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# Analysis of Bending characteristics of Autoclave Forming CFRP Structural Members

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## Abstract

우주선, 항공기, 수송차량 등은 기능은 집적·다양화 그리고 성능의 고도와 됨에 따라 에너지 효율성을 위해 구조부재의 경량화가 중요성은 증가되고 있다. 경량화 구조부재 재료 중에는 알루미늄 합금, 세라믹, 복합재료 등이 개발되어 우주선, 항공기, 수송차량 구조부재에 적용하기 위한 많은 연구가 이루어지고 있다. 이들 중, 20세기 초 알루미늄합금이 초 경량화 구조부재로서 많이 이용되었다. 본 논문에서는 경량화 재료 중 이방성을 가지는 복합재료를 구조부재에 적용하였다. 그러나 구조부재에 적용되기 위한 이방성 복합 재료는 강한 충격 이후 취성의 특징 때문에 하중과 흡수에너지가 급속히 감소하는 단점을 가지고 있다. 그래서 이방성 복합재료의 각 층간을 완전히 접합하여 성질이 매우 우수한 부재를 제작할 수 있는 Autoclave 성형법으로 제작하였다. 이방성 복합재료 중 CFRP를 설계 메커니즘 변수에 따라 Autoclave 성형을 하고 하중과 흡수에너지가 높음 평가하기 위해 굽힘실험을 하였다.

**Key words** : Light-Weight, Carbon Fiber Reinforced Plastics, Load, Absorbed Energy, Bending Test.

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## 1. Introduction

It is light weight of member structures that is definitively necessary for the high performance and various integrated functions for automobile, railroad, and airplane. Responding to this requirement for light weight, the use of light weight materials such as aluminum alloy, plastic and composite is increasingly developing and researching. Together with this, the demands for high performance composite materials are gradually increased and researches on this are also actively carried out. Composite materials of anisotropy have high strength in comparison with the weight, elasticity coefficient, and lower thermal transformation and therefore, they are broadly used in space and aviation industry, sport and leisure industry, and general structure members including parts. However, it is the reality that these materials are not used as primary structural members of working much load in airplane or spaceships due to short history of composite materials and lack of general consciousness and reliability. Therefore, autoclave molding is used among various molding methods as its quality is generally considered as excellent. Autoclave molding is complex in its process and requires lots of supplementary materials and has disadvantages of

longer time of process and manufacturing as well as expensive price of equipments but also has advantages of elimination of volatilization generated from resin and complete adhesion between layers of each prepreg since it can maintain vacuum inside as providing pressure from outside of vacuum pack and therefore, it is possible to manufacture very excellent members. As one of composite materials, rectangular beam shape members of CFRP were molded by autoclave. CFRP is changed characteristic of mechanism on design mechanism of thickness, stacking sequence, stacking angle, ect. It had carried out much research about thickness and stacking sequence. On this study it is manufactured square member according to change stacking angle and put to the bending test. I analyze load-displacement graph obtained after bending test.

## 2. Test method

### 2.1 Specimen

In order to manufacture rectangular beam shape CFRP member mandrel and jig with soft machining were manufactured. After panting lubricant on mandrel, like Fig. 1, release film was wrapped 2~3 plies and carbon/epoxy one-direction carbon fiber prepreg sheet (HANKUK

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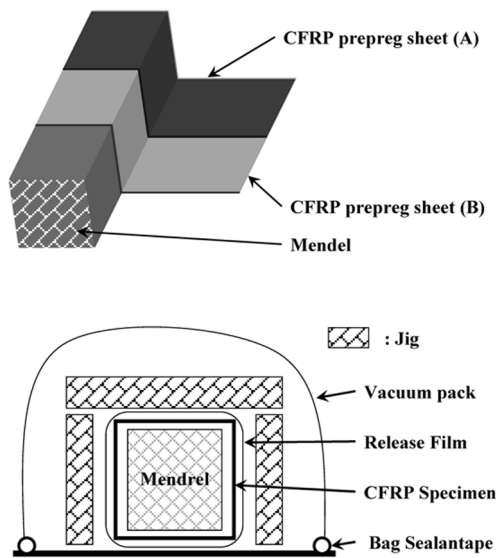


Fig. 1. Schematic view of fabrication.

Table 1. Characteristics of CFRP prepreg sheet.

Characteristics	Types	Fiber (Carbon)	Resin (Epoxy #2500)	Prepreg sheet (CU125NS)
Density [kg/m]		1.83	1.24	-
Tensile strength [GPa]		4.89	0.08	2.53
Elastic Modulus [GPa]		240	3.6	138
Breaking Elingation [%]		2.1	3	1.7
Poissons ratio		-	-	0.3
REsin Content		-	-	37 [% Wt]
Curing temperature [°C]		-	130	130

Carbon, CU125NS, Carbon Fiber uni-direction 125g/m<sup>2</sup> stacked in 8 plies. Properties of CFRP are like Table 1. It was stacked by providing proper pressure so that it was well adhered without generating air pore between prepreg sheet and prepreg sheet. And it was put a few jigs around specimen for making rectangular tube shape. It was molded by vacuum compression at autoclave using jig so that it is molded in rectangular beam shape. As one of anisotropy materials, CFRP has very different hardness and strength according to the changes of the stacking orientation angles of fibers due to differences of properties of fiber and base material.

That is, mechanical properties change significantly according to the changes of stacking orientation angles. Each 3 of 6 different kinds were manufactured by changing stacking orientation angles. Kinds according to stacking orientation angles are [+0/-0]<sub>4</sub>, [+15/-15]<sub>4</sub>, [+45/-45]<sub>4</sub>, [+90/-90]<sub>4</sub>, [90/0]<sub>4</sub>, and [0/90]<sub>4</sub>. Stacking angle is based on the direction of length of member. In case of [A/B]<sub>4</sub>, stacking order was A, B, A, B, A, B, A, and B. Length of

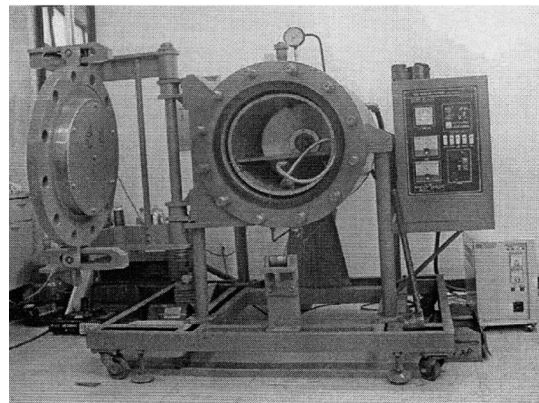


Fig. 2. Autoclave.

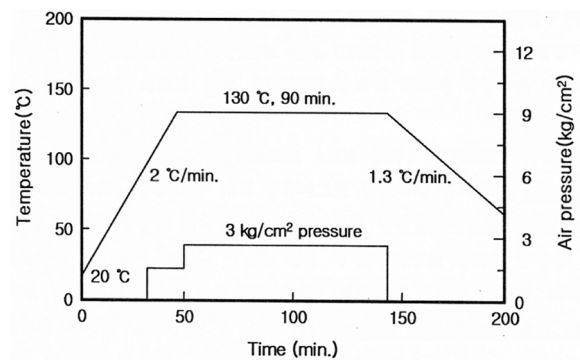


Fig. 3. Curing cycle of CFRP specimen.

member was determined as 495 mm according to ASTM standards [3]. Both ends were cut using diamond cutter so that residual stress does not produced after manufacturing.

## 2.2 Autoclave

In Fig. 2 is an actual feature of autoclave used in this study. Autoclave has installed a fan in rear wall of the inside in order to circulate air inside of the container by force. In general, a motor is installed at the autoclave to rotate this fan and axis of the fan is rotated. In this case, vicinity of rotating axis of the fan must be sealed completely so that internal pressure does not escape. This method is very complex and also has problems of maintenance and repair due to wear and tear. The autoclave used in this study has installed the fan motor inside the chamber of the autoclave to solve this issue and have solved the issue of sealing the axis of fan by circulating water around the motor.

Inside of the autoclave, indirect heating method that heater provides heats by surrounding inside of the chamber was used so that heat is delivered mainly by the current of air and the air was circulated by force using a fan in order to maintain the even inside temperature.

During manufacturing by the autoclave, the hardening conditions were set up as the hardening temperature of 130°C, the hardening time 90 minute, and the vacuum pressure of  $10^{-1}$  Pa. It was also compressed up to  $3 \times 10^5$  Pa from the outside of the vacuum bag. Fig. 3 shows curing cycle of CFRP specimen

### 2.2 Three points bending test

In carrying out bending test of composite materials, three point bending test method is simple and easy and used broadly. In this study, like Fig. 4, load nose device and supports device of three point bending test machine was manufactured according to ASTM standards that a semi circle shape with a radius of 10mm. Load nose device was located in the center of member and the distance of supports device was 225 mm.

Load nose device and supports device were installed between load cell and actuator of UTM machine. And then, members were place on top of supports device and bending test was conducted by moving load nose device into the direction of load at the speed of 10mm/min. Displacement was controlled up to 50mm. Load-displacement curve measured after bending test was integrated to obtain the amount of energy absorbed of members like a equation (1)

$$E_a = \int_0^S P ds \quad (1)$$

In here,  $E_a$  is absorption energy,  $P$  is bending load, and  $S$  is compressed length of specimen.

### 3. Result and Discussion

Fig. 5 shows load-displacement curve graph of  $[90/0]_4$  and  $[+15/-15]_4$  members after bending test.  $[+15/-15]_4$  member is lower maximum load than  $[90/0]_4$  member but  $[+15/-15]_4$  member is showed the drawing moderate curve more than  $[90/0]_4$  after maximum load point. It is noticed

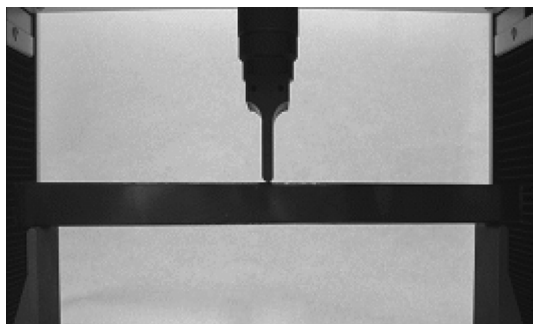


Fig. 4. Three point bending test.

that  $[+15/-15]_4$  member have significantly higher average load and absorption energy than  $[90/0]_4$  member whose load is rapidly lowered after the maximum load point.

In the maximum load,  $[90/0]_4$  member is higher than  $[0/90]_4$  member (show Fig. 6). When comparing  $[90/0]_4$  member with outer layer of  $0^\circ$  and  $[0/90]_4$  member with outer layer of  $90^\circ$ , it was noticed that they were almost same on standard deviation.  $[+45/-45]_4$  member is second. It is noticed members like woven fabric were higher than.

In the mean load,  $[+15/-15]_4$  is highest. The next thing is  $[+45/-45]_4$  and  $[+90/-90]_4$ . It is decreased as stacking angle increased from  $15^\circ$  to  $90^\circ$ . Each member produced different elastic deformation as fiber breakage, delamination, fiber-matrix debonding and matrix cracking. In the  $15^\circ$  member, it has happen several mechanisms (fiber breakage, delamination, fiber-matrix debonding and matrix cracking) but it has not happen few mechanisms as fiber breakage and fiber-matrix debonding from close  $90^\circ$ .  $[90/0]_4$  member is higher than  $[0/90]_4$  member and it was noticed that they were almost same on standard deviation too. In the absorbed energy, it is same with mean load result.

If Stacking angle is  $0^\circ$ , it is lower than  $15^\circ$  member on test result. Because  $0^\circ$  members was produced just fiber

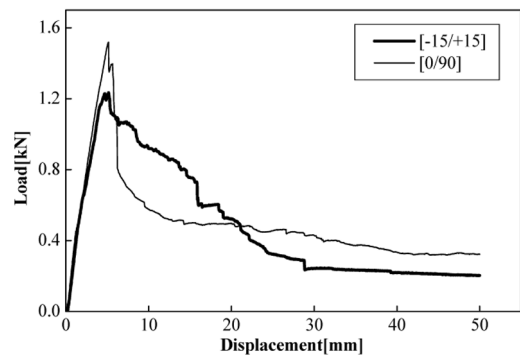


Fig. 5. Load and Displacement curve of  $[0/90]_4$  and  $[+15/-15]_4$ .

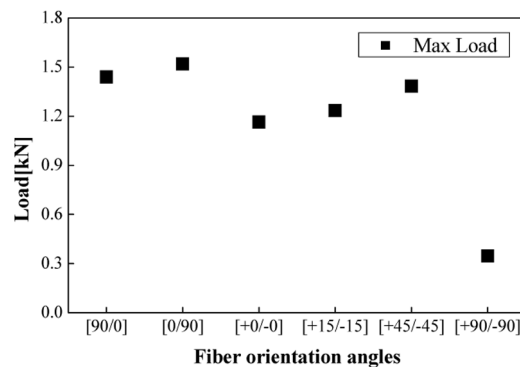


Fig. 6. Max Load under bending load with change of the fiber orientation angles.

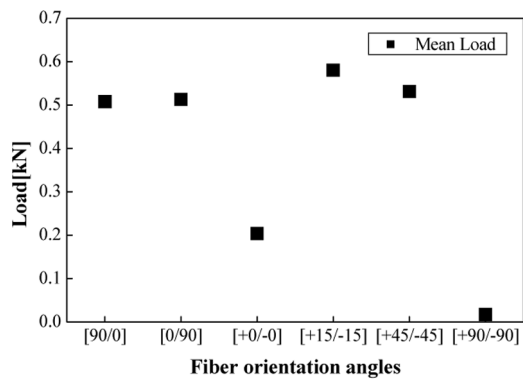


Fig. 7. Mean Load under bending load with change of the fiber orientation angles.

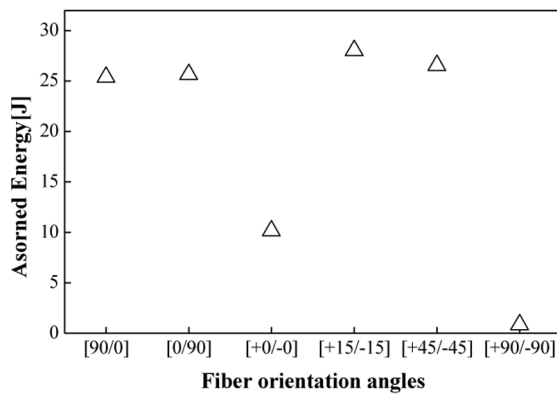


Fig. 8. Absorbed Energy under bending load with change of the fiber orientation angles

breakage in the side and matrix breakage in upper and lower surface.

When it compare with maximum and average load & absorption energy, there was no special trend.

#### 4. Conclusion

CFRP, which is a popular light weight material, could be molded by autoclave molding and indicated the characteristics of bending of this rectangular CFRP member as follows according to the stacking angle.

(1) [+15/-15]<sub>4</sub> member have significantly higher average load and absorption energy than [90/0]<sub>4</sub> member whose

load is rapidly lowered after the maximum load point due to the drawing moderate curve more than [90/0]<sub>4</sub> after maximum load point..

(2) In the maximum load, Good members are [90/0]<sub>4</sub> and [0/90]<sub>4</sub> like as woven fabric. If you want high strength CFRP member, recommend the member like woven fabric

(3) [+15/-15]<sub>4</sub> member that happened several mechanisms (fiber breakage, delamination, fiber-matrix debonding and matrix cracking) is highest in average load and absorbed energy result. When someone need more light-weight, lower brittleness (high absorbed energy) using CFRP composite, recommend method that CFRP square member stack ± 15° and manufacture by autoclave.

In the mean load, It is decreased as stacking angle increased from 15° to 90°. It happen matrix breakage without fiber breakage and fiber-matrix debonding from close 90°.

In case of stacking angle is 0°, it is lower than 15° member on test result. Because 0° members was produced just fiber breakage in the side and matrix breakage in upper and lower surface.

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