# CONTROLLING POLYMER DIGITAL MATERIAL COMPOSITION WITH LAYERING

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**ABSTRACT**: The advances in polymer 3D printing enables multi-material printing of different types of polymer into a single part which is known as digital material. Polyjet 3D printing and Multijet printing (MJP) are methods used to print digital materials. Control of the polymeric compositions is however not made available. A range of digital materials made up of the same two or three types of polymers with different composition are pre-set in the software with the composition unknown to the users. Layering is a way for users to control the composition. In this project, the method of layering involves manually slicing the computer-aided design (CAD) part into multiple thin layers in the loading direction and assigning each layer with a specific polymer type to make up the desired composition. The effect of layering was studied by conducting tensile tests on the layered and non-layered samples. It is shown that layering reduces specimen's tensile strength however this effect diminishes over time.

**KEYWORDS:** Digital materials, Polymer printing, Testing, Printing methods

## Introduction

There are different types of additive manufacturing (AM) or 3D printing techniques available. Current advancements in technology have introduced multi-material printing within a single print job. However this is only limited to 3D printing of polymers [1] and metals [2]. Polyjet is one of the AM techniques which allows multi-material printing of polymers with a range of properties from rigid plastic (Vero series) to rubbery elastomers (Tango series) to high temperature polymers and biocompatible polymers [3]. These polymers exist as liquid photopolymer resins before they are printed. The polyjet print head dispenses these resins according to the sliced computer-aided design (CAD) file dimensions and shape. The photopolymer resins are cured hence solidified by ultraviolet radiation which floods the build chamber. This process is repeated layer after layer until the part is completed [4].

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Digital materials are 3D printed multi-materials which can have a range of properties based on the materials they are made up of. An example is mixing a Vero type resin with a Tango type resin which will result in a digital polymer material with either rigid plastic type properties, elastomer type properties or a mixture of both depending on the polymeric composition.

One of the printers capable of printing polymer digital materials is the Objet500 Connex3 polyjet 3D printer by Stratasys. The printer can print parts made up of a maximum of 3 different photopolymer resins. The printer however does not offer the ability to control the polymeric composition without the Voxel Print Software from Stratasys. The user can only choose a range of preset digital materials in the Objet Studios printing software but their polymeric compositions are unknown. As such the user has no control as well as no knowledge of the polymeric composition which can be a hindrance to research. Layering is one way to have control over polymeric digital materials.

## Layering

Layering is achieved by manually slicing the CAD file of a part using a CAD software. These layers are assembled together before being converted into the stereolithography file format (.stl). Each layer is then assigned to a specific resin type in a specific order to ensure homogeneity. It is important to note that the slicing direction must be the same as the loading direction.
In a related research to this paper, layering was applied to the printing of a polymer digital material made up of TangoPlus (rubber-like) and VeroClear (rigid plastic) with a polymeric composition of 50:50 into a dumbbell specimen for tensile testing as seen in Figure 1. The things to note for any layering procedure are the geometry of the part, dimensions and loading direction.

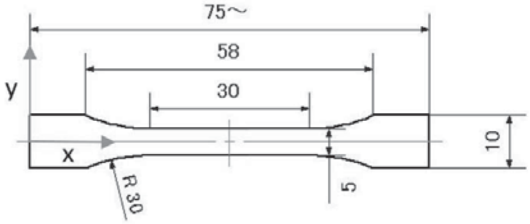

Figure 1: ISO 527-2 Type 1BA dumbbell (dimensions in mm)

For a dumbbell specimen, the part geometry is shown in a 2-dimensional (2D) plane (xy plane) with the thickness in the z-axis. Therefore, layering can be performed as each layer will be identical to each other. A specimen is meant for tensile test with the loading direction along the x-axis, as such the CAD file should be sliced along the x-axis as well. Since the CAD file is sliced along the x-axis, this means that the layers will be stacked along the z-axis hence the control parameter is the thickness of the specimen. The printer has a minimum layer thickness of 30 μm and for a specimen thickness of 2 mm, a layer thickness of 40 μm was chosen to give 50 identical layers as seen in Figure 2. As such, the 50:50 polymeric composition can be achieved by alternating layers of TangoPlus and VeroClear.

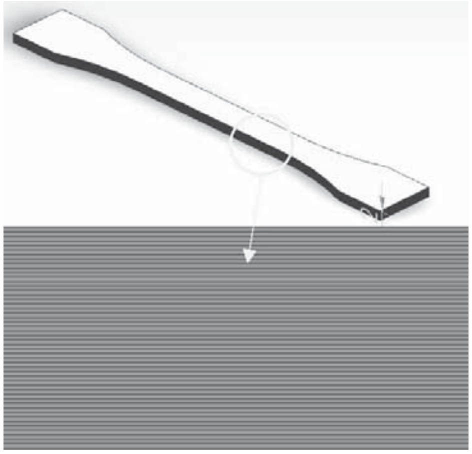

Figure 2: ISO 527 specimen sliced into 50 layers

**Testing**

To observe the effect of layering on the 3D printed parts, two different types of specimens were prepared: layered specimens and non-layered specimens. These specimens were in the form of ISO 527-2 type 1BA dumbbell made up of purely VeroClear photopolymer resin. Six specimens were printed for each specimen type. Three specimens each were tested immediately after being conditioned in a dark and dry environment for 16 hours and an additional 3 hours in the lab environment. The remaining three each were left in the dark and dry environment for an additional 7 days followed by the 3 hours conditioning in the lab environment. An Instron Universal Testing Machine was used to conduct the tensile testing at a strain rate of 10 mm/min. ISO 527-2 standard test method was adopted to achieve the purpose of this study[5].

The results of the experiments were summarized in Table 1.

Table 1: Summarized Experimental Results

| **Specimens** | **Conditioned for 16 hours** | | **Conditioned for 1 week** | |
|---|---|---|---|---|
| | **Ultimate Tensile Strength (MPa)** | **Elastic Modulus (GPa)** | **Ultimate Tensile Strength (MPa)** | **Elastic Modulus (GPa)** |
| Layered | 49.058 | 1.877 | 58.129 | 2.173 |
| | 46.625 | 1.780 | 57.084 | 2.093 |
| | 46.017 | 1.625 | 58.431 | 2.211 |
| | **Mean: 47.233** | **Mean: 1.760** | **Mean: 57.881** | **Mean: 2.159** |
| | **SD 1.609** | **SD: 126.882** | **SD: 0.577** | **SD: 49.323** |
| Non-layered | 52.621 | 2.041 | 57.563 | 2.149 |
| | 52.073 | 1.849 | 54.725 | 2.136 |
| | 52.360 | 1.959 | 57.563 | 1.951 |
| | **Mean: 52.352** | **Mean: 1.950** | **Mean: 55.325** | **Mean: 2.079** |
| | **SD: 0.274** | **SD: 95.877** | **SD: 1.638** | **SD: 90.624** |

The stress-strain responses from the tensile tests of the layered and non-layered VeroClear specimens are as shown in Figure 3. The measured ultimate tensile strength (UTS) for the layered and non-layered specimens have a mean of 47.2 MPa and 52.4 MPa respectively. The measured elastic modulus (E) have a mean of 1.76 GPa and 1.95 GPa respectively. The measured UTS and E for layered specimens were lower by 9.92% and 9.74% respectively. After performing a t-test for, it was found that layering has a statistically significant effect on the UTS but not E ($p < 0.5$).

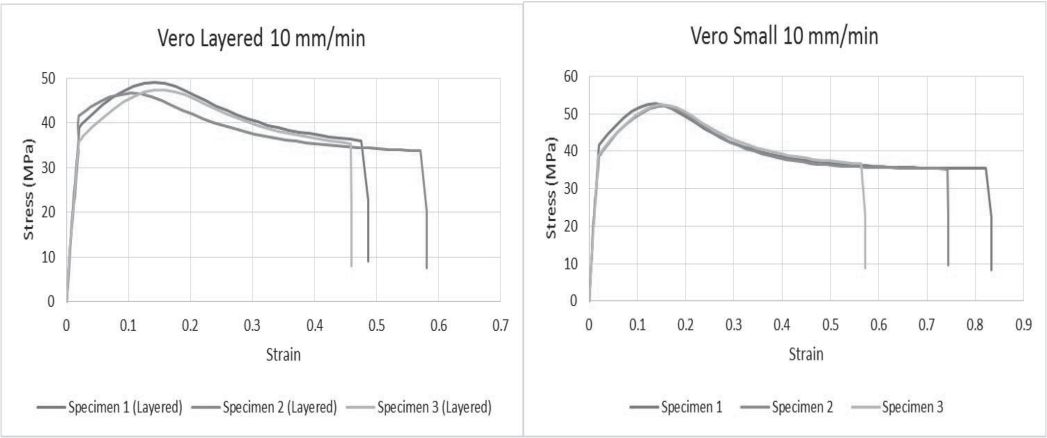

Figure 3: Stress-strain curves of layered and non-layered specimens

Tensile tests were repeated on specimens which were left for 1 week after printing. The stress-strain responses are shown in Figure 4. The measure UTS for the layered and non-layered specimens have a mean of 57.9 MPa and 55.3 MPa respectively. The measured E have a mean of 2.16 GPa and 2.08 GPa respectively. Although the means were higher, a t-test shows that there were no significant difference ($p > 0.5$).

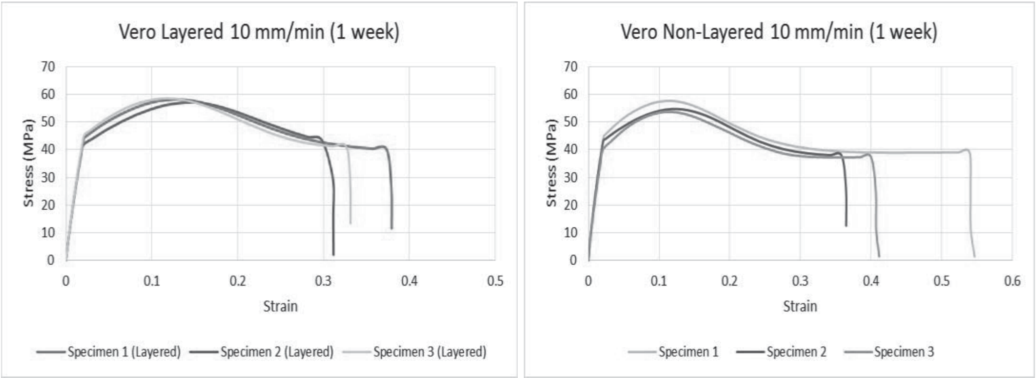

Figure 4: Stress-strain curves of layered and non-layered specimens left for a week

## Discussion

In order to use layering as an alternative method to control polymer digital materials, it must not affect the resulting mechanical properties significantly. This can only be achieved when the digital materials were conditioned for a week. The exact conditioning time has yet to be determined which may be lesser than 1 week. The reason to why layering results in a weaker part when tested after 16 hours of conditioning could be due to partially uncured resins at the interfaces of the layers. This will result in lesser cured polymer bearing the tensile load hence a significantly lower UTS.

Polyjet polymers' mechanical properties are found to be time dependent for the layered specimens post printing. The UTS and E increased by 22.7% and 40.0% respectively. The same cannot be said for the non-layered specimens, though there is an increase in UTS and E by 5.53% and 6.67% respectively, a t-test conducted found that it is not statistically significant ($p > 0.5$). Therefore, for the layered specimens, it can be said that their mechanical properties are affected by curing time. It is important to note that the specimens were stored in a dark environment during conditioning, hence the strengthening and stiffening is not due to exposure to ultraviolet radiation.

## Conclusion

It can be concluded that layering can be an alternative method to control the polymeric compositions of polymer digital materials only after conditioning for a certain amount of time. From the test results of this study, the recommended conditioning time is one week but further research is recommended to determine the minimum conditioning time when the effect of layering on the mechanical properties are no longer significant.

Time may also have an effect on 3D printed polymers but it is inconclusive from the results of this study. Further research in this area is required in order to better understand how curing time affects the mechanical properties of 3D printed polymers.

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