Advances in Machinery, Materials Science and Engineering Application IX
M. Chen et al. (Eds.)

doi:10.3233/ATDE230458

Study on Performance and Size of 3D Printing of Polycarbonate Materials

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Abstract. The method of melting the 3D printed parts of polycarbonate materials in the high temperature resistant mold by high temperature heating, holding them for a period of time, and then placing them in the air for Free cooling to reshape the internal parts. For the corner brackets, post-processing was conducted, followed by testing for tensile strength, roughness, installation precision analysis, and installation surface analysis. The results showed that, when the melting temperature was 280℃ with a retention time of 25 minutes, the tensile strength of the corner brackets increased by 227.71% compared to the original brackets, and the roughness decreased by 61.72%. The positioning dimension error values of the brackets were all less than 1%, and the inner hole dimension error values were all less than 3.5%. Although there was a granular or uneven surface phenomenon in the installation surface of the three different placement positions, they still met the assembly requirements.

Keywords. Post-processing, angular code, tensile strength, dimensional error

1. Introduction

3D printing, also known as additive manufacturing, is a type of rapid prototyping technology that uses digital model files to produce complex physical structures layer by layer using materials such as powdered metal or plastic. Currently, FDM (fused deposition modeling), SLS (selective laser sintering), DLP (digital light processing), among others, are the main 3D printing technologies, with FDM being the most widely used. FDM mainly uses polymers such as PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), and PC (polycarbonate) as primary printing materials. Among them, PC is one of the fastest developing engineering materials among polymer materials, with excellent impact resistance, firm durability, heat aging resistance, excellent insulation performance, fatigue resistance, dimensional stability, as well as being tasteless and non-toxic. Based on these outstanding physical and mechanical properties and usability, PC has a wide range of applications, including mechanical equipment,

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medical instruments, optical lighting, electronic appliances, building materials, aerospace, and other fields [1].

In mechanical design, due to its low acid resistance, poor UV resistance, and relatively lower mechanical properties compared to metals, 3D printed parts made of PC materials as the base material are difficult to meet the requirements for high precision, mechanical properties, and mechanical performance in applications where such requirements are particularly high or in special needs. 3D printing of PC mechanical parts is commonly used in the printing of corner brackets, cams, bolts, and crankshafts, all of which have connecting and transmission functions [2-3]. Corner brackets are widely used mechanical connector components and require high performance in their own right, as they are used to connect 90° right-angled intersecting components and provide support and fixation while also needing to withstand significant loads in engineering applications.

In this study, pure NaCl was used as the dielectric material for analysis; different melting temperatures were set at the same retention conditions, and a post-processing technique of melting and reshaping and cooling molding was utilized on 3D printed parts made of PC materials as the base material. The corner bracket was selected as the object of study to improve its mechanical properties, lower surface roughness, and ensure precise dimensions of important assembly holes and surfaces.

2. Corner Bracket Experiment Section

2.1. Main Materials

Polycarbonate (PC): Diameter 1.75mm, melting point 260℃, printing temperature 250-270℃, Suzhou Jufu Polymer Material Co., Ltd.;

Analytical grade NaCl: NaCl content ≥99.5%, molecular weight 55.84, pH value 5-8, drying loss ≤0.5%, Tianjin Dingsheng Chemical Co., Ltd.

2.2 Main instruments and equipment

Electric hot air drying oven: K1 101-OAB, Tianjin ZSE Analytical Instruments Manufacturing Co., Ltd.;

Grinder: Power 200W, grinding amount 80g/time, Zhejiang Supor Co., Ltd.;

Tensile machine: JITAI-10KN, test machine level 0.5, Beijing Jitaike Instrument Testing Equipment Co., Ltd.;

Printer: PRT-300, Hanin Advanced Printing Technology Innovation Laboratory;

Surface roughness tester: TR200, Beijing Jitaike Instrument Testing Equipment Co., Ltd.

2.2. Sample Preparation

The 3D model of a 30mm high, 20mm wide corner bracket with an assembled bar-shaped hole inner diameter of 5mm and a center distance of 5mm was designed using Solidworks software, as shown in figure 1. The model was saved in STL format and sliced using Cura software. Based on the FDM printing principle and the characteristics of PC material, the main parameters of the 3D printer were set as follows: printing temperature of 260-280℃, printing speed of 60-90mm/s, printing layer height of 0.2mm, printing density of 100%, and bed temperature of 100℃. The model was further converted into Gcode format that the 3D printer could recognize and imported into the printer. Basic printing parameters were set, and the corner bracket model was printed layer by layer using the 3D printer.

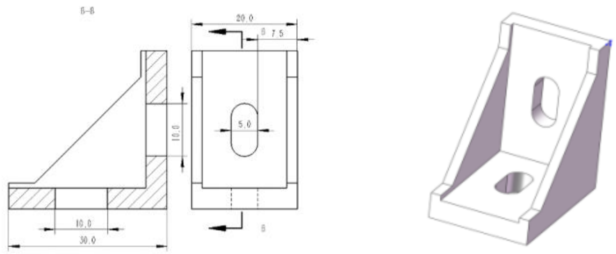

Figure 1. Corner code size diagram.

According to the printing environment temperature range of PC material (70-80°C), a heating device was used during printing to keep the internal temperature of the printing chamber at a constant 80±5°C. A small amount of solid glue or adhesive patterned paper was applied to the print bed to increase the adhesion between the printed parts and the bed, ensuring the printing quality of the corner bracket.

Mold making: NaCl was used as the raw material for mold making. Due to the large particle size of NaCl, it was first ground into powder using a grinder before the experiment. The powder was then filtered through a 110-150 mesh filter sieve to obtain the finest powder. The filtered powder was placed in a glass container and heated in a drying oven for 5-10 minutes to evaporate any moisture in the powder. The dried powder was first spread on the bottom of the glass container, and then the PC material-printed corner bracket was placed on the powder. The powder was then compressed on both sides of the corner bracket, and the powder was also compressed inside the assembly hole of the corner bracket to provide support. Finally, the powder was evenly spread over the top of the corner bracket so that it was submerged and then compressed to reduce the gaps within the powder. To reduce the errors caused by different placement positions of the corner bracket in the mold, three different positions were used for each melting temperature corner bracket, as shown in figure 2, which were placed on one side, vertically, and inverted for the melting experiments.

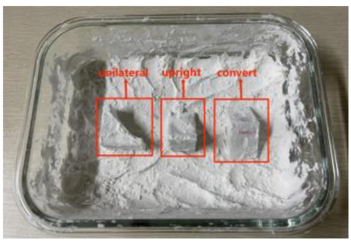

Figure 2. The placement form of the corner codes in the mold.

During the experiment, the made mold is put into the drying box, heated to the predetermined temperature, the corner code is melted in the mold again, insulated to the set time, the mold is taken out and put in the air to slowly cool, and the corner code is remolded in the mold. According to the properties of pc material, the melting temperature, insulation time and placement mode of the corner code in the mold are set as shown in table 1.

Table 1. Post-processing melting temperature, insulation time and placement mode.

Experimental serial number	temperature (℃)	Thermal insulation time (min)	Put way
1	260	25	unilateral upright convert
2	270	25	unilateral upright convert
3	280	25	unilateral upright convert

2.3. Performance Testing and Characterization

Mechanical properties test: the corner code is fixed on the fixture, the upper and lower ends of the tension machine are clamped above and below the fixture, the tensile speed is set to 1mm / min, as shown in figure 3.

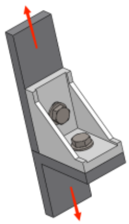

Figure 3. Corner code tensile test clamp diagram.

Roughness test: sampling length 2.5mm, assessment length 12.5mm, sliding speed 1 mm/s, and surface roughness was evaluated using contour arithmetic mean deviation Ra.

3. Results and Discussion

3.1. Mechanical Properties Analysis

The tensile strength of corner codes without postprocessing was 8.01 Mpa. The tensile strength of the corner code after post-processing is shown in table 2.

Table 2. Corcode tensile strength test data after processing.

	Experimental serial number	1	2	3
	temperature (℃)	260	270	280
	time (min)	25	25	25
	unilateral	24.31	24.19	25.96

Tensile Strength (MPa)	upright	23.58	26.48	28.04
	convert	21.88	27.65	26.1
	average value	23.25	26.10	26.25

The significant change in the tensile strength of the corner bracket after post-processing is mainly due to the FDM deposition printing method, which melts and extrudes 3D printing materials from the nozzle to stack and form layers, leaving gaps that cannot be filled during the filling process. During post-processing, the corner bracket was placed in a high-temperature mold and heated to a set temperature in an oven, causing it to return to a liquid state. As the corner bracket cooled at room temperature, it gradually reshaped, filling the unfilled gaps left during the 3D printing process, resulting in a more compact internal structure and an improvement in tensile strength. Additionally, the differences in melting temperature and placement caused differences in the flow properties of the corner bracket in a liquid state during cooling, resulting in overfill or gaps on the surface of the corner bracket, diminishing its tensile strength [4-5].

As can be seen from figure 4, after post-processing, the three different placement methods of the corner bracket in the three experimental groups yielded a significant increase in tensile strength. To reduce the errors caused by different placement positions, the average tensile strength of different placement methods of the same melting temperature of the corner bracket was calculated and compared. The average tensile strengths were 23.25 MPa, 26.10 MPa, and 26.25 MPa, respectively. Among them, when the melting temperature was set to 280℃ and the retention time was 25 minutes, the average tensile strength of the corner bracket increased by 227.71% relative to the original one, the best improvement in tensile strength.

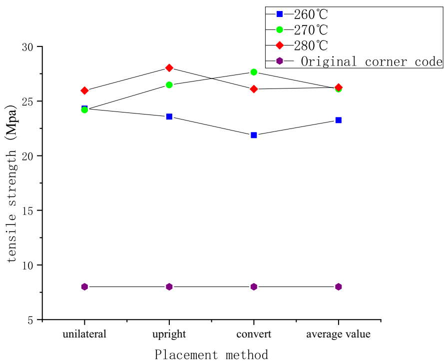

Figure 4. The tensile strength of the angular code after post-processing.

3.2. Assembly Accuracy Analysis

The measurement position and mark are shown in figure 5, and the measurement positions are a, b, c, d, e, f, g, and h respectively.

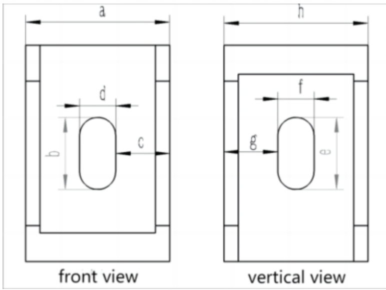

Figure 5. Measuring position and label.

In order to reduce the measurement error, the same angular assembly sizes with different melting temperature measured 8 main assembly sizes, and each size was measured at 3 different positions, the average was taken as the final size, and the original size error with the angular size was calculated. The calculation formula is shown in (1). The final experimental results are shown in table 3 [6].

$$E = \left|\frac{L-L_0}{L_0}\right| \times 100\% \tag{1}$$

E ——— Error in Eq
L——— Actual measured dimensions
L_0———Stamp with the size

Table 3. Corner code, the main assembly size error values.

Experimental number		1			2			3		
temperature (℃)		260			270			280		
time (min)		25			25			25		
Put way		unilateral	upright	convert	unilateral	upright	convert	unilateral	upright	convert
Error value E (%) for the primary assembly size	a	0	0.90	0.80	0	2	0.6	0	0.70	0.50
	b	4.60	5.20	3.40	7.2	5.80	5.20	5.4	1.60	3
	c	0	1.37	0.27	0	2.40	5.48	0	1.50	1.40
	d	9.60	2	11.20	6	3.20	12	2.80	0	4.40
	e	3.33	3.56	1.56	1.33	1.96	2	3.80	3.10	0.43
	f	3.83	4.78	2.61	0.44	1.28	4.89	3.40	1.77	0.42
	g	0	1.28	0.53	0	1.87	3.33	0	1.5	0.76
	h	0	0.80	0.90	0	0.20	1.4	0	1.10	0

To reduce errors caused by different placement positions, the mean error values of the eight main assembly dimensions of the corner bracket for different placement positions with the same melting temperature were calculated, as shown in figure 6. It can be clearly seen from figure 6 that when the melting temperature was 280℃, the average error value of the eight main assembly dimensions of the corner bracket was the lowest. Among them, the positioning dimensions of a, c, h, and g of the corner bracket had error values of 0.40%, 0.97%, 0.75%, and 0.37%, respectively, all of which were less than 1% and had little effect on the assembly and positioning of the corner bracket. The inner hole dimensions of b, d, e, and f of the corner bracket had error values of 3.33%, 2.40%, 2.44%, and 1.86%, respectively, compared to the original dimensions. These dimensions were only used for tightening bolts and could be corrected with reaming or the addition of washers, and their error values did not affect the assembly accuracy of the corner bracket in practical applications [7-8].

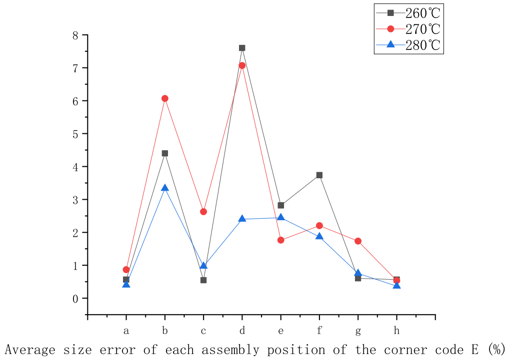

Figure 6. Corner code, main assembly size error average.

3.3. Analysis of Assembly Surface and Roughness of the Corner Bracket

During post-processing, the gaps inside the corner bracket are refilled, and the surface texture also changes after reshaping, producing a particle-like feeling or partial surface defects. To ensure the feasibility of the subsequent installation of the corner bracket, an analysis of the post-processing installation surface is conducted [9].

Based on the above analysis, as the corner bracket's tensile strength and assembly accuracy are optimal when the post-processing melting temperature is 280°C, three different placement methods of the corner bracket at 280°C melting temperature are selected for analysis of the installation surface, as shown in figure 7.

From figure 7, it can be observed that for the corner bracket placed on one side, the cooled surface after the melting is relatively smooth on the bottom surface with defects on the top surface, and two mutually perpendicular installation surfaces are smooth. For the vertically placed corner bracket, the cooled and shaped product is intact, with slight bulges on the side surface and two mutually perpendicular installation surfaces smooth [10-11]. For the inverted placed corner bracket, there are indentations at the intersection of the vertical faces of the melted support beams, and the vertical faces have slight concavities, but still meet the assembly requirements.

a) Unilateral placement b) vertical placement c) inverted placement

Figure 7. The corner code installation surface after post-processing.

When the melting temperature is 280°C, the roughness of the corner brackets with three different placement methods is tested, as shown in figure 8. It can be seen from figure 8 that the surface roughness Ra of the original corner bracket before heat treatment was 15.78μm. After heat treatment, the roughness of the corner brackets placed on one side, vertically, and inverted were 12.77μm, 9.97μm, and 6.04μm, respectively. Compared with the original corner bracket before heat treatment, the roughness was reduced by 19.07%, 36.81%, and 61.72%, respectively. Among them, the corner bracket placed in an inverted position showed a significant improvement in surface quality [12-13].

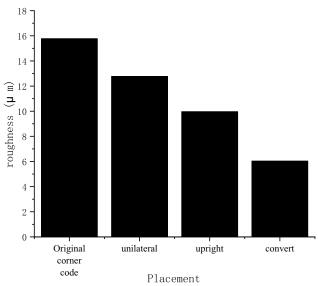

Figure 8. Surface roughness of different positions of corner codes.

4. Conclusion

(1) When the post-processing melting temperature is set to 280°C and the insulation time is 25 minutes, the corner bracket of the 3D printed part melts into a liquid in a high-temperature mold and is reshaped at room temperature. The gaps inside the corner bracket are filled sufficiently, and the tensile strength and surface roughness of the corner bracket improve significantly. The tensile strength of the corner bracket is increased from 8.01Mpa to 26.25Mpa, which is a performance improvement of 227.71%. The surface roughness is reduced from 15.78μm to 6.04μm, which is a surface quality improvement of 61.72%.

(2) After post-processing, the main assembly accuracy of the corner bracket only changed slightly compared to the original corner bracket, with the positioning size of the corner bracket less than 1% and the inner hole size less than 3.5%. The main installation surface of the corner bracket has good quality and can still meet the assembly requirements.

Acknowledgement

This project is supported by Fujian Province Young and Middle aged Project (project number: JAT200913), College Student Innovation and Entrepreneurship Project (Project No. 320)

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