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THE EFFECT OF DIFFERENT STRUCTURE AND GRADIENT INFILL ON MECHANICAL BEHAVIOR POLYLACTIDE ACID MATERIALS (PLA)

Imam Akbar[1)*], M Rizky Hidayat[1)], Dewi Rawani[1)], Rita Maria Veranika[1)], Hariman Al Faritzie[2)], Romli[3)]

[1)]Department of Mechanical Engineering, Faculty of Engineering, Tridinanti University, Palembang, South Sumatra, Indonesia

[2)]Department of Civil Engineering, Faculty of Engineering, Tridinanti University, Palembang, South Sumatra, Indonesia

[3)]Department of Mechanical Engineering, Faculty of Engineering, Politeknik Sriwijaya University, Palembang, South Sumatra, Indonesia

*email corresponding: imam@univ-tridinanti.ac.id

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ABSTRACT

The purpose of this study is to analyze the effect of our gradient infill on the mechanical behavior of polylactide acid (PLA) materials resulting from 3d printing, which has an impact on the efficiency of material use while still providing good mechanical support. In this study, the specimens were designed using nTopology software and there were 4 variations of the structure, namely square, honeycomb, diamond, and gyroid, each of which was made gradient and non-gradient, then a bending test was carried out to determine its mechanical behavior thats PLA materials. The results of this study indicate that a comparison between specimens with gradient and non-gradient models with 50% porosity can increase the deflection of the specimen, namely square 15.7-19.1 mm, honeycomb 16.3-20.6 mm, Diamond 19.7-21.8 mm, and gyroid 20.3-22.1 mm, with an average deflection of 2.04 mm. In addition, there is a linear correlation of the relationship between thickness to deflection and flexural modulus whereas the thickness value increases, the deflection and flexural modulus will increase. The conclusion of this research is that giving a gradient to the structure can improve mechanical behavior, especially deflection.

Keywords: *Infill, Gradient, PLA, 3D printing*

1 INTRODUCTION

Additive Manufacturing (AM), commonly known as 3D printing, is a promising technology that enables the production of complex components based on Computer Aided Design (CAD) models that are often unachievable by traditional subtractive manufacturing or Computer Numerical Control (CNC). The emergence of low-cost open-source 3D printers has led to significant proliferation of the technology in recent years. One of these printers is the Fused Deposition Modeling (FDM) 3D printer, which forms geometry by layering heated thermoplastic filaments (Mensah et al., 2022). Additionally, the material used, PLA, has a relatively low melting point between 190ºC-230ºC (Shanmugam et al., 2020)

Regarding FDM 3D printing technology, when printing an object, we can adjust parameters such as layer thickness, printing speed, and object orientation. Previous studies (ERYILDIZ, 2021; Shubham et al., 2016). It was found that these parameters have a significant influence on the mechanical strength of the printed object. Additionally, we can choose between two options: first, whether we want to make the material completely solid, which would take more time and material but would provide strong mechanical properties, and second, to apply infill structures into the object to make it lighter, use less material, and provide stability in mechanical behaviour (Trachtenberg et al., 2014). Therefore,(Johnson & French, 2018; Torres et al., 2016). Concluded that the shape and thickness of the infill structure are crucial in optimizing strength. Given the importance of infill structures, the infill design market has significantly grown, with various infill structures available, such as lattice structures and even Triply Periodic Minimal Surface (TPMS) structures, each with unique mechanical properties such as stiffness and strength.

In recent years, research on infill structures has only focused on the uniform thickness of the infill structure (Fernandez-Vicente et al., 2016; Martín et al., 2021; Tanveer et al., 2019) and when the specimen is tested, say in the tree point bending test, the stress concentration will occur in the center area of the specimen where the stress concentration indicates an area where failure will occur first, so the researcher hypothesizes that by giving a gradient thickness infill, where the infill is slightly denser in the area of the middle specimen, the stress concentration may change resulting in a higher deflection value. So that the novelty in this study is that researchers try to develop and investigate the effect of gradient thickness infill on mechanical behavior such as deflection and flexural modulus, there are 4 structural variations used in this study, namely square, honeycomb, diamond and gyroid which were made with generatif design software that uses algorithms to create new design automatically and experimental approach bending test. This research is expected to be used as a reference to improve the efficiency of material use while still providing good mechanical support.

2. MATERIALS AND METHODS

2.1 Specimen Design

In this study, the specimens were designed using the nTopology software where first create a rectangle according to ASTM D790 (ASTM INTERNATIONAL, 2002) with dimension 125mm×3.5mm×12.7mm then operate the shell with a thickness of 0.5 mm then operate the volume infill feature select the lattice structure model (square and honeycomb) and TPMS (gyroid and diamond) according to the dimensions of the specimen then operate the Boolean union feature on the shell and infill structure so that the shell and infill become one part. Furthermore, to create an infill gradient, the researcher uses the RAMP operation with values and the overall design can be seen in Figure 1. In addition, in this study all specimens were made with a uniform porosity of 50% which can be seen in table 1.

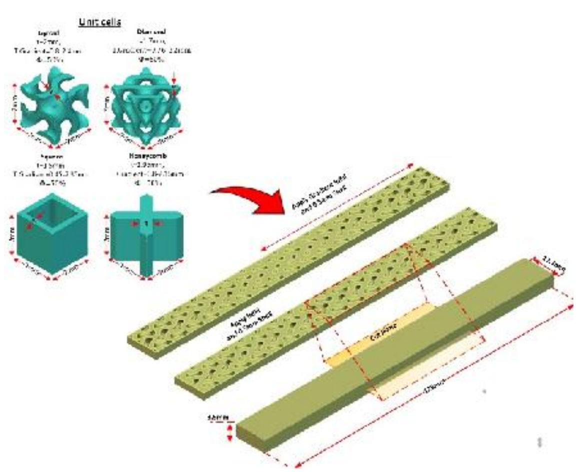

Figure 1. Design Specimen

Table 1. Specimen's characterization

Model	V_{Infill} (mm)	V_{Total} (mm)	Φ (%)	t (mm)
Gyroid	2565	5161	50	2.1
G.Gyroid	2565	5161	50	0.8-2.4
Diamond	2568	5161	50	1.95
G.Diamond	2576	5161	50	0.76-2.22
Honaycomb	2573	5161	50	1.15
G.honaycomb	2572	5161	50	0.8-2.15
Square	2545	5161	50	1.94
G.Square	2570	5161	50	0.45-2.35

G. : Gradient
V_{Infill} : Volume Infill
V_{Total} : Volume Total
Φ : Porosity
T : Thickness

2.2 Specimen Fabrication Using 3D Printing

In this study, before fabricating the designed specimens, they were sliced using Ultimaker Cura 5.1.0 software with the printing parameters shown in table 2 and then the specimens were fabricated using 3D type printing Fused Deposition Modeling (FDM) with filament material polylactide acid (PLA).

Table 2 Printing Parameters

No	Parameters	Value
1	layer Hight	0.15 mm
2	Temperature	210°C
3	Printing Speed	50 mm/s

2.3 Specimen Fabrication Using 3D Printing

Figure 2 shows the specimens resulting from the design and fabrication results using 3D printing technology.

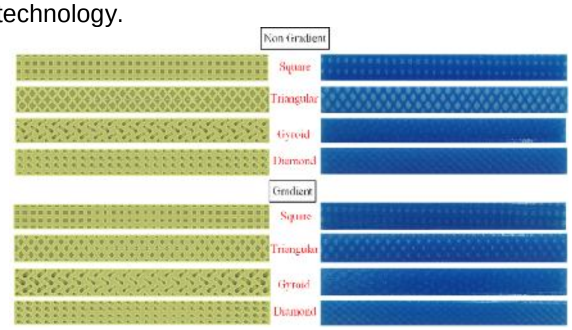

Figure 2 Fabricated Specimens

2.4 Bending Test

In this study, the bending test was carried out using the Pruftgerat Universal Workstoff with a maximum load of 50 KN which was carried out at the Universitas Politeknik Sriwijaya which can be seen in Figure.3. In this test, the standard used was ASTM D790 with a deflection rate of 0.01 KN.

Figure 3. Bending Test

In this study, it is also necessary to note that each unit cell is made with the same porosity value of 50% which can be seen in table 2 which it is based on facts from previous studies that the porosity in the unit cell has a very significant influence on mechanical behaviour (Soufivand et al., 2020)

3. RESULTS AND DISCUSSION

In this study this section contains the findings and results of data analysis that has been carried out to achieve the research objectives. This information is expected to provide answers and a more comprehensive understanding of the research topic being studied.

3.1 Mechanical Behaviour Analysis

Based on the results of this research, the comparison between specimens with gradient and non-gradient models with 50% porosity, as seen in Figure 4, shows that providing gradient thickness in infill can increase the deflection of specimens, including the square (15.7-19.1 mm), honeycomb (16.3-20.6 mm), Diamond (19.7-21.8 mm), and gyroid (20.3-22.1mm), with an average deviation of deflection of 2.04 mm. This could be because when the specimens are subjected to bending loads, the thicker infill areas provide better structural support or are able to withstand bending forces more effectively, while thinner infill areas deform more quickly, resulting in larger deflection. The findings from this study provide valuable insights into the use of infill with gradient thickness to increase the deflection of the samples.

The implications of this discovery are not limited to prototyping or manufacturing small mechanical components. This study can be used to design more effective and safer structures in various fields, such as architecture, aviation, automotive, dental implant and bone scaffold implant (Akbar et al., 2021; Prakoso et al., 2023; Zamheri et al., 2020). This discovery can also assist in the development of new manufacturing techniques that can optimize material usage and reduce production costs. However, several parameters still need to be researched to obtain more accurate conclusions regarding the optimal infill thickness to achieve a balance between strength, stability, rigidity, and production efficiency. Future research can focus on studying the effect of infill thickness on other mechanical properties, such as tensile strength, impact resistance, and fatigue behavior, as well as the overall mechanical behaviour of the structure. In addition, the influence of printing parameters, such as print speed, layer height, and nozzle diameter, on structural performance should also be investigated to optimize the printing process.

Overall, this research highlights the potential of infill with gradient thickness as a way to improve the mechanical performance of structures. Further research in this field can pave the way for new design approaches that can maximize the strength and efficiency of structures while minimizing material waste and production costs.

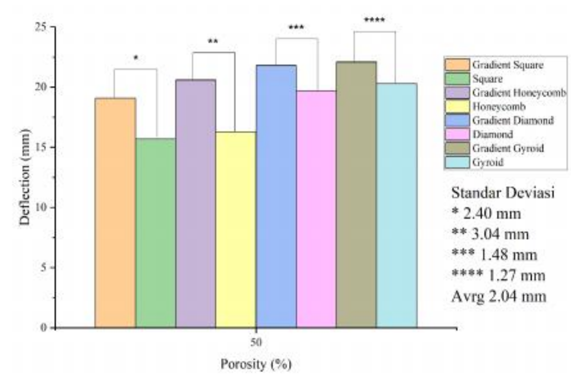

Figure 4. Comparison of gradient and non-gradient on deflection specimens

Based on the results of this study, Figure 5. A and B. is the relationship between deflection to the average thickness of the gradient infill structure and the thickness of the non-gradient infill structure which was predicted using linear regression with $R^2 = 0.67$ for gradient and $R^2 = 0.99$ for non-gradient this explains that the greater the average thickness value on the gradient structure and the thickness value on the non-gradient structure, the deflection will increase significantly so that these results confirm why in Figure 3.1 even though the overall porosity is 50%. Infill with a square structure, the deflection value is lower when compared to honeycomb, diamond and gyroid, this is because the square has a smaller thickness value. however, many studies claim that porosity is a very significant parameter affecting mechanical behaviour (Zhao et al., 2018). However, in this study we also claim that a very significant parameter affecting mechanical behaviour is thickness.

The TPMS structures such as gyroids and diamonds have the best structure, their mechanical behaviour is comparable to our previous research (Akbar et al., 2023) which says, gyroids and diamonds have very good mechanical behaviour.

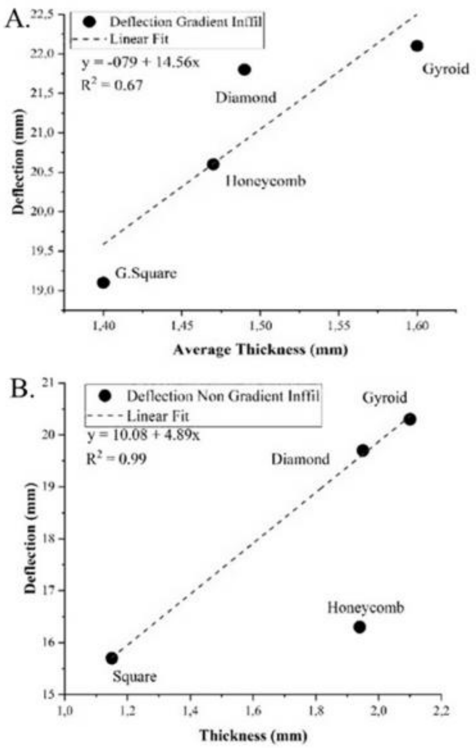

Figure 5. The relationship between A. Average gradient thicknesses infill and deflection B. Non gradient thicknesses infill and deflection

Based on the results of this study, Figures 6. A and B. Explain the relationship between thickness infill and flexural modulus, where it can be seen that thickness has a very significant relationship to flexural modulus, where this relationship is predicted using linear regression with R^2=0.78 for gradient infill and R^2=0.72 for non-gradient infill this explains that, increasing value of thickness infill, the flexural modulus will increasing significantly. However, when compared between infill with a gradient and without a gradient (non-gradient), the value of the flexural modulus, which has a gradient thickness, is much increased when compared to infill without a gradient, this indicates that with the same volume or amount of material used the same flexural value. Modulus can be increased. Therefore in the future, it is very important to review other parameters that can be controlled to optimize 3D printing. Getting the flexural modulus results of PLA material with the right infill is very important because it can help select the right material and use the right printing parameters for the resulting product. Flexural modulus is a measure of a material's resistance to bending or stretching under load. In this case, PLA is a type of plastic often used in 3D printing and has good strength and stiffness, but its resistance to bending can be affected by factors such as the type of infill used. Flexural modulus is a measure of a material's resistance to bending or stretching under load. In this case, PLA is a type of plastic often used in 3D printing and has good strength and stiffness, but its resistance to bending can be affected by factors such as the type of infill used. Flexural modulus is a measure of a material's resistance to bending or stretching under load. In this case, PLA is a type of plastic often used in 3D printing and has good strength and stiffness, but its resistance to bending can be affected by factors such as the type of infill used.

In 3D printing, an infill is a structure used to fill empty spaces in a print. Different types of infill have different effects on the strength and stiffness of the impression material. By knowing the exact flexural modulus of a PLA material with a certain infill, we can choose the right type of infill to produce printed products with the desired mechanical properties. In addition, this research can also assist in the development of stronger and more efficient moulding materials, which can improve the quality of the products produced. By understanding the mechanical properties of PLA materials with different infill's, we can optimize 3D printing for a wider range of applications and produce better products overall.

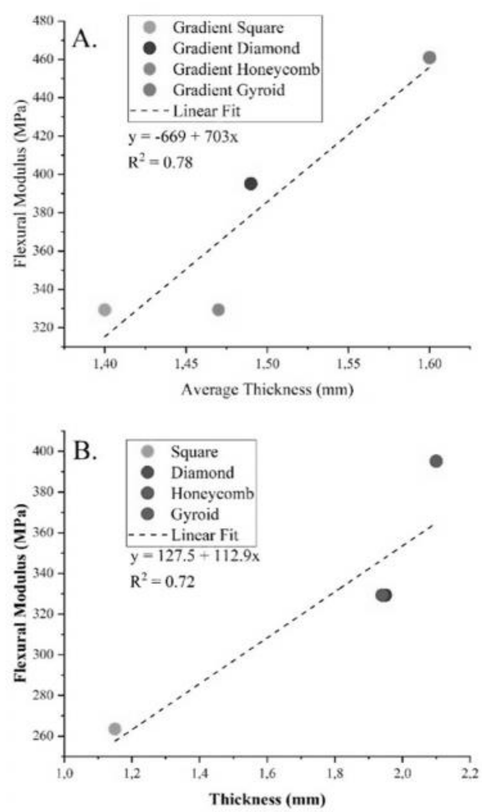

Figure 6. The relationship between A. Average gradient thicknesses infill and deflection B. Non gradient thicknesses infill and flexural modulus

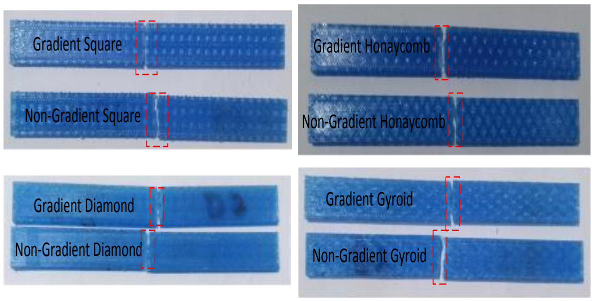

Figure 7. Fracture Specimens

In this study, Figure 7 shows the fracture of the specimen in the bending test, when compared it can be seen that there is a change in the fracture pattern between the non-gradient specimen and the gradient specimen where in the non-gradient specimen the fracture occurs in the middle of the specimen, but the gradient specimen has no fracture pattern. In the middle of the specimen, this may be due to the specimen gradient in the middle of the specimen having the highest thickness, therefore the stress concentration does not occur in the middle areas of the specimen.

4. CONCLUSION

Based on the results of this study, we conclude that by providing a gradient thickness infill, the mechanical behavior of 3D printed objects, especially their deflection, can be improved. Moreover, the thickness of the infill has a significant linear relationship with the flexural modulus and deflection. This means that an increase in infill thickness causes a significant increase in deflection and flexural modulus. When comparing lattice structures such as square and honeycomb with TPMS structures such as gyroids and diamonds, the TPMS structures exhibit superior mechanical behavior in terms of deflection and flexural modulus. Therefore, this study obtained excellent results and can be used as a reference for further research on parameters that can actively affect mechanical behavior and the development of new structures that are more optimal.

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