

Processing dates: received on 2025-03-13, reviewed on 2025-04-18, accepted on 2025-05-17 and online availability on 2025-06-30

Effect of internal geometry on the tensile strength of SLA-printed resin using a Formlabs 3D printer

Roberth M. Ratlalan*, Muh Farid Hidayat

Department of Mechanical Maintenance Engineering, Bantaeng Manufacturing Industry Community Academy, Bantaeng 92461, Indonesia

*Corresponding Author: roberthmratlalan@gmail.com

Abstract

Stereolithography (SLA) is developing rapidly as a 3D printing technology in manufacturing high precision resin-based parts. This research investigates the influence of internal geometry on the tensile strength of samples printed with a Formlabs SLA printer using dental resin. Three types of internal geometries of solid control, triangular lattice, and honeycomb lattice were compared and evaluated. Samples were designed using Autodesk Inventor according to ASTM D638 standards and printed with symmetry axis dimensions of 5 mm and 10 mm and a consistent thickness of 5 mm. Tensile testing was conducted to analyze the influence of resin material type, internal geometry design, and dimensional parameters on their mechanical properties. The results showed that the solid internal geometry achieved the highest average tensile stress of 33.33 MPa meanwhile the triangular geometry with 5 mm configuration exhibited superior tensile performance compared to the honeycomb design.

Keywords:

Internal geometry, 3D printing SLA, tensile test

1 Introduction

In recent years, 3D printing technology has experienced rapid development, especially in the fields of manufacturing and product design. One of the most popular methods in 3D printing is Stereolithography (SLA), which uses liquid resin solidified with ultraviolet light [1]. Formlabs type 3D printers which are known for their high print quality and precision. However, to understand more about the application of resin materials in this technology, an in-depth analysis of the material's strength is needed, especially through tensile testing [2].

Tensile testing is a common method used to evaluate the strength of materials, including resins used in 3D printing. Through this test, we can obtain information about the material's resistance to tensile force, as well as other mechanical properties. The data generated from this tensile test is not only important for understanding the characteristics of the material, but also for developing better applications in various industries [3].

One relevant study showed that the tensile strength of resins can vary depending on the type of resin used, the printing process, and post-processing conditions. In this study, the authors noted that resins processed by the SLA technique can show higher tensile strengths compared to other printing methods, such as Fused Deposition Modeling (FDM). These data demonstrate the importance of proper resin selection and printing parameter settings to achieve optimal results [4].

For resin-based 3D printing is expected to reach USD 5.5 billion by 2025, with growth driven by increasing demand for rapid prototyping and complex component production. This suggests that

a good understanding of resin material strength will become increasingly important for professionals in this field [5]. In developing prosthetics using resin printed with SLA printers, tensile test results show that the material has sufficient strength to be used in medical applications. These results not only demonstrate the potential use of resin in critical applications but also emphasize the need for more in-depth analysis of the mechanical properties of the resin to ensure the safety and effectiveness of the final product [6].

Thus, based on the background described in this study regarding the design of a product seen from the influence of internal geometry on the resulting mechanical properties. The study compared samples with a control geometry as a triangle and a honeycomb. The purpose of this study is to create a product design produced using SLA 3D printer technology, type Formlabs, and to test the strength of the material tensile test sample using a Tensile testing machine. This study also has several shortcomings, namely the use of so many types of printers and orientation directions that make the internal geometry variables that will be observed influenced by the printing orientation. This study will analyze the mechanical properties of SLA 3D printing objects, which are influenced by the type of Resin material, internal geometry design, and its dimensional ratio. The research data is expected to be used as a reference or consideration in making three-dimensional objects using SLA 3D printing.

2 Method

The framework is arranged systematically and is directed to obtain research results that are right on target by the research objectives and problem formulation of the research. The steps in the research process are as follows:

2.1 Type of research

This study uses a real experimental method that is directly on the object to be studied. With several stages of research or work, from making product designs using Autodesk Inventor® 2024 software with a manufacturing process produced using SLA 3D Printer Type Formlabs, and analyzing the differences in the results of tensile test samples of 15 specimens with 3 different variation models carried out using a tensile testing machine. The flowchart of research can be seen in Fig. 1.

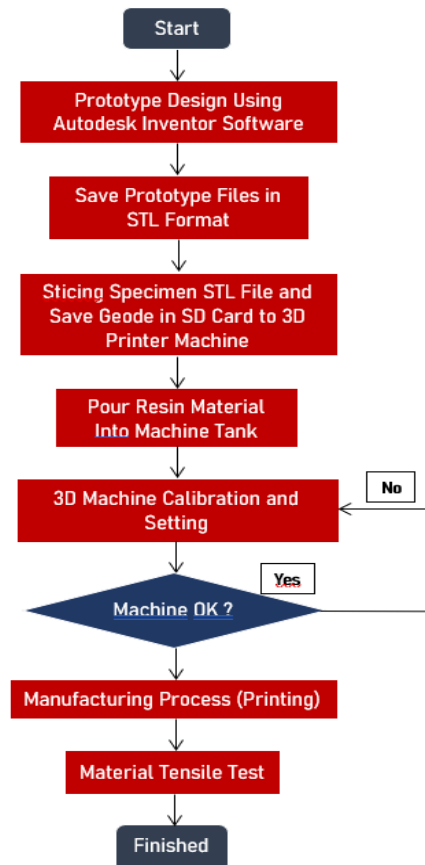


Fig. 1. Research flowchart

2.2 Tools and materials

2.2.1 Autodesk Inventor® 2024 software

Autodesk Inventor® (Fig. 2) is a CAD program specifically designed for engineering purposes such as product design, machine design, mold design, construction design, or other engineering needs. Autodesk Inventor® is a solid modeling program based on parametric features, meaning that all objects and relationships between geometries can be modified again, even though the geometry is finished, without having to start over.



Fig. 2. Autodesk Inventor® 2024 view

2.2.2 PreForm™ Software

PreForm™ (Fig. 3) is software developed by Formlabs to prepare and manage the 3D printing process using SLA based resin printers. This software is designed to make it easier for users to configure 3D models before printing, with an intuitive interface and automatic features that optimize print settings. Users can import 3D files in various formats, adjust model orientation, add supports, and determine layer thickness to produce precise prints.

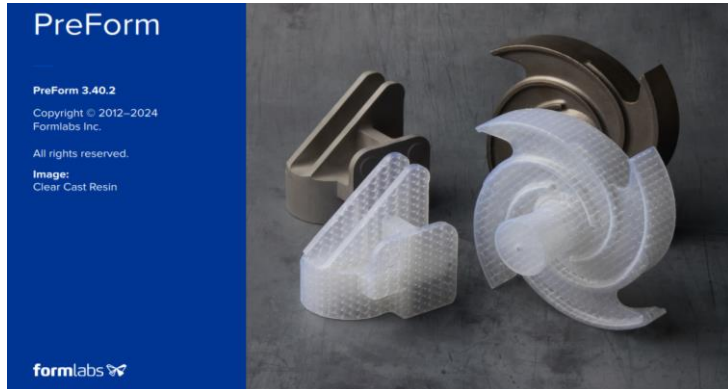


Fig. 3. PreForm™ software view

2.2.3 3D printer SLA

3D printer SLA (Fig. 4) has a large manufacturing volume (130 x 130 x 180 mm), which can meet any needs in the industry. The equipment with real-time printing progress displayed on the digital control panel, no need to pay attention to the printing progress frequently. Generally, it is high-precision printing, high-quality printing, and a fast-scanning speed.

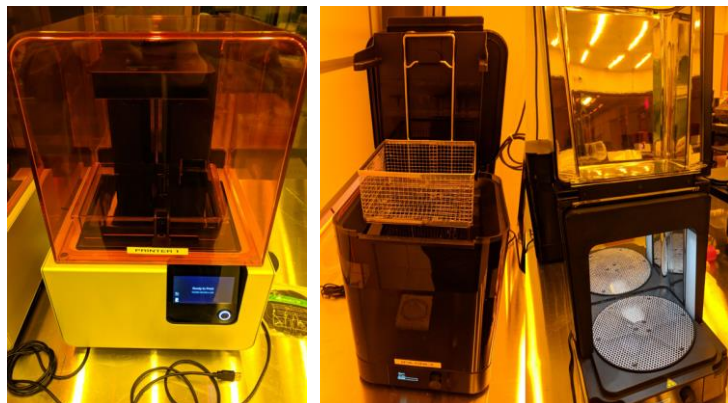


Fig. 4. Formlabs 3D printer SLA

2.2.4 Tensile testing machine

Tensile testing machine (Fig. 5) has a maximum load capacity of 500 kN (kilonewton), with a load measurement range ranging from 2% to 100% of full capacity, allowing for accurate testing of materials with low or high loads. The load measurement accuracy reaches $\pm 0.5\%$ to $\pm 1\%$, ensuring that test results remain precise in various test scenarios.



Fig. 5. WAW-500E UTM machine

2.3 Research procedures

Product design using the results produced using the Formlabs Type SLA 3D Printer and analyzing the results of the material tensile test samples can be done with the following steps:

- Design: Use CAD software or 3D scan data to design your model, and export it in a 3D printable file format (STL or OBJ). Every SLA printer includes software to define print settings and slice the digital model into layers for printing. Once setup is complete, the print preparation software sends instructions to the printer via a wireless or wired connection.
- Print: After quick confirmation of the correct settings, the printing process begins, and the machine can run unattended until the print is complete. In cartridge printers, the material is automatically refilled by the machine.
- Post Process: After printing is complete, the part requires a rinse with isopropyl alcohol to remove any uncured resin from its surface. Once the rinsed part is dry, some materials require a post-cure, a process that helps the parts achieve the highest possible strength and stability. Finally, remove the supports from the part and sand away any remaining support marks for a clean finish.
- Material Tensile Test: a mechanical testing method used to determine the tensile strength and elastic properties of a material. This test is performed by pulling the material to break using a tensile testing machine.

3 Results and discussion

3.1 Internal geometry design

Internal design of geometry and dimensions referring to established test standards to ensure the consistency and reliability of test results. This geometry is designed to minimize the effects of untested parts and ensure uniform loading during testing. Precise dimensions are needed to obtain accurate results regarding the mechanical properties of materials such as tensile strength, elongation, and modulus of elasticity. The following is Fig. 6 of the internal design of geometry and dimensions (mm).

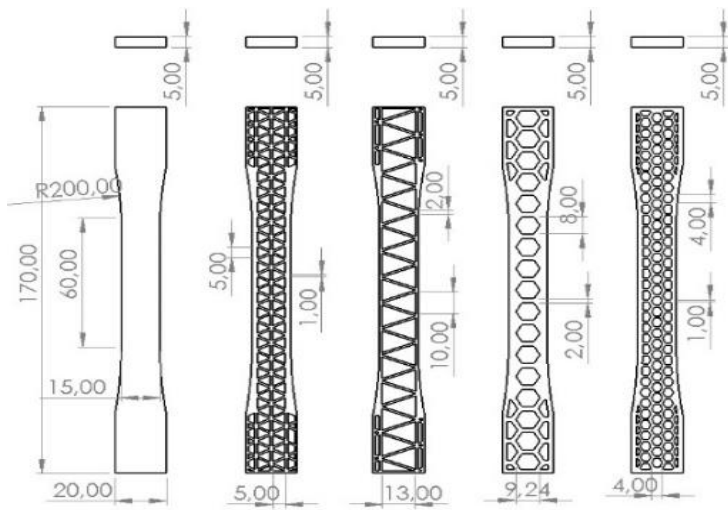


Fig. 6. Internal design geometry and dimensions (mm)

3D Design The object that will be printed first has a two-dimensional design using Inventor® software with dimensions that comply with the ASTM D638 standard. The output of the two-dimensional object is in .dwg format or a drawing that will be transferred from the PreForm™ software to be extruded and then saved in .stl format. For the design dimensions with the results have differences due to several factors, including:

- The photopolymer resin used in SLA will shrink when hardened due to the polymerization process.
- If the resin is exposed to UV light for too long, the printed area can widen slightly from its original size.
- Calibration errors also result in differences between the design dimensions and the physical print results.
- After printing, usually through an irradiation or drying process to harden, it usually experiences shrinkage or small changes in shape, especially if the curing is uneven.
- The dimension design has tolerances that are too tight or unrealistic for the printing process, especially for precision joints or small cavities.

3.2 SLA printing process

The process allows for high-resolution printing and very fine detail, making it ideal for applications that require precision. It also allows for rapid testing and validation of designs before moving on to large-scale production. The SLA process on tensile test specimens is carried out in three main stages:

Model preparation and slicing: At this stage, the 3D model to be printed is imported into the slicer software. The model is optimized by specifying printing parameters such as layer thickness, print speed, and structural support if needed. The software slices the model into thin layers and generates a G-code file containing instructions for the printing process.

- Printing: The printing process begins by preparing the resin in the printer container. The UV laser is then directed to harden the resin according to the predetermined layer pattern. After one layer is completed, the print platform will move down slightly to make room for the next layer until the object is finished printing. To produce 3D objects with high resolution and precise details through the use of light-cured resin with a smooth and accurate surface quality end product, making it ideal for those requiring high precision, can be seen in Table. 1.

Table 1. Length and thickness ratio (SLA) of the specimen

Internal geometry		
Control	Triangle	Honeycomb
Internal length ratio of geometry		
Solid	5 mm	5 mm
	10 mm	10 mm
Print layer thickness (SLA)		
108 Layer		
Estimated time		
2 – 3 Hours		

- Cleaning and Finishing: After printing is complete, the object is usually still wet with unhardened resin residue. To remove hardened resin, the time required for cleaning the object is 20 minutes. After cleaning, the object often requires additional curing under UV light to ensure that the resin is fully hardened and provides optimal strength and stability so that the temperature used in the preheating process is 600 C with a duration of 60 minutes. After the process, the object is ready to be used or continued to the finishing stage to improve the appearance or functionality.

3.3 SLA process results

The results of the SLA process of 3D objects are characterized by high detail and smooth surface quality. Each SLA process result is obtained for 3 specimens, including control, triangle, and honeycomb, with a total number of each amounting to 3 can be described in more detail as follows:

- Control Specimen (Fig. 7): is a sample or object used as a standard of comparison in an experiment or test to ensure the validity and reliability of the results obtained. The specimen usually does not receive the experimental treatment or conditions applied to the test group, so that the results obtained can indicate whether the observed changes are caused by other experimental treatments.

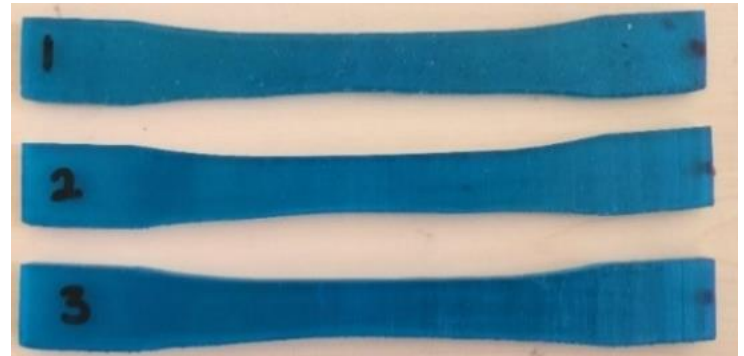


Fig. 7. SLA results of control specimens

- Triangle Specimen (Fig. 8): refers to a triangle-shaped geometry used in various contexts, such as material testing or simulation processes, to evaluate the physical properties or behavior of a material or design. In 3D printing, triangles are often used because of their simple yet strong shape, allowing for testing of stability, durability, and production efficiency.

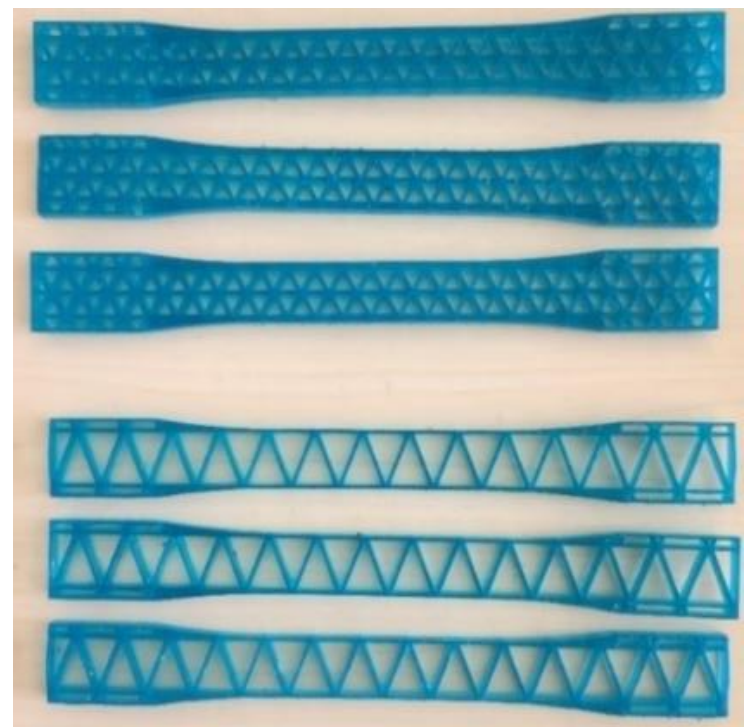


Fig. 8. SLA results of triangle specimen's ratio 5 mm and 10 mm

c. Honeycomb Specimen (Fig. 9): refers to a honeycomb-shaped structure used in various applications and materials to test the strength, efficiency, and stability of structures. The honeycomb structure consists of interconnected hexagonal cells, resulting in a lightweight yet extremely strong shape, which optimally distributes loads and stresses across the area.



Fig. 9. SLA Results of honeycomb specimens with ratios of 5 mm and 10 mm

3.4 Tensile test analysis results

In the tensile testing of the machine used in this study, with the type UTM WAW-500E. The samples used use flat plate samples with a certain width and often have a slightly narrowed part in the middle to ensure the fracture point. The number of samples used is 5 types of specimens with 3 samples each, which aims to determine the mechanical properties of the resin material under load (Fig. 10).

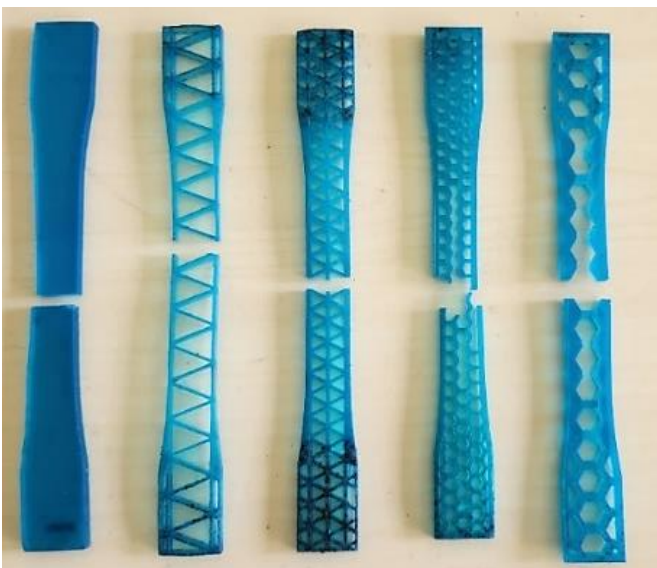


Fig. 10. Fracture form results of tensile test treatment

The test result data obtained is in the form of nominal load when reaching maximum stress and maximum strain of the sample is damaged or broken. For the parameter of the maximum strength value of the sample prepared using a 3D Printer machine is 40-70 MPa. The maximum strength value of the test can be higher or lower, depending on the printing using a 3D Printer Formlabs machine. Based on the tests carried out, it can be described as follows:

3.4.1 Tensile test stress value (σ)

The stress value in a tensile test is a quantity that indicates how much force per unit area is applied by the material until it reaches a certain limit. In the testing process, the stress increases as the force

applied increases until it reaches a maximum value, which is called the maximum tensile stress. The maximum stress indicates the strength limit of the material before undergoing deformation or permanent damage. The following results of the tensile test stress value data analysis can be seen in Fig. 11.

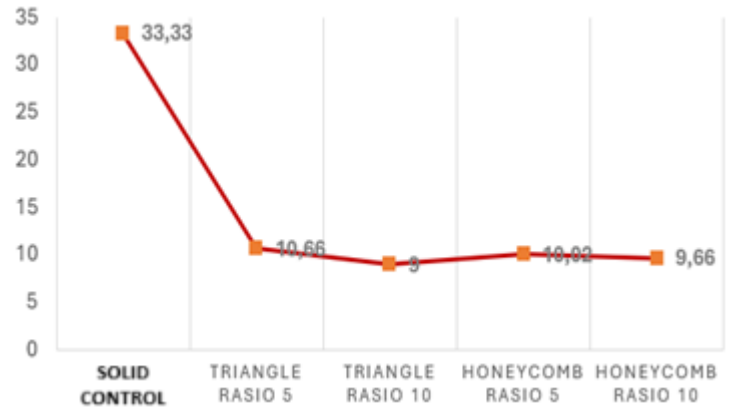


Fig. 11. Tensile test stress value graph

Tensile stress test samples, triangle and honeycomb, with symmetry axis size with the ratio of 5 mm and 10 mm, were used to for the maximum stress value generated from each sample. It is known that the sample with internal geometry has an average tensile stress test value of 33.33 MPa. The nominal is higher compared to the tensile test sample with internal geometry, Triangle, and honeycomb.

3.4.2 Tensile test strain value (ϵ)

The strain value in the tensile test shows the change in material due to the applied tensile force compared to the initial one. Strain is calculated by dividing the change by the initial sample. This strain data is very important in assessing the ductility or flexibility of the material, which is a reference for understanding how much deformation the material can tolerate without being damaged. The following results of the analysis of the tensile test strain value data can be seen in Fig. 12.

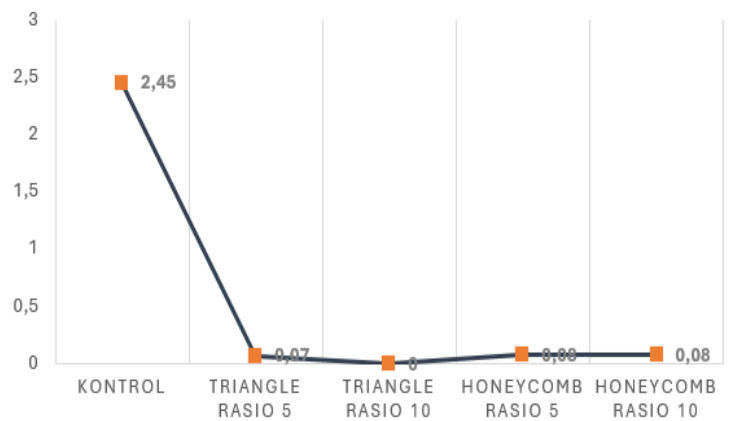


Fig. 12. Tensile test strain value graph

The strain value of each sample is presented by the tensile test strain graph of the sample, having an average strain value of 2.45%. From these data, it is known that samples with internal tensile geometry can withstand greater strains than samples with internal honeycomb geometry at each size of the symmetry axis.

3.4.3 Elasticity modulus value E

Modulus of elasticity is a measure of the stiffness or flexibility of a material in response to tensile or compressive forces. This modulus indicates how much stress a material can experience per unit strain within its elastic limits. Mathematically, the modulus of elasticity E is expressed as the ratio between stress (σ) and strain (ϵ) in the elastic region. The higher the modulus of elasticity, the stiffer the material, meaning that the material only experiences slight deformation when given force. The following results of the analysis of the modulus of elasticity data can be seen in Fig. 13.

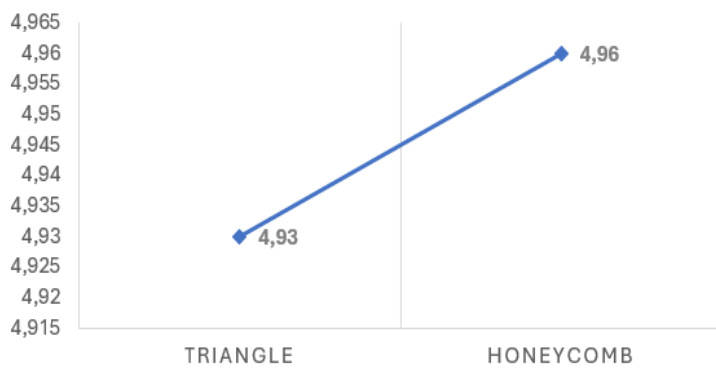


Fig. 13. Elasticity modulus value

The modulus of elasticity graph presents the overall sample data of the average total number of triangle and honeycomb samples with internal geometry variations of the test results. The modulus of elasticity value for samples with a triangle internal geometry is 4.93 MPa for a ratio of 5 mm and 10 mm. The modulus of elasticity value of 4.96 MPa is owned by samples with honeycomb internal geometry with symmetry axis sizes of 5 mm and 10 mm. The highest modulus of elasticity value based on the type of internal geometry is produced by samples with honeycomb internal geometry. So, based on the size of the internal geometry symmetry axis, the highest modulus value is owned by samples with an internal geometry symmetry axis size of 5 mm with a hexagonal geometry shape. Thus, the results show that the difference in internal geometry, consisting of thickness (distance) between objects, the number of geometries, mass, and volume, produces different tensile strength values.

4 Conclusion

The tensile test results demonstrate that the internal geometry of printed samples affects their mechanical properties. Samples with a solid internal structure showed the highest average tensile stress value of 33.33 MPa, outperforming both triangular and honeycomb geometries with 5 mm and 10 mm symmetry axes. This indicates greater strength capacity before failure. Strain analysis further revealed their deformation behaviour under tensile load, providing essential insight into its ductility. Samples with internal geometry showed an average strain of 2.45%, with triangular geometries demonstrating greater strain tolerance than honeycomb designs. The modulus of elasticity was highest in samples with honeycomb internal geometry, reaching 4.96 MPa, particularly with a 5 mm symmetry axis, indicating increased stiffness. These results confirm that internal geometry plays a significant role in determining the strength and flexibility of SLA-printed resin parts.

References

- [1]. E. Puspitasari, W. Wirawan, and S. Hadi, "Analysis of 3D Printer Printing Layer of 0.05 mm Multiple PLA Plastic Specimens Against Impact Energy," *Info-Teknik*, vol. 21, no. 2, pp. 139–154.
- [2]. Ginting, M., Sani A. A., AK. Wirda N., & Astra D, "The Effect of Rapid Prototyping Process Parameters with Stereolithography Technology on the Hardness of Test Specimens," *Jurnal Austenit*, vol. 2, no. 2, p. 2, 2019.
- [3]. Goh, G. D., et al. (2020). "3D printing of prosthetic devices: A review." **Journal of Biomedical Materials Research Part B: Applied Biomaterials**, 108(2), 292-307.
- [4]. ISO 12180-1:2011 Geometrical product specifications (GPS) — Cylindricity — Part 1: Vocabulary and parameters of cylindrical form.
- [5]. Lu, B., Li, D., & Tian, X. (2015). Development Trends in Additive Manufacturing and 3D Printing. *Engineering*, (1), 085–089. <https://doi.org/10.15302/J-ENG-2015012>.
- [6]. Lubis S. and Sutanto. D, "Object Position Orientation Settings in Rapid Prototyping Process Using 3D Printers on Process Time and Product Quality," *Journal of Mechanical Engineering*, vol. 16, no. 1, p. 2, 2014.

- [7]. M. A. Satrio. "Pengaruh Suhu Post Curing Terhadap Kekuatan Bending Komposit Sandwich Menggunakan Core 3D Printing Pola Square." *Jurnal Teknik dan Material*, 2023.
- [8]. Mahamood, S., Khader, M. A., & Ali, H. (2016). Applications of 3-D Printing in Orthodontics : A Review. *International Journal of Scientific Study*, 3(11), 267–270. <https://doi.org/10.17354/ijss/2016/99>.
- [9]. P. B. Frandika. "Pengaruh Infill Geometry, Printing Speed, dan Nozzle Temperature Terhadap Kekuatan Impak Menggunakan Filamen ST PLA." *Jurnal Teknik dan Material*, 2021.
- [10]. R. Fadhlurrohman. "Studi Numerik Heat Sink Model Mosquito Hotend pada FDM 3D Printer untuk Mengetahui Karakteristik Perpindahan Panas." *Jurnal Teknik Mesin dan Energi*, 2023.
- [11]. R. Muhammad. "Pengaruh Proses Annealing dan Building Orientation pada 3D Printed Fused Deposition Modelling (FDM) Terhadap Kekuatan Tarik pada Hasil Cetak Berbahan Polylactic Acid (PLA+)." *Jurnal Teknik Material*, 2024.
- [12]. Rinanto, A., & Sutopo, W. (2017). Rapid Prototyping Technology Development: Literature Study. 18, 105–112.
- [13]. Roberth M. Ratlalan, "Design of Handwell Universal Tool Grinding Machine Prototype Using 3D Printer Technology Manufacturing Concept", *Synergy Mechanical Engineering Journal*, Vol. 20. 2022.
- [14]. Romli, Seprianto, D., Putra, D. P., Zamheri, & Rasid, M. (2020). The Effect of Parameters on the Process of Making Objects with Rapid Prototyping Digital Light Processing Technology on the Bending Stress. *Journal of Physics: Conference Series*, 1500(1). <https://doi.org/10.1088/1742-6596/1500/1/012027>.
- [15]. Tofail, S. A. M., et al. (2018). "3D printing of polymers: A review." **Materials Today**, 21(1), 22-36.
- [16]. Wohlers Associates. (2021). **Wohlers Report 2021: 3D Printing and Additive Manufacturing State of the Industry**. Wohlers Associates, Inc.
- [17]. Wohlers TT (2014) Wohlers report 2014 : additive manufacturing and 3D printing state of the industry: annual worldwide progress report. Fort Cplins, Wohlers Associates.
- [18]. Y. Subakti, T. Mesin, and P. Manufaktur Negeri Bangka Belitung, "The Effect of Process Parameters on the Tensile Strength of ST-PLA Filaments Using the Taguchi Method," 2021.
- [19]. Satankar, R. K. (2017). Investigating the process parameters of 3D printer extruder of Fused Deposition Modeling- A review. *Journal of Emerging Technologies and Innovative Research*, 4(10), 1–9.
- [20]. Seprianto, D., Iskandar, Wilza, R., & Adesta, E. Y. T. (2019). Influence of internal fill pattern, polishing time and Z-Axis orientation on the tensile strength of the 3D printed part. *International Journal of Recent Technology and Engineering*, 7(6), 170–174.
- [21]. Seprianto, Dicky, & Wilza, R. (2017). Parameter Optimization in 3D Printing Object Manufacturing Process with FDM Technology on Geometry Accuracy. November, 37–49.
- [22]. Setiawan, A. A., Karuniawan, B. W., & Arumsari, N. (2018). 3D Printing Parameter Optimization on Dimensional Accuracy and Surface Roughness of Products Using Taguchi Grey Relational Analysis Method. *Proceedings Conference on Design Manufacture Engineering and Its Application Program*, 2654.
- [23]. Valentincič, J., Peroša, M., Jerman, M., Sabotin, I., & Lebar, A. (2017). Low cost printer for DLP stereolithography. *Strojnicki Vestnik/Journal of Mechanical Engineering*, 63(10), 559–566. <https://doi.org/10.5545/sv-jme.2017.4591>.