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A Study on Fracture Behavior Affected by Mechanical Clamping Pressure at CFRP Panel with Laminate Angle through Analytical Investigation

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Abstract

Objectives: The adhesive is used at CFRP (Carbon Fiber Reinforced Polymer) composite with the bolt joint method now. This study aims at settling the fracture property due to the clamping pressure about laminate angle. **Methods/Statistical Analysis:** As an analytical study, this paper investigates the fracture behavior of a panel stacked at 30, 45, 60 and 75 when the clamping pressure caused by mechanical fastening is applied to a CFRP panel stacked at 5mm with a laminate angle. Through this study, the fracture property happened at the panel composed of CFRP is investigated through the analytical method prior to the experiment. **Findings:** As the fracture characteristics of the CFRP panel with laminate angles, the highest stress value was demonstrated at a laminate degree of 30 and the lowest at 60 based on the analytical result. By examining together with the result related to deformation energy, the differences of a maximum of 52% in stress value and 71% for deformation energy were seen. Through the result of this study, it is shown that the material property still higher is kept at the applied clamping pressure in case of the laminate angle of 60. Based on the analysis result of this paper, even if the same carbon fiber is used at the laminate angle of 60°, the mechanical property of the material can be enhanced through the application of laminate angles. The data of structural safety as optimal design can be secured at the stacking of composites with the applied clamping pressure. **Improvements/Applications:** The result of this study is expected to be enhanced and to be contributed to the evaluation through the data on durability and safety with regard to the fractures.

Keywords: Carbon Fiber Reinforced Plastic, Clamping Pressure, Fracture Property, Laminate Angle, Mechanical Clamping

1. Introduction

In modern industry, the advent of CFRP (Carbon Fiber Reinforced Plastic) is considered to have contributed significantly to replacing existing metal materials with reinforced plastic. Equipped with high-intensity and hardness as well as outstanding fatigue attenuation properties when compared to metal, it has been receiving the limelight in industries that require lightweight materials[1–3]. The studies on CFRP are concentrated on enhancing the property of material. However, such studies related to applying the structural stability are insufficient. Moreover, the chemical adhesion method using adhesives which have only been applied recently to structures with CFRP is being recommended but the existing mechanical clamping method is still widely used. With regard to fiber reinforced plastic, the mechanical clamping method may cause

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the fracture due to the clamping pressure. This phenomenon is due to the brittleness of plastic which is different from metal materials. As it is not ductile, leading to fatigue fracture in terms of yield strength[4–8]. Furthermore, unlike metal materials in which the extensive fracture characteristics have been established for a long period of time, the studies on fiber reinforced plastic such as CFRP are usually focused on the improvement of mechanical property of materials up until now. But there were a lot of difficulties in studying the fracture characteristics of fiber reinforced plastic since it was comprised of a stacking structure between fibers, making it more complex compared to metal materials and also because it was affected by various environmental variables. In this paper, through an analytical study of fiber reinforced plastic using ANSYS analysis program, the fracture characteristics which might occur were analyzed prior to the actual experiment in order to analyze the effects of the mechanical clamping method depending on each laminate angle. Through this study, the fracture characteristics which may occur were analyzed prior to the actual experiment and it can be assumed that such analysis could be utilized as basic information which could contribute to the safe design of the CFRP structure based on the analysis.

2. Analysis Method

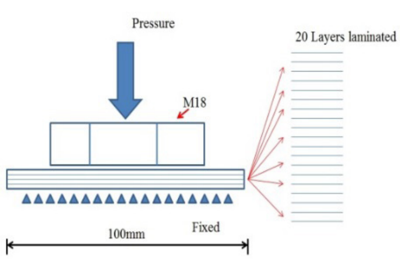

Figure 1. Analysis model and constraint condition.

The Figure 1 shows the analysis for the analysis model from a side angle in which the top pressure at clamping at the upper part of the M18 bolt is exerted with 100 MPa. In addition, with regard to the fixing condition, it was fixed at the bottom of the CFRP panel. Moreover, with regard to the CFRP panel, the thin carbon fiber sheets with a 0.25mm thickness were stacked into 20 and 4 sheets that were made into 1 ply and then stacked 5 times in total. With regard to the laminate degree of each stacked fiber, it was designed as the symmetric form in a single direction of 30, 45, 60, and 75° in order to analyze the impact of the laminate angle. The following Table 1 indicates the property of material of CFRP. The bolt applying the pressure to the panel was set as one rigid body.

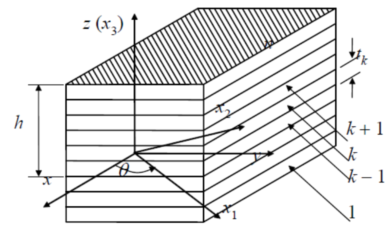

Figure 2. Laminate axes.

The Figure 2 indicates the characteristics which can be seen in long fiber including unidirectional carbon fiber. x1 indicates the fiber direction, x2 indicates the direction vertical to the fiber within the laminate and x3 indicates the direction vertical to the laminate. Therefore, this condition can be seen in Formula (1). The left part of Formula (1) refers to the stress while the right part refers to the matrix with regards to the deformation rate and [Cij] represents the matrix related to hardness. Furthermore, the unidirectional carbon fiber applied to the analysis is considered as transversely isotropic material. As such, based on the characteristics of E1>>E2 and E2 = E3, the correlation between the fiber direction of the following Formula (2) along with the Poisson's ratio of the direction vertical to the fiber and the elasticity coefficient is determined. Based on this condition, the fracture characteristics under the analysis condition were analyzed.

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 = \tau_{23} \\ \sigma_5 = \tau_{31} \\ \sigma_6 = \tau_{12} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \epsilon_4 = \gamma_{23} \\ \epsilon_5 = \gamma_{31} \\ \epsilon_6 = \gamma_{12} \end{bmatrix} \quad (1)$$

$$\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2} = \frac{\nu_{13}}{E_1} = \frac{\nu_{31}}{E_3} = \frac{\nu_{23}}{E_2} = \frac{\nu_{32}}{E_3} \quad (2)$$

3. Results

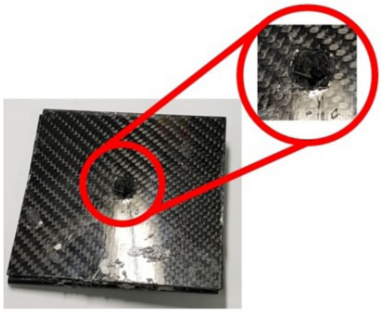

Figure 3. Delamination of CFRP by clamping pressure.

The Figure 3, as a representative example of the fracture shape of the panel caused by clamping pressure, shows that the delamination happens when the fracture of the panel surface causes the fiber to separate. At this point, fine cracks are distributed in the surrounding area as well as in the resin used to solidify the fiber. Brittleness is also produced which is another cause for a fracture in the panel. With regard to the analysis result, it can be estimated that such fracture takes place in the stress beyond the CFRP's property of material.

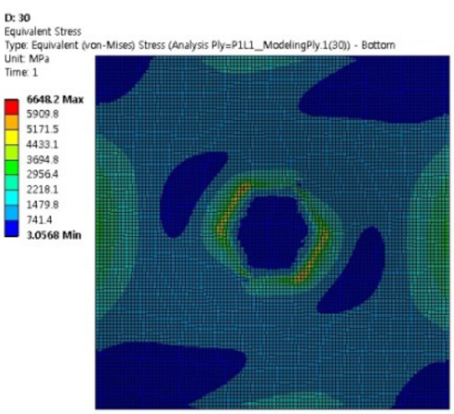

Figure 4. Equivalent stress at the laminate angle of 30°.

The Figure 4 shows the equivalent stress distribution at the CFRP panel comprised of a 30° laminate angle and the biggest result value can be seen in the central area where the clamping pressure of the bolt occurs. Here, 6648 MPa demonstrates that the shear stress of the property of material is exceeded. Through it, the fracture in the clamping area of bolt can be predicted at a laminate angle of 30° and this indicates that the fracture takes place in the overall central area of the panel. Figure. 5 shows the deformation amount of such CFRP panel and when examined together with the deformation energy, it records a higher value compared to the other laminate angle following it. As a result, it can be determined that the laminate angle of 30° is inappropriate for structures with the mechanical clamping method.

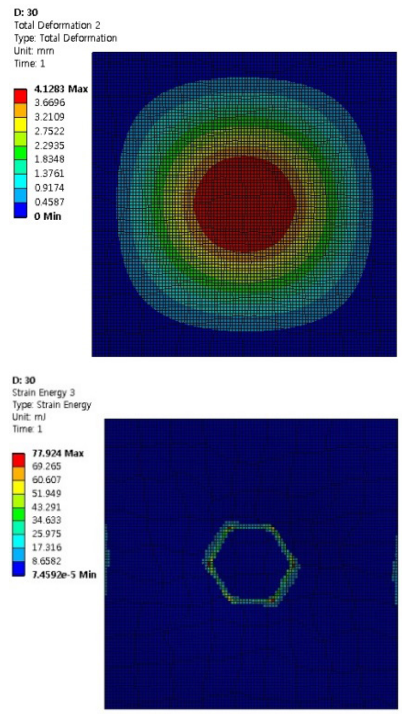

Figure 5. Deformation (upper) and energy (lower) at the laminate angle of 30°.

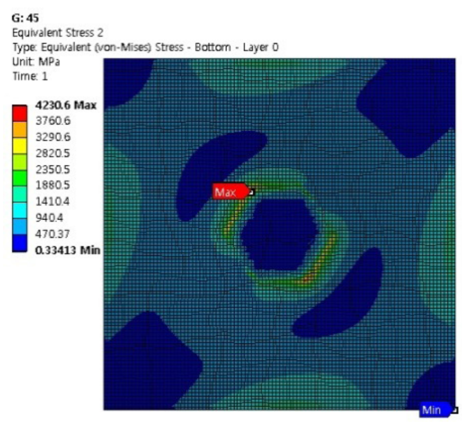

Figure 6. Equivalent stress at the laminate angle of 45°.

The Figure 6 indicates the equivalent stress at the laminate angle of 45° and when compared to the laminate angle of 30°, it has a significantly reduced angle laminate. This demonstrates that stress can be effectively dispersed by depending on the fiber direction. The stress occurring at this point is 4230 MPa which falls in the stable range with regards to the structure. As for the deformation amount and the deformation energy in Figure 7, it can be seen that it is reduced to almost half when compared to the laminate angle of 30°.

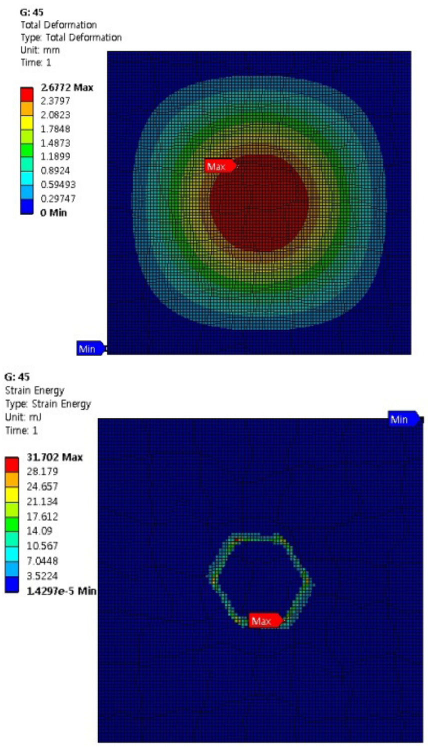

Figure 7. Deformation (upper) and energy (lower) at the laminate angle of 45°.

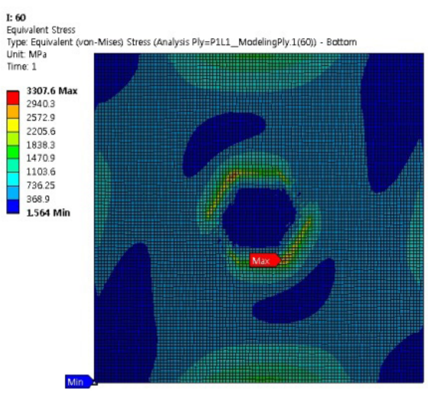

Figure 8. Equivalent stress at the laminate angle of 60°.

The result of Figure 8 too indicates that the most stable result value can be seen in the laminate angle of 60°. Even from the stress state, the result value of 3300 MPa can be seen through effective dispersion so it seems to be most suitable to the mechanical clamping method of the structure. In addition, even with regard to the deformation amount and deformation energy in Figure 9, a minimum value is shown.

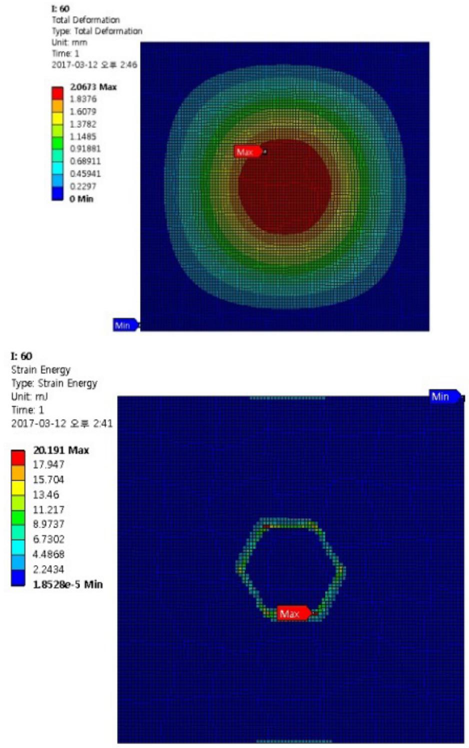

Figure 9. Deformation (upper) and energy (lower) at the laminate angle of 60°.

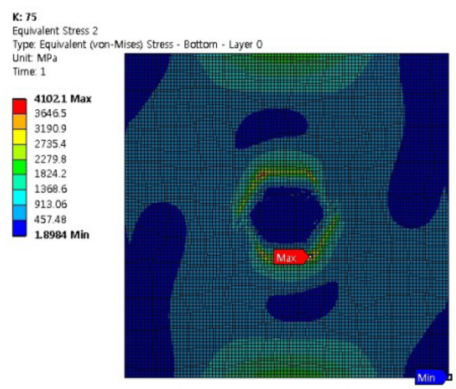

Figure 10. Equivalent stress at the laminate angle of 75°.

Figure 10 shows the equivalent stress at the laminate angle of 75°. As the biggest characteristics which can be seen in the concerned laminate angle, it indicates that as the laminate angle increases and that the equivalent stress does not reduce in a linear form. This state shows that the increase of the laminate angle does not always disperse the stress in terms of the mechanical clamping method. Furthermore, the same aspect can be found in Figure 11 with regard to the deformation and deformation energy of the panel. In summarizing the result values of Figure 12 and 13, such results indicate that the angle increases again starting from the laminate angle of 60°. As a result, the laminate angle with the property of materials of Poisson's ratio and elasticity coefficient that are capable of effectively dispersing environmental stress, where the pressure applied to the structure can be determined as it enables the prevention of separation in the clamping area caused by the separation of fiber and the fine cracks in the surrounding area. As such stability can be secured when applying such a method to the structures.

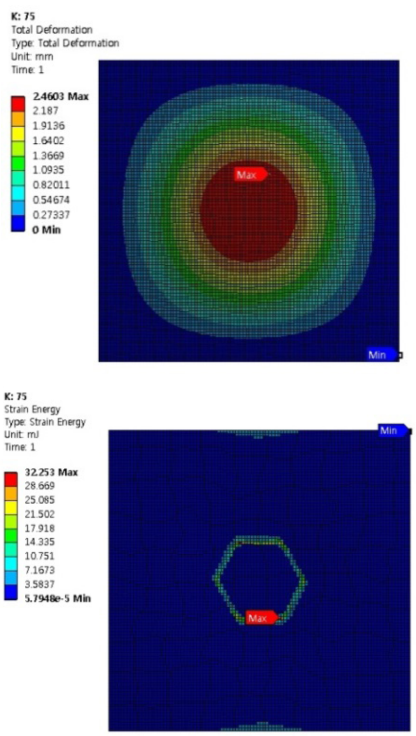

Figure 11. Deformation (upper) and energy (lower) at the laminate angle of 75°.

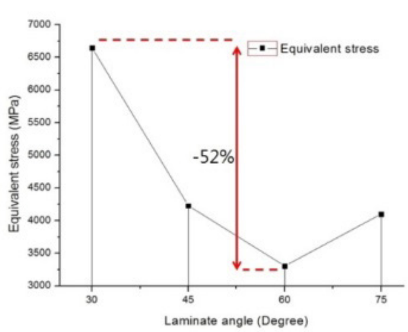

Figure 12. Comparison of equivalent stress at each laminate angle.

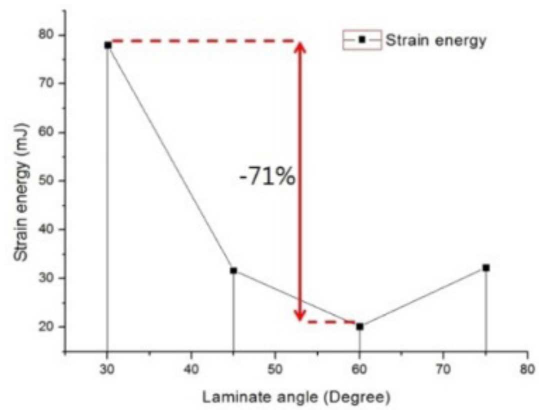

Figure 13. Comparison of deformation energy at each laminate angle.

4. Conclusion

In this paper, the following conclusions were drawn with regard to the impact of clamping pressure on fracture characteristics in applying the mechanical clamping method to the CFRP panel with laminate angles:

1. With regard to CFRP panels applied with laminate angles, it could be used as a scale to determine whether the stress can be effectively dispersed by starting from the laminate angle of 60°. In the case that mechanical clamping is required in the designing of the structure, this paper demonstrates that it is safe to apply the laminate angle of 60°.
2. With regard to CFRP panels applied with laminate angles, it can be used as a scale for safe design when the deformation of the panel is created by starting from the laminate angle of 60°. When mechanical the clamping method is applied to the structure, it can be considered as the safest laminate structure in terms of deformation.
3. Based on the analysis result of this paper, even if the same carbon fiber is used at the laminate angle of 60°, the mechanical property of the material can be enhanced through the application of laminate angles. Through this study result, it can be concluded that the structural safety can be secured in an environment with the applied clamping pressure. In addition, the optimal laminate angle was identified in order to secure the stability of the connection area applied with the mechanical clamping method and the basic data for the safe design was secured.

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