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Research Paper

A Comparative study of durability property on compact tension specimen with unique CFRP and inhomogeneous iron through analysis

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Abstract

Most damage of mechanical structures is due to cracks within the structure. This study is to develop the design of safer structures with strength characteristics by material. We have performed 3D modeling for compact tension specimen such as CFRP material, stainless steel and aluminum alloy, and stainless steel and copper alloy as inhomogeneous material. The boundary conditions are applied to each CFRP and compact tension specimen model with inhomogeneous material and the identical conditions are also applied to each specimen model. The simulation tension analysis has been carried for this study to investigate the strength characteristic. The inhomogeneous material in mechanical structure can be maximized with durability and material strength combined with the advantages of each metal. The material used for these mechanical structures is an essential factor. CFRP made of carbon fiber has been received the attention for a high level of durability and lightweight characteristics. If we apply CFRP material to mechanical structures, we may reduce deformation and stress that occurs, maximize durability of mechanical structures, and prevent deformation and damage. Comparing each specimen model, we can consider the CFRP compact tension specimen model to be the most suitable material for real application as its maximum deformation and maximum equivalent stress turned out to be lower than the other inhomogeneous material specimen models. We could find out that although it is a single material, it possesses a stronger durability and strength characteristic compared to inhomogeneous material combined with the advantages of each material. In this study, the durability and strength characteristics of specimen models are thought to be improved by applying simulation analysis after designing compact tension models for each material.

Keywords: *Strength; CFRP Material; Inhomogeneous Material; Compact Tension Specimen; Durability*

1. Introduction

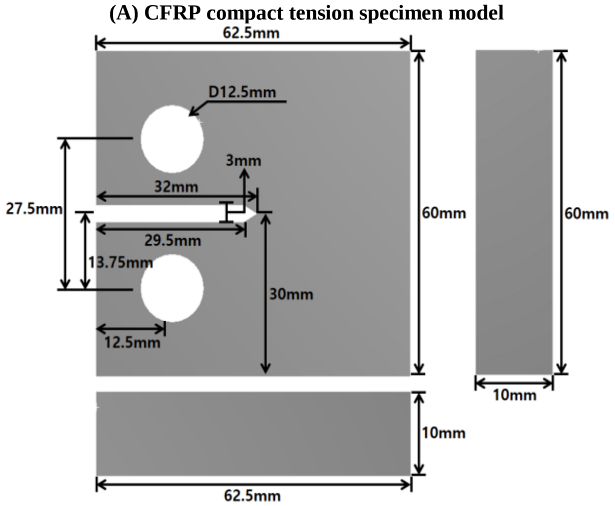
Most deformation or damages of mechanical structures are from cracks that occur within the structure. Cracks cause deformation and damage of mechanical structures, and bring about the possibility of casualties. The material used for these mechanical structures has an essential issue for durability. For example, these materials have the lightweight characteristics of plastic resin or fiber. Even a single metal bonded with another metal can be maximized at durability and material strength combined with the advantages of each metal. Nowadays, CFRP made of carbon fiber has been received the attention for a high level of durability and lightweight characteristics (Virgin, L., 2017), (Castori, G., and Speranzini, E., 2017), (Yates, E. A., and Rudd, T. R., 2016), (Patil, R., and Anand, S., 2017), (Hadidi, A. et al., 2017).

This study is to develop the design of safer mechanical structures, and produce data of durability and strength characteristics according to material property by compact tension specimen models using CFRP material, stainless steel and aluminum alloy, and stainless steel and copper alloy as inhomogeneous material. We have performed a simulation tension analysis research for this study. We have analyzed factors that may cause damage within each material, and found out the destruction possibilities of mechanical structures according to the type of material. Also, we try to utilize study results as the basic data for designing mechanical structures with a safe level of durability (Parisi, F., and Augenti, N., 2017), (Zhang, J., and Rizzoni, G., 2015), (Li, Y. J. et al., 2017), (Song, J., and Sun, B., 2017), (Modares, M., and Venkitaraman, S., 2015).

2. Research methods and models

As shown by Fig. 1, we have designed compact tension specimen models using the CATIA program to compare and analyze durability and fracture characteristics of compact tension specimens according to CFRP and inhomogeneous material (stainless steel-aluminum alloy, stainless steel-copper alloy). Also, the property values of specimen model materials used in this study are listed on Table 1, and 2 (Frosi, P. et al., 2013), (Wu, F. et al., 2017).

(A) CFRP compact tension specimen model



(B) Stainless steel-aluminum alloy and stainless steel-copper alloy compact tension specimen model

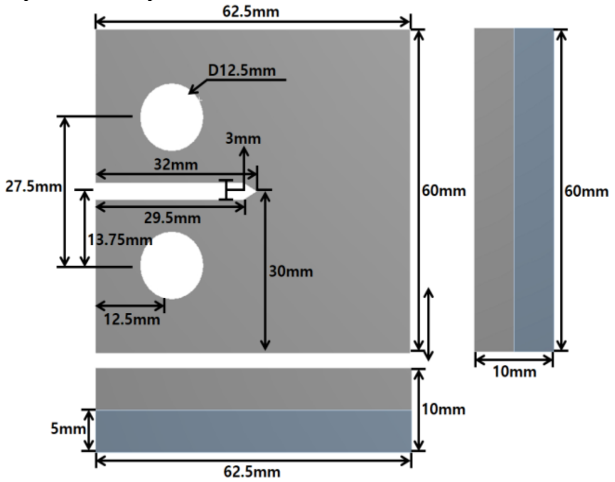


Fig. 1: Configuration of Compact Tension Specimen Models.

Table 1: Material Properties of CFRP

Material	CFRP
Density	1.57kg/M3
Poisson's Ratio(V12)	0.3
Poisson's Ratio(V23)	0.74
Tensile Modulus(E1)	132gpa
Tensile Modulus(E2)	8.98gpa
Tensile Strength(Xt)	1447mpa
Tensile Strength(Yt)	51.72mpa
Compressive Strength(Xc)	1447mpa
Compressive Strength(Yc)	206.2mpa

Table 2: Material Properties of Stainless Steel, Aluminum Alloy, and Copper Alloy

Material	Stainless steel
Density	7750kg/m3
Young's Modulus	193GPa
Poisson's Ratio	0.31
Yield strength	207MPa
Ultimate strength	586MPa
Material	Aluminum alloy
Density	2770kg/m3
Young's Modulus	71GPa
Poisson's Ratio	0.33
Yield strength	280MPa
Ultimate strength	310MPa
Material	Copper alloy
Density	83000kg/m3
Young's Modulus	110GPa
Poisson's Ratio	0.34
Yield strength	280MPa
Ultimate strength	430MPa

3. Boundary conditions

Fig. 2 shows the boundary conditions applied to each CFRP and inhomogeneous material as compact tension specimen model to perform simulation tension analysis, and the conditions applied to each specimen model are identical. We have assumed the specimen models to be attached to the tension tester, and the bottom hole of the specimen model to be fixed onto the tension tester. We have applied and fixed the cylindrical support conditions, and assumed that the specimen model was pulled towards the Y axis from the left hole of the tension tester. We have performed analysis by also granting the force condition and pulling the model with strength of 500N. Table 3 shows the numbers of nodes and elements applied to each specimen model (Cranston, B. et al., 2017), (Shafiei, E., and Dehghani, K., 2017), (Gussev, M. N. et al., 2016).

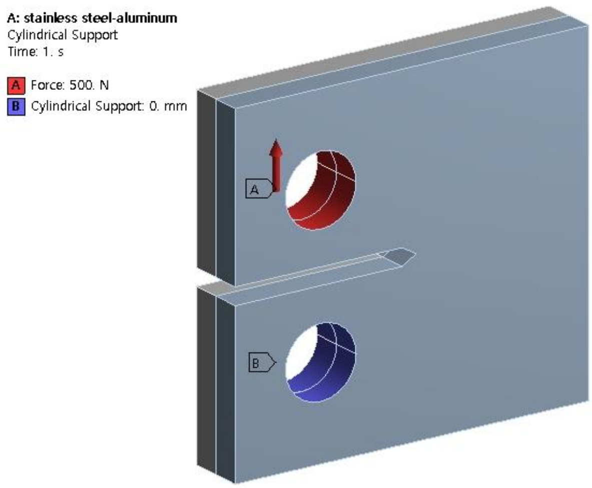


Fig. 2: Boundary Conditions of Compact Tension Specimen Models.

Table 3: Elements and Nodes of Compact Tension Specimen Models

	Elements	Nodes
CFRP	4490	22309
Stainless steel- aluminum alloy	5403	29135
Stainless steel-copper alloy	5403	29135

4. Simulation analysis results

Fig. 3 is the results of simulation analysis of compact tension specimen models made of CFRP material. The total deformation of specimen models is shown, and the maximum deformation turned out to be approximately 0.0096mm.

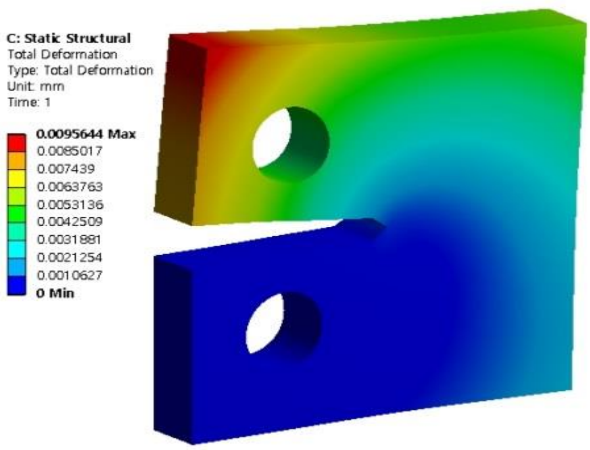


Fig. 3: Total Deformation of CFRP Compact Tension Specimen Model.

Fig. 4 shows the stress distribution of specimen models and we can see that the maximum stress that occurs for specimen models is approximately 30.6MPa. Also, it is found that the maximum stress occurs near the crack that exists within the specimen model.

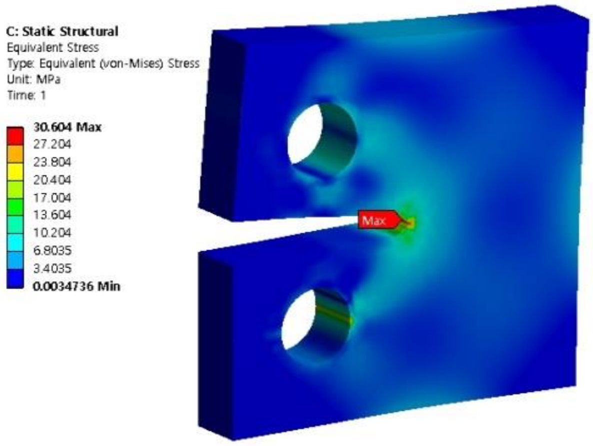


Fig. 4: Equivalent Stress of CFRP Compact Tension Specimen Model.

Fig. 5 shows the result of strain energy, and we can see that the maximum strain energy is approximately 0.0076mJ for CFRP compact tension specimen models. Like the result of stress, strain energy also occurs near the crack that exists within the specimen model.

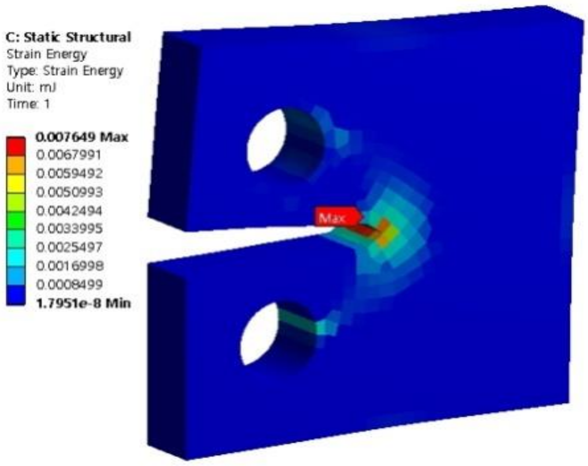


Fig. 5: Strain Energy of CFRP Compact Tension Specimen Model.

Fig. 6 shows the results of total deformation of compact tension specimen models made of stainless steel and aluminum alloy dissimilar material. The maximum deformation of the specimen model is approximately 0.0142mm.

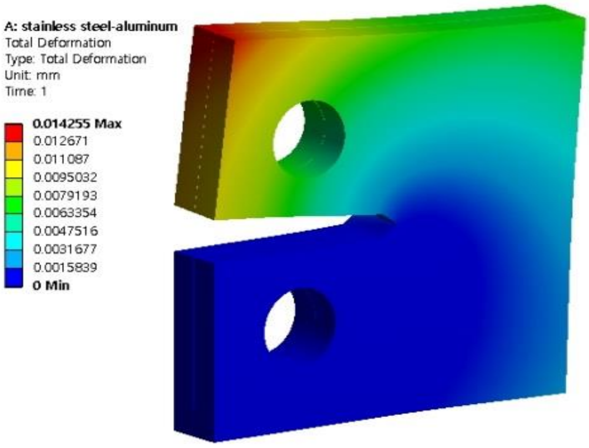


Fig. 6: Total Deformation of Stainless Steel-Aluminum Alloy Compact Tension Specimen Model.

Fig. 7 shows the stress contour of the dissimilar material specimen model, and the maximum stress of the specimen model was approximately 46.69MPa. Like the CFRP material specimen model, the maximum stress occurs near the crack that exists within the specimen model.

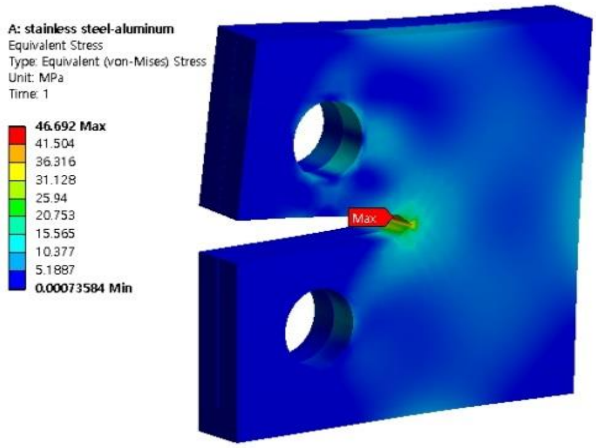


Fig. 7: Equivalent Stress of Stainless Steel-Aluminum Alloy Compact Tension Specimen Model.

Also, like the CFRP material specimen model, Fig. 8 shows the strain energy of the stainless steel and aluminum alloy as specimen model with inhomogeneous material, and we can see that the maximum strain energy is approximately 0.0141mJ. Strain energy occurred near the crack that existed within the specimen model.

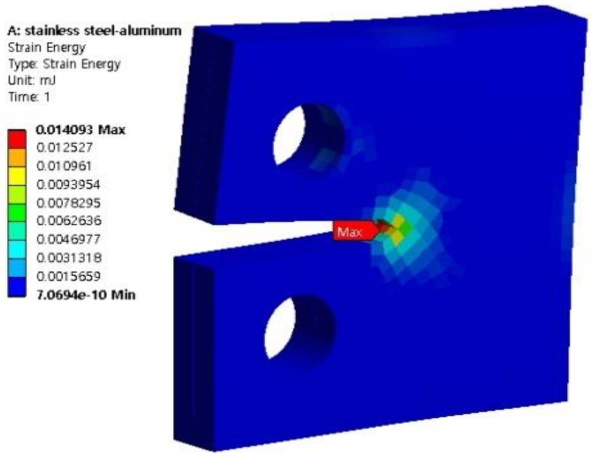


Fig. 8: Strain Energy of Stainless Steel-Aluminum Alloy Compact Tension Specimen Model.

Fig. 9 is the results of simulation analysis of compact tension specimen models made of stainless steel and copper alloy as inhomogeneous material. The total deformation of specimen models is shown, and the maximum deformation turned out to be approximately 0.0118mm.

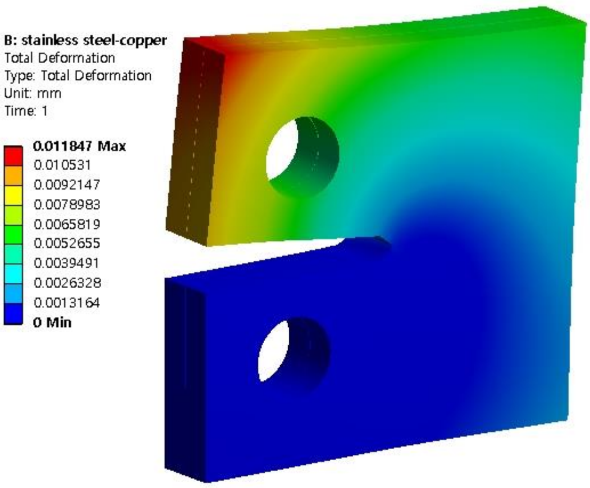


Fig. 9: Total Deformation of Stainless Steel-Copper Alloy Compact Tension Specimen Model.

Fig. 10 shows the stress contour of dissimilar material specimen models and we can see that the maximum stress that occurs for the specimen model is approximately 38.78MPa. Like the CFRP material specimen, and stainless steel and aluminum alloy as specimen model with inhomogeneous material, we can see that the maximum stress occurs near the crack that exists within the specimen model.

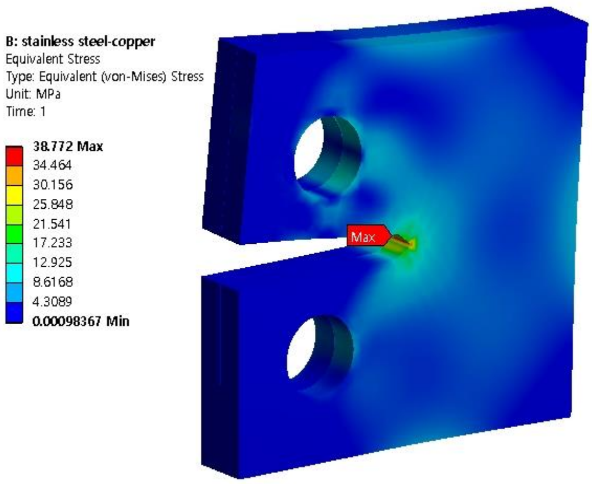


Fig. 10: Equivalent Stress of Stainless Steel-Copper Alloy Compact Tension Specimen Model.

Like the specimen models previously mentioned, Fig. 11 shows the result of strain energy of stainless steel and copper alloy as inhomogeneous material, and we can see that the maximum strain energy is approximately 0.0104mJ. Strain energy occurs near the crack that exists within the specimen model.

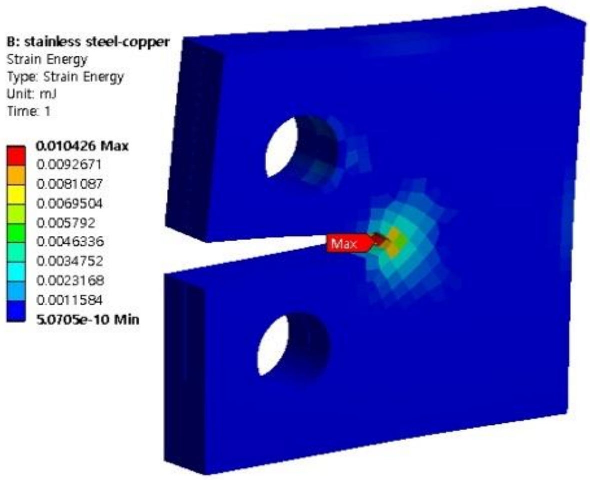


Fig. 11: Strain Energy of Stainless Steel-Copper Alloy Compact Tension Specimen Model.

5. Comparison of analysis results and contemplation

Table 4 shows the comparison of simulation tension analysis results of CFRP material, stainless steel and aluminum alloy, and stainless steel and copper alloy as compact tension specimen models with inhomogeneous material. The maximum deformation of the CFRP material compact tension specimen model was approximately 0.0096mm, the maximum equivalent stress turned out to be approximately 30.6MPa, and the maximum strain energy was approximately 0.0076mJ. In the case of the stainless steel and aluminum alloy as compact tension specimen model with inhomogeneous material, the maximum deformation was approximately 0.0142mm, and the maximum equivalent stress turned out to be 46.69MPa. We could see that the maximum strain energy was approximately 0.0141mJ. The maximum deformation of the stainless steel and copper alloy as compact tension specimen model with inhomogeneous material was approximately 0.0118mm, the maximum equivalent stress turned out to be approximately 38.78MPa, and the maximum strain energy was approximately 0.0104mJ. As a result of comparing each specimen model, we can consider the compact tension specimen model with CFRP material to be the most suitable material for real application as its maximum deformation and maximum equivalent stress turned out to be lower than specimen models with the other inhomogeneous material. We could find out that although it is a single material, it possesses a stronger durability and strength characteristic compared to inhomogeneous material consolidated with the advantages of each material. If we apply CFRP material to mechanical structures, we may reduce deformation and stress that occurs, maximize durability of mechanical structures, and prevent deformation and damage. Also, the study results can be utilized for the basic data to design mechanical structures with safer durability.

Table 4: Comparison on Analysis Results of C-T Specimen Models

	maximum deformation(mm)	maximum equivalent stress(mpa)	minimum strain energy(mj)
cfrp	0.0096	30.6	0.0076
stainless steel aluminum alloy	0.0142	46.69	0.0141
stainless steel-copper alloy	0.0118	38.78	0.0104

6. Conclusions

1) In this study, the simulation analyses have been performed by designing CFRP material, stainless steel and aluminum alloy, and stainless steel and copper alloy as compact tension specimen models with inhomogeneous material. We have deduced the following conclusion by analyzing this study result.
2) We could evaluate the durability and strength characteristics of specimen models by performing simulation tension analysis after designing compact tension models for each material.
3) According to research results, the maximum deformation of the compact tension specimen model with CFRP material was approximately 0.0096mm, the maximum equivalent stress was approximately 30.6MPa, and the maximum strain energy was approximately 0.0076mJ. In case of stainless steel and aluminum alloy as the compact tension specimen model with inhomogeneous material, the maximum deformation was approximately 0.0142mm, and the maximum equivalent stress turned out to be 46.69MPa. We could see that the maximum strain energy was approximately 0.0141mJ. The maximum deformation of stainless steel and copper alloy as the compact tension specimen model with inhomogeneous material was approximately 0.0118mm, the maximum equivalent stress turned out to be approximately 38.78MPa, and the maximum strain energy was approximately 0.0104mJ.
4) Because of comparing each specimen model, we can consider the compact tension specimen model with CFRP material to be the most suitable material for real application as its maximum deformation and maximum equivalent stress turned out to be lower than specimen models with the other inhomogeneous material. We could find out that although it is a single material, it possesses a stronger durability and strength characteristic compared to inhomogeneous material consolidated with the advantages of each material.
5) If we apply CFRP material to mechanical structures, we may reduce deformation and stress that occurs, maximize durability of mechanical structures, and prevent deformation and damage. Also, the study results can be utilized for the basic data to design mechanical structures with safer durability.

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