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A Study on the Interlaminar Shear Strength of Carbon Fiber Reinforced Plastics Depending on the Lamination Methods

Min Sang Lee, Hee Jae Shin, In Pyo Cha, Sun Ho Ko, Hyun Kyung Yoon, Hong Gun Kim, Lee Ku Kwac

***Abstract*—**The prepreg process among the CFRP (Carbon Fiber Reinforced Plastic) forming methods is the short term of 'Pre-impregnation', which is widely used for aerospace composites that require a high quality property such as a fiber-reinforced woven fabric, in which an epoxy hardening resin is impregnated the reality. However, that this process requires continuous researches and developments for its commercialization because the delamination characteristically develops between the layers when a great weight is loaded from outside to supplement such demerit, three lamination methods among the prepreg lamination methods of CFRP were designed to minimize the delamination between the layers due to external impacts. Further, the newly designed methods and the existing lamination methods were analyzed through a mechanical characteristic test, Interlaminar Shear Strength test. The Interlaminar Shear Strength test result confirmed that the newly proposed three lamination methods, i.e. the Roll, Half and Zigzag laminations, presented more excellent strengths compared to the conventional Ply lamination. The interlaminar shear strength in the roll method with relatively dense fiber distribution was approximately 1.75% higher than that in the existing ply lamination method, and in the half method, it was approximately 0.78% higher.

***Keywords*—**Carbon Fiber Reinforced Plastic (CFRP), Pre-Impregnation, Laminating Method, Interlaminar Shear Strength (ILSS).

I. INTRODUCTION

CARBON fiber is a high-performance material that has high tensile strength, shear strength, elasticity and thermal characteristic, and is widely used in military, shipbuilding and aeronautical sectors. Carbon fiber reinforced plastics (CFRP) is a prospective new material in the areas that require high strength and light weight, e.g., for the body of the transportation equipment, because it has good strength, fatigue-resistance and ultra-light weight [1].

M. S. Lee , H. J. Shin, and I. P. Cha are with Department of Mechanical Engineering Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju, 560-759, Korea (e-mail: lovely-lms@hanmail.net, ostrichs@naver.com, chainpyo007@nate.com, respectively).

S.H. Ko is with ITLE Co., Ltd., Research&test-Laboratory#2207, JIAT, Gunsan, 573-879, Korea (e-mail: royal2588@naver.com).

H. K. Yoon is with Department of Carbon fusion Engineering Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju, 560-759, Korea (e-mail: iylovehk@naver.com).

H. G. Kim is with Department of Mechanical and Automotive Engineering Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju, 560-759, Korea (e-mail : hkim@jj.ac.kr)

L. K. Kwac is with Department of Carbon and Nano Engineering Jeonju University, 303 Cheonjam-ro, Wansan-gu, Jeonju, 560-759, Korea (corresponding author to provide phone: +82-63-220-3063; fax: +82-63-220-2959; e-mail: kwac29@jj.ac.kr).

The fiber is considered the most important element in CFRP. It generally occupies the largest volume in a composite material; further, delivers the heaviest loads. It is, therefore, important to select proper types of the fibers, quantity, and stacking angles. Therefore, the mechanical characteristics of a fiber should be identified. As the composite material manufactured through the prepreg vacuum forming process was vacuum pressed to remove its internal fabrication and surplus plastics, a more excellent fiber volume ratio was presented compared with the hand lay-up process [2]. The material has a merit of presenting the very even quality under constant vacuum and temperature conditions; however, has a demerit of the temperature maintenance technologies and costs and the highly expensive prepreg when it is hardened. Therefore, the prepreg lamination structure is frequently applied to special fields. the lamination structure has a characteristics that its destruction develops to a kind of delamination between layers when a heavy external weight is loaded; moreover, has a demerit of more work force needed for forming and longer lamination time [3].

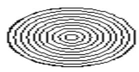
CFRP is fabricated by laminating plane carbon fibers, and the problem of delamination between the carbon fiber layers need to be improved, compared with the high mechanical strength in the direction of the carbon fiber plane [1].

In this study, three lamination methods (Roll, Half, Zigzag) were proposed instead of the existing CFRP prepreg lamination method (Ply) to supplement the aforementioned demerit and to minimize the delamination between layers affected by the external impacts. To compare the mechanical interface characteristics between the carbon fiber layers according to the lamination methods, an interlaminar shear strength (ILSS) test was conducted to determine the shear strength between the layers.

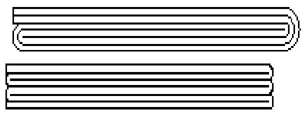
II. TEST METHOD

The CRFP composite material, in this study, was used with the WSK-3K which is a kind of woven fabric carbon fiber prepreg for the test. The CFRP prepreg lamination method stacks a sheet of prepreg at each layer. Therefore, the existing Ply lamination method was compared with the newly designed three lamination method. To compare each lamination methods, the same quantity of the prepreg was used. the newly designed lamination methods include the Roll that a prepreg was rolled up, the Half that a sheet of the prepreg is folded in half, and the Zigzag lamination that a sheet of prepreg is folded into a zigzag form. Fig. 1 shows the figures of the newly designed three lamination methods, and Tables I and II present their prepreg components and mechanical properties, respectively [3].

(a) Ply Lamination



(b) Roll Lamination



(c) Half Lamination (d) Zigzag Lamination

Fig. 1 Several types of laminating method [3]

TABLE I
COMPOSITION OF WSN3K [3]

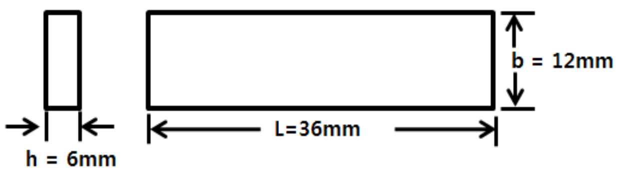
Thickness [mm]	Fiber areal Wt. [g/m2]	Resin content [%]	Total Wt. [g/m2]
0.227	240	41	336

TABLE II
MECHANICAL PROPERTIES OF WOVEN FABRIC CFRP [3]

Tensile strength [kgf/mm^2]	Tensile modulus [kgf/ mm^2]	Fiber density [g/cm^2]	Resin density [g/cm^2]
450	24×10^3	1.77	1.2

For the Interlaminar Shear Strength (ILSS) test, each three specimens were manufactured for the tensile test specimens were manufactured by the Ply, Roll and Half lamination methods. Each lamination method was used with the same prepregs size, and the Interlaminar Shear Strength (ILSS) test specimens were manufactured in accordance with ASTM D-2344 [4]. Both ends of the test specimen were simply supported, and a load was applied with a crosshead in the center of the specimen to produce the maximum shear stress. The ILSS was calculated using the following (1) [4]. F is Shor-beam strength [MPa] and P is maximum load observed during the test [N], b is measure specimen width [mm], h is measure specimen thickness. Specimen span distance is 24mm and crosshead speed is 1mm/min. Fig. 2 shows Sketch of ILSS test specimen and the appearances of the completed specimens test. Fig. 3 shows the construction of the test equipment.

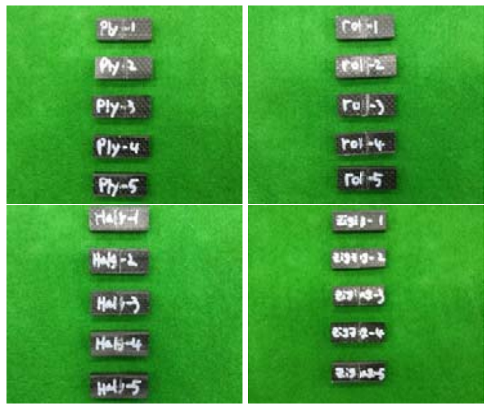
$$F = 0.75 \times \frac{P}{b \times h} \quad (1)$$



(a) Sketch of specimen

III. RESULT

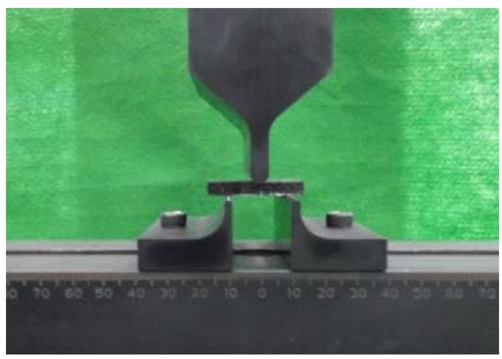
The Interlaminar Shear Strength (ILSS) test were conducted to compare the newly proposed Roll, Half and Zigzag lamination methods with the conventional lamination Ply method; and each lamination method was used with five specimens [5]. Fig. 4 shows the graphs of the ILSS test results of each lamination method, and Fig. 5 shows the Average graph from Interlaminar shear strength test Table III presents the values of the results in a comparison.



(b) ILSS Specimen

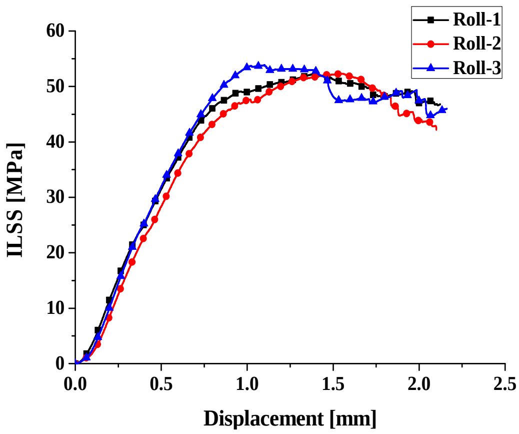
Fig. 2 ILSS Test specimen of CFRP

(a) Full Shot of the ILSS Test

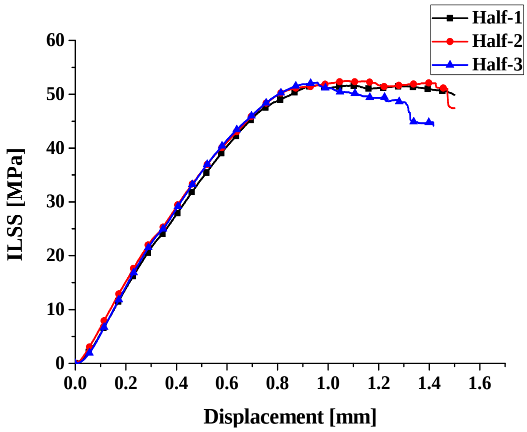


(b) Close up of the ILSS Test

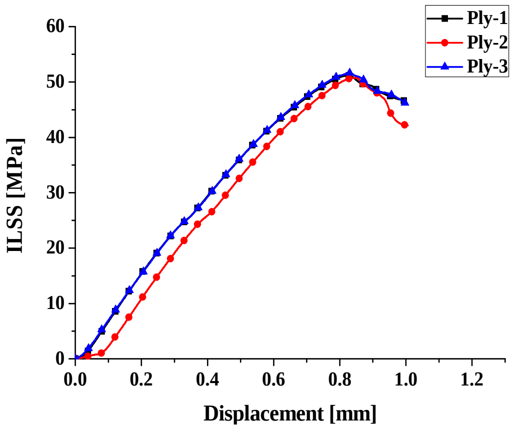
Fig. 3 Experiment System for ILSS Test



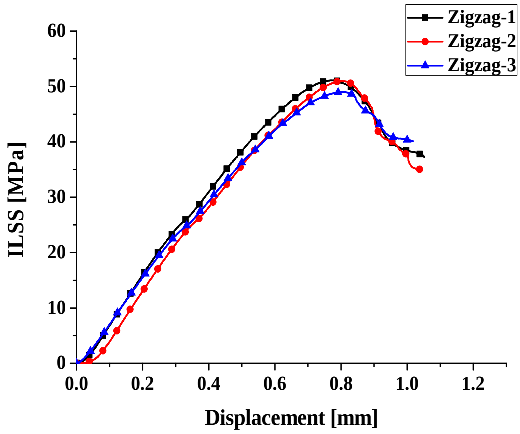
(a) Roll Lamination Mehtod



(b) Half Lamination Method



(c) Ply Lamination Method



(d) Zigzag Lamination Method

Fig. 4 Results Obtained from Interlaminar Shear Strength Test

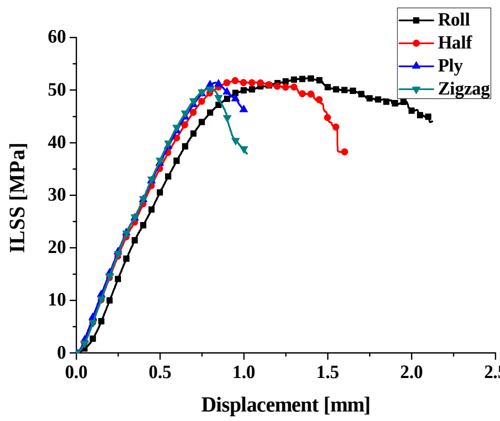


Fig. 5 Average graph from Interlaminar shear strength test

TABLE III
NUMBER OF LAYERS OF EACH SPECIMEN

Lamination method	Max ILSS [MPa]	Strain [mm/mm] at max ILSS
Roll	52.3	1.34
Half	51.8	0.96
Ply	51.4	0.81
Zigzag	50.3	0.79

The interlaminar shear strength was highest in the roll method, followed by half, ply and zigzag method, in that order. At the highest interlaminar shear strength, the deformation was also highest in the roll method, followed by half, ply and zigzag method, in that order. It seems that the fibers in the plane direction and those for axial support were distributed more in the roll and half methods than in the ply and zigzag methods, and thus, the interlaminar bonding force was lower in the latter methods. Under the maximum load, the ply and zigzag methods showed an abrupt decrease in the stress and the resulting rupture, whereas the roll and half methods had 50% or more deformation and were maintained.

IV. CONCLUSION

In this study, to reduce the demerits of the forming methods using the prepreg laminations among CFRP composite materials, four different lamination methods were proposed to analyze their mechanical interface characteristics through the Interlaminar Shear Strength test. as the result of the test, the following conclusion was obtained.

(1) The Interlaminar Shear Strength test result confirmed that the newly proposed three lamination methods, i.e. the Roll, Half and Zigzag laminations, presented more excellent strengths compared to the conventional Ply lamination. The interlaminar shear strength in the roll method with relatively dense fiber distribution was approximately 1.75% higher than that in the existing ply lamination method, and in the half method, it was approximately 0.78% higher. In addition, it was seemingly a lamination method for structures that need interlaminar bonding force because there was an interval of deformation with the maximum interlaminar shear strength maintained.

(2) The zigzag lamination method had a lower stress than that in the ply lamination method because the zigzag lamination had voids at both ends of the lamination and insufficient fiber in the load direction, and also had fewer horizontal fibers than those in the ply lamination method, which resulted in a lower interlaminar shear strength.

Acknowledgment

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