IN SITU RESIN IMPREGNATION BEHAVIOR DURING 3D PRINTING OF CONTINUOUS CARBON FIBER REINFORCED PLASTICS

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Abstract

Currently 3D printing technology has attracted much attention as new molding methods for carbon fiber reinforced thermoplastics (CFRTP). The purpose of this study is to investigate in situ resin impregnation during 3D printing of continuous carbon fiber reinforced plastics. The specimen was manufactured by fused deposition molding (FDM) using carbon fiber yarn including 3000 mono-filaments and polylactic acid (PLA) filament. Resin impregnation ratio measurement and tensile tests were conducted on the molded specimens in order to investigate the effect of process parameters during 3D printing on mechanical properties. As a result, the modeling temperature was a parameter that influenced the tensile strength. In this study, we recommend the modeling temperature T = 200°C for the PLA composites. The layer height was a parameter that remarkably influenced the impregnation ratio. The quality of the model can dramatically be improved by using continuous carbon fiber, so it was shown that this technology could be applied to various applications.

1. Introduction

Carbon fiber reinforced plastics (CFRP) has been increasingly used in the aerospace industry and others due to its excellent specific strength, specific rigidity and fatigue resistance. However, the present molding process of composites is very complicated and expensive, so that it is not suitable for use in medium-sized passenger aircraft or automobile industry. Therefore, in order to expand the usage of the composite material, it is necessary to simplify the molding process and reduce the cost of molding.

Manufacturing of carbon fiber reinforced thermoplastic composites (CFRTPC) using 3D printing has been studied as a new molding process. However, it has not been applied to structural members, because the strength of the shaped object has not reached a practical level. As a solution, it is possible to improve strength and stiffness of 3D printed parts by using continuous carbon fiber, it can be expected to be applied to small lot production of many products of structural member.

On the other hand, there are several issues for practical use of 3D printer molding of continuous carbon fiber reinforced composites. Matsuzaki et al. [1], Tian et al. [2] reported that the fiber volume content of the moulded specimen were 6.6% and 27%, respectively. These values are low for use as structural members, and in order to put it into practical use, it is necessary to mold with higher fiber volume content. Secondly, there is a lower resin impregnation in the carbon fiber yarn. If it is possible to impregnate the resin in the carbon fiber yarn the inside of the print nozzle during molding, the fiber volume content can be controlled by process parameters.

In this study, the behavior of in situ resin impregnation for 3D printing with higher fiber volume content and resin impregnation were investigated. Cross-sectional observation and tensile tests were performed to investigate the factors of resin impregnation for test specimens with changing process parameters of 3D printing.

2. 3D Printing of Continuous Carbon Fiber Reinforced Composite Materials

Currently, there are various types of molding methods in 3D printers. In this study we used a 3D printer with fused deposition method (FDM), as one of the standard 3D printing technologies. In the FDM process, the thermoplastic resin filament is continuously fed into the nozzle and heated to a semiliquid state, and extruded onto the previous layer along the modeling path. At the time of modeling, improvement in the mechanical properties of the moulded objects is expected by simultaneously feeding the carbon fiber yarn. In-situ resin impregnation in this study has the advantage to control the resin impregnation to reinforcing fiber yarn at the nozzle parts without using intermediate material. This technology is expected as a new molding method that could maximize material properties of CFRP.

3. Experimental method

3.1. Production of specimen using 3D printer

The carbon fiber reinforced PLA composites (CF / PLA) specimen was molded by 3D printer of simultaneously feeding the PLA filament and the carbon fiber yarn (T300B-3000 40 B, 3000 fiber in a tow, Toray). The modeling path is shown in Figure 1. This molding path is newly created for CF / PLA specimen, and it is designed to draw specimen shape with one stroke to continuous supply fiber tow. The values of process parameters used for molding specimens are listed in Table 1. In the 3D printing of CF/PLA, there are many process parameters which may be affected on the produced specimens. In this study, the specimens were molded by changing the modeling temperature T and the layer thickness h. The values of T and h are listed in Table 2. Modeling temperature affects the melting flow properties of the plastics. Layer thickness will change the contact pressure between the nozzle and deposited layer, also the fiber content of the printed composite.

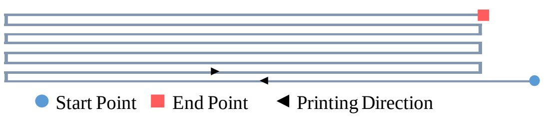

Figure 1. Schematic view of printing track of first layer.

Table 1. Process parameters for 3D printer.

Nozzle Diameter [mm]	1.5	Filament Diameter [mm]	1.75
Modeling Temperature [°C]	T	Heat Bed Temperature [°C]	60
Print Speed [mm/min]	60	Layer Thickness [mm]	h
Line Width [mm]	1.8		

Table 2. Process parameters of modeling temperature *T* and print speed *v* for 3D printer.

	T [°C]	*h* [mm]
CF/PLA_T190	190	0.25
CF/PLA _T200	200	0.25
CF/PLA _T210	210	0.25
CF/PLA _T220	220	0.25
CF/PLA _h0.25	190	0.25
CF/PLA _h0.5	190	0.5

3.2. Tensile test

A universal testing machine (AG-IS 50 kN, Shimadzu Corporation) equipped with a 50 kN load cell was used for the test. A strain gauge (KFGS-1, Kyowa Electronics) was adhered to the center of the parallel portion to measure the strain behavior.

3.3. Cross sectional observation

Cross sections of CF / PLA specimen were observed for the measurement of impregnation states. The resin impregnation ratio was measured from a sectional photograph of fiber yarn taken with an optical microscope. The resin impregnation ratio is represented by the following equation.

$$\boldsymbol{I = N_w / (N_w + N_B)} \tag{1}$$

I: resin impregnation ratio, N_W: number of pixels of the impregnated region (white), and N_B: number of pixels of the unimpregnated region (black).

4. Experimental results and discussion

4.1. Modeling temperature

Tensile strength, elastic modulus and impregnation ratio were measured for the specimens prepared with different temperature of the printing head. The results are shown in Figure 2. Impregnation ratio did not change with temperature. There was no effect of viscosity due to temperature, because the nozzle contact pressure during molding was dominant. Tensile strength decreased with increasing temperature over 200°C. This result suggested that thermal degradation of PLA resin due to high temperature occurred. From these results, the appropriate modeling temperature could be determined as 200 °C.

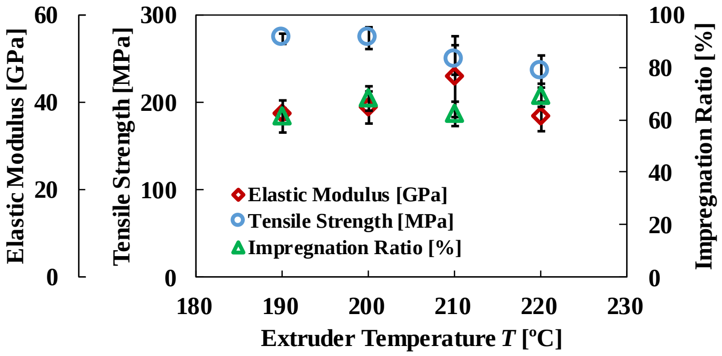

Figure 2. Result of tensile testing and impregnation ratio observation for CF/PLA specimen molding by 3D Printer. Effect of extruder temperature *T* (*T* = 190°C, 200°C, 210°C and 220°C).

4.2. Layer thickness

Tensile strength, elastic modulus and impregnation ratio were measured for the specimens prepared with different layer thickness. The results are shown in Figure 3. The impregnation ratio was improved with decreasing the layer height. It is considered that the contact pressure is increased with decreasing layer thickness, because the distance between the modeling surface and the nozzle tip became close. From the results of tensile strength and modulus of elasticity, both values are improved by layer thickness reduction (At *h* = 0.5 mm it was 190 MPa, 24 GPa, at *h* = 0.25 mm it was 273 MPa, 37 GPa). Reducing the layer thickness is considered to be two effects, such as improving the resin impregnation ratio and increasing the fiber volume content ratio. However, it is necessary to determine the value according to the intended use of modeling object, since the molding time is prolonged by decreasing the layer height.

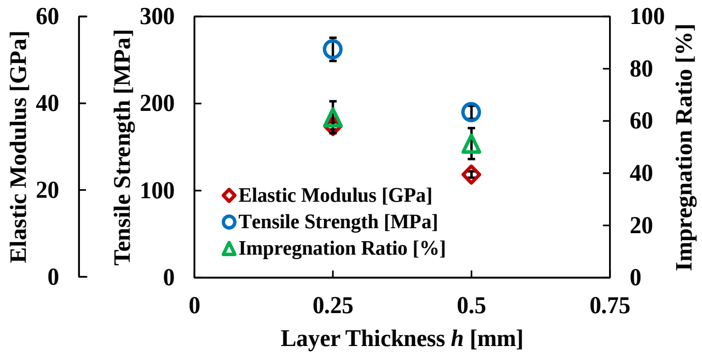

Figure 3. Result of tensile testing and impregnation rate observation for CF/PLA specimen molding by 3D Printer. Effect of layer thickness *h* (*h* = 0.25 mm and 0.5 mm).

5. Conclusions

Process parameters during molding a CF / PLA specimen by 3D printing were optimized from tensile testing and resin impregnation measurement. The molding temperature may affect the properties of the resin, except for the resin impregnation ratio. For the PLA composites, we recommend the modeling temperature *T* = 200°C. The layer height was a parameter that remarkably influenced the impregnation ratio. Finally, the quality of the model can dramatically be improved by using continuous carbon fiber, so it was shown that this technology could be applied to various applications.

References

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