Journal of Mechanical Engineering and Mechatronics
ISSN: 2527-6212, Vol. 6 No. 2, pp. 119-126

EFFECT OF EXTRUSION PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF 3D PRINTED PLA PRODUCT

Nanang Ali Sutisna[1,a], Rakha Amrillah Fattah[2,b]

[1,2]Mechanical Engineering Study Program, Faculty of Engineering, President University Jl. Ki Hajar Dewantara, Jababeka Education Park, Bekasi 17550

[a]nanang.ali@president.ac.id, [b]rakha.fatah.rf@gmail.com

Abstrak.
Metode produksi item melalui penyimpan material secara serempak level demi level, berdasarkan model digital 3D, disebut Additive Manufacturing (AM) atau pencetakan 3D. Di antara banyak metode AM, teknik Fused Deposition Modeling (FDM) bersama dengan bahan PLA (Polylactic acid) umumnya digunakan dalam pembuatan aditif. Sampai saat ini, sifat mekanik komponen AM tidak dapat dihitung atau diperkirakan sampai komponen tersebut dirakit dan diperiksa. Dalam karya ini, pendekatan baru disarankan tentang bagaimana proses ekstrusi mempengaruhi sifat mekanik komponen yang dicetak untuk mendapatkan bagaimana bagian tersebut dapat diproduksi atau dicetak untuk mencapai sifat mekanik yang lebih baik. Metodologi ini didasarkan pada prosedur eksperimental di mana kombinasi parameter untuk mencapai yang optimal dari percobaan manufaktur dan nilainya dapat ditentukan, hasil yang diperoleh menunjukkan pengaruh proses ekstrusi terhadap sifat mekanik.

Kata kunci. *AM, PLA, FDM, Sifat Mekanik, printer 3D, Proses Ekstrusi.*

Abstract.
The method of producing items through synchronously depositing material level by level, based on 3D digital models, is named Additive Manufacturing (AM) or 3D-printing. Amongs many AM methods, the Fused Deposition Modeling (FDM) technique along with PLA (Polylactic acid) material is commonly used in additive manufacturing. Until now, the mechanical properties of the AM components could not be calculated or estimated until they've been assembled and checked. In this work, a novel approach is suggested as to how the extrusion process affects the mechanical properties of the printed component to obtain how the parts can be manufactured or printed to achieve improved mechanical properties. This methodology is based on an experimental procedure in which the combination of parameters to achieve an optimal from a manufacturing experiment and its value can be determined, the results obtained show the effect of the extrusion process affects the mechanical properties.

Keywords: *AM, PLA, FDM, Mechanical Properties, 3D printer, Extrusion Process.*

Introduction

Technology has changed in the modern era, we should have found the other method to wipe the conventional method. Optimization is the way to change the old method to the new method, and now there is a technology it's called Additive Manufacturing (AM). Additive Manufacturing (AM), known for the past three decades, is a technology that can create real objects or called finished products made from raw materials. This process requires computerization with special software called Computer-Aided Design (CAD) directly, which is used to give the printer information to create the object. The method of creating this object is done by adding layer by layer gradually until it becomes a real object that you want to print. The Additive Manufacturing (AM) process differs because it has advantages

over conventional manufacturing processes by focusing on adding new material rather than producing residual material, making it a more efficient and fast process.
Extrusion is a method in Additive Manufacturing (AM) that is currently frequently used, a process in which objects are created with a fixed cross-section and a nozzle that cramps upwards and downwards and sides. The advantage of the extrusion process is that it can make objects with complex cross-sections, geometries, and complex cavities. Also, can process materials by the extrusion process only works by the press. This extrusion application is considered environmentally friendly so that it can be used in home 3d printing and also is easier to develop the product.

In view of the rapid growth of 3d printers, this study will discuss the effect of extrusion process parameters on the mechanical properties of 3d printed products with polylactic acid (PLA) filament.

Literature Review

Additive Manufacturing (AM) as known as a 3D printer, the method used to generate a large range of 3D model structures and complex geometries. The method involves printing sequential multiple layers shaped over each of one another. Based on the ASTM definition [1], additive manufacturing (AM) is the process of combining materials to create objects from 3D model data, usually layer by layer, as opposed to subtractive manufacturing methodologies. Other terminologies to describe additive manufacturing includes additive fabrication, additive processing, additive engineering, additive coating, and free form fabrication. Customized manufacturing processes are as of now has become the trend in 3D printing, as expected by Wohlers Associates, which envisaged that around 50 percent of 3D printing would occur all over the development of consumer products in 2020 [2].

AM are having many methods to develop until this day of 3D printers. The most popular 3D printing process, most of which uses polymer filaments, are identified as material extrusions, such as fused deposition modelling (FDM) or fused filament fabrication (FFF). The other is selective laser sintering (SLS), selective laser melting (SLM) or liquid binding in three-dimensional printing (3DP), material jetting, stereolithography apparatus (SLA), direct energy deposition (DED), laminated object manufacturing (LOM), and hybrid, are the methods of AM. Each system has its process material, Polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are the key polymers commonly using for 3D composite printing [3].

Additive processing has been commonly used in numerous fields, there is prototyping, construction, and biomechanical. Implementation of 3D printing there in the construction sector was, in specific, quite slow and marginal given the benefits of, for example, less waste, freedom of design, and automation[4].

There are many researches that have been conducted related to optimization of 3D printing process parameters on mechanical properties of printed product using different materials. Boparai, et al. [5] discusses the optimization of extrusion process parameters in aluminum alloy materials, while Sagias, et al. [4] discusses the mechanical properties of 3d printed polymer of specimens. The method that using in this journal is the Taguchi method and using ABS material. In addition, Tontowi, et al [6] discusses the optimization of process parameters in the Polylactic acid printed (PLA) part with Taguchi method and Setiawan, et al [7] reported the optimization of 3D printing parameters on dimensional accuracy and surface quality using Taguchi-Grey relational analysis. This research is focuses on the effect of extrusion process parameters on mechanical properties of 3D printed PLA product.

Methodology

This observation is carried out in the extrusion process and the printout of the filament, especially the PLA filament, which will be printed with a 3D printer at the President University Lab. To determine the effect of the extrusion process on a 3d printer on mechanical properties here is an observation by printing an object from a filament, which is commonly called a PLA product. Parameters have a lot of influence on the object. This happens because each different parameter will produce different results, then in terms of its mechanical properties, one of which will be a tensile test to determine the mechanical properties of these objects.

Identification

In identifying this thesis's writing, the author decided to focus on the PLA analysis of products that have been printed using a 3D printer with different parameters and tested using the tensile test. This research aims to make a good product by analyzing the print results of a 3D printer product so that it can be seen the effect of the extrusion process with different parameters on the mechanical properties produced from a filament PLA, the illustration would be described in figure 1 below

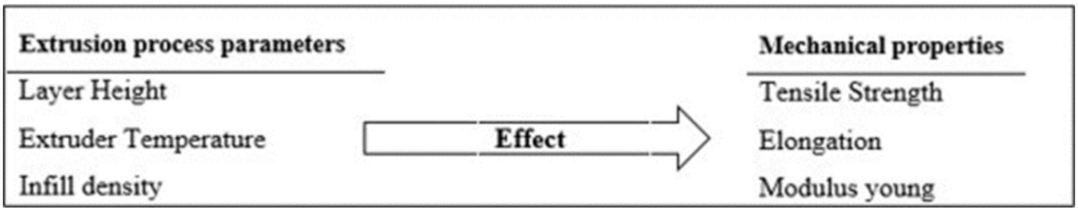

Figure 1 Identification Problem

Data Collection

The next step is to collect data for the final project after studying all theoretical studies. Initial data in the form of specimens that will be tested for tensile testing is designed using CAD software by adjusting the tensile testing machine found in the lab president university. The specimen that would be use is following the standart which is ASTM D638 TYPE I standard test method for tensile properties of plastics [8]. The specimen itself has a thickness of 3mm.

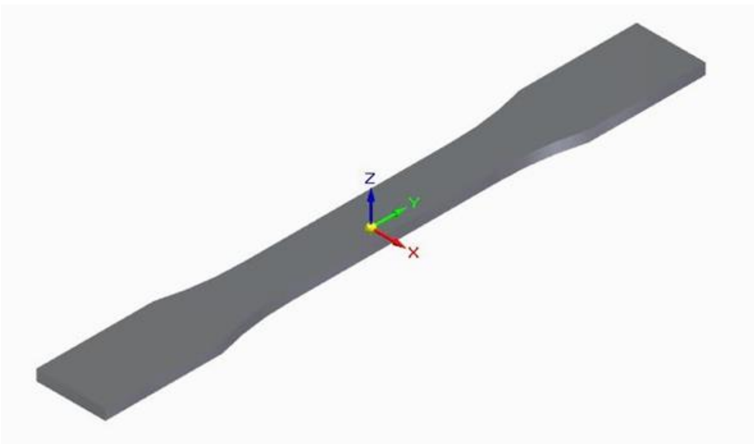

Figure 2 Design 3D of the specimen

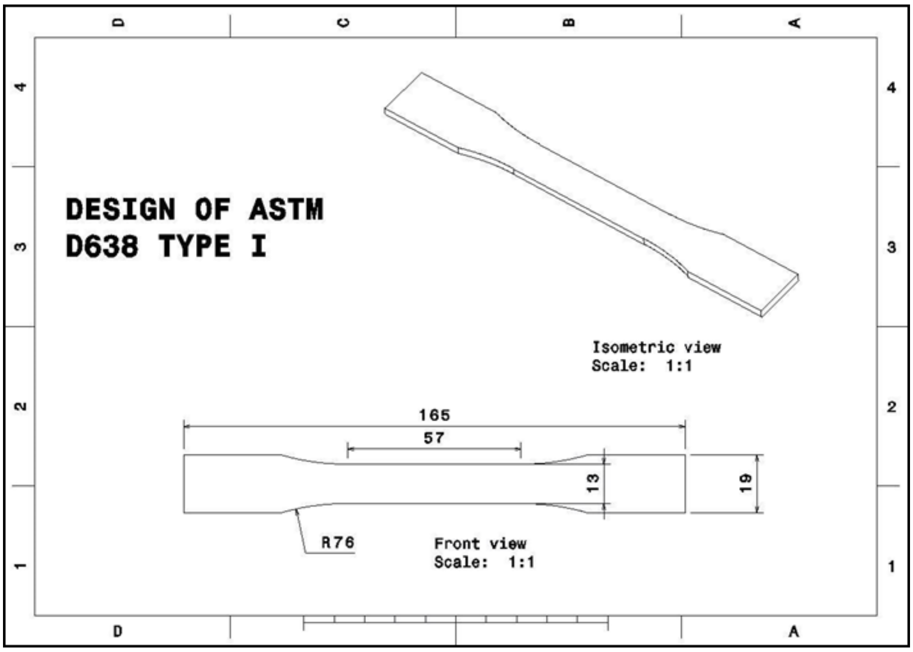

Figure 3 Design of the specimen [8]

The next parameter is the extruder temperature, which determines which filament is too liquid or not. The temperature, which will be mentioned later, will be based on the filament supplier's recommendations. The fill density used for filling in the physical model results is the next parameter and parameter. The data will be described in the form of parameter variations, which will be written using the table below.

Table 1 Parameter of the specimen

Parameter	**Level 1**	**Level 2**	**Level 3**
Layer Height (LH)	0.05 mm	0.1 mm	0.2 mm
Extruder Temperature (ET)	200°C	205°C	210°C
Infill Density (ID)	10%	20%	30%

Table 1 explains the parameter used in this thesis to know the effect on mechanical properties, which is this parameter will be the model physic, for level 1 using 0.05 mm layer height, 200°C extruder temperature, and 10% the infill density. Level 2, the layer height increase becomes 0.1 mm, 205°C extruder temperature, and 20% infill density for level 3 using the most significant layer height 0.2 mm, 210°C extruder temperature, and 30% the infill density. The experimental data will be written in an orthogonal matrix using Table 2 below.

Table 2 Experiment of the specimen

Specimen	**LH**	**ET**	**ID**
1	0.05 mm	200°C	10 %
2	0.05 mm	205°C	20 %
3	0.05 mm	210°C	30 %
4	0.1 mm	205°C	30 %

5	0.1 mm	210°C	10 %
6	0.1 mm	200°C	20 %
7	0.2 mm	210°C	20 %
8	0.2 mm	200°C	30 %
9	0.2 mm	205 °C	10 %

Data Analysis

This part discusses a complete explanation of the stages of data analysis that have been mentioned above, which will be tested using a tensile testing machine in the President University lab as shown in Figure 4, with different parameters as exhibited in Table 1.

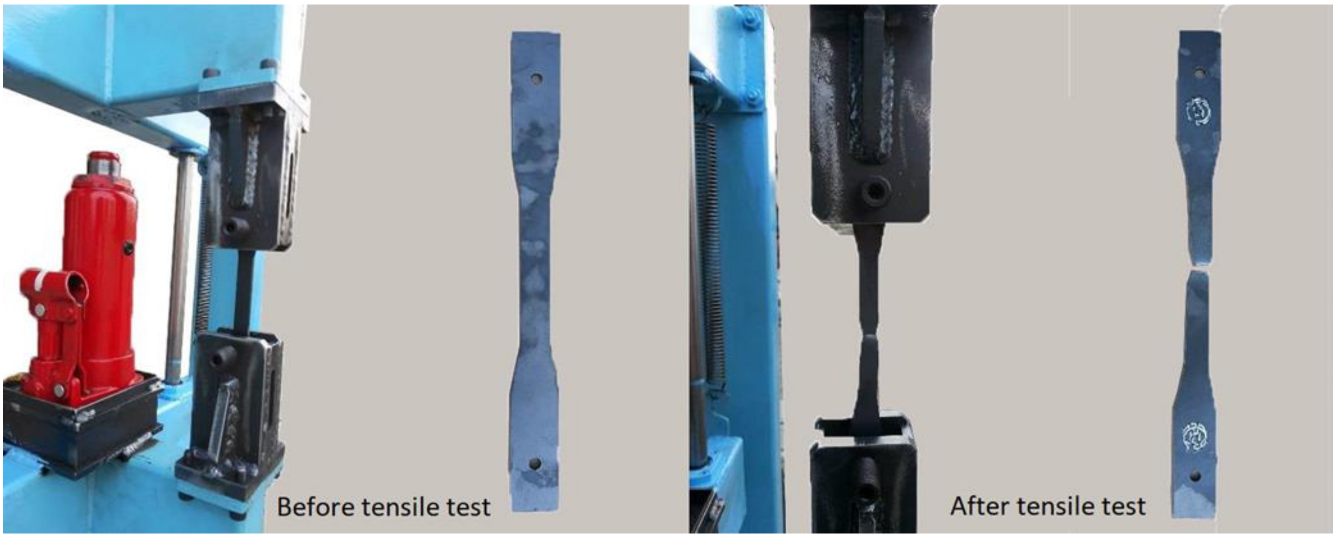

Figure 4. Specimen before and after tensile testing

The following equations are used in the testing analysis.

Tensile Strength $$\sigma = F/A \qquad (1)$$

Elongation $$\varepsilon = \Delta l/l \times 100\% \qquad (2)$$

Young's Modulus $$E = \sigma/\varepsilon \qquad (3)$$

Result & Discussion

After all specimen data that have been printed and tested produce specimen parameter data and tensile strength. According to Figure 4 about result testing of the specimen below, the specimen has successfully been implemented by methodology in the previous chapter. The fracture of the specimen is not always the same as the other because the strength of the specimen has different parameters

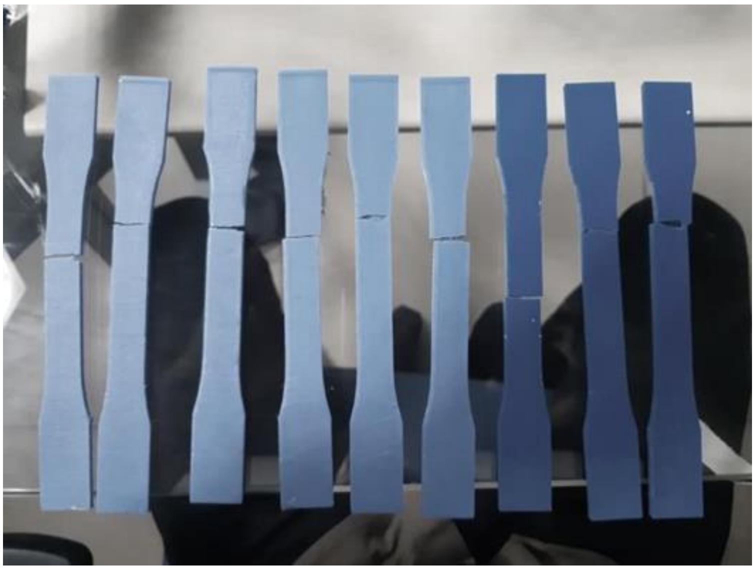

Figure 4 Result testing of the specimen

All of the specimens are showing the influence of the mechanical properties, the most influential parameters the author could say is layer height. Extrusion Process parameters were set at the start of the experiment, the parameters embrace is the result above. The optimum extrusion process parameters, resulting in the highest ultimate tensile strength was the following Table 3 with the yellow line :

Table 3. Extrusion parameters and the effect on mechanical properties

Specimen	LH	ET	ID	Tensile Strength	Elongation	Young Modulus
1st	0.05 mm	200°C	10 %	27.9 Mpa	2.04 %	1,368 Mpa
2nd	0.05 mm	205°C	20 %	32.1 Mpa	1.60 %	2,006 Mpa
3rd	0.05 mm	210°C	30 %	33.4 Mpa	1.00 %	3,340 MPa
4th	0.1 mm	205°C	30 %	25.4 Mpa	2.59 %	981 Mpa
5th	0.1 mm	210°C	10 %	28.8 Mpa	1.66 %	1,735 Mpa
6th	0.1 mm	200°C	20 %	28.4 Mpa	2.32 %	1,224 Mpa
7th	0.2 mm	210°C	20 %	28 Mpa	2.89 %	969 Mpa
8th	0.2 mm	200°C	30 %	24.8 Mpa	1.90 %	1,305 Mpa
9th	0.2 mm	205 °C	10 %	21.5 Mpa	2.80 %	768 Mpa

After all, due to the various parameters, it is found that the strongest specimen at about 33.4 MPa (experiment 3) besides this specimen happened after deformed before its fracture. In this final project, these factors were reduced, To investigate the benefits for producing parts to identical mechanical properties using various AM parameters. The results above is that the optimum parameters of the extrusion process having a major effect on the mechanical properties at the specimens produced.

Conclusion

After all methods and analyze the object, it is concluded that:

1. Extrusion process parameters such as layer height, infill density and extruder temperature. Layer height is most affect the mechanical properties especially tensile strength because the layer height is how many the layer built by the height it makes the specimens strong. Also the other parameters such as infill density and extruder temperature also affect the mechanical properties.
2. The optimum parameters that produce a good product are experimental number 3 that had the highest strength, i.e ; LH : 0.05 mm, ET : 210°C , Infill Density : 30%.

Recommendations

Further research on other parameters is required and the findings of other filaments or other types of AM can also be used, as this study only analyzes and performs research on PLA generated from FDM type machine.

References

[1] ISO/ASTM 52900:2015 [ASTM F2792-12a], "Additive manufacturing - General principles - Terminology Standard".

[2] Wohlers Associates. " Wohlers Report 2020: 3D Printing and Additive Manufacturing, Global State of the Industry", 2020.

[3] N. A. Sutisna, "A Preliminary Design of a Hybrid Machine for Additive and Subtractive Manufacturing," Journal of Mechanical Engineering and Mechatronics, vol. 5, no. 1, 2020, pp. 48–56.

[4] V.D. Sagias, K.I. Giannakopoulos and C. Stergiou, "Mechanical properties of 3D printed polymer specimen Thermo-mechanical modeling of a high pressure turbine blade of an airplane gas turbine," *ScienceDirect, Procedia Struct. Integr.*, vol. 10, pp. 85–90, 2018.

[5] K. S. Boparai, R. Singh, and H. Singh, "Modeling and optimization of extrusion process parameters for the development of Nylon6–Al–Al2O3 alternative FDM filament," *Prog. Addit. Manuf.*, vol. 1, no. 1–2, pp. 115–128, 2016, doi: 10.1007/s40964-016-0011-x.

[6] A. Tontowi, L. Ramdani, R. Erdizon, & D. Baroroh. "Optimization of 3D-Printer Process Parameters for Improving Quality of Polylactic Acid Printed Part". *International Journal of Engineering and Technology*. Vol 9, No. 2, 2017, pp.589-600.

[7] A.A Setiawan, B.W. Karuniawan, & N. Arumsari. "Optimasi Parameter 3D Printing Terhadap Keakuratan Dimensi dan Kekasaran Permukaan Produk Menggunakan Metode Taguchi Grey Relational Analysis". Conference on Design and Manufacture and Its Aplication, Vol 2 No 1, 2018, pp. 165-168.

[8] ASTM International, "Standard Practice for Preparation of Metallographic Specimens," *ASTMInt.*, vol. 82, no. C, pp. 1–15, 2016, doi: 10.1520/D0638-14.1.

[9] B. Berman, “3-D printing: The new industrial revolution,” Bus. Horiz., vol. 55, no. 2, 2012, pp. 155–162, doi: 10.1016/j.bushor.2011.11.003.

[10] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, “Additive manufacturing (3D printing): A review of materials, methods, applications and challenges,” Compos. Part B Eng., vol. 143, December 2017, pp. 172–196, doi: 10.1016/j.compositesb.2018.02.012.

[11] H. Lee, C. H. J. Lim, M. J. Low, N. Tham, V. M. Murukeshan, and Y. J. Kim, “Lasers in additive manufacturing: A review,” Int. J. Precis. Eng. Manuf. - Green Technol., vol. 4, no. 3, 2017, pp. 307–322, doi: 10.1007/s40684-017-0037-7.

[12] J. Z. Manapat, Q. Chen, P. Ye, and R. C. Advincula, “3D Printing of Polymer Nanocomposites via Stereolithography,” Macromol. Mater. Eng., vol. 302, no. 9, 2017, pp. 1–13, doi: 10.1002/mame.201600553.

[13] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, “Additive manufacturing (3D printing): A review of materials, methods, applications and challenges,” Compos. Part B Eng., vol. 143, no. December 2017, pp. 174, doi: 10.1016/j.compositesb.2018.02.012.

[14] LASERTEC 65, 3D: Additive Manufacturing in Milling Quality. Available: http://us.dmgmori. com/blob/354972/caef73fe2f4d3e0baff239006d465164/pl0us-lasertec-65-3dpdf-data.pdf [Dec. 10th, 2020]

[15] Y. Song, Y. Li, W. Song, K. Yee, K. Y. Lee, and V. L. Tagarielli, “Measurements of the mechanical response of unidirectional 3D-printed PLA,” Mater. Des., vol. 123, 2017, pp. 154–164, doi: 10.1016/j.matdes.2017.03.051.

[16] A. B. Reddy et al., Polyethylene Terephthalate-Based Blends: Natural Rubber and Synthetic Rubber. Elsevier Inc., 2015.

[17] H. F. Giles, Jr. "Extrusion: The Definitive Processing Guide and Handbook" William Andrew Publishing, 2005