INFLUENCE OF STACKING SEQUENCE ON TENSILE STRENGTH OF ORTHOTROPIC CFRP FABRICATED WITH PREPREG CONTAINING CELLULOSE NANO FIBERS (CNFs)

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Keywords: Carbon Fiber Reinforced Plastic (CFRP), Prepreg, Cellulose Nano Fibers (CNFs)

Abstract

The purpose of this study is to find the optimum condition of determining lamina thickness to improve the strength of orthotropic Carbon Fiber Reinforced Plastic (CFRP) laminate when the prepreg for the lamination was modified with Cellulose Nano Fibers (CNFs). Two types of stacking sequences were applied to compare the mechanical properties of CFRP modified with CNF. The experimental results showed that the tensile strength of CFRP of "thick layered laminates" was improved about 10% by the addition of CNF, while the tensile strength of CFRP of "thin layered laminates" was not almost affected by the addition of CNF. It was found that the application of "thick layered" sequence was effective to utilize the enhancing technique with the addition of CNF to improve the tensile strength of CFRP.

1. Introduction

Carbon Fiber Reinforced Plastic (CFRP) is widely used for the aerospace industrial fields because CFRP has high specific strength and stiffness. It is necessary to improve the mechanical properties of CFRP as the expansion of the fields of applications. Previous studies showed that the mechanical properties of fiber reinforced plastic (FRP) were improved by the addition of nano-sized filler[1-4]. In some studies, Cellulose Nano Fiber (CNF) was also focused as a kind of enhancing nano fibers having extremely high tensile strength and Young's modulus with nano-meters size of very thin diameter, to improve the mechanical property of CFRP[5-6]. Takagaki et al. showed that the mechanical property of plain-woven CFRP fabricated by the method of hand lay-up was improved by the addition of CNF[7].

It was also known that fabrication with thin prepregs prevented the growth of micro-cracking[8]. Kawabe et al. developed a method of spread fiber tows with large fiber tows without any damages and fabrication of prepreg which has thinner thickness than that of practical product. To obtain further improvement of mechanical property, parallel application of those methods of modifying resin with CNF and reducing lamina thickness using spread fiber tows was expected for improvement of mechanical properties of the CFRP laminate. In order to proceed with it, the appropriate condition of lamina thickness should be cleared for the applications in engineering. The purpose of this study is to find the optimum condition of determining lamina thickness to improve the strength of orthotropic CFRP laminate when the prepreg for the lamination was modified with CNF. Two types of stacking sequences were applied to compare the mechanical properties of CFRP modified with CNF. The tensile tests of CFFR were conducted and fracture surfaces were observed with SEM.

2. Experimental

2.1 Fabrication process of epoxy resin film containing CNFs

Figure 1 shows the fabrication process of epoxy resin film containing CNFs. To prepare prepreg sheets with modified resin for the matrix, CNFs were randomly dispersed in the liquid of epoxy resin by conventional planetary mixer (PLM – 15H, INOUE MFG, INC.). Epoxy resin after kneading was coated uniformly on a release paper by resin coating machine (Hirano Tecseed Co., Ltd). The thickness of coated resin on a release paper was 17 micro meter.

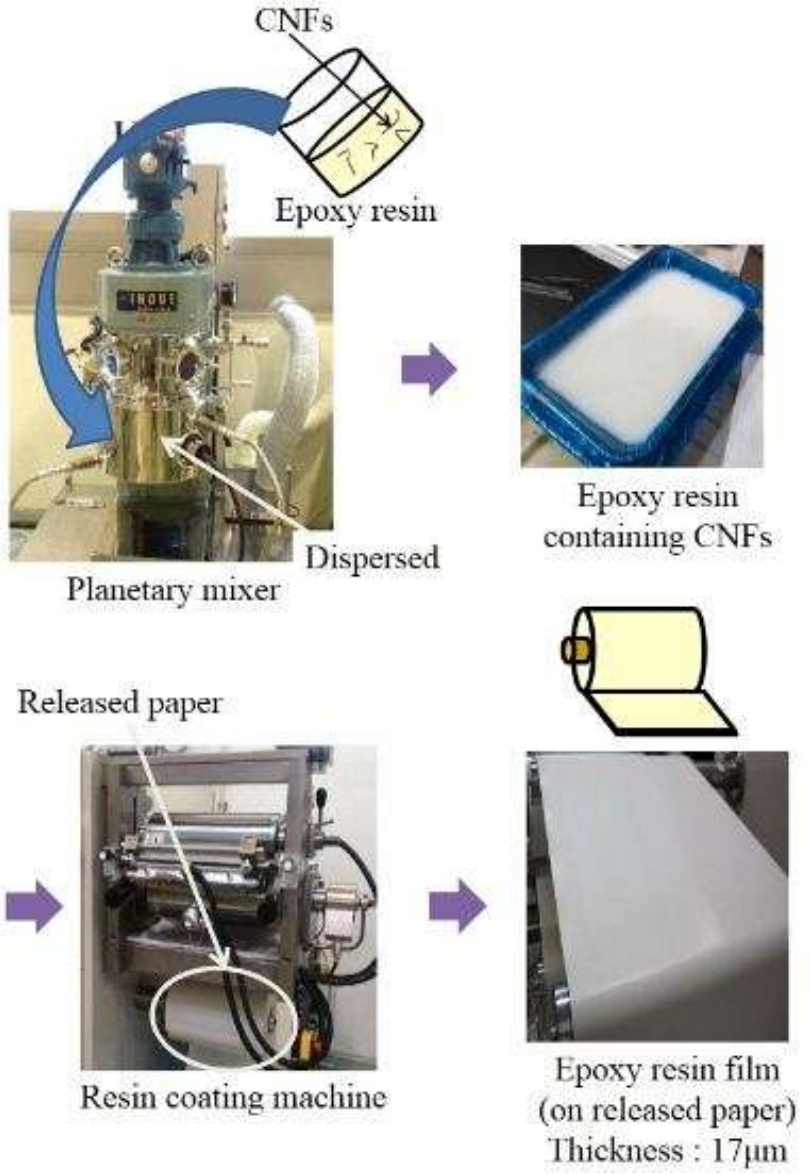

Figure 1. Fabrication process of epoxy resin film.

2.2 Fabrication process of prepreg

Figure 2 shows the fabrication process of prepreg sheet. Carbon fiber tows with 4.9MPa of tensile strength and 240GPa of Young's modulus (PYROFIL® TR50S15L, Mitsubishi Rayon Co., Ltd) were used as reinforcement of the composite. Carbon fibers in tows were spread by passing through a spreading machine where the air flows at the perpendicular to the direction of fiber tows. Unidirectional prepreg sheet was fabricated by using spread carbon fiber tows and epoxy resin film. The thickness and volume fraction of fibers of the prepreg were 40 micro meters and 57%, respectively.

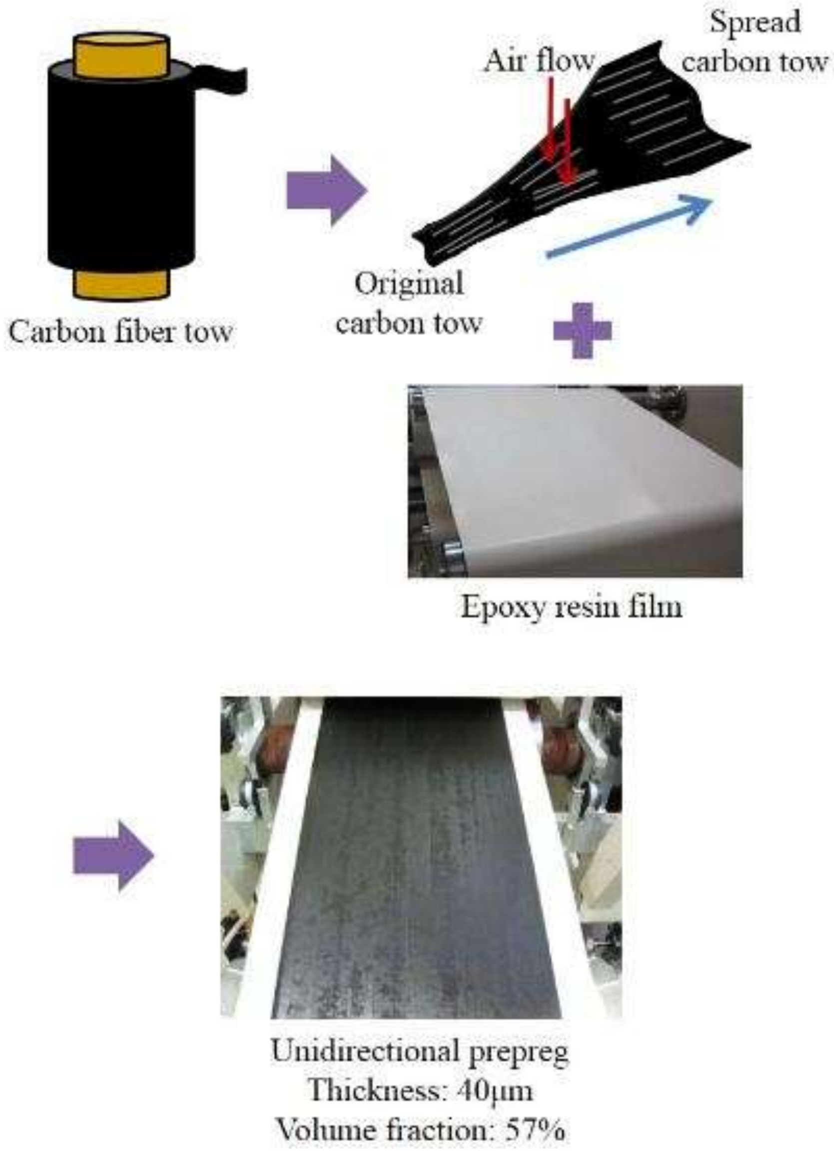

Figure 2. Fabrication process of prepreg.

2.3 Stacking sequence

Prepreg sheets were cut to the square shape (330mm×330mm) and laminated under the condition of 50%RH at 23°C. Two types of stacking sequences were applied to compare the mechanical properties. Figure 3 shows schematic view of stacking sequences for laminations in this study. Conventional laminate was called “thin layered laminate” in this study, where the thickness of each layer was 40 micro meters which was the same with that of prepreg. The other type of laminate was called “thick layered laminate”, where 4 laminates were collectively stacked in the same orientation to make a so called “plying group” and, namely, the composite had 6 “plying groups” with same orientation and property. The laminated prepreg sheets were cured at 130 degrees Celsius for 2 hours under 0.5MPa.

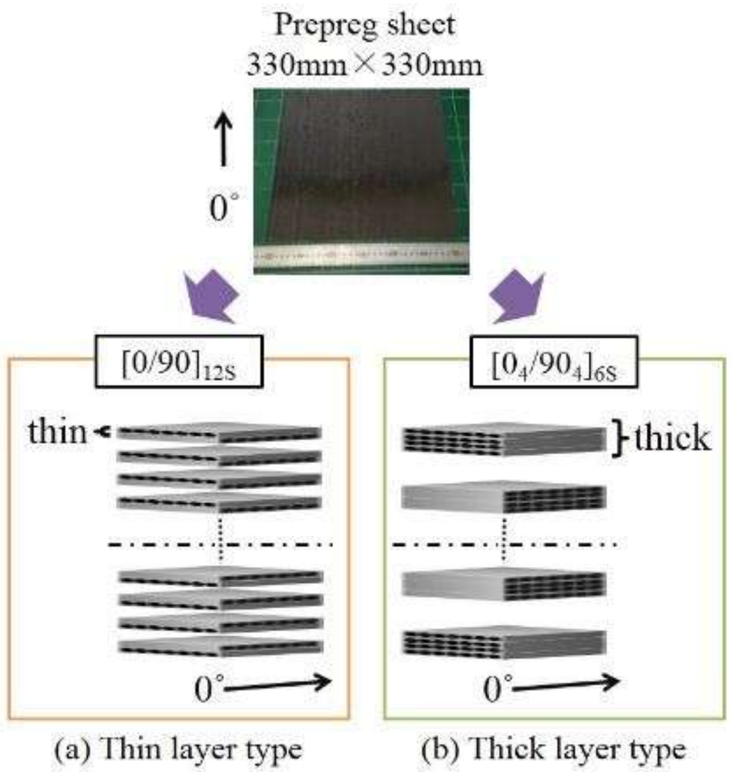

Figure 3. Stacking sequences for laminations.

2.4 Tensile test

Dimensions of the coupon specimen for tensile tests were 200mm × 25mm × 1.92mm (thickness). The tensile tests were conducted at 1mm/min of a crosshead speed.

3. Results and discussion

3.1 Tensile strength of modified CFRP

Figure 4 shows the results of tensile tests of unmodified and modified CFRP. The experimental results showed that the tensile strength of CFRP of “thick layered laminates” was improved about 10% by the addition of CNF, while the tensile strength of CFRP of “thin layered laminates” was not almost affected by the addition of CNF.

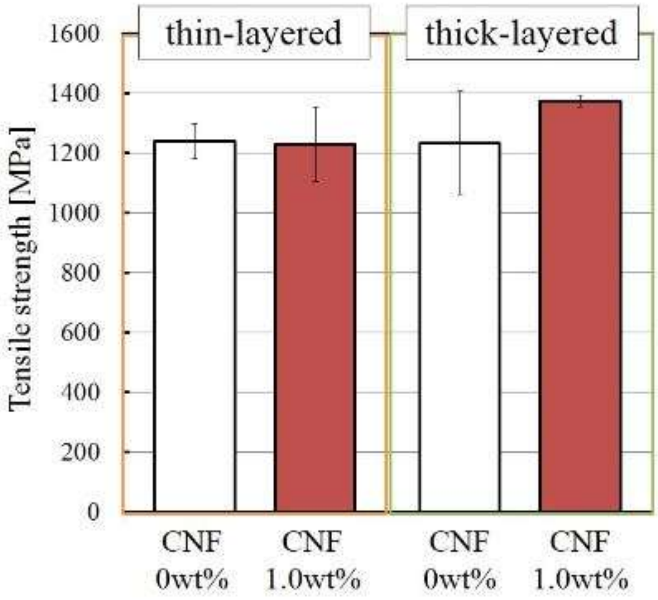

Figure 4. Tensile strengths of unmodified and modified CFRP.

3.2 Fracture appearances

Figure 5 and 6 show the SEM images of the fracture surfaces of "thin layered laminates" and "thick layered laminates", respectively. Remained resin was clearly observed on the surface of carbon fibers when the CNF was added into the matrix regardless of laminate type. However, cracks with large scales were observed at the interface between 0 and 90 degree layer in the "thin layered laminates", while they were not appeared in the "thick layered laminates" (Figure 7). These results suggested that deformations around the interface between 0 and 90 degree layer were prevented, if the composite was fabricated to be "thick layered laminates".

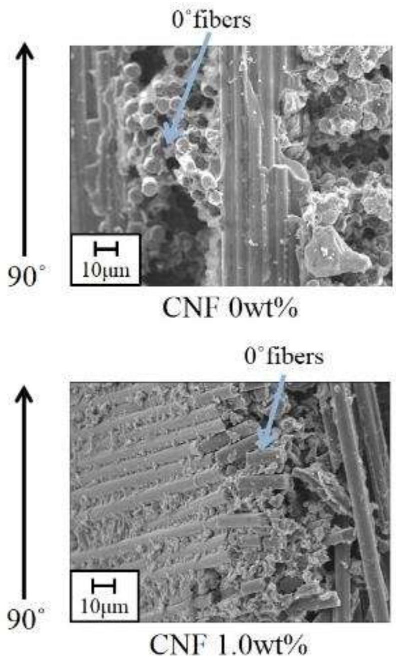

Figure 5. Examples of fractured of specimens (thin layered).

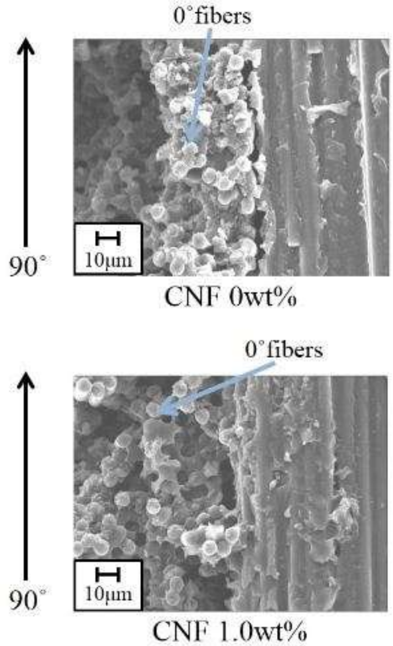

Figure 6. Examples of fractured of specimens (thick layered).

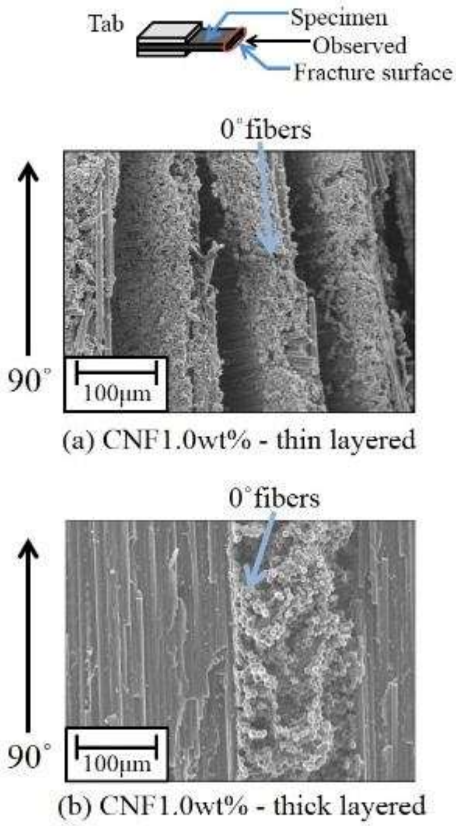

Figure 7. SEM images of fracture surface of 1.0wt% - thin layered and thick layered laminates.

Figure 8 shows the schematic views of fracture surface of unmodified and modified CFRP. The fracture surface with large cracks at the interface of orthotropic directions was observed in "thin layered laminate" when CNF was added in the matrix. In "thick layered laminate", the fracture behavior by 0 degree fiber with each layer attached was observed. It was suggested that the crack initiation observed in "thin layered laminate" was prevented because displacements around the interface between 0 and 90 degree layer were constrained in "thick layered laminate" by the addition of CNF. It was found that the application of "thick layered" sequence was effective to utilize the enhancing technique with the addition of CNF to improve the tensile strength of CFRP.

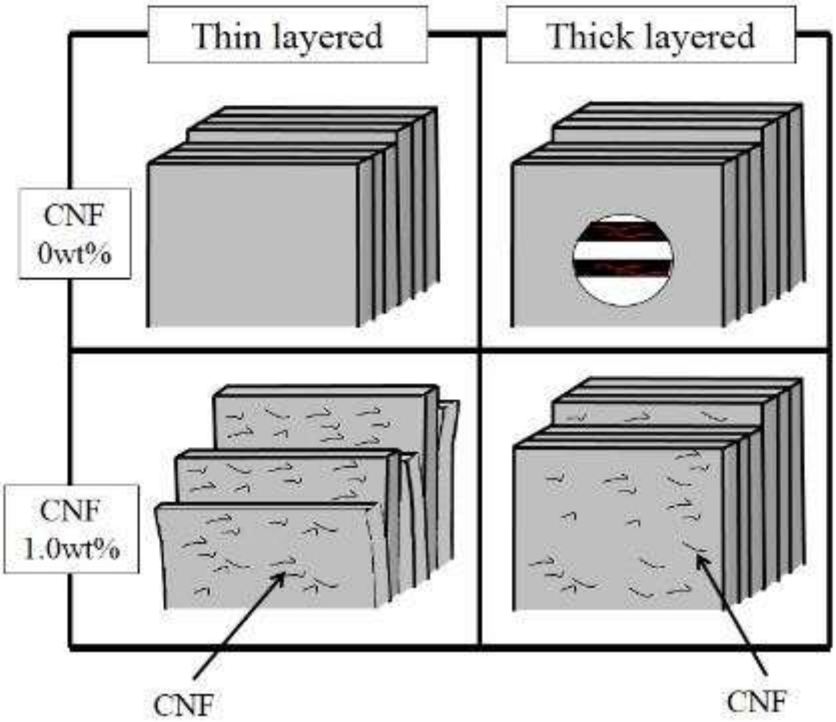

Figure 8. Schematic views of fracture surfaces of unmodified and modified CFRP.

4. Conclusions

In this study, two types of stacking sequences were applied to compare the mechanical properties of CFRP. The experimental results showed that the tensile strength of CFRP of "thick layered laminates" was improved about 10% by the addition of CNF, while the tensile strength of CFRP of "thin layered laminates" was not almost affected by the addition of CNF. It was suggested that the crack initiation observed in "thin layered laminate" was prevented because displacements around the interface between 0 and 90 degree layer were constrained in "thick layered laminate" by the addition of CNF. It was found that the application of "thick layered" sequence was effective to utilize the enhancing technique with the addition of CNF to improve the tensile strength of CFRP.

Acknowledgement

This study was supported by the Strategic reseach project on "Development of New Polymer Matrix Composites based on the Optimal Control Technique of Nano Fibers and Particles" on

Doshisha University and Ministry of Education, Culture, Sports, Science and Technology, Japan.

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