The Influence of Fused Deposition Modeling Process Parameters on the Impact Properties of Polylactic Acid

Wei Zou[1,*], Fuhan Wei[1], Xinshuo Li[1], Yizhuo Chen[1], Guanghong Wang[1,*], Kaipeng Liang[1], Huaiyu Huang[1], Yuqing Wei[1], Jiahua Li[2], Qingwu Zeng[2], Han Wu[3]

[1]School of Mechatronic Engineering, JiangSu Normal University, No.101, Shanghai Road, Xuzhou, Jiangsu, 221116, P.R. China
[2]Beijing Everloyal Technology Co., Ltd., Rm 1101-1105, B Block, Huizhi Building, Road No.9 Xueqing, Haidian District, Beijing.100080, P.R. China
[3]Guangdong LESSO & KEEN Technology Co., Ltd, Foshan, Guangdong, 528318, P.R. China

*Wei Zou(corresponding author): zw5562@jsnu.edu.cn
Fuhan Wei:992662715@qq.com
Xinshuo Li: lixs1219@qq.com
Yizhuo Chen: 3020221468@jsnu.edu.cn
*Guanghong Wang(corresponding author):guanghwang@163.com
Kaipeng Liang: 18351295123@163.com
Huaiyu Huang:18098581892@163.com
Yuqing Wei:1505816749@qq.com
Jiahua Li:lijiahua@everloyal.com.cn
Qingwu Zeng: support@everloyal.com.cn
Han Wu:wuhan@lesso.com

Abstract. As one of the main forming processes in Additive Manufacturing (AM), FDM(Fused Deposition Modeling) has the advantages of low cost, fast speed, no need for molds during forming, high forming flexibility, and can quickly adapt to customized market demands. Therefore, it has received increasing attention in recent years. During the use of FDM products, the mechanical properties, especially the impact performance of FDM products are also of great concern. It has been investigated that the influence of FDM forming process parameters, including layer thickness, infill density, and infill pattern, on the impact performance of polylactic acid (PLA) in this article with the single factor method. The range analysis results indicate that the infill density has the greatest impact on the impact performance of PLA, followed by layer thickness. In addition, the infill pattern also has a significant impact on the impact performance of PLA.

Keywords: FDM, polylactic acid (PLA), impact properties, 3DP, process parameters.

H. Bilgin et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Engineering, Environment Resources and Energy Materials (CCESEM 2024)*, Advances in Engineering Research 253,
https://doi.org/10.2991/978-94-6463-606-2_2

1 Introduction

Additive manufacturing, also known as 3D printing, is a manufacturing method based on the discrete-stacking principle. Due to its fast-manufacturing speed, high flexibility, and easy customization, it has received widespread attention in recent years. According to ASTM F42 and ISO TC 261, Additive Manufacturing processes are divided into Vat photopolymerization, Powder bed fusion, Material extrusion, Material jetting, binder jetting, sheet lamination, and Directed energy deposition[1]. As one of the earliest processes of material extrusion, FDM has been widely used due to its advantages of low material cost, simple equipment, and low cost of use and maintenance.

Polylactic acid (PLA) is a novel biodegradable material with excellent mechanical and physical properties, good biocompatibility, and environmental friendliness. Therefore, in recent years, PLA has been widely used, especially FDM. By using FDM technology to form PLA products, PLA products can be quickly manufactured with a simple manufacturing process that is not sensitive to the complexity of the product shape. However, due to the fact that FDM is based on the principle of layer by layer stacking manufacturing, its mechanical properties are relatively low compared to traditional extrusion molding and injection molding products. How to improve the mechanical properties of PLA products has become a hot topic. Many scholars have conducted extensive research on the influence of FDM process parameters on the properties of polylactic acid products. Wei[2] and Ramadan[3]respectively studied the effects of FDM process parameters on the tensile properties and energy consumption of PLA products. Nyabadza et al[4]. studied the effect of FDM process parameters on the compression and antibacterial properties of their PLA products. Venkateswar et al[5]. studied the effect of FDM process parameters on the tensile strength of carbon fiber reinforced PLA products. Kartikeyan et al[6]. investigated the effect of layer thickness on the mechanical properties of PLA manufactured by FDM through experimental and theoretical analysis. This article discusses the effects of printing layer thickness, infill density, and infill patterns on the impact performance of polylactic acid.

2 Experimental

2.1 Materials and Equipment

The experimental materials PLA wire and 3D printer (model CR-5 Pro) were purchased from Shenzhen Creality 3D Technology Co., Ltd.

2.2 Sample Preparation

The FDM impact specimens are first designed using Solidworks software according to the GB/T 1843-2008 standard, and then saved in STL file format. Then, the slicing software provided by the 3D printer is imported to set the printing parameters and generate a G-code file. Finally, the G-code is input into the 3D printer to print the specimen spline.

2.3 Impact Performance Testing

An Izod Impact Tester (TY-4020, Jiangsu Tianyuan Testing Equipment Co., Ltd., China) was employed to conduct impact tests according to GB/T 1843 (2008). All tests were conducted at room temperature and five specimens were used in each test to obtain the average value.

2.4 SEM

The scanning electron microscope (JSM 6510, Japan Electronics Corporation) was used to observe the fracture surface of the impact specimen. The PLA fracture surface was covered with carbon spraying before observation.

2.5 Experimental Parameter Design

This article uses the controlled variable method to design experiments to study the effects of printing layer thickness, infill density, and infill pattern on the impact performance of PLA. Among them, the parameter design is shown in Table 1.

Table 1. Experimental Parameters

No.	layer thickness /mm	infill density /%	infill pattern
1	0.12	20	cubic
2	0.16	20	cubic
3	0.20	20	cubic
4	0.24	20	cubic
5	0.28	20	cubic
6	0.20	20	cubic
7	0.20	40	cubic
8	0.20	60	cubic
9	0.20	80	cubic
10	0.20	100	cubic
11	0.20	20	cubic
12	0.20	20	lines
13	0.20	20	triangle
14	0.20	20	Tri-Hexagon
15	0.20	20	grid

3 Results and Discussion

3.1 Impact Strength Properties Analysis

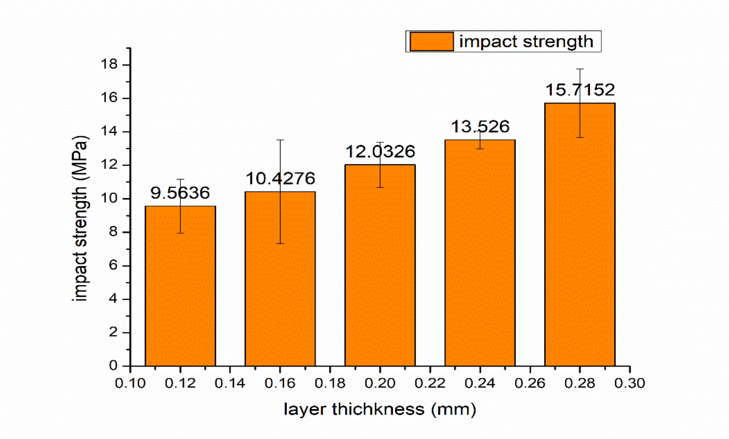

Fig. 1. The relationship between impact strength and layer thickness

Layer thickness refers to the thickness of each layer printed during the printing process. In this experiment, the layer thickness increased from 0.12mm to 0.28mm. From Fig. 1, it can be seen that as the layer thickness increases, the impact strength value of the sample also increases, from 9.56 to 15.715 KJ/m2, with an increase of about 65% in impact strength. As the layer thickness increases, the number of layers will decrease, and the interface between layers will also decrease accordingly. The strength reduction caused by the interface is naturally less. Therefore, with the increase of layer thickness, the impact toughness of the sample will also increase[7].This indicates that increasing the printing layer thickness can improve the impact toughness of PLA products. The range of impact strength in this group is 6.15.

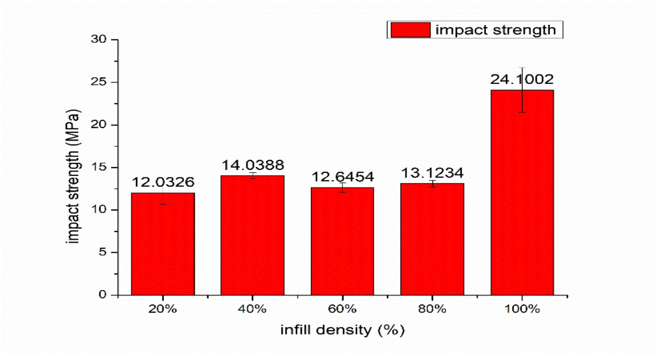

Fig. 2. The relationship between impact strength and infill density

From Fig. 2, it can be seen that as the infill density increases, the impact strength of PLA products first increases and then slightly decreases. When the infill density reaches 100%, the impact strength of PLA products reaches 24.1KJ/m^2, which is about twice the impact strength of the sample with the infill density of 20%. This may be closely related to the decrease in porosity of PLA products. When the infill density of the product is 100%, the porosity is basically zero, and the internal material of the specimen bears all the impact, thus greatly improving its impact toughness. However, while increasing the infill density, the time and material usage of 3D printing also increase. Therefore, if considering impact toughness, manufacturing cost, and manufacturing efficiency, the infill density can be prioritize set to 40%. The range of impact strength in this group is 12.07.

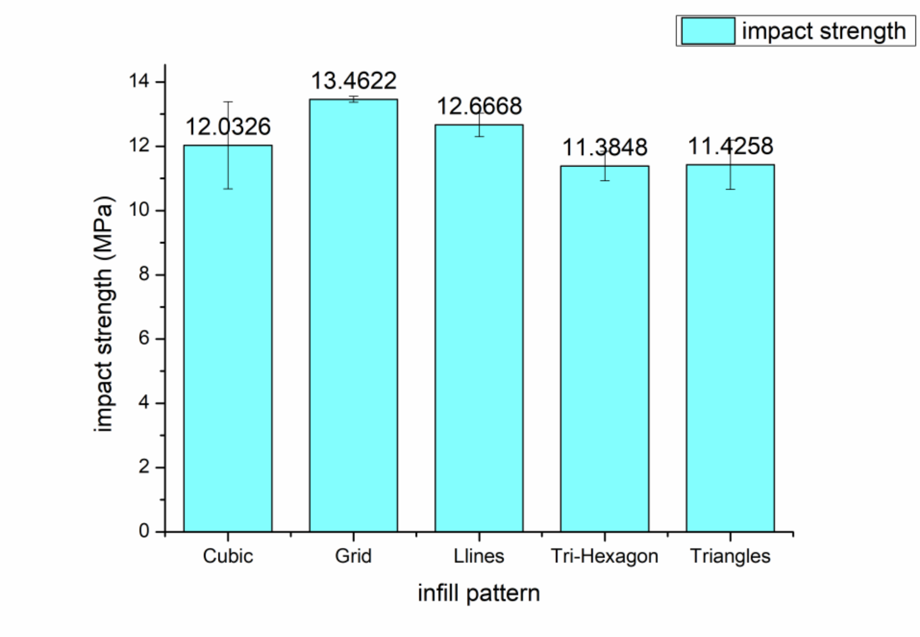

Fig. 3. The relationship between impact strength and infill pattern

A infill pattern is a pattern of printed fill material. Fig. 3 shows the relationship between the internal infill pattern and impact performance of PLA products. As shown in the figure, when the internal infill pattern is a grid, the impact toughness of the product is the best, which is 13.462 KJ/m2. Moreover, the variance of the test results for products with grid shapes as fill patterns is also very small, indicating their stability. The range of impact strength in this group is 2.08.

The analysis of the range of impact strength data for several sets of process parameters shows that the infill density has the greatest impact on the impact toughness of the sample.

3.2 SEM Morphology of the Fracture of the Specimens

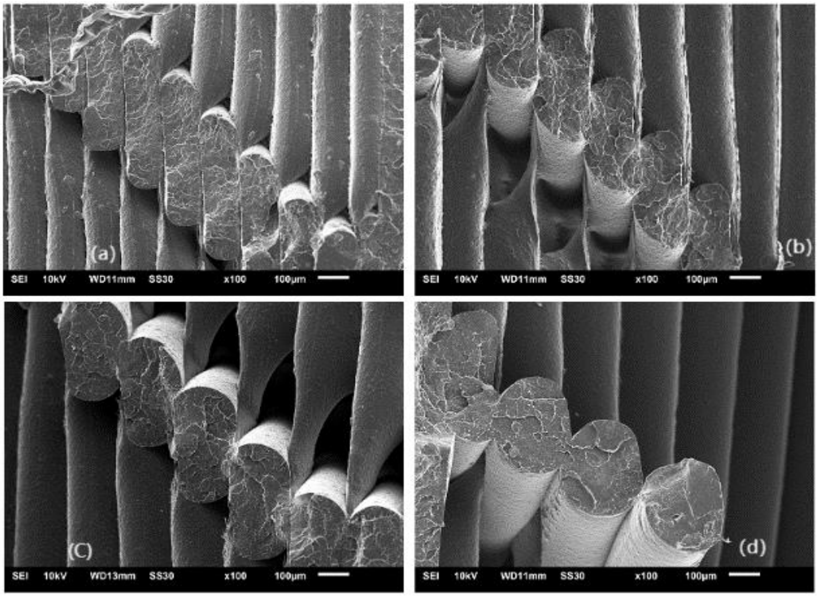

Fig. 4. SEM images of fracture surfaces at different layer thickness :(a)0.12mm,(b)0.16mm,(c)0.20mm,(d)0.24mm,

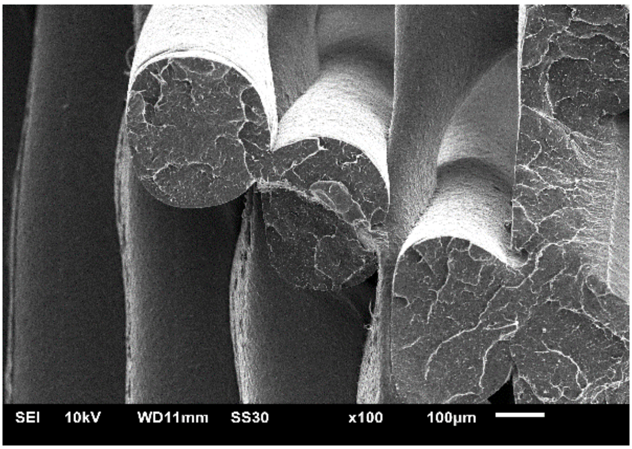

Fig. 5. SEM images of fracture surfaces at layer thickness of 0.28mm

The microstructure of the cross-section of the sample after impact was observed under a scanning electron microscope, as shown in Fig. 4 and Fig.5. It can be seen that as the printing layer thickness increases, the roughness of the fracture surface gradually increases, and the cross-section of the PLA filament material gradually approaches a circular shape. At the same size, as the layer thickness increases, the number of layers decreases, and the interface between layers is generally a weak link in mechanical properties. This proves the conclusion in the experimental results that increasing the layer thickness is beneficial for the material to absorb impact energy, and the impact toughness of the sample gradually increases.

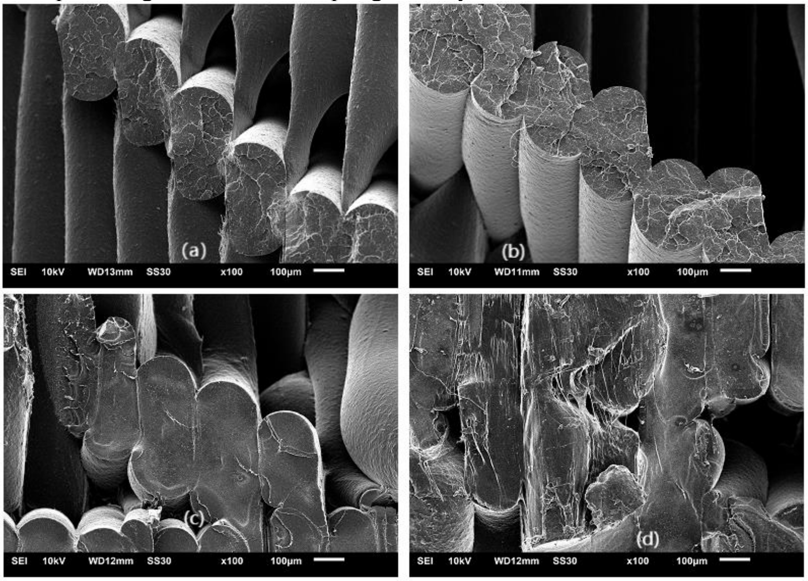

Fig. 6. SEM images of fracture surfaces at different infill densities: (a)20%,(b)40%,(c)60%,(d)80%

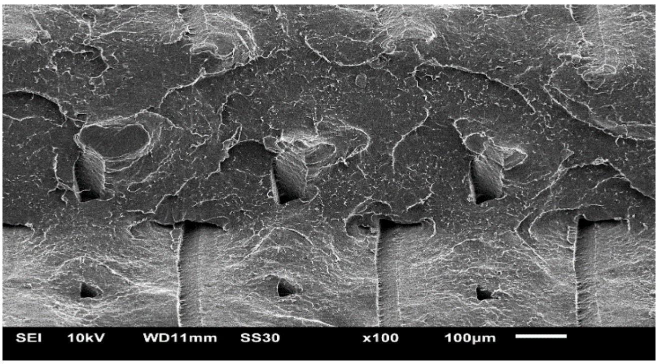

Fig. 7. SEM images of fracture surfaces at different infill densities: of 100%

The microstructure of the cross-section of the sample after impact was observed under a scanning electron microscope, as shown in Fig. 6.and Fig.7. From Fig.6 (b), it can be seen that when the infill density is 40%, the fracture surface is rougher compared to (a), (c), and (d), which explains the experimental results that the impact strength of the PLA sample first increases and then decreases. In Fig.7, it can be seen that when the infill rate reaches 100%, the overall fracture surface is relatively rough, and the porosity is also the lowest. The materials that can withstand impact are also the most, which explains why the impact strength reaches the highest value when the infill density reaches 100%. Within a certain range, the impact toughness of the product will increase with the increase of infill density. After reaching 40-50%, the impact toughness of the product will first decrease and then increase.

4 Conclusions

Based on the above experimental data, the following conclusions can be drawn:

(1) The infill thickness will affect the impact toughness of the product, and as the infill thickness increases, the impact toughness of the product continues to increase. However, due to the step effect, the surface of the product will become rougher.

(2) As the infill density increases, the impact toughness of PLA products will first increase, then decrease, and finally increase again. The two peak points are at an infill density of 40% and 100%, respectively. The impact strength value reaches its maximum when the sample infill density is 100%.

(3) The infill pattern can also affect the impact toughness of the product, among which products with grid shaped infill patterns have better mechanical properties compared to other cubes, lines, tri-hexagons, and triangles, with better impact toughness and higher stability of the product.

(4) The range analysis of impact strength data shows that compared to layer thickness and infill pattern; infill density has the greatest impact on the impact toughness of the sample.

Acknowledgment

The authors are grateful for the support sponsored by China Postdoctoral Science Foundation(2017M622890), the Natural Science Foundation of the Jiangsu Higher Education Institutions of China (20KJB460021), Natural Science Foundation of Jiangsu Normal University (19XSRX014, 16XLR018),Special Funding for Marine Economic Development of Guangdong Province (GDMC[2023]51, [2022]23), the Natural Science Foundation of Jiangsu Province (BK20220680) , Graduate Research and Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX24 3060).

Reference

1. Gibson I., Rosen D., Stucker B. Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing, second edition(2015).Springer,New York.https://doi 10.1007/978-1-4939-2113-3.
2. Wei, H., Tang, L., Qin, H., Wang, H., Chen, C., Li, Y., Wang, C.(2024) Optimizing FDM 3d printing parameters for improved tensile strength using the takagi–sugeno fuzzy neural network. Materials Today Communications, 38.DOI:10.1016/j.mtcomm.2024.108268.

3. Ramadan, S., Altwarah, Q., Abu-Shams, M., & Alkurdi, D.(2024) Optimizing tensile strength and energy consumption for FDM through Mixed-Integer Nonlinear Multi-objective optimization and design of experiments.Heliyon, 10(9). DOI:10.1016/j.heliyon.2024.e30164.
4. Nyabadza, A., Mc Donough, L.M., Manikandan, A., Ray, A.B., Plouze, A., Muilwijk, C., Freeland, B., Vazquez, M. and Brabazon, D., (2024). Mechanical and antibacterial properties of FDM additively manufactured PLA parts. Results in Engineering, 21, 101744.
5. Reddy, M.V., Hemasunder, B., Chavan, P.M., Dish, N. and Savio, A.P., (2023) Study on the significance of process parameters in improvising the tensile strength of FDM printed carbon fibre reinforced PLA. Materials Today: Proceedings.
6. Kartikeyan, B., Ponshanmugakumar, A., Saravanan, G., BharathGanesh, S. and Hemamalini, V., (2023) Experimental and theoretical analysis of FDM AM PLA mechanical properties. Materials Today: Proceedings.Carneiro,
7. Carneiro, O. S., Silva, A. F., & Gomes, R.,(2015) Fused deposition modeling with polypropylene. Materials & Design, 83, 768-776.