Effect of 3D Printing Process Parameters on Flexural Strength of Mixing PLA and PCL Polymer

By Hendri Chandra

Effect of 3D Printing Process Parameters on Flexural Strength of Mixing PLA and PCL Polymer

DP Putra[1], Romli[2], Akbar Teguh Prakoso[1], NY Mahendra[1], Muhammad Imam Ammarullah[5], Muhammad Yanis[1], Hendri Chandra[1], Ardiyansyah Syahrom[3,4], Jamari[5] and Hasan Basri[1,a)]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indralaya, OganIlir, Indonesia.
[2]Department of Mechanical Engineering, State Polytechnic of Sriwijaya, Jalan Srijaya Negara Bukit Besar Palembang, Sumatera Selatan, 30139, Indonesia.
[3]Applied Mechanics and Design, School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia 81310 UTM Johor Bahru, Malaysia.
[4]Medical Devices and Technology Centre (MEDiTEC), Institute of Human Centred and Engineering (iHumEn), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.
[5]Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Tembalang 50275, Semarang, Central Java, Indonesia.

[a)] *Corresponding author: hasan_basri@unsri.ac.id*

Abstract. 3D Printer is a breakthrough in manufacturing technology based on a layer-by-layer printing process through various raw material input techniques. One of them is additive manufacturing technology, namely 3D Printing, widely used in the medical device industry. This study aims to obtain parameters that affect the mixture of polylactic acid and polycaprolactone on the flexural strength of test specimens for applying bone plate for orthopaedic implants with print temperature, print speed, and layer thickness referring to ASTM-D790 with dimensions of 120x10x4 mm. The test data were analyzed based on a two factorial level experimental design with a three interaction factor design model, which was processed using the Anova method. The results of the analysis show that the parameters that affect the flexural strength are printing temperature of 32%, the printing speed of 30%, and layer thickness of 29%, with the conclusion that the Print temperature parameter has the most significant contribution to the flexural strength of a mixture of PLA and PCL specimens.

INTRODUCTION

The leading cause of bone damage or fracture problems that often occur in the general population is the mechanical impact or bone abnormalities. The cast made from polymer and fibreglass is one of the treatments often used in most patients with bone damage. The cast is a combination of several substances that hold the position of the damaged bone during the healing process [1]. According to medical records at Bhayangkara Hospital Palembang, there have been 3,015 (30,15%) fracture cases with details per 2015 with 541 cases, in 2016 with 1,471 and in 2017 with 1,003 fracture cases in the last six years.

Currently, the industrial world engaged in manufacturing continues to experience changes because innovations make the industrial world overgrow [2]. One of them is additive manufacturing technology, namely 3D Printing, widely used in the healthcare industry. The application of 3D printing in the health sector is not a new thing. This technology helps the medical world in visualizing medical images into three-dimensional models [2]. 3D printers use polymer materials in the form of filaments to three-dimensional print objects. The widely used polymer materials are polylactic acid (PLA), polycaprolactone (PCL), acrylonitrile butadiene styrene (ABS), and others [3,4].

Toward Adaptive Research and Technology Development for Future Life
AIP Conf. Proc. 2689, 070002-1–070002-6; https://doi.org/10.1063/5.0116239
Published by AIP Publishing. 978-0-7354-4470-6/$30.00

Current polymer materials have made it possible to manufacture various products, especially medical devices with low cost, weight, and high performance, and have become a core part of technological developments and society [5,6].

The mixing material uses a small PCL pallet mixed homogeneously with PLA pellets set as a fixed variable fabricated into a new filament through an extrusion process with the help of an extruder machine. Then the extrusion results are printed using additive manufacturing technology, namely 3D Printer. The difference in this fabricated filament material is the amount of mixture of PLA and PCL with a mixing volume ratio of 80 gr PLA and 20 gr PCL resulting in a composite filament of PLA and PCL weighing 100 gr.

The main objective of this research is to improve the quality of the mechanical properties of a mixture of PLA and PCL, which is fabricated into filaments and then printed using a 3D Printer FDM machine. The filaments were then subjected to flexural testing to determine the flexural strength of the new material from the mixing process for application to bone plates for orthopaedic implants.

EXPERIMENTAL SETUP

In this study, mixing PLA and PCL pallets using a single screw extruder resulted in the type of biodegradation 80PLA20PCL filament alloy by volume mixing, namely 80 gr PLA and 20 gr PCL, followed by a printing process using a 3D Printer FDM machine to form a flexural test specimen referring to ASTM-D790. The test specimen further tested the flexure to obtain the flexible strength of each of the tested parameters of the test specimen. The stages of the new PLA-PCL filament fabrication process are as shown in Fig. 1.

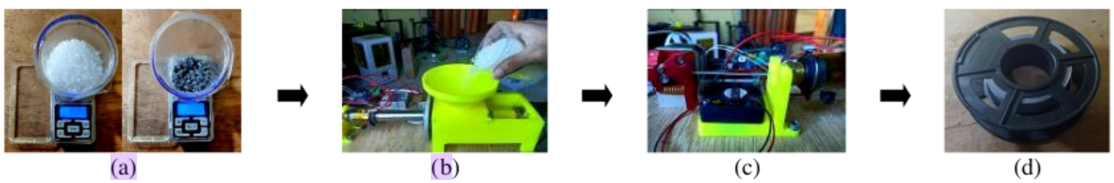

FIGURE 1. (a) PLA and PCL Pellets (b) Pouring (c) Extrusion Process (d) PLA and PCL Pellets blend

The filament fabrication process is carried out by mixing PLA and PCL materials at a predetermined ratio. The materials then enter the hopper of the extruder machine and then forwarded to a 150kg-cm extrusion screw at a speed of 19 rpm and transport the material to a nozzle heated at 180°C to produce filaments with a diameter of ±1.75mm with a length of 635mm per minute.

Testing Specimens

The manufacture of flexural test specimens is carried out in three stages:

1. Design the three-dimensional shape of the ASTM-D790 using CAD software, as shown in Fig. 2.
2. Slice and export the design of the test specimen using the Simplify 3D software.
3. Print test specimens using the FDM 3D Printer tool.

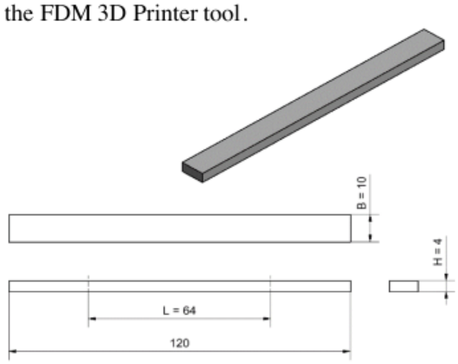

FIGURE 2. Testing specimen ASTM-D790

When starting the printing process, adjusting the object's position is very important in Simplify 3D software because the software adjusts the printing process parameters on the 3D printer, affecting the printed object's quality.

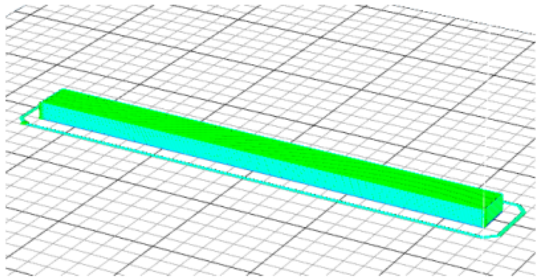

FIGURE 3. Part orientation

The tested specimen is arranged in a horizontal position, as shown in Fig. 3. FDM 3D Printer prints by extruding the layer filament so that different places have different layers and can affect the strength of the printed structure. In this study, 16 test specimens were printed according to ASTM-D790, as shown in Fig. 3, to obtain the mechanical properties of the filament fabricated to manufacture the bone plate.

After the specimen moulding process, as shown in Fig. 4, a flexural test was carried out on the 16 specimens to obtain the flexural strength of the newly fabricated filament material.

(a) (b) (c)

FIGURE 4. (a) Specimen printing process (b) ASTM-D790 flexural test specimen printing result (c) Flexural test process

As shown in Fig. 4, there are 16 test specimens printed using the FDM 3D Printer with the specified parameters. Flexural testing is carried out on each test object to determine the flexural strength of the test object and then processing the variance analysis data from each combination of parameters determined from the test results assisted by design expert software.

Data Processing

In conducting this Anova experiment, the parameters selected were Print Temperature (PT), Print Speed (PS), and Layer Thickness (LT) as independent variables, namely, PT; 195-210 °C, LT; 0.1 mm - 0.2 mm, and PS; 45 mm/s - 65 mm/s. Each range of independent variables has two levels in Table 2 and the dependent variable in Table 1.

TABLE 1. Dependent variable

Parameter	Value	Unit
PLA/PCL	100	gram
Heated Bed Temperature	60	°C

Parameter	Value	Unit
Infill Density	100	%

TABLE 2. Independent variable

Parameter	Level 1	Level 2	Unit
Print Temperature	195	210	°C
Print Speed	45	65	mm/s
Layer Thickness	0.1	0.2	mm

The primary purpose of this research is to see the flexural strength of the test object on the effect of each combination of parameters. The final result of the experiment must have a solid flexural strength, and then data processing is carried out using the ANOVA method, which is calculated by the equation as shown in Table 3.

TABLE 3. ANOVA formula

Source	Sum of Squares	Degrees of Freedom	Mean Square	F_0
Overall model	SS_{model}	$(k_A k_B)-1$	$SS_{model}/(k_A k_B)-1$	MS_{model}/MS_E
Main Effect of A	SS_A	v_A	SS_A / v_A	MS_A/MS_E
Main Effect of B	SS_B	v_B	SS_B / v_B	MS_B/MS_E
Main Effect of C	SS_C	V_C	SS_C / v_C	MS_C/MS_E
A x B interaction	SS_{AB}	v_{AxB}	SS_{AB}/ v_{AxB}	MS_{AB}/MS_E
A x C interaction	SS_{AC}	v_{AxC}	SS_{AC}/ v_{AxC}	MS_{AC}/MS_E
B x C interaction	SS_{BC}	V_{BxC}	.SS_{BC}/ v_{BxC}	MS_{BC}/MS_E
A x B x C interaction	SS_{ABC}	v_{AxBxC}	SS_{ABC}/ v_{AxBxC}	MS_{ABC}/MS_E
Error	SS_E	v_e	SS_E / v_e	
Total	SS_{Total}	v_T		

Data Analysis

Analysis of variance with the experimental method of two levels of factorial design using three factors and one response was determined to see the effect of each combination of test parameters. Specimen testing was carried out randomly according to the measurement design matrix in Table 4, with two repetitions.

TABLE 4. Design matrix

STD	RUN	Parameter			Flexurel Test (N/mm^2)
		PT (°C)	PS (mm/s)	LT (mm)	
11	1	210	45	0,1	7,88
13	2	195	45	0,1	7,25
16	3	210	45	0,2	6,75
7	4	210	65	0,1	7,42
14	5	195	65	0,1	5,58
6	6	210	65	0,2	6,17
1	7	195	65	0,1	5,6
3	8	195	65	0,2	5,1
10	9	195	45	0,2	6,25
4	10	195	45	0,2	6,28
9	11	195	45	0,1	7,28

STD	RUN	Parameter			Flexurel Test (N/mm^2)
		PT (°C)	PS (mm/s)	LT (mm)	
15	12	210	65	0,1	7,44
5	13	210	45	0,1	7,95
2	14	210	45	0,2	6,79
8	15	210	65	0,2	6,19
12	16	195	65	0,2	5,12

RESULT

As shown in Table 4, the data from the measurement design for the test specimens obtained the minimum, maximum, average, standard deviation, and the ratio of each response and factor in the test, as shown in Table 5 and Table 6.

TABLE 5. The mean and standard deviation of test results

Factor	Name	Units	Min	Max	-1 (Code)	Mean	Std. Dev
A	Print Temperature	°C	195	210	195	202,5	10,6066
B	Print Speed	mm/s	45	65	65	55	14,214
C	Layer Thickness	mm	0.1	0.2	0.1	0,15	0,070711

TABLE 6. Response testing with the 3FI model design

Name	Units	Observ.	Analysis	Min	Max	Mean	Std. Dev	Ratio
Flexural Test	N/mm^2	16	Factorial	5,1	7,95	6,565	0,924561	1,55882

From the measurement data in Table 5 and Table 6, the following process analyzes the influence on the flexural strength of the test specimen, and the results of the analysis are shown in Table 7, as follows:

TABLE 7. ANOVA test results

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	12,82	7	1,83	2959,25	< 0.0001	*significant*
A-Print Temperature	4,13	1	4,13	6676,45	< 0.0001	
B-Print Speed	3,81	1	3,81	6161,22	< 0.0001	
C-Layer Thicness	3,75	1	3,75	6066,92	< 0.0001	
AB	0,77	1	0,77	1244,45	< 0.0001	
AC	0,21	1	0,21	338,27	< 0.0001	
BC	0,043	1	0,043	69,59	< 0.0001	
ABC	0,098	1	0,098	157,83	< 0.0001	
Pure Error	4,950E-3	8	6,187E-4			
Cor Total	12,82	15				

From the results of the Anova experiment, as shown in Table 7, it can be seen that the significant F value is the printing temperature which is the main factor affecting the flexural strength of the test object.

Table 7 shows the effect of the main factors on flexural strength. By using the equation in Table 3, it is possible to calculate the percentage value of the contribution of each factor that affects the flexural strength of the test object, namely:

A Factor= Print Temperature : $\frac{4{,}13 - 0{,}00495}{12{,}86} = 32\%$

B Factor = Print Speed : $\frac{3{,}81 - 0{,}00495}{12{,}86} = 30\%$

C Factor = Layer Thickness : $\frac{3{,}75 - 0{,}00495}{12{,}86} = 29\%$

A x B interaction : $\frac{0{,}77 - 0{,}00495}{12{,}86} = 6\%$

A x C interaction : $\frac{0{,}21 - 0{,}00495}{12{,}86} = 2\%$

B x C interaction : $\frac{0{,}043 - 0{,}00495}{12{,}86} = 1\%$

A x B x C interaction : $\frac{0{,}098 - 0{,}00495}{12{,}86} = 1\%$

CONCLUSION

The results of the analysis show that the parameters that affect the flexural strength are printing temperature of 32%, the printing speed of 30%, and layer thickness of 29%, with the conclusion that the Print temperature parameter has the most significant contribution to the flexural strength of a mixture of PLA and PCL specimens.

ACKNOWLEDGMENTS

The research publication of this article was funded by the DIPA of Public Service Agency of Universitas Sriwijaya 2021. Under the Rector's Decree Number: 0014/UN9/SK.LP2M.PT/2021, On May 25, 2021. We gratefully thank the Mechanical Engineering Department, Faculty of Engineering, Universitas Sriwijaya for their strong support of this study, along with the Medical Device and Technology Center (MEDITEC), Institute of Human-Centered and Engineering (iHumEn), Universiti Teknologi Malaysia, Department of Mechanical Engineering, and State Polytechnic of Sriwijaya for their encouragement and many fruitful discussions on this research.

REFERENCES

1. Rezaei R. The Easy Wrap Orthopedic Cast. 2017;
2. Dahlan M, Gunawan B, Hilyana FS. RANCANG BANGUN PRINTER 3D MENGGUNAKAN KONTROLLER ARDUINO MEGA 2560. In: SNATIF. 2017. p. 105–10.
3. Plastics Europe. Plastics – the Facts 2015: An analysis of European plastics production, demand and waste data. 2015.
4. Hopewell J, Dvorak R, Kosior E, Hopewell J, Dvorak R, Kosior E. Plastics recycling : challenges and opportunities Plastics recycling : challenges and opportunities. 2009;(June).
5. Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Manag [Internet]. 2009;29(10):2625–43. Available from: http://dx.doi.org/10.1016/j.wasman.2009.06.004
6. Kreiger M, Anzalone GC, Mulder ML, Glover A, Pearce JM. Distributed Recycling of Post-Consumer Plastic Waste in Rural Areas. MRS Proc [Internet]. 2013/02/27. 2013;1492:91–6. Available from: https://www.cambridge.org/core/article/distributed-recycling-of-postconsumer-plastic-waste-in-rural-areas/C553E81AD6A084FE7FC30FEEA51CA9AC

Effect of 3D Printing Process Parameters on Flexural Strength of Mixing PLA and PCL Polymer

ORIGINALITY REPORT

17%
SIMILARITY INDEX

PRIMARY SOURCES

1	www.atlantis-press.com Internet	151 words — 7%
2	www.ndsu.nodak.edu Internet	48 words — 2%
3	prr.hec.gov.pk Internet	23 words — 1%
4	repository.uki.ac.id Internet	20 words — 1%
5	www.slideshare.net Internet	20 words — 1%
6	pt.scribd.com Internet	15 words — 1%
7	www.mdpi.com Internet	14 words — 1%
8	hal.univ-lorraine.fr Internet	13 words — 1%
9	D. S. Liu. "INFLUENCES OF MATERIAL SOURCE, WAFER PROCESS AND LOCATION ON SILICON DIE FRACTURE STRENGTH", Experimental Techniques, 11/2002	11 words — < 1%

Crossref

10	hrmars.com Internet	11 words — < 1%
11	G N Amani, D Wahyudin. "IoT based wearable personal air monitoring for sinusitis", IOP Conference Series: Materials Science and Engineering, 2020 Crossref	10 words — < 1%
12	ebin.pub Internet	10 words — < 1%
13	eurjanat.com Internet	10 words — < 1%
14	www.researchgate.net Internet	10 words — < 1%
15	Aiswarya Sidharthan K, Shiny Joseph. "Green synthesis of polyvinyl-alcohol-montmorillonite clay cation exchange membrane for alkaline direct methanol fuel cell", International Journal of Hydrogen Energy, 2022 Crossref	9 words — < 1%
16	soar.wichita.edu Internet	8 words — < 1%
17	webharvest.gov Internet	8 words — < 1%
18	idoc.pub Internet	6 words — < 1%

EXCLUDE QUOTES ON EXCLUDE SOURCES OFF

EXCLUDE BIBLIOGRAPHY ON

EXCLUDE MATCHES OFF