3D PRINTING OF INTEGRATED COMPOSITE HONEYCOMB SANDWICH STRUCTURES WITH CONTINUOUS CARBON FIBER

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ABSTRACT

In the coming years, it is expected that the application of composite in the aerospace and automobile industry will be increased through the development of 3D printing technology using carbon fiber-reinforced resin. Sandwich structures currently used in aerospace components are formed of a skin material and a core material adhered to each other to form an integral structure. In these structures, it is necessary to thoroughly investigate the functional characteristics of the core material and shape it in the best way to take full advantage of its unique characteristics.

Therefore, in this research, we investigate the possibility of designing and fabricating a free-form core shape, and investigate the feasibility of molding these integrated sandwich structures using a 3D printer capable of laying continuous carbon fibers. In the proposed experimental method, the diameter of the filament is smaller than that used in a general FDM-type 3D printer; to accommodate thin filaments in the molding process, we modified a 3D printer accordingly. As continuous carbon fiber 3D printers have a simple arrangement without a cutting mechanism, all shapes molded must be formed under single-stroke writing conditions. Therefore, in forming the core material in this research, the unit cell must satisfy the periodic boundary condition, making one-stroke molding possible. Notably, the tension in the continuous carbon fiber enables the formation of wide bridge spaces without the support material.

Experimental results show that it is both possible to design core shapes such as a honeycomb structure freely and to mold integrated sandwich structures using the proposed method.

1 INTRODUCTION

The 3D printer [1] (Additive Manufacturing, or AM) technology that appeared in the 1980s has developed significantly in recent years. Unlike traditional high cost manufacturing methods using molds and large-sized equipment, 3D printers can perform three-dimensional shaping tasks quickly and at a low cost using only 3DCAD or 3DCG data, and potential applications for their use are increasing in the fields of welfare and medical care. However, the mechanical properties of objects constructed using fused deposition modeling (FDM)-type 3D printers are poor [2] and must be improved before widespread adoption of this technology can occur. Recent aerospace structures have achieved high strength and weight reduction by using continuous carbon fiber-reinforced resin [3]; this material is expected to be applied in automobile manufacturing in the future. However, the main carbon fiber-reinforced resin molding methods of filament winding and autoclaves curing make it difficult to form complex shapes. From this viewpoint, the use of 3D printer technology [4] to construct objects with carbon fiber-reinforced plastic using resin as a base material could accelerate the application of 3D printers in the aerospace and automobile industries.

A sandwich-type structure such as a honeycomb is used in an aerospace member [5] for the purpose of weight reduction and high strength by forming an integrated structure of a skin material that resists tension and compression bonded to a lightweight core material that resists shear forces.
such sandwich structures, it is necessary to thoroughly consider the functional properties of the core shape and to mold it to best utilize the characteristics of the material. [6] For that purpose, techniques that enable the core shape to be freely designed and constructed using integral molding with a continuous carbon fiber 3D printer are required.

Accordingly, the purpose of this research is to investigate the possibility of designing and molding a free core shape, such as a honeycomb, using a continuous carbon fiber 3D printer (Figure 1).

Figure 1: Schematic diagram of the integral molding of a sandwich structure
2 3D PRINTING MECHANISM USING CARBON FIBER FILAMENT

The filaments used in an FDM-type 3D printer are generally made of PLA (Polylactic acid) or ABS (Acrylonitrile butadiene styrene) with a diameter of 1.75 mm. In this experiment, we used TORAYCA® T300 Markforged [7] Carbon Fiber Filament (CFF) impregnated with Nylon® (dry). The CFF has a diameter of 0.4 mm. Therefore, when this CFF is used in a general FDM-type 3D printer, filament buckling occurs in the nozzle owing to the difference between the diameter of the filament and the inner diameter of the passage inside the nozzle, and the heating section of the heater block is also longer than optimal. Therefore, a PTFE (polytetrafluoroethylene) tube having an inner diameter of 0.5 mm and an outer diameter of 1.7 mm was passed through the nozzle immediately before the tip. In addition, a shearing force being generated between the nozzle tip and the continuous carbon fiber filament during molding, and the filament is torn. To compensate for this issue, the inside of the nozzle tip was chamfered so that the filament would smoothly emerge. Figure 2 shows a sectional view of the heater block and nozzle modified to accept the small diameter CFF.

![Figure 2: Cross sectional view of the heater block and nozzle](image)

3 PROPOSED METHOD OF MOLDING SANDWICH STRUCTURE

A sandwich structure is mainly composed of a core material sandwiched between two skin materials. In continuous carbon fiber 3D printers, all products are formed under single-stroke writing conditions. To produce the skin material of a sandwich structure, after the first straight and linear CFRTP is printed to the target length, it is turned back. Then, a new CFRTP is linearly printed next to it, and this process is repeated to laminate the 0° direction of the skin material. After returning to the molding start position and moving the Z-axis corresponding to the laminating pitch, stacking is performed in the 90° direction in the same manner as the 0° direction. To produce the core material shape, unit cells are designed that satisfy the periodic boundary condition, thereby enabling modeling in a single stroke. Figure 3(a) shows the shaping process for a honeycomb structure using a “hat shape” as the unit cell. Figure 3(b) illustrates that as a result of the tension of the continuous carbon fibers, it is possible to print wide bridge spaces to deposit the top skin material over the core material without using any support material.
4 MOLDING EXPERIMENT

4.1 Molding conditions and core shapes

In this experiment, an FDM-type 3D printer BS 01+ (Bonsai lab) is used. Table 1 provides the nozzle temperature and bed temperature during molding. There are 5 layers of skin material in each of the upper and lower surfaces and 20 layers of core material laminated in between for a total of 30 layers in the structure. Figure 4 illustrates the unit cell shapes to be molded in the sandwich structure: (a) honeycomb, (b) rhombus, (c) rectangle, and (d) circle.

4.2 Result of molding

Figure 5 shows the results of the core shape molding experiment. A photograph taken during bridge space modeling is shown in Figure 6. Every tested core shape was able to be integrally formed, but because the inner side of the nozzle tip was chamfered and larger than the filament diameter, deviations in print pass and rounded corners both occurred. It was also confirmed that the skin across bridge space can be fabricated without sagging of the filament thanks to the fiber tension.

<table>
<thead>
<tr>
<th>Molding parameters</th>
<th>Conditions</th>
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<tbody>
<tr>
<td>Nozzle temperature</td>
<td>[°C]</td>
</tr>
<tr>
<td>Bed temperature</td>
<td>[°C]</td>
</tr>
<tr>
<td>Nozzle diameter</td>
<td>[mm]</td>
</tr>
</tbody>
</table>

| Nozzle temperature | 240         |
| Bed temperature    | 70          |
| Nozzle diameter    | 0.9         |

Table 1: Modeling conditions in this experiment
5 EVALUATION OF SURFACE SHAPE

The surface shape of the upper skin material after bridge space molding was evaluated and compared to a sandwich structure made of PLA resin and molded with an FDM 3D printer. For the measurement, a 3D microscope (Keyence VR - 3000) was used. The surface roughness $Ra$ was calculated from the measured data and is given in Table 2, which shows that a surface roughness equal to or higher than that of the PLA resin sandwich structure was obtained. As a result, we think that the base of the upper skin material was able to be solidly formed because it was molded with filament fibers tensioned during bridge space modeling.

<table>
<thead>
<tr>
<th>Sandwich structure</th>
<th>Surface roughness $Ra$ [$\mu$m]</th>
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<tr>
<td>CFRTP</td>
<td>19 ±2.6</td>
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<tr>
<td>PLA</td>
<td>32 ±5.2</td>
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</tbody>
</table>

Table 2: Surface roughness measurement results
6 CONCLUSIONS

In this experiment, sandwich structures such as a honeycomb core shape were molded using a continuous carbon fiber 3D printer modified to deposit small diameter filaments. Following the proposed method, it was confirmed that molding of CFRTP sandwich structures is possible using an FDM type 3D printer relying on unit cells satisfying the periodic boundary condition and fiber tension during molding. It was also confirmed that a surface roughness equal to or higher than that of a sandwich structure could be obtained using a conventional PLA 3D printing resin.

REFERENCES


