EFFECT OF FIBER ORIENTATION ON MECHANICAL PROPERTY OF CFRP FABRICATED BY AM

T. Tanaka[1], T. Tateno[1,2] , and T. Kojima[2]

[1]*Graduate School of Science and Technology, Meiji University*
1-1-1 Higashimita, Tama-ku, Kanagawa 214-8571, Japan
[2]*Department of Mechanical Engineering Informatics, Meiji University*
1-1-1 Higashimita, Tama-ku, Kanagawa 214-8571, Japan

e-mail: ce172047@meiji.ac.jp

1. Introduction

Additive Manufacturing (AM) known as a layered fabrication method is a technique of laminating thin layers based on 3D model data and shaping an object. In recent years, due to the development of this technology, it has become possible to produce complicated shapes that were difficult in the past. There are various shaping methods in AM. Among them, Fused Filament Manufacturing (FFM), which melts an elongated resin material known as Fused Deposition Manufacturing (FDM) and extrudes it from a nozzle by heat, is known as a method for manufacturing practical parts at low cost.

However, In general, FFM uses plastic resins such as ABS and PLA, and it is said that its strength is limited. In recent years, attention has been paid to the application of carbon fiber in order to improve the strength. However, since FFM stacks layered materials, there is a difference in strength depending on the alignment of the additive process due to the influence of the adhesive surface. Conventional CFRP prevents anisotropy on strength by weaving fiber, but FFM can't weave between layers. For this reason, it is expected that the anisotropy is controled by the process alignment in FFM.

In this work, the effect of fiber orientation in FFM process on tensile strength of CFRP. Several specimens, which have different orientation of the fiber in each layer, are prepared. Tensile strength and Young's modulus were measured through tensile tests. Furthermore, by observing the broken part and considering from the stress-strain curve, the effective alignment pattern was discussed. Finally, as an application of FFM with CFRP, a high strength cell structure for shock absorption is proposed. The cell structure is devised considering process alignment from two points of view, which are easy for FFM and large capacity of energy absorption.

2.1. Tensile test specimen

The shape model of the specimen was formed by using a FFM modeler (Mark Two, Markforged, Inc.) and the orientation of the carbon fiber was set with a dedicated slicer (Eiger). The materials, which are fused nylon and carbon fiber, are extruded from a nozzle and allocated with nozzle motion. As a result, it is possible to incorporate carbon fibers in the nylon model. Orientation angle of fiber in one layer can be set by 15 degree (15n: n=0~6) so that the carbon fiber in each layer of the specimen in each layer is aligned with respect to the loading direction. The size of the specimen was unified with a length of 15 mm, a width of 150 mm, and a thickness of 0.75 mm.

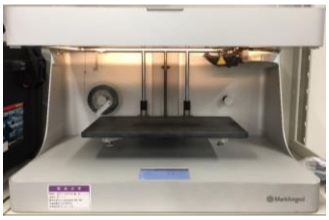

Fig 1: AM machine used in the experiment

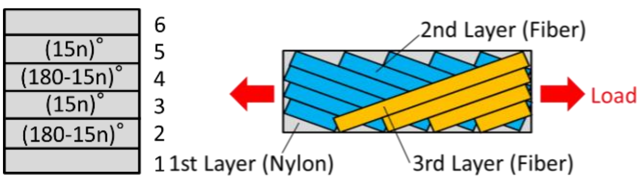

Fig 2: Cross-sectional view and top view of test specimen

2.2. Result of tensile test

The results of the tensile test are shown in Tables 2 and 3 below. When the fiber orientation angle is near perpendicular to the load direction, the tensile strength decreases. In addition, for the test piece with the fiber angle of 60 degree or more, the tensile strength was lower than that of the test piece without carbon fiber. The reason for this was thought that peeling between inter-layer surfaces was occurred prior to breaking of the fiber. Furthermore, the fracture factors were classified into the following three loading condition modes by considering the stress-strain curve and the broken part of the test piece.

i) Most of the nylon is under load.
ii) Both nylon and carbon fiber are under load.
iii) Most of the carbon fiber is under load.

Fiber angle [deg]	0,180	15,165	30,150	45,135	60,120	75,105	90,90	No fiber
Tensile strength [MPa]	346	254	79	71	27	23	17	43

Table 1: Result of tensile strength.

Fiber angle [deg]	0,180	15,165	30,150	45,135	60,120	75,105	90,90	No fiber
Young’s modulus [GPa]	20	17	4.3	2.9	1.7	1.8	1.8	0.2

Table 2: Result of Young’s modulus.

3. Proposal of shock absorbing structure

FFM realizes to fabricate the internal structure, which was difficult to do with the conventional processing method. Here, we propose a high strength cell structure for shock absorbing by using AM of CFRP material. The orientation of carbon fiber in each layer is not straight but bended along the honeycomb structure. The structure is designed to have space for elongation and for efficient reinforcement. The fiber orientation was specified for each layer, and the fiber alignment pattern is applied in vertical between the even layer and the odd layer. Furthermore, the shape of the cell structure itself was also examined. We designed a general auxetic structure, which can be transformed to a honeycomb structure with a positive Poisson's ratio and a special auxetic with a pseudo negative Poisson's ratio.

4. Conclusions

Tensile test of CFRP fabricated by FFM was carried out in different condition of carbon fiber orientation. It was confirmed that even if carbon fiber was applied to the shaped object, there was orientation condition that is not effective for reinforcement. Therefore, it is necessary to consider the fiber orientation which can be efficiently strengthened in the design stage. Considering the test results, a structure for shock absorbing parts was designed.

References

[1] Li Yang, Ola Harrysson, Harvey West and Denis Cormier. Mechanical properties of 3D re-entrant honeycomb auxetic structures realized via additive manufacturing. International Journal of Solids and Structures. 69-70, 2015, 475-490.
[2] A. Sohouli, M. Yildiz and A. Suleman. Design optimization of thin-walled composite strucrures based on material and fiber orientation. Compsite Structures. 176, 2017, 1081-1095.