A Study on the Tensile Strength of Liquid 3D Printing

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Abstract— *Currently, 3D printing technology is penetrating into all areas of life. The development of 3D printing technology is many, and products made from 3D printing technology are very diverse. In particular, liquid 3D printing technology meets the requirements of print speed, accuracy, and smoothness of the product. But the mechanical product quality of liquid 3D printing technology still needs to be further researched and improved to meet the needs of use. This research presents the results of researching the influence of 3D printing parameters on the tensile strength of the product. The parameters studied are layer thickness and exposure time*.

Keywords— *Liquid 3D printing, tensile strength layer thickness, exposure time, tensile strength*

I. INTRODUCTION

Among the different types of additive manufacturing techniques, liquid 3D printing is a form of 3D printing technology used for creating models, prototypes, patterns, and production parts in a layer-by-layer fashion using photochemical processes by which light causes chemical monomers and oligomers to cross-link to form polymers [1]. Those polymers then make up the body of 3D solid. Research in this area had been conducted during the 1970s, but the term was coined by Chuck Hull in 1984 when he applied for a patent on the process, which was granted in 1986 [2]. Stereolithography can be used to create prototypes for products in development, medical models, and computer hardware, as well as in many other applications. Although stereolithography is fast and can produce almost any design, it can be expensive.

Since several processing parameters influence the mechanical properties of parts manufactured by the SLA process, recent research has focused on studying these parameters. Christiyan et al. [3] investigated the effect of a few process parameters on mechanical properties of the acrylonitrile butadiene styrene (ABS) + hydrous magnesium silicate composite material and suggested that low printing speed and low layer thickness can improve the mechanical properties of the material. Chacón et al. [4] studied the effect of build orientation, layer thickness and feed rate on the tensile and flexural properties of polylactic acid material and concluded that upright orientation resulted in the poorest mechanical performance, whereas the edge and flat orientations resulted in the highest strength and stiffness. Ziemian et al. [5] studied the dependence of the mechanical properties of ABS parts produced by FDM on raster orientation and concluded that the mechanical properties display anisotropic behavior with the orientation of rasters and directionality of polymeric molecules. Durgun and Ertan [6] investigated the influence of different raster angles and build orientations on the surface roughness, tensile strength and flexural strength of ABSplus-P430 parts and suggested that the build orientation has a more significant effect than the raster angle on the surface roughness and mechanical behavior of the parts. Wu et al. [7] carried out an investigation into the influence of layer thickness and raster angle on the mechanical properties of *polyether ether ketone* parts. They reported that the optimal mechanical properties were found at a layer thickness of 300 µm and a raster angle of 0º.

To determine the input parameters, the single-element probe experiment was conducted in turn with the following parameters: layer thickness (D), exposure time (t), angle alpha (α), and beta angle (β). The single-factor experimental results indicate that the two parameters, layer thickness (D) and beta angle (β), have the most influence on tensile strength, so the author only chose these two parameters for multi-weak testing factors to determine the appropriate index of the input parameters to achieve the highest tensile strength.

II. Experimental Method

Along with the development of 3D technology and printers, the development of *3D printing materials* is no less competitive. The original printing material was mainly plastic, metal powder, or porcelain powder, but with the relentless study of human studies, the printing materials were increasingly diverse, from plastic, nylon, enough copper, lead, gold, silver, steel, and titanium to environmentally friendly, food-safe plastics, and even edible organic materials such as chocolate and sugar glasses. Depending on 3D products, there are specific applications that choose objects material accordingly. In this study, the ISO-3167 A1 standard was used to determine tensile strength of liquid 3D printed specimens.

In this research, four parameters of liquid printing were observed as layer thickness, normal exposure time, alpha angle, and beta angle. For the layer thickness, this parameter varies from 0.02 mm to 0.06 mm. In traditional 3D printing, the thicker layer reduces the printing time; however, the strength is reduced. Furthermore, the normal exposure time has an impact on the resolution, the hardness of the cured material, and the adhesion between the cured layer and the Teflon film. The normal exposure time depends on the resin being used and the layer thickness. In this study, the exposure time was changed from 6 s to 10 s to observe its effect on the tensile strength of a product. Third, the alpha and beta angles were changed from 0° to 90°.

Table 1. Parameters for testing

No.	Layer thickness (mm)	Normal exposure time (s)
1.	0.02	10
2.	0.03	
3.	0.04	
4.	0.05	
5.	0.06	
6.	0.05	6
7.		7
8.		8
9.		9
10.		10

III. Results and Discussion

Liquid 3D printing is a broadly used technology in the field of rapid prototyping. One of the disadvantages of this method is poor mechanical properties of its products. Thus, to approach the mechanical properties of an original part, the mechanical properties of a printing part, such as tensile strength, should be researched for improvement. In this study, there are many parameters that affect the tensile strength of parts, which should be studied. Among them, the *layer thickness*, *normal exposure time*, and alpha and beta angles are the most significant ones. These parameters will be used for liquid printing with the parameter as listed in Table 1.

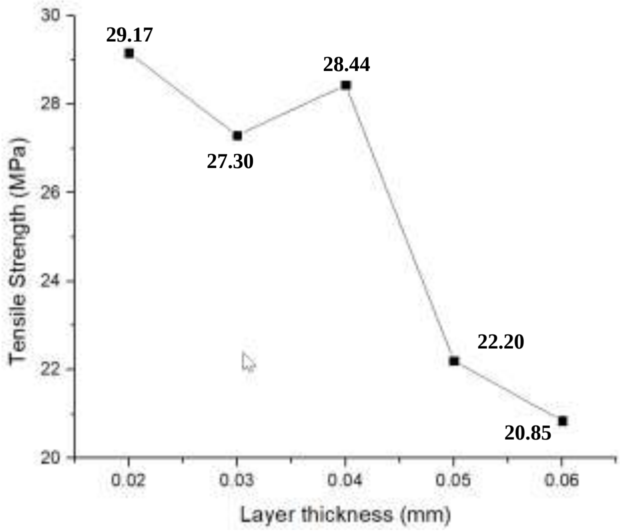

Fig. 1. Effect of layer thickness on the tensile strength

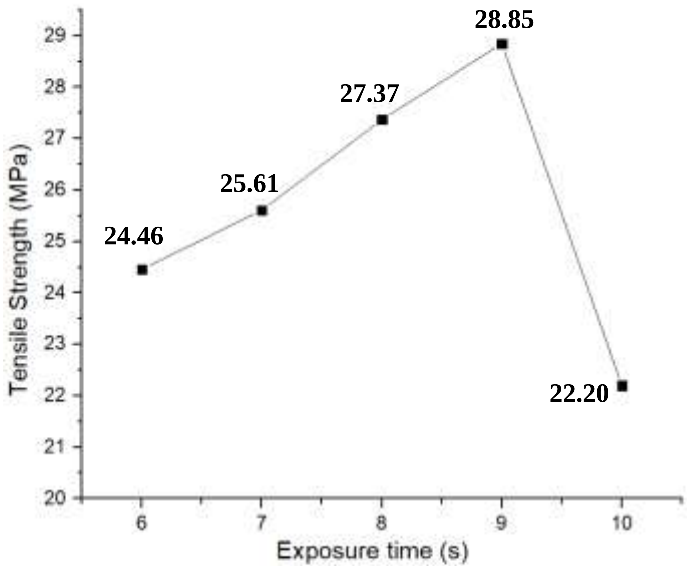

Fig.2. Effect of exposure time on the tensile strength

For observing the influence of layer thickness on the tensile strength, the tensile testing specimen was printed with the layer thickness increasing from 0.02 mm to 0.06 mm. In this group, the *normal exposure time* is 10 s, and the alpha and beta angles are 0°. The results were collected and compare as illustrated in Figure 1. These results indicate that the tensile strength is almost the same when the layer thickness varies from 0.02 mm to 0.04 mm. However, the strength was reduced clearly when the layer thickness kept rising to 0.05 mm and 0.06 mm. This result is due to the fact that with the thin layer, the power of the machine is enough for the adhesion between layers, however, with the thicker layer, the power should be higher for the reaction of material. The tensile test indicates that when the layer thickness increases from 0.02 mm to 0.04 mm, the tensile strength varies in the range of 27.30 to 29.17 MPa. With the larger layer thickness, the strength was reduced down to 20.85 MPa and then to 22.20 MPa.

In liquid 3D printing, the exposure time is the amount of time that each layer will be exposed to the light source during printing. Different SLA/DLP/LCD 3D printers have different cure times for resins. In this study, to observe the influence of exposure time on the tensile strength of a part, the exposure time of 10 s will be applied for the 3D printing with a layer thickness of 0.05 mm and the alpha and beta angles of 0°. The tensile strength was compared as illustrated in Figure 2. This result indicates that the longer exposure time results in increased tensile strength. However, the limitation in this model is 9 s, which will reach 28.85 MPa. For the longer exposure time, the material's properties will change, and the tensile strength will be reduced.

IV. CONCLUSIONS

In this study, the liquid 3D printing was achieved for the sample of tensile strength testing at different values layer thickness and exposure time. The results indicate that the strength could be kept in a range of 27.30 to 29.17 MPa with the layer thickness in a range of 0.02 to 0.04 mm. A larger layer thickness results in clear reduction of strength. With the exposure time parameter, the longer exposure time will results in an increase in tensile strength because the rigidity reaction appears in a longer time. However, in this tensile testing sample, the limitation of exposure time is 9 s. If the exposure time is longer than 9 s, the tensile strength will be reduced.

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