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A Study on the Analysis of Bending Strength of Carbon Composite Skin Using Wire Mesh

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Abstract: *Composite materials with advantage of high strength, rigidity, corrosion resistance than a normal metal material are widely used in applications such aerospace, automotive, marine requiring safety and weight reduction by continuous research and development, especially large in electromagnetic shielding areas spotlighted. In conventional electromagnetic shielding areas, where metal materials are mainly used, polymers and composite materials are drawing attention as a substitute material for it. Composites mechanical properties are changed in accordance with the stacked alignment angle, the number of stacked layers and the layered material. By laminating the carbon fiber pre-preg and the Wire Mesh the test specimens were created. The bending tests were performed and by using an S-S Curve the bending strength and bending stiffness were analyzed.*

Keywords : *autoclave molding, bending test, carbon fiber reinforced plastic, wire mesh*

I. Introduction

Carbon fiber reinforced plastic (CFRP) is advantageous in strength, rigidity and anti-corrosion characteristics compared with metal materials, and has excellent mechanical characteristics for diverse types of loads. Accordingly, it is widely used for aviation, automotive and marine industries, resulting in active studies and also a lower price suitable for its application to diverse sectors. In addition, it is also used as a shielding material against the electromagnetic wave emitted from electric and electronic appliances which are in increasing demand [1]. In the application of CFRP, the rigidity and strength characteristics can be controlled by direction of material, manufacturing method and lamination thickness according to the required structure. In composite materials, the properties of fiber and matrix material differ, and it is very important to determine the rigidity characteristics. However, it is determined by test because it is not easily calculated with theoretical equations [2]. In this paper, the metal wire mesh was used to make test specimens according to the number of lattices and lamination sheets, and the bending strength was tested to ensure the reliability of the mechanical properties. Thus, the use of composite material was examined for the applications in the shielding material industry, which mostly uses metal materials, and other diverse sectors [3,4]. CF-(Number1) and SUS(Number2)-(Number3) in this paper are abbreviations. CF represents CFRP 3K prepreg; Number1, the number of its lamination layers; SUS, the STS304 wire mesh; Number2, the number of lattices of STS304 wire mesh, and Number3, the number of its lamination layers.

II. Theoretical Background

2.1 CFRP(Carbon Fiber Reinforced Plastics)

High strength, high elastic composite materials with carbon fiber as reinforcement are generally called CFRP. It has excellent characteristics as structural material. It is known that its specific strength is six times that of steel, and its specific modulus is three times that of steel [5]. It is divided into thermosetting and thermoplastic material according to the injected resin, and has diverse characteristics according to its types.

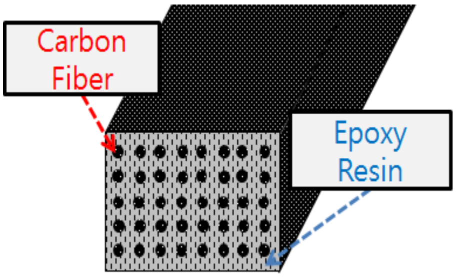


Figure 1.Schematic of carbon composites

2.2 Autoclave molding process

There are many forming method for CFRP. In the autoclave forming method, vacuum-bag forming and additional external pressure are simultaneously applied to improve the forming characteristic of the composite material. Figs. 2 and 3 show the autoclave forming device and its working principle [6].

Figure 2.Autoclave molding press machine

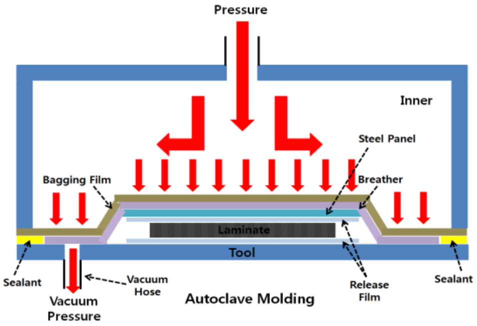


Figure 3. Schematic of autoclave molding press machine

III. Mechanical Strength Test

3.1 Manufacturing of specimen

In this study, CFRP and wire mesh hybrid lamination material was fabricated, with the textile plain carbon fiber prepreg from SK Chemical used as CFRP. Table 1 shows the properties of the material [7].

Table1 Physical properties of carbon 3K prepreg

Physical Properties
- Prepreg Type : Woven fabric- Fiber Areal Weight : 203g/m^2 - Weave Style : Plain - Resin Content : 40% - Weave Density[WARF/FILL] : 12.5/13.5 - Fiber Volume : 50.1% -Thickness : 0.277mm- Total Weight : 336 g/m^2

The metal wire mesh was made of STS304 in 200 mesh/inch and 400 mesh/inch lattice specifications. They had 0.05 mm and 0.03 mm wire mesh diameters, respectively. Tables 2 and 3 show the detailed properties and chemical compositions (%, Max).

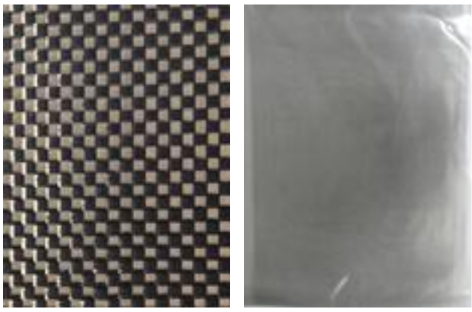


Figure 4.Carbon fiber 3K prepreg and STS304 wire mesh

Table2 Physical and mechanical properties of STS 304

Physical Properties
- Specific Gravity : 7.93g/cm^2 - Resistivity : 72μΩ·cm - Thermal Conductivity : 16.3W/m·K (standard 100℃)
Mechanical Properties
-Yield Strength : 21kg·mm^2 - Tensile Strength : 53kg·mm^2 - Elongation : 40% - Hardness : 170~410hv

Table3 Chemical composition of STS 304(%, Max)

C	Si	Mn	P	S	Cr	Ni
≤0.08	≤1.00	≤2.00	≤0.040	≤0.030	18.00~ 20.00	8.00~ 10.50

The materials were used to fabricate hybrid test specimens. According to the number of wire mesh lattices, five test specimens were fabricated as shown in Fig. 5.

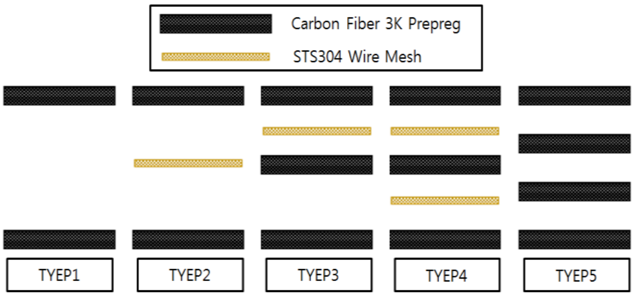


Figure 5.Laminating method

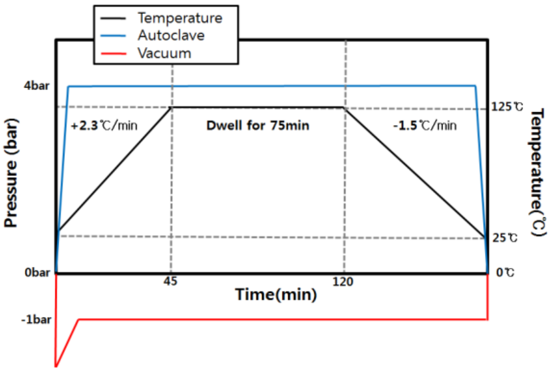


Figure 6. Autoclave molding cycle

The aforementioned autoclave forming was used to fabricate the test specimens, with approximately 75 min curing time at 125℃. The vacuum pressure was –1 bar, and the autoclave pressure was 4 bar. Fig. 6 shows the forming cycle. The fabricated test specimen sheet was processed according to ASTM D 790 to make bending test specimens. The length was 50.8 mm and the width was 12.7 mm, which were below 1.6T according to the specification. Fig. 7 shows the shape of the specimen [8].

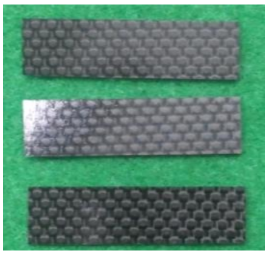


Figure 7. Test specimen product on ASTM D 790

3.2 Flexible testing

The elastic analysis of bending strain can be conducted in many ways. The elastic theory solution is used when 5% or higher accuracy is required, and the simple beam theory is used when plate streams, bars and poles are bent in three- or four-point bending types [9,10].The measurement for the bending test was conducted using the universal material tester ST1001 (Salt, South Korea), as shown in Fig. 8. The head speed was analyzed using Equation 1, the bending strength, using Equation 2, and the bending strain, using Equation 3 [11,12].

$$R = ZL^2 \tag{1}$$

where :
R = rate of cross head motion, mm/min
L = span, mm
D = depth of beam, mm
Z = rate of straining of the outer fiber, mm/mm/min

$$\sigma = 3PL/2bd^2 \quad (2)$$

where :
σ = stress in the outer fibers at midpoint, MPa
P = load at a give point on the load-deflection curve, N
L = support span, mm
b = width of beam tested, mm
d = depth of beam tested, mm

$$\varepsilon = 6Dd/L^2 \quad (3)$$

where :
ε = strain in the outer surface, mm/mm
D = maximum defection of the center of the beam, mm
L = support span, mm
d = depth of beam tested, mm

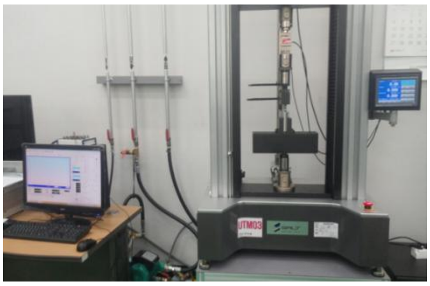
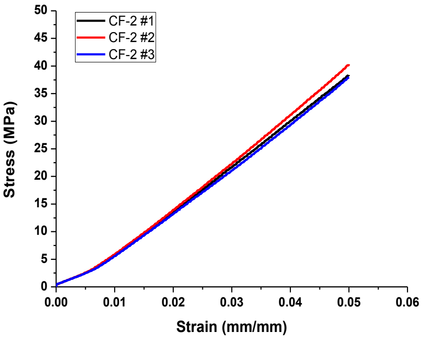


Figure 8. Flexible testing machine

IV. Results and Discussion

The eight test specimens, which were fabricated by laminating CFRP 3K prepreg and STS 304 wire meshes,were analyzed about the bending strength characteristic within a 0.5 mm/mm strain according to the specification.In the case with CF-2, which had CFRP lamination only, the bending strength was 33.99 MPa, and the elastic modulus was 0.86 GPa. When 1-ply SUS200 and SUS400 were added, the bending strength was 76.68 MPa and 61.87 MPa, respectively, and the elastic modulus was 1.52 GPa and 1.21 GPa, respectively.



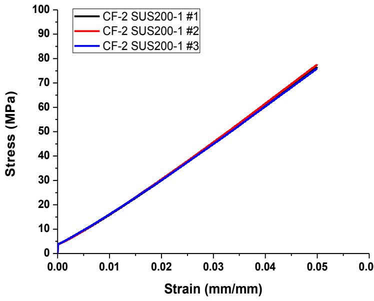


Figure9. Stress-strain curve(CF-2)Figure 10. Stress-strain curve(CF-2 SUS200-1)

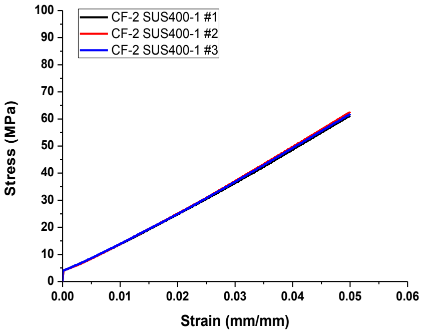
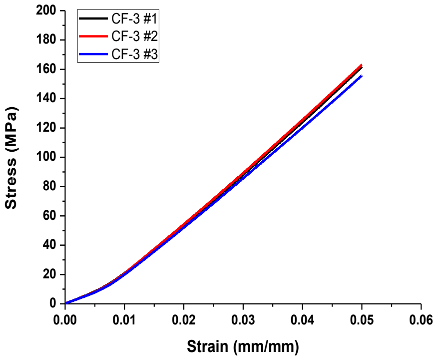


Figure11.Stress-strain curve(CF-2 SUS200-1)

Table4 Mechanical property measurement results of a average value (CF-2, CF-3, CF-2 SUS200-1, CF-2 SUS400-1)

Type	Average Flexible Strength(MPa)	Average Tangent Modulus of Elasticity(GPa)
CF-2	38.88	0.86
CF-2 SUS200-1	76.68	1.52
CF-2 SUS400-1	61.87	1.21
CF-3	160.21	3.49

In the case with CF-2 SUS200-1 test specimen, the strength and elastic modulus were 37.8 MPa and 0.66 GPa higher than those of CF-2, respectively. In the case with CF-2 SUS400-1 test specimen, the strength and elastic modulus were 22.99 MPa and 0.35 GPa higher than those of CF-2, respectively. Thus, SUS 200 lamination resulted in a 15 MPa strength increase and a 0.31 GPa elastic modulus increase compared with SUS 400 lamination. In addition, the wire mesh insertion resulted in a decrease in the strength and rigidity compared with CF-3. However, the strength and rigidity were deemed to be relatively high, considering the 0.2T thickness increase by 1-ply CF lamination and 0.02T thickness increase by wire mesh lamination. The resulting data from all test specimens were linear after 0.05 mm/mm, and the error range among the data was high at about 5%.



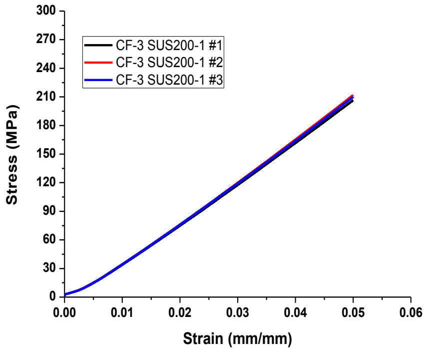
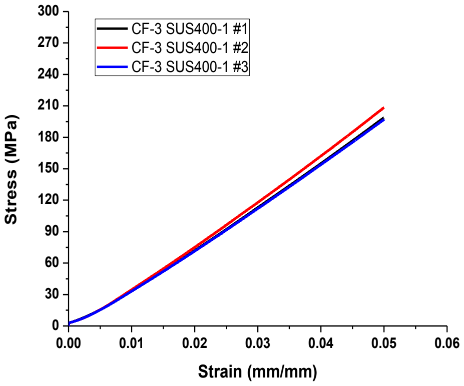


Figure 12. Stress-straincurve(CF-3)Figure 13. Stress-strain curve(CF-3 SUS200-1)



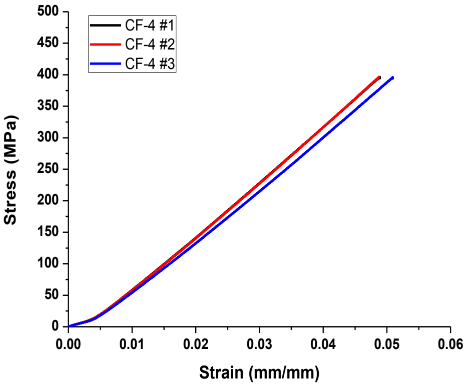
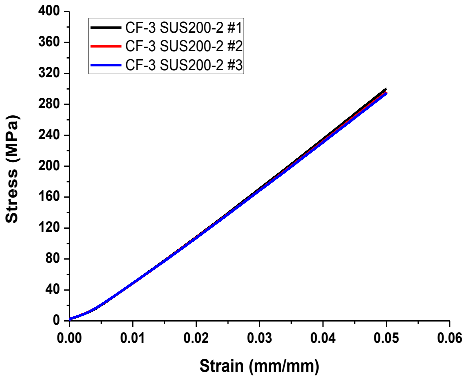


Figure 14. Stress-straincurve(CF-3 SUS400-1)Figure 15. Stress-strain curve(CF-4)

Table5 Mechanical property measurement results of a average value (CF-3, CF-4, CF-3 SUS200-1, CF-3 SUS400-1)

Type	Average Flexible Strength(MPa)	Average Tangent Modulus of Elasticity(GPa)
CF-3	160.21	3.49
CF-3 SUS200-1	209.33	4.39
CF-3 SUS400-1	201.31	4.2
CF-4	396.42	8.61

When 1-ply SUS200 and SUS400 were laminated on CF-3, the bending strength was 209.33 MPa and 201.31 MPa, respectively, and the elastic modulus was 4.39 GPa and 4.2 GPa, respectively.In the case with CF-3 SUS200-1 test specimen, the strength and elastic modulus were 49.12 MPa and 0.9 GPa higher than those of CF-3, respectively. In the case with CF-3 SUS400-1 test specimen, the strength and elastic modulus were 41.1 MPa and 0.71 GPa higher than those of CF-3, respectively. Thus, SUS 200 lamination resulted in an 8 MPa strength increase and a 0.19 GPa elastic modulus increase compared with SUS 400 lamination.Wire mesh resulted in a lower strength and rigidity than in the case with CF-4, but considering the thickness in the same way as in the previous result data, it was deemed to have a high strength and rigidity increase.As in the previous results, the resulting data from all test specimens were linear after 0.05 mm/mm, and the error range among the data was high at about 5%.



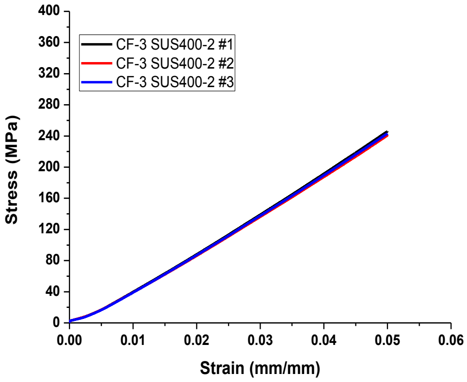


Figure 16. Stress-strain curve(CF-4 SUS200-1) **Figure 17.** Stress-strain curve(CF-4 SUS200-1)

Table6 Mechanical property measurement results of a average value (CF-3, CF-4, CF-3 SUS200-2, CF-3 SUS400-2)

Type	Average Flexible Strength(MPa)	Average Tangent Modulus of Elasticity(GPa)
CF-3	160.21	3.49
CF-3 SUS200-1	209.33	4.39
CF-3 SUS400-1	201.31	4.2
CF-4	396.42	8.61

When 2-ply SUS200 and SUS400 were laminated on CF-3, the bending strength was 296.77 MPa and 243.41 MPa, respectively, and the elastic modulus was 6.22 GPa and 5.11 GPa, respectively.In the case with CF-3 SUS200-2 test specimen, the strength and elastic modulus were 136.56 MPa and 2.73 GPa higher than those of CF-3, respectively. In the case with CF-3 SUS400-2 test specimen, the strength and elastic modulus were 83.2 MPa and 1.62 GPa higher than those of CF-3, respectively. Thus, SUS 200 lamination resulted in a 53 MPa strength increase and a 1.11 GPa elastic modulus increase compared with SUS 400 lamination. Wire mesh resulted in a lower strength and rigidity than CF-4, but it was deemed to have a higher strength and rigidity increase compared with the 1-ply wire mesh lamination test specimen. Thus, a thicker test specimen resulted in a higher strength and rigidity, which was seemingly because the S-S curve abruptly rose by the cross head contact on the low-ductility material.

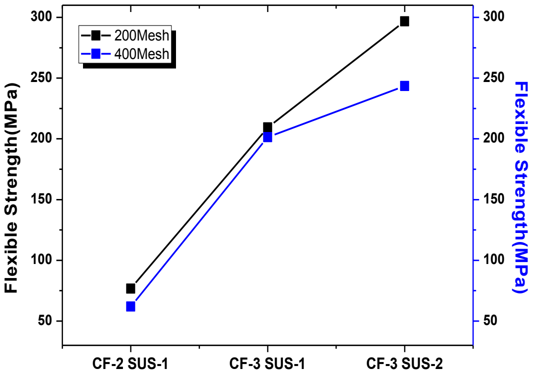


Figure 18. Comparison graph of the average value of the strength

As shown in Fig. 18, the 200 mesh resulted in higher bending strength and elastic modulus than those of 400 mesh.This was because of the mesh diameter size. The 200 mesh lattice test specimen with a relatively large pores helped resin impregnation during the forming process and improved the bonding force between layers, leading to the improvement in mechanical strength.

V. Conclusion

A In this study, hybrid composite material test specimens were fabricated with CFRP 3K prepreg, STS 304 wire mesh 200 and wire mesh 400 for bending tests. The characteristics and tendencies were examined by type for the mechanical evaluation of the material as the electromagnetic wave shielding skin material.All test specimens showed linear strength increase in the S-S curve regardless of the number of lamination sheets, and the elastic modulus also increased in proportion to it. This is a clear result of the accuracy in the test specimen fabrication process and the increase in the thickness.In addition, the 200 mesh test specimen had a higher strength and rigidity than the 400 mesh test specimen, which was seemingly because a larger pores in the wire mesh helped the resin impregnation during the forming process, and it resulted in an increase in the bonding force between layers. 1-ply wire mesh test specimens had a lower increase in the bending strength and rigidity than CFRP, but it seems that it has a sufficient competitive power as the skin material, considering the relative thickness and weight ratio. The electromagnetic wave shielding effect of the material has already been proven in the previous study, and it is expected to be an appropriate material for actual application considering its cost.

Acknowledgements

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