Research on 3D Printing Technology of Polylactic Acid

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Abstract. Additive manufacturing technology(3D printing) as a rapid development of rapid prototyping technology in recent years. However, the surface quality and mechanical properties of the molded parts are worse than those of traditional material reduction manufacturing due to the special bottom-up processing and forming principle. In this paper, the performance of FDM parts is improved by studying the process parameters. According to the actual research situation, this paper selected the filling density, printing speed, printing temperature, stratification direction for experimental research. Through orthogonal test and single factor method, the best strength combination is obtained as filling density 80%, printing speed 35mm/s, printing temperature 195℃. After range analysis, it is found that the filling density has the greatest influence on tensile strength, followed by printing speed and printing temperature. the lamination direction also has a significant influence on tensile strength.

Keywords: Nonmetal Additive Manufacturing; Polylactic Acid; Mechanical Properties; Process Parameters; Laminated Direction.

1. Introduction

Additive manufacturing technology (3D printing) first appeared in the 1980s, has been 42 years ago, since the 20th century, with the continuous development of computer, materials science and other disciplines, this technology has also been rapid development. Charles Hur first used a 3D printer in 1984 to produce a 3D model from a digital model. At the end of the 20th century, a variety of materials processing technologies were developed and quickly put into use [1-3]. According to the forming principle, forming materials, etc., the additive process can be divided into: Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Stereo Lithography Apparatus, SLA) technology and Fused Deposition Modeling (FDM) [4] technology. The principle of FDM is to use a heated metal nozzle to melt the filamentlike thermoplastic polymer material. The polymer material is extruded out of the nozzle due to pressure and is formed layer by layer in accordance with the path specified by the computer program, so as to obtain the required THREE-DIMENSIONAL objects [5].FDM printers are the first choice for personal 3D printers with the advantages of simple operation, easy to use, environment-friendly consumables and no odor in the printing process [6].

The most commonly used materials for FDM 3D printing are polylactic acid (PLA), acrylonitrile-butadiene-styrene (ABS), etc. [7]. the raw material of POLylactic acid (lactic acid) is mainly fermented from starch and further polymerized to produce polylactic acid. Its melting point is 155-185℃ and processing temperature is 170-230℃.PLA is the most widely used material in FDM 3D printing at present. it is a non-toxic and non-irritating green polymer material with good biocompatibility and mechanical properties and biodegradation properties [8-9]. Therefore, environment-friendly polylactic acid material has become the first choice for FDM 3D printing.

In the process of FDM 3D printing, the setting of related parameters directly affects the quality, precision and strength of forming parts. Jia Xian et al. [10] studied the influence of different process parameters on the compressive mechanical properties of PLA material model in the vertical direction, and the results showed that reasonable setting of printing process parameters can effectively improve the compressive mechanical properties of 3D printing model. Bai He et al. [11] studied the influence of five kinds of FDM printing process parameters on mechanical properties of PLA specimen through orthogonal test, and found that shell thickness had the most obvious influence on mechanical properties of the workpiece.

In this paper, the mechanical properties of polylactic acid products are closely related to the selection of printing process parameters, and the change of printing parameters has a great influence on the mechanical properties of the printed products. In this paper, the effects of packing density, printing speed, printing temperature and lamination direction on mechanical properties are studied by single factor method and orthogonal test.

2. Test Portion

2.1 Materials and Equipment

3D printer: LD5-400, Guangzhou Lingchuang 3D Technology company; Electronic universal testing machine: E44.304, MTS Systems Inc; PLA wire material: diameter (1.75±0.02) mm. The nozzle diameter of 3D printer is 0.4mm, the filling density is 0-100%, the printing speed is 25-50mm/s, the printing temperature is 190-210℃, and the hot bed temperature is 40-70℃.The schematic diagram of FDM is shown in Figure 1.

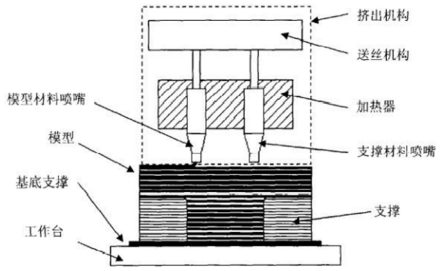


Fig 1. The principal diagram of the FDM

2.2 Tensile Test

The national standard GB/T1040.2-2006 was used to make the type I sample, as shown in Fig.2.UG and SOLIDWORKS software were used to make a 3D digital model and converted into the corresponding SLT format. Cura software was used to control the corresponding technological parameters and slice the sample.

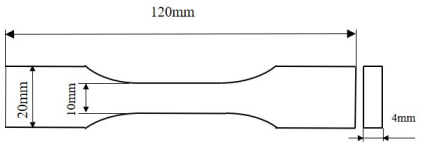


Fig 2. Plan of sample

The printing parameters are as follows: layer thickness 0.1mm, filling degree 20%-80%, printing speed 35-50mm/s, printing temperature 195-210℃.The effects of filling degree, printing speed, printing temperature and lamination direction on tensile strength were studied in detail. in this experiment, 16 samples were made using three factors and four levels, namely L16 ($3^{4)}$. The three factors were filling density (A), printing speed (B), and printing temperature (C). The four levels were 20%, 40%, 60%, and 80% of the filling density, and the printing speed was 35mm/s, 40mm/s, 45mm/s, and 50mm/s. Print temperature 195℃, 200℃, 205℃, 210℃.Table 1 is the level table of orthogonal test factors. The laminated direction is printed in the XYZ direction. When studying the influence of different stratification directions on the tensile strength of samples, the optimal combination of the above 16 samples was selected for printing parameters.

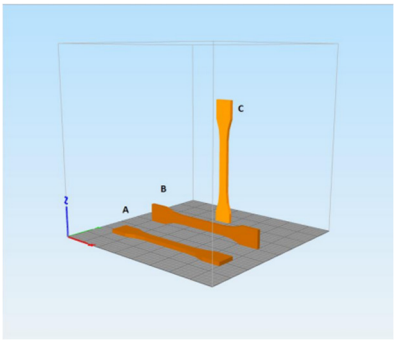


Fig 3. The slices of the sample are printed in different stratification directions (A: XYZ) (B: XYZ) (C: ZYX)

Table 1. Factor level tab l

Level	Factor		
	Filled Density (%)	Print speed (mm/s)	Print temperature (℃)
1	20	35	195
2	40	40	200
3	60	45	205
4	80	50	210

3. Results and Discussion

3.1 Orthogonal Test and Range Analysis

E44.304 electronic universal testing machine was used to measure the tensile strength of the sample, and the results are shown in Table 2.

As can be seen from Table 2, the tensile strength of 13# is the highest (37.719Mpa), while the tensile strength of 3# is the lowest (19.448Mpa).

Table 2. Orthogonal test results

Test number	Experimental factor			Tensile strength (Mpa)
	A	B	C	
1#	1(20)	1(35)	1(195)	31.669
2#	1(20)	2(40)	2(200)	28.393
3#	1(20)	3(45)	3(205)	19.448
4#	2(20)	4(50)	4(210)	30.878
5#	2(40)	1(35)	1(195)	31.909
6#	2(40)	2(40)	2(200)	29.353
7#	2(40)	3(45)	3(205)	30.156
8#	3(40)	4(50)	4(210)	22.279
9#	3(60)	1(35)	1(195)	25.9
10#	3(60)	2(40)	2(200)	25.389
11#	3(60)	3(45)	3(205)	28.675

Test number	Experimental factor			Tensile strength (Mpa)
	A	B	C	
12#	4(60)	4(50)	4(210)	29.608
13#	4(80)	1(35)	1(195)	37.719
14#	4(80)	2(40)	2(200)	33.689
15#	4(80)	3(45)	3(205)	34.766
16#	4(80)	4(50)	4(210)	32.399

Table 3. Strength range analysis

Item	Level	A	B	C
Factor K	20	110.39	-	-
	35	-	122.96	-
	40	113.70	120.85	-
	45	-	113.04	-
	50	-	115.16	-
	60	109.57	-	-
	80	138.37	-	-
	195	-	-	122.96
	200	-	-	120.85
	205	-	-	113.04
	210	-	-	115.16
K average	20	27.60	-	-
	35	-	30.74	-
	40	28.42	30.21	-
	45	-	28.26	-
	50	-	28.79	-
	60	27.39	-	-
	80	34.59	-	-
	195	-	-	30.74
	200	-	-	30.21
	205	-	-	28.26
	210	-	-	28.79
Optimal levels		80	35	195
R		7.20	2.48	2.48
The level of the number		4	4	4
Number of repeats per level		4.0	4.0	4.0

Note: "-" indicates that the level data does not exist. The level mean of each factor in intensity is shown in Figure.4.

According to Table 2, the intensity range analysis of the orthogonal test is shown in Table 3.

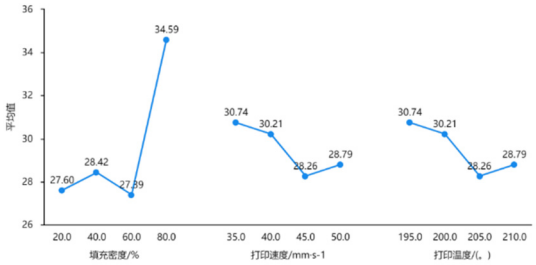


Fig 4. Mean values of intensity factors at different levels

According to the mechanical properties of type-I sample analyzed in the table above and the figure above, the range values (R) of filling density (A), printing speed (B) and printing temperature (C) are 7.20, 2.48 and 2.48, respectively. It can be seen that the filling density has the most significant effect on the tensile strength of the type-I specimen, and the printing speed and printing temperature have the second effect on the strength of the specimen.

3.2 Effect of Filling Density on Tensile Strength

It can be seen from Fig.4 that the tensile strength increases as the filling density increases. In this test, the tensile strength reached its maximum value when the filling density was 80%.

When Cura slices are used, the interior of the sample model can be evacuated, and the original solid model will be filled with grid. When the printing model looks the same, the length of printing time is closely related to the size of filling density. When the filling density is small, the corresponding printing time is short, and the strength of the printed sample is relatively small; When the filling density increases, the corresponding printing time will also increase, and the strength of the printed sample will also increase. Therefore, before the actual printing, it is necessary to select the appropriate filling density according to the specific appearance of the printing model and the required strength requirements, and then print the model.

3.3 Effect of Printing Speed on Tensile Strength

Fig.4 shows that the maximum tensile strength occurs when the printing speed is 35mm/s. When the printing speed is increased to 45mm/s, the tensile strength is minimal. when the speed increases to 50mm/s, the tensile strength increases, but it is still lower than that at 35mm/s.

In the process of melt lamination (FDM), because the size of the extruded wire is not stable, when the printing speed is too slow, the wire will be stacked, the surface cross-sectional area of the wire will become larger, and even blocked the nozzle; When the printing speed is too fast, the former layer is not completely cooled and formed, the latter layer is laid, resulting in the printing collapse and wire drawing and other phenomena. At the right printing speed, the material can be fully heated in the nozzle, and the bond between layers is closer. In this test, when the printing speed is 35mm/s, the tensile strength is the largest, and the tensile strength decreases with the increase of the printing speed.

3.4 Effect of Printing Temperature on Tensile Strength

Fig.4 shows that the maximum tensile strength occurs when the printing temperature is 195℃.When the printing temperature is increased to 205℃, the tensile strength is the lowest. When the printing temperature is increased to 210℃, although the tensile strength increases, it is still lower than the tensile strength at 205℃.

In the process of melt lamination (FDM), the solid-solute-solid changes appear in the wire. The printing temperature determines the sustainability of the extrusion and the adhesion of the material in the melting state, and then affects the printing accuracy and mechanical properties of the sample. when the printing temperature is too high, the solid to the solution in the process of change is likely

to be too high temperature into liquid, liquid liquidity, resulting in the upper layer is not cooled molding, the next layer is laid, and then the specimen collapse phenomenon. When the printing temperature is too low, the wire cannot be fully melted, the material viscosity is large, and even lead to nozzle blockage. In this test, when the printing temperature is 195℃, the tensile strength is the largest, and when the printing temperature increases, the tensile strength generally decreases. In order to ensure that the wire is always in the melting state in the actual printing process, the optimal printing temperature should be selected by comprehensive analysis.

3.5 Effect of Stratification Direction on Tensile Strength

The stratification direction refers to the placement Angle of the nozzle on the timing axis of the first layer of the printed sample. When exploring the influence of the stratification direction on the tensile strength, the basic parameters of sample 13# above were selected and the single factor method was used to explore the influence of three stratification directions on the tensile strength of the sample. The specific results are shown in Table 4.

Table 4. Tensile strength in different stratification directions

	Stratification directions		
	XYZ	XZY	ZYX
Tensile strength	37.719	31.909	4.948

It can be seen from Table 4 that the tensile strength of type-I sample reaches the maximum when it is laminated along the XYZ direction. the tensile strength of the type-I specimen is the smallest when laminated along the ZYX direction.

Tensile diagram of samples with different stratification directions is shown in Figure 5. Samples XYZ and XZY are stretched in X direction, and samples ZYX direction are stretched in Z direction. When printing along the ZYX direction, the tensile direction of the sample is consistent with the direction of the layer melting superposition of the wire, and its tensile strength mainly depends on the degree of adhesion between layers. When the sample is laminated along the XYZ and XZY directions, the tensile direction of the sample is perpendicular to the stacking direction of the silk material. The tensile strength of the sample is not only related to the degree of adhesion between layers, but also related to the properties of the silk material itself. Therefore, the tensile strength of the sample laminated along the XYZ and XZY directions is much greater than that of the sample laminated along the ZYX direction.

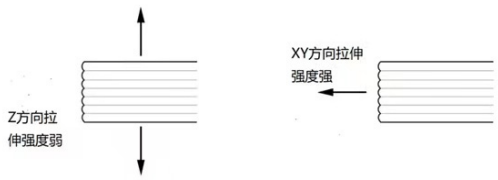


Fig 5. Overall assembly drawing of seeder

4. Conclusion

Through orthogonal test and range analysis, the optimal process is A4B1C1, that is, filling density 80%, printing speed 35mm/s, printing temperature 195℃; The influence of each data parameter on the PLA material printing sample is as follows: filling density > printing speed > printing temperature. The single factor test shows that the stratification direction also has a significant effect on the tensile

strength, and the tensile strength of the sample printed along the XYZ and XZY directions is much greater than that of the sample printed along the ZYX direction.

The tensile strength of the printed specimen is 37.719MPa by using the optimal process parameters. However, there are many factors affecting the printing process, so variable parameters should be strictly controlled in the printing process to reduce data deviation. This experiment only studied three process parameters, but this paper explains some phenomena and principles of the printing process, for better use of the machine, the material has a certain positive significance.

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