) or fully (melting) by a high-power directional heating source such as laser that result to a solidified layer of fused powder . SLS, on the other hand, does not need structural support since the powder cake acts as support for the printed item; allowing complicated objects to be printed with ease. The sintering mechanism of SLS allows only thermoplastic polymers such as polycaprolactone (PCL) and polyamide (PLA), ceramics and metals to be printed; taking into consideration the complex consolidation behavior and molecular diffusion process. The surface smoothness of a print of an SLA is better than SLS.

(5) Three-dimensional printing (3DP)

Three-Dimensional Printing (3DP) is another type of Powder Bed Fusion (PBF) additive manufacturing technology developed at the Massachusetts Institute of Technology [81]. It is quite similar to SLS except that in 3DP, a liquid binding material is deposited via binding jet over the powder bed, which serves as a substrate, to bind the powder particles together to create the two-dimensional shape of the layer. A fresh layer of powder is rolled over the previous layer after a lowering mechanism carries down the already printed layers.

(6)Laminated object manufacturing (LOM)

Laminated Object Manufacturing is widely used in the industry as a rapid prototyping and additive manufacturing technique. As illustrated in Fig. 9, the printing cycle generally consists of rolling out a heat-activated sheet material which is then laminated onto a substrate via the heat roller; the layer is formed by laser-cutting the pattern and cross-hatches the non-part area to be disposed to the waste roll. The platform moves down to prepare for the next layer

(7)PolyJet technology

PolyJet is considered an advanced inkjet technology where instead of using ink, multiple print nozzles accurately spray tiny droplets of liquid photopolymer or other liquid materials, hence, the name poly jet. A UV light instantly cures the droplets creating ultra-thin layers on the build platform to form the 3D object. Complex prints require support, which should be removed manually. The post curing of the final product is unnecessary. Its advantages include high resolution and simultaneous multi-material printing. It can also incorporate a selection of colors to produce multi-colored final product.

4. MECHANICAL PROPERTIES OF 3D-PRINTED POLYMERS

This part summarizes research works aimed at understanding the mechanical properties of additively manufactured parts. For utilization of 3D printed parts in real world applications, its strength in all aspects should be similar to the part that it will replace, or to those produced by conventional processing methods(e.g. injection molding) . It should be noted that the mechanical properties of additive manufactured parts can be affected by both the unprinted material properties and the manufacturing method. Moreover, polymers with defined functional and mechanical properties also have to be developed. Usually, reinforcements/fillers are incorporated in polymers to enhance their mechanical properties, or by post processing. .Layered processing of polymeric materials, as is the case for 3Dprinting, has many issues that limit its applications. These issues must be addressed for additively manufactured parts to have broad adoption in rapid prototyping and rapid manufacturing, i.e. to employ 3D printing for the manufacture of high quality and reliable end-use parts.

5. SEVERAL POST-PROCESSING METHODS FOR SLS-PRINTED PARTS IN 3D HUBS

1) Media Tumbled (vibro polish) – polishing is done in media tumblers or vibro machines. These devices contain small ceramic chips responsible for gradually eroding the surface of the part

2) Dyeing – the part is soaked in a hot color bath.

3) Spray paint or lacquering

4) Water tightness – silicones and vinyl acrylates are usually used to enhance water resistance.

5) Metal coating – metallic materials such as stainless steel, cop-per, nickel, gold and chrome are being coated on the surface of the parts in order to improve the mechanical and electrical properties.

6. ASSESSMENT OF TEST METHODS

The mechanical properties of 3D-printed parts vary depending on the following factors: material used (brand, density, molecular weight, quality, etc), AM technology used, infill %, printing orientation (build and raster), layer height (resolution), infill pat-tern, cross-sectional area, post-processing (method and time), build number, and others. It is quite complicated and difficult to predict how a part would behave given a certain mechanical load.

7. SUMMARY AND CONCLUSION

Additive manufacturing technologies have gained significant advancement through the years and the products of which are now being considered to replace those parts/materials that were manufactured through conventional methods. This report gave a brief overview of Additive Manufacturing (AM) and AM Technologies. The commonly-used ASTM and ISO mechanical test standards which have been used by various research groups to test the strength of the 3D-printed parts have also been reported. Lastly, a comprehensive review of the mechanical characteristics of parts produced by the various AM methods have been discussed. These include results from different mechanical tests such as tensile, bending, compression, fatigue, impact and others. Properties at cryogenic temperatures have also been included. Effects of nano filler additions have been briefly discussed. Also, the effects of post-processing on the mechanical properties have been detailed for most of the AM methods. 3D-printed materials have large anisotropy especially for the FDM- and SLS-printed parts. The effects of post-processing on the mechanical properties are also significant especially in the case of SLA parts. Although it is still not possible to replace parts with the same material considering the anisotropy and the relatively lower strength of Additively Manufactured parts, there is a strong possibility that, with the wide variety of materials available for AM , the needed material properties could still be satisfied. And in some cases, exceed the original parts or those produced via traditional methods. With the different additive manufacturing technologies, print-ing parameters and considerations, it seems that we will not be seeing a single standard for a particular mechanical test. In the end, what is important is to have test standards in order to set a foundation to make the products more reproducible.

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