3D printing for continuous carbon fiber composites

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Introduction

3D printing first appeared in the 1980s and has experienced significant development in recent years. Since the cost of 3D printers that use thermoplastic filaments (Filament Deposition Molding or FDM) has been greatly reduced, they have started to see widespread use. However, since the mechanical properties of objects molded by FDM 3D printers are generally poor, they are not suitable for structural applications. Meanwhile, the use of carbon fiber reinforced plastics (CFRP) has increased in the aeronautical and automotive industries but is mostly limited to parts with simple shapes (i.e. straight or bent) due to difficulties associated with printing complex shapes. Conversely, the manufacturing of complex parts has been found to be easier when carbon fiber reinforced thermoplastics (CFRTP) is used for 3D printing instead. Thus, 3D printing using CFRTP is desired industrially. Though the mechanical properties of an object printed from a filament that is impregnated with carbon nanotubes, grass fibers and carbon fibers tend to be good, an object 3D printed from a filament impregnated with continuous carbon fiber (CFRTP filament) is generally considered to result in better mechanical properties. The purpose of this study is to manufacture an object using an FDM 3D printer that has sufficient strength for aeronautical and automotive applications. To accomplish this purpose, a CFRTP filament and an FDM 3D printer with a cutting mechanism (Fig.1) for cutting the CFRTP filament were developed.

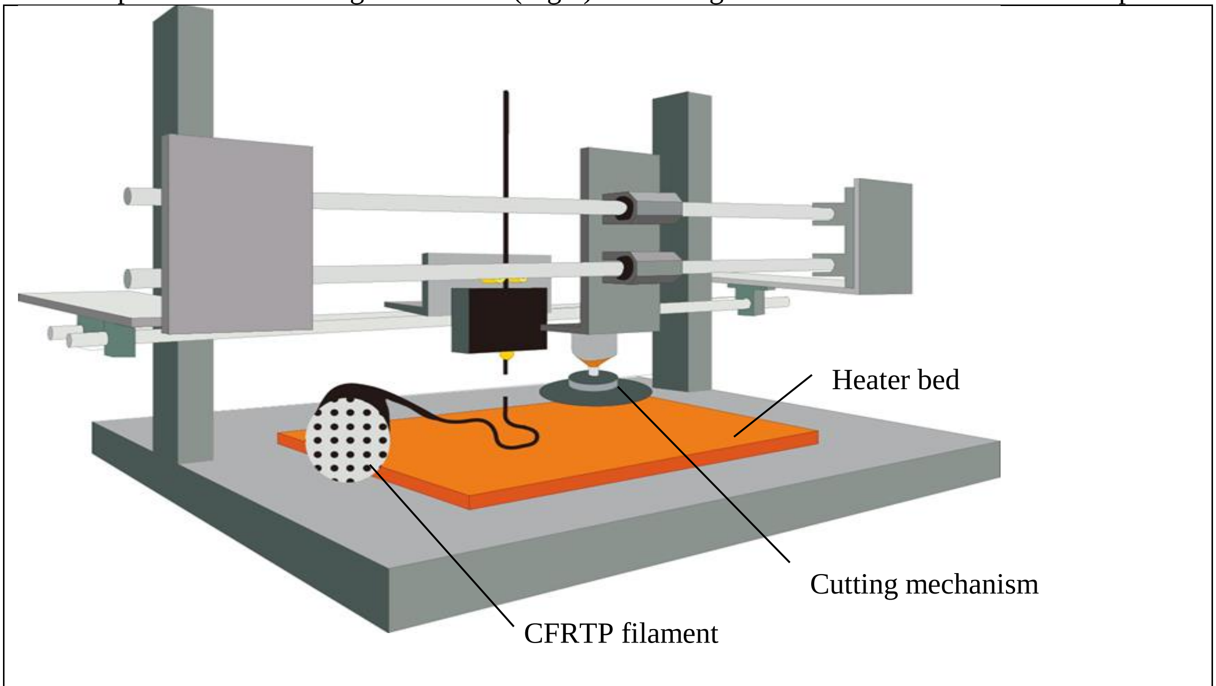

Figure 1: *Schematic diagram of the 3Dprinter with continuous carbon fiber and cutting mechanism.*

Manufacturing filament impregnated with continuous carbon fiber

In general, the filament for an FDM 3D printer is made using a filament extruder. However, since CFRTP filaments cannot be made in this way, they were instead fabricated by extraction from a heater. Acrylonitrile butadiene styrene (ABS) was used as the matrix. The temperature of the heater was set at 250 °C (which is 20 °C higher than the melting point of ABS) in order to lower the viscosity of the ABS. This enables the resin to impregnate the carbon fiber. The diameter of a completed filament was 1.75 (±0.5) mm. 8000 carbon fibers were used for a single CFRTP filament.

Manufacturing CFRTP specimen and conducting a test

A total of three CFRTP and ABS specimens was manufactured with using the FDM 3D printer. These specimens were then subjected to a tensile test at a rate of 1 mm/min to evaluate the mechanical properties of each specimen. The results showed that the tensile strength of the CFRTP specimens was four times higher than that of the ABS specimens. The modulus of elasticity of the CFRTP specimens was found to be 4.8 times higher than that of the ABS specimens. A cross-sectional observation of the CFRTP specimen revealed resin-rich and resin non-impregnated spheres.

Conclusions

CFRTP specimens were manufactured using an FDM 3D printer and were subjected to a tensile test. The modulus of elasticity of the CFRTP specimens was improved by 4.8 times as compared with the ABS specimens. However, these values were lower than the theoretical values calculated from the law of mixtures. The data from the cross-sectional observations showed poorer mechanical properties in the case of resin-rich and resin non-impregnated spheres.