Experimental Analysis of High Temperature PEEK Materials on 3D Printing Test

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***Abstract*—As a kind of semi crystalline thermoplastic engineering plastics, Polyetheretherketone (PEEK) has excellent mechanical properties and chemical stability. Aiming at the high temperature properties of PEEK, test and analysis of PEEK fused 3D printing performance was carried out by the fused deposition modeling(FDM), the experimental research date has been obtained by the effect of temperature on the mechanical properties and forming precision, the sheet forming. The result shows that adjusting the hot bed temperature, ambient temperature and filling ratio, it can improve the bonding strength, and it ultimately can improve the mechanical properties and the printing precision of PEEK. Compared to the PLA material, the maximum tensile strength of PEEK reached up to around 77Mpa, which was much larger than the tensile strength of PLA, and has good forming properties in thin layer parts. The analysis of this paper provides an effective basis for the analysis of high temperature 3D material PPEK printing, and provides a new solution for the performance control of high temperature material 3D printing.**

Keywords- PEEK; Temperature effect; Forming precision; 3D printing

I. INTRODUCTION

3D printing is a new manufacturing technology, related to materials, computing mathematics and other disciplines, 3D printing has shown a huge advantage for the automotive, aerospace manufacturing industry has brought a lot of convenience [1]. With the development of 3D printing technology, variety materials printing methods have been developed, such as the most commonly used fused deposition molding Technology (FDM) printing technology, using computer aided design of layer by layer manufacturing print, has the advantages of low cost, easy maintenance and so on [2]. ABS [3] and PLA [4] are currently more commonly used in FDM technology, and scholars have published articles including mechanical properties test, the tensile and torsion test, the elastic mechanical properties of materials were measured, and finally get the printing properties of materials. Senatov et al also studied the mechanical properties of PLA porous scaffolds in medical implants [5]. FDM printing technology in medical applications are gradually increasing, Martins [6] using FDM technology proposed a new three-dimensional bone scaffold manufacturing methods, and create a macro structure of medical support.

In the development of 3D printing technology, the print path planning has always been the key to the quality of the model printing. Song G. H. et al [7] proposed a tree support structure design method to improve the printing quality and efficiency, the literature [8] proposed a construction method for composite forming process of biological CAD/CAM system, which can solve the problem of 3D printing bracket forming precision.

Peek is a semi crystalline thermoplastic engineering plastics, has high temperature resistance, excellent mechanical strength and excellent chemical stability. It is precisely because of these advantages, PEEK can be very ideal for applications in biomedical [9]. Of course, this material is not very mature in the application process; many are in the research and experimental stage. Roskies et al [10] studied the print medical stents in craniofacial implantation and reconstruction process by 3D SLS printing technology. The tensile and bending properties of materials and the printing process of PEEK material in parameter adjustment [11], but overall, mechanics of PEEK can be better than ordinary materials, more suitable for 3D printing [12].

In this paper, we propose an experimental analysis method, which included the influence analysis of temperature on the mechanical properties of materials and the printing performance of PEEK and PLA materials. By means of experiment and data, the printing performance parameters of PEEK materials were obtained, which provided a new solution for the forming process and printing performance of high temperature printing materials.

II. 3D PRINTER FEATURES AND EXPERIMENTS

High temperature material PEEK printer is different with the general material type FDM 3D printer, PLA and ABS material print head temperature is 190 degrees -230 degrees, the hot bed temperature is 110 degrees; but the print head temperature of PEEK material require at least more than 340 degrees, so it needs special printing equipment and the print head to complete PEEK printing. The PEEK special type 3D printer and high temperature print head are shown in Figure 1. The 3D printer increased environmental temperature control module, thermal cycle modules and other subsystems compared with ordinary 3D printer, the print head is high temperature type for PEEK printing requirements, designed as total metal with maximum temperature of 450 degrees.

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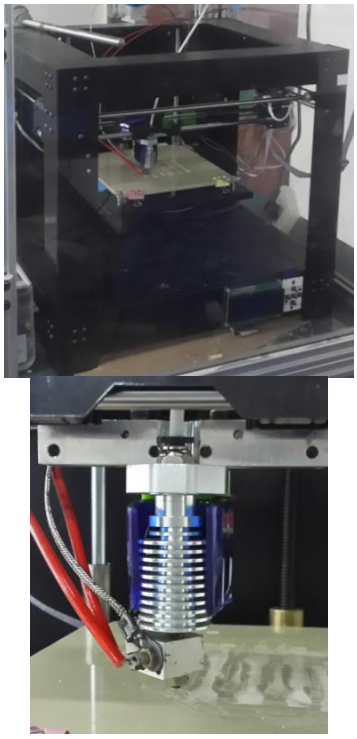

Figure 1 High temperature PEEK printer and print head

As a kind of semi crystalline polymer, the temperature of the printing head and the cooling temperature of the PEEK will affect the crystallization of the material, and the mechanical properties of the parts will be affected too. Therefore, it is necessary to carry out experimental means analysis of this material: the experiment uses 1BA type tensile test specimens, the test results can be directly used as the basis for the analysis of tensile strength data. The experimental parameters: high precision is 0.2mm, shell thickness is 0.8mm, print speed is 20mm/s, filling mode is 45 degrees oblique direction 100% filling, filling direction between two layers is 90 degrees, the nozzle diameter is 0.4mm, as shown in figure 2. In the tensile test, the drawing speed is set to 5mm/s, and the data of tensile strength and elongation at break are recorded.

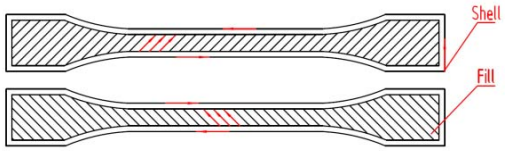

Figure 2 Print track and model settings

Mechanical properties and print performance of PEEK are obtained under different temperature conditions. The hot bed and environmental temperature are mainly analyzed. The temperature of the print head is set to a constant 430 degrees. The bottom plate is 5mm PEEK plate in order to better adhesion.

III. PERFORMANCE IMPACT ANALYSIS OF PEEK MATERIAL

A Effect of temperature on mechanical properties

Firstly, the mechanical properties of PEEK is analyzed under different temperatures, the experiment is divided into 4 kinds. The hot bed temperature is 130 degrees; the printing environment temperature is 60 degrees. The hot bed temperature is 110 degrees; the printing environment temperature is 25 degrees. The hot bed temperature is 25 degrees; the printing environment temperature is 25 degrees. The last case is different from the above three kinds, the filling rate is set to 50%, hot bed and print environment is not heated. Figure 3 shows that a sample of 6 models, the results of the experimental data are shown in table 1 accordance with the requirements of the ISO527 standard tensile experiments.

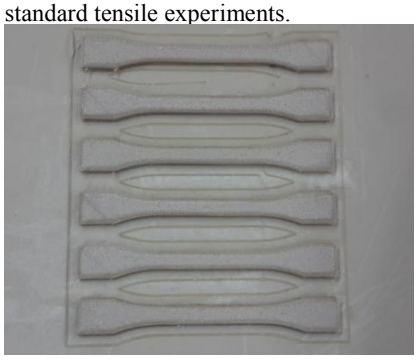

Figure 3 Experiment print sample

As can be seen from the table 1, the tensile strength and the fracture rate of the samples are the highest in the presence of the hot bed temperature and the ambient temperature. Among them, the fracture rate also fully reflects the merits of the performance of the material, under the conditions of the experiment 1, the material fracture rate reached 19.7%, is also the highest in the four groups of experiments. In the third and fourth groups, the tensile strength and the fracture rate of the materials have rebounded, which shows that the structure of the hollow truss can also guarantee the strength. Under such experimental conditions, the maximum tensile strength of PEEK is 75MPa, and the tensile strength can be predicted to be more than 80MPa based on the optimized printing parameters.

Table 1 The tensile test data of temperature

Number	Temperature setting		Filling ratio	Experimental data						
	Hot bed	Environmental		Name	1	2	3	4	5	average value
①	130°	60°	100%	tensile strength /MPa	71.7	75.2	63.3	74.2	71.7	71.2

				Fracture rate /%	17.3	20.5	17.2	23.4	20.2	19.7
②	110°	25°	100%	tensile strength /MPa	79.1	61.7	77.2	65.7	58.4	68.4
				Fracture rate /%	21.9	19.5	20.8	18.9	12.1	18.6
③	25°	25°	100%	tensile strength /MPa	53.6	51.1	40.1	40.9	45.2	46.2
				Fracture rate /%	18.1	19.1	11.9	12.1	13.5	14.9
④	25°	25°	50%	tensile strength /MPa	53.6	51.2	50.7	52.6	55.4	52.7
				Fracture rate /%	20.9	14.6	19.1	16.2	19.9	18.1

B The forming precision of the material of temperature effect

PEEK material is a kind of high temperature materials, in the process of printing and forming, the influence of temperature on the forming accuracy will also have a greater impact. As shown in Table 2, the accuracy of the shape and size of the sample is measured. The measured data and error values are obtained using venire caliper. Standard size sample is 5mm × 2mm, the percentage error in the table is calculated according to the standard value.

As can be seen from table 2, the greater the molding error is expressed with higher temperature; the visible environment temperature has an important influence on the forming accuracy in the cooling process. In the fourth set of data, the accuracy is relatively good, and it shows that the appropriate low filling ratio can improve the forming precision of the 3D printing material.

Table 2 experimental measurement accuracy /mm

T—transverse, P—portrait

	N.	1	2	3	4	5	average value	error /%
①	T	5.2	5.4	5.5	5.3	5.3	5.34	6.8
	P	2.4	2.3	2.3	2.4	2.3	2.34	17
②	T	5.2	5.4	5.3	5.4	5.1	5.28	5.6
	P	2.3	2.3	2.4	2.5	2.5	2.4	20
③	T	5.5	5.5	5.5	5.6	5.4	5.5	10
	P	2.6	2.5	2.5	2.5	2.5	2.52	26
④	T	5.3	5.2	5.3	5.3	5.3	5.28	5.6
	P	2.3	2.3	2.4	2.4	2.3	2.34	17

C The analysis of thin layer parts forming

Print molding performance of PEEK materials is analyzed and tested in thin layer model parts printing experiment. As shown in Figure 4 and 5, the sample is printed by PEEK material in Figure 4, and the sample is printed by PLA material in Figure 5, the two models are the same. The thickness of the samples is 1 layer, which is about 0.4mm. The PEEK sample printed out with high temperature environment and high bed temperature control. The PLA material sample printed out with room temperature, no special control temperature.

Figure 4 The printing model of PEEK material

Figure 5 The printing model of PLA material

By comparison, it can be found that the parts printed by PEEK material are superior to the PLA material in both the stiffness and the molding. The small hole phenomenon appeared in PLA printing materials of the same thin model, and there is a flaw in the bend. As shown in Figure 6, the box model sample is printed out by PEEK material, the overall stiffness and accuracy of the sample molding are better than PLA material samples. Therefore, PEEK material has good printing performance, and the complex model printing has a natural advantage.

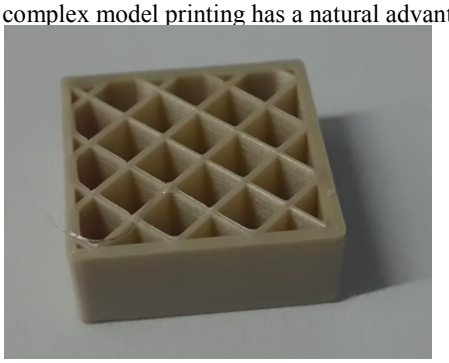

Figure 7 The box model sample of PEEK material

IV. Conclusions

1. The temperature has great influence on the mechanical properties of PEEK, and the mechanical properties can be improved by the increase of temperature. In these few experiments, the tensile strength is the highest under highest hot bed and the ambient temperature, can reach 75MPa. It shows that increasing temperature can enhance the PEEK binding force between layers in the printing process, which can make the model more excellent mechanical properties. As shown in Figure 7, it shows 5 groups of curves, the first 4 groups are divided into the corresponding tensile properties, and the last group is the mechanical properties of the PLA materials.

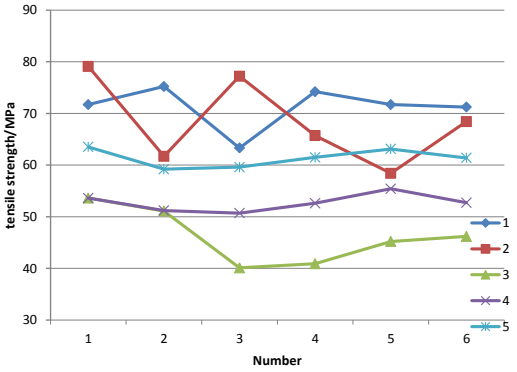

Figure 7 Comparison of tensile strength of PEEK

2. The mechanical properties of PEEK materials have a certain relationship with the filling rate, low filling ratio can even improve the performance of the material. From the 3 and 4 test curve can be seen in Figure 7, in the same temperature and printing parameters, the average tensile strength with 50% filled is 52MPa, higher than 100% filled 46MPa.

3. The temperature has a great influence on the molding precision of PEEK material, and the forming precision is the worst at room temperature. As the temperature increasing, the forming precision of the material can be promoted.

4. In the process of printing materials, the temperature of the environment needs to keep constant. Under high temperature conditions, the effect of temperature on the mechanical properties is not a simple monotonic function, it is a complex phenomenon.

5. The forming performance of PEEK material is better than that of PLA and other common materials. Through the analysis of the parts in the previous 2.3 chapters, it can be seen that the PEEK material has excel

In this paper, we use the high temperature FDM type 3D printer; analyze three aspects of PEEK material.

The experimental results show that the tensile strength can reach 75MPa under the condition of good printing environment and printing parameters, and the forming properties of PEEK materials are higher. But it can be predicted that, the performance of PEEK materials should be improved to 90MPa by optimizing the temperature and printing parameters. Through the research and analysis of this paper, it provides an effective experimental data and analysis basis for the application of PEEK materials.

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