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THE EFFECT OF ANNEALING TEMPERATURE ON THE TENSILE STRENGTH OF POLYLACTIC ACID FILAMENT PRINTED BY 3D PRINTER

(PENGARUH SUHU ANNEALING TERHADAP KEKUATAN TARIK DARI FILAMEN POLYLACTIC ACID YANG DIHASILKAN OLEH PRINTER 3D)

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ABSTRACT

The development of the industrial world is getting faster from time to time. The manufacturing industry is one of the industries that is very developed, especially in the use of technology. Although there have been some studies on the tensile strength of PLA filaments however, it is not yet clear about the effect of annealing treatment on the tensile strength of PLA filaments from 3D printers. Therefore, this study was conducted to determine the effect of annealing temperature on the tensile strength of polylactic acid material printed by 3D printers. This research uses experimental methods with the following conditions: The filament used is polylactic acid (PLA), specimens are printed to ISO 527-2 standard and the annealing treatment temperature are 50ºC and 70ºC. From the results of testing and data analysis that has been carried out, it can be concluded that annealing treatment is quite influential on the tensile strength value of polylactic acid (PLA) materials. The greater the annealing temperature, the higher the tensile strength value. At 50ºC annealing the average tensile strength value is 15.89 MPa, while at 70ºC annealing the average tensile strength value is 16.66 MPa.

Keyword: additve manufacturing, annealing, fused deposition modeling, polylactic acid, tensile strength.

ABSTRAK

Perkembangan dunia industri semakin pesat dari waktu ke waktu. Industri manufaktur merupakan salah satu industri yang sangat berkembang terutama dalam pemanfaatan teknologi. Meskipun telah ada beberapa penelitian mengenai kekuatan tarik filamen PLA, namun belum jelas mengenai pengaruh perlakuan annealing terhadap kekuatan tarik filamen PLA dari printer 3D. Oleh karena itu, penelitian ini dilakukan untuk mengetahui pengaruh suhu annealing terhadap kekuatan tarik bahan polylactic acid yang dicetak dengan printer 3D. Penelitian ini menggunakan metode eksperimen dengan ketentuan sebagai berikut: Filamen yang digunakan adalah polylactic acid (PLA), spesimen dicetak sesuai standar ISO 527-2 dan suhu perlakuan annealing 50ºC dan 70ºC. Dari hasil pengujian dan

analisis data yang telah dilakukan dapat disimpulkan bahwa perlakuan annealing cukup berpengaruh terhadap nilai kekuatan tarik bahan asam polilaktat (PLA). Semakin besar suhu annealing maka semakin tinggi nilai kuat tariknya. Pada suhu annealing 50ºC nilai kuat tarik rata-rata sebesar 15,89 MPa, sedangkan pada suhu annealing 70ºC nilai kuat tarik rata-rata sebesar 16,66 MPa.

Kata Kunci: additive manufacturing, annealing, fused deposition modeling, kekuatan tarik, polylactic acid.

INTRODUCTION

The development of the industrial world is getting faster from time to time. The manufacturing industry is one of the industries that is very developed, especially in the use of technology (Attaran, 2017).

Additive manufacturing is a technology that continues to evolve for industrial manufacturing use. One of the advantages of additive manufacturing is the ability of a sustainable production system (Javaid et al., 2021). Additive manufacturing is a production process by adding material (Arif, 2016). One method of additive manufacturing is fused deposition modeling or FDM.

Fused deposition modeling (FDM) is the printing of three-dimensional objects with a lower cost and relatively fast process (Riza et al., n.d.). The most popular use of fused deposition modeling technology is 3D printing.

3D printer machines are one technology that is increasingly receiving great attention. 3D printer technology is increasingly widely used and the price is increasingly affordable with various types. 3D printer machines use filaments as raw materials for printing three-dimensional objects (Ardiansyah et al., 2021).

Filament is a form filler material used in fused deposition modeling. There are several types of filaments, namely polyethylene terephthalate glycol (PETG), acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) and et cetera. Each of these filaments has its advantages and disadvantages.

Figure 1. Polylactic acid filament

PLA filaments are commonly used as materials in 3D printers because they have the advantages of being easy to form, relatively cheap and have good enough strength. PLA has a printing temperature ranging from 180ºC to 210ºC (Grabowik et al., 2017).

There have been several studies on tensile strength in polylactic acid (PLA) materials (Valerga et al., 2018) (Wicaksono and Darmawan, 2023) (Ikhsanto and Zainuddin, 2020) (Romero et al., 2021). Research by Lubis (Lubis et al., 2021) regarding the influence of process parameters on the tensile test of 3D printing products made from polylatic acid. The results showed that the temperature

of the extruder has a great influence on the tensile strength value. Further research by (Pratama et al., 2021) states that the parameters that have the most major influence on tensile strength are nozzle temperature, layer thickness and printing speed.

Annealing is the process of heating the material at a certain temperature then continued with slow cooling. This process is carried out to obtain the desired material structure. (Affandi et al., 2022) (Istiqlaliyah and Rhohman, n.d.) (Amanto and Daryanto, 2006).

Research conducted by Affandi (Affandi et al., 2022) regarding the effect of annealing steel ST 37 on tensile strength. The results stated that before the annealing process, the average tensile strength of ST 37 steel was 50.56 kgf / mm^2. The average tensile strength of ST 37 steel after annealing is 31.45 kgf/mm^2.

Research by Puspasari (Puspasari et al., n.d.) about the effect of annealing on the hardness of AISI 410-3MO-3Ni steel. The results stated that the most optimal hardness is AISI 410-3Mo-3Ni steel with an annealing process at a temperature of 760 °C for 6 hours, which is 35.9 HRC.

Research by Istiqlaliyah (Istiqlaliyah and Rhohman, n.d.) about the effect of annealing temperature variations on the hardness of steel joints ST 37 has the result, namely the increase in annealing temperature and holding time affects the level of hardness at test points, especially in welded joints.

Study by Owen (Owen et al., 2023) regarding the effect of high temperature optimization on the properties of natural kenaf fiber-filled engineering plastic composites. The best processing temperature was found to be 240°C. At this temperature, the material had the best combination of mechanical and thermal properties, and the coated fillers adhered well to the matrix. This was better than what was seen at 250°C and 260°C. Due to their high-temperature resistance, these composites are well-suited for demanding applications in industries like automotive and construction.

Research by Takeuchi (Takeuchi et al., 2023) stated that bamboo fibers that were mixed with various polymers (PE, PP, PA12, ABS, PA6 and Durabio)

Figure 2. 3D printer

using a single extruder and injection-molded into cylindrical shape specimens were then heated using injection molding temperature at 170ºC, 200ºC, 215ºC, 225ºC, 230ºC, 240ºC, 250ºC, 260ºC and 270ºC. Heating bamboo fibers to temperatures higher than 250 degrees for a constant period significantly weakens them. The tensile strength of bamboo fibers were greatly decrease. The tensile strength of the bamboo fibers heated at 250 °C for 7 min was relatively 50% of that heated at 210 °C.

Although there have been some studies on the tensile strength

of PLA filaments (Subakti et al., 2021) however, it is not yet clear about the effect of annealing treatment on the tensile strength of PLA filaments from 3D printers. This is important because annealing has a positive influence on the tensile strength of a materal. Therefore, this study was conducted to determine the effect of annealing temperature on the tensile strength of polylactic acid material printed by 3D printers.

METHOD

This research uses experimental methods with the following material and conditions:

1. The filament used is polylactic acid (PLA).
2. Specimens are printed to ISO 527-2 standard (ISO 527-2, 2019)
3. Specimens are printed using Kingroon KP3S 3D printer machine.
4. The annealing treatment temperature are 50ºC and 70ºC

Table 1. Printing parameters

Annealing Temperature (ºC)	Nozzle Temperature (ºC)	Layer Thickness (mm)	Printing Speed (mm/s)
50	200	0.2	40
70	200	0.2	40

The stages of the experiment are as follows:

1. Creation of three-dimensional specimen design based on ISO 527 standard using TinkerCAD software. The three-dimensional design is then sliced using Cura software.
2. Printing the specimens: 5 specimens for each annealing process (50ºC and 70ºC). Each specimen were then proceeded to annealing process. Total specimens are 10.
3. Each specimen is tested with a tensile testing machine so that the tensile strength value is obtained.

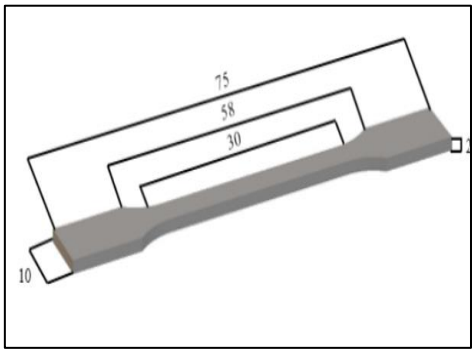

Figure 3. Specimen dimension ISO 527-2

RESULTS AND DISCUSSION

Tensile Testing Results

Specimens that have been printed using the Kingroon KP3S machine are then annealing with temperatures of 50ºC and 70ºC. The specimen is heated in a closed chamber. The temperature is varied to know how the relation of the temperature with its dependent variable. The duration is 1 hour. After the annealing process is finished, the specimen would be cool down for about 3 hours. Each temperature uses 5 test specimens. After the annealing process, tensile test testing is then carried out.

Figure 4. Testing specimens

Table 2. Tensile Test Results with 50ºC Annealing

Unit	Tensile Strength (MPa)
Specimen A1	16.22
Specimen A2	15.99
Specimen A3	16.61
Specimen A4	14.97
Specimen A5	15.70
Average	15.89

Table 3. Tensile Test Results with 70ºC Annealing

Unit	Tensile Strength (MPa)
Specimen B1	17.57
Specimen B2	16.90
Specimen B3	15.67
Specimen B4	17.39
Specimen B5	15.77
Average	16.66

Table 2 shows the results of tensile testing with 50ºC annealing treatment. Of the 5 specimens tested, the highest value was 16.61 MPa and the average tensile strength value was 15.89 MPa.

From Table 3. shows the results of tensile testing with annealing treatment 70ºC. Of the 5 specimens tested, the highest value was 17.57 MPa and the average tensile strength value was 16.66 MPa.

Tensile Testing Analysis

After tensile testing is carried out, an analysis is carried out to see the effect of annealing on tensile strength.

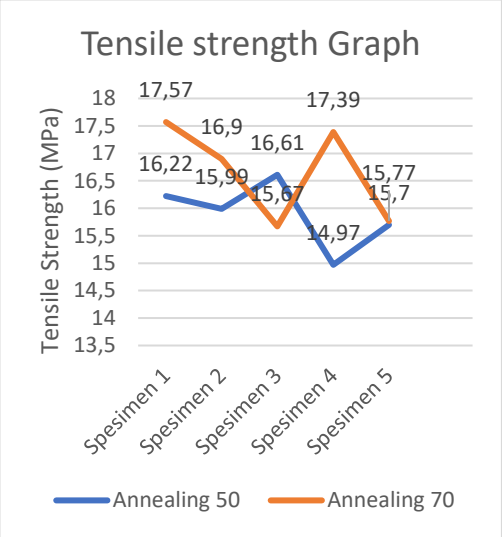

Figure 5. Tensile Strenth of polylactic acid filament

In Figure 3 it can be seen that the tensile strength value of the specimen at 50ºC annealing has the lowest tensile strength value is 14.97 MPa and the highest tensile strength value is 16.61 MPa. While the tensile strength value of the annealing specimen of 70ºC has the lowest tensile strength value is 15.67 MPa and the highest tensile strength value is 17.57 MPa.

An increase in annealing temperature indicates an influence on the mechanical properties of polylactic acid materials.. When a thermoplastic polymer is under a thermal energy, the intermolecular bond can move relatively easier among the other. Also, because of the weakening of the intermolecular bond, the structure of the PLA will start to realign and restructure itself into a crystalline formation. The crystallization of the polymer chain in PLA is divided into two area which is crystallization growth and nucleation controlling which both depend on the thermal energy within. Polylactic acid material becomes harder and less ductile

CONCLUSION

From the results of testing and data analysis that has been carried out, it can be concluded that annealing treatment is quite influential on the tensile strength value of polylactic acid (PLA) materials. The greater the annealing temperature, the higher the tensile strength value. At 50ºC annealing the average tensile strength value is 15.89 MPa, while at 70ºC annealing the average tensile strength value is 16.66 MPa.

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REFERENCES

Affandi, Nasution, A.R., Tanjung, I., Siregar, A.M., 2022. Pengaruh Annealing Baja St 37 Terhadap Kekerasan Dan Kekuatan Tarik. Jurnal Rekayasa Material, Manufaktur dan Energi 5.

Amanto, H., Daryanto, 2006. Ilmu Bahan, 3rd ed. Bumi Aksara, Jakarta.

Ardiansyah, R., Sirwansyah Suzen, Z., Erwansyah, E., 2021. Pengaruh Parameter Proses Terhadap Kekuatan Tarik Produk 3d Printing Menggunakan Filamen Polylactic Acid (PLA) Buatan R3d Maker. jist 2, 2153–2164. https://doi.org/10.36418/jist.v2i12.300

Arif, M., 2016. Bahan Ajar Rancangan Teknik Industri. Deepublish.

Attaran, M., 2017. The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons 60, 677–688. https://doi.org/10.1016/j.bushor.2017.05.011

Grabowik, C., Kalinowski, K., Ćwikła, G., Paprocka, I., Kogut, P., 2017. Tensile tests of specimens made of selected group of the filament materials manufactured with FDM method. MATEC Web Conf. 112, 04017. https://doi.org/10.1051/matecconf/201711204017

Ikhsanto, L.N., Zainuddin, Z., 2020. ANALISA KEKUATAN BENDING FILAMEN ABS DAN PLA PADA HASIL 3D PRINTER DENGAN VARIASI SUHU NOZZLE. mesin 21, 9–17. https://doi.org/10.23917/mesin.v21i1.9418

ISO 527-2, 2019. Plastics — Determination of tensile properties [WWW Document]. International Organization for Standardization. URL https://www.iso.org/obp/ui/#iso:std:iso:527:-1:ed-3:v1:en

Istiqlaliyah, H., Rhohman, F., n.d. PENGARUH VARIASI TEMPERATUR ANNEALING TERHADAP KEKERASAN SAMBUNGAN BAJA ST 37.

Javaid, M., Haleem, A., Singh, R.P., Suman, R., Rab, S., 2021. Role of additive manufacturing applications towards environmental sustainability. Advanced Industrial and Engineering Polymer Research 4, 312–322. https://doi.org/10.1016/j.aiepr.2021.07.005

Lubis, G.S., Taufiqurrahman, M., Ivanto, M., 2021. Analisa Pengaruh Parameter Proses Terhadap Uji Tarik Produk Hasil 3D Printing Berbahan Polylatic Acid. JEEMM 5, 39. https://doi.org/10.30588/jeemm.v5i2.877

Owen, M.M., Achukwu, E.O., Shuib, S.B., Ahmad, Z.R., Abdullah, A.H., Ishiaku, U.S., 2023. Effects of high-temperature optimization and resin coating treatment on the mechanical, thermal, and morphological properties of natural kenaf fiber-filled engineering plastic composites. Polymer Composites 44, 2512–2529. https://doi.org/10.1002/pc.27260

Pratama, W.H., Hasdiansah, Husman, 2021. Optimasi Parameter Proses 3D Printing Terhadap Kuat Tarik Material Filamen PLA + Menggunakan Metode Taguchi. SJoME 3, 39–45. https://doi.org/10.36655/sprocket.v3i1.568

Puspasari, V., Prasetyo, M.A., Hala, J.V.T., Anwar, S., Herbirowo, S., Mabruri, E.,

n.d. PENGARUH ANNEALING TERHADAP KEKERASAN DAN STRUKTUR MIKRO BAJA TAHAN KARAT AISI 410-3MO-3Ni.

Riza, E.I., Budiyantoro, C., Nugroho, A.W., n.d. PENINGKATAN KEKUATAN LENTUR PRODUK 3D PRINTING MATERIAL PETG DENGAN OPTIMASI PARAMETER PROSES MENGGUNAKAN METODE TAGUCHI.

Romero, A.E., Piovan, M.T., Mainetti, C.A., Stechina, D., Mendoza, S., Martín, H.D., Maggi, N.C., 2021. Tensile Properties of 3D Printed Polymeric Pieces: Comparison of Several Testing Setups. Ing. Inv. 41, e84467. https://doi.org/10.15446/ing.investig.v41n1.84467

Subakti, Y., -, H., Kurniawan, Z., 2021. Pengaruh Media, Temperatur Dan Waktu Perlakuan Annealing Pada Spesimen Standar ASTM D638 Type IV Menggunakan Filamen ST PLA. SJoME 3, 7–14. https://doi.org/10.36655/sprocket.v3i1.569

Takeuchi, T., Luengrojanaku, P., Ito, H., Rimdusit, S., Shibata, S., 2023. Effect of processing temperature and polymer types on mechanical properties of bamboo fiber composites. BioRes 19, 41–52. https://doi.org/10.15376/biores.19.1.41-52

Valerga, A., Batista, M., Salguero, J., Girot, F., 2018. Influence of PLA Filament Conditions on Characteristics of FDM Parts. Materials 11, 1322. https://doi.org/10.3390/ma11081322

Wicaksono, L.H., Darmawan, R., 2023. ANALISA KEKUATAN TENSILE MATERIAL POLYLACTIC ACID HASIL 3D PRINTER DENGAN SPESIMEN ISO 527-2 2.