Chapter 7

Finite Element Analysis of Glass/Carbon Hybrid Composite Pipes

Mehmet Çağrı Tüzemen[1]

Abstract

In recent years, due to the diversification of needs in industries, studies on hybrid composites in which different fibers are used together have begun to attract attention. In this study, Glass/Carbon interlayer hybrid composite pipes made of glass and carbon fibers with different stacking sequences were investigated by using the finite element analysis (FEA). Ansys was used for the FEA. In the models created from eight layers, the thickness of each layer is 0.25 mm and the wall thickness of the composite pipes is 2 mm. In hybrid composite samples, four layers of glass fiber and four layers of carbon fiber were used. In addition to eight hybrid composite samples with different stacking sequences, another two models consisting of pure glass fiber and pure carbon fiber was designed as a reference sample. Unidirectional (UD) glass fiber and UD carbon fibers were used when creating the models. While creating the mesh structure on the models, it was checked whether the skewness was within acceptable values. For this purpose, optimization was made in the mesh structure size. While fixed support was applied to the models from one end, tensile force was applied from the other end. Tsai-Wu criterion was used in the FEA. It was concluded that the use of carbon fiber in the inner layers of interlayer hybrid composites increased the strength. Among the interlayer hybrid composites, approximately 25% increases in maximum force were obtained with the change of the stacking sequence.

1. Introduction

Continuous fiber reinforced polymer matrix composites are frequently used in high technology products thanks to their low weight and high strength [1]. However, despite the high specific strength of carbon fiber, its usage area may be limited because it is a very expensive material [2].

1 Dr. Öğr. Üyesi, Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik-Mimarlık Fakültesi, Metalurji ve Malzeme Mühendisliği Bölümü, cagrituzemen@nevsehir.edu.tr, 0000-0002-1746-2864

https://doi.org/10.58830/ozgur.pub390.c1544

On the other hand, glass fiber has lower strength than carbon fiber, but it is a cheaper reinforcement element [3,4]. For this reason, studies on hybrid composite structures in which different fiber types are used together have gained momentum in recent years. Thus, while the cost will decrease compared to the final product consisting only of carbon fiber, the loss in specific strength will be lower compared to the final product consisting only of glass fiber.

There are various hybridization methods in composites such as intralayer, interlayer or woven [5–8]. In intralayer hybrid composites, different fibers are used in the same layer. The same applies to woven hybrids. In interlayer hybrid composites, different fiber structures are used in different layers. Hybrid composite pipes can also be produced in a wide variety of shapes using different production methods and different fiber reinforcements [9–11]. The mechanical properties of interlayer hybrid composites may also vary depending on the sequence. Since the mechanical properties of the fibers are different, each fiber adds a different feature to the hybrid structure. While glass fiber reinforcement has chemical resistance, heat and electrical insulation, carbon fiber has higher load-carrying capacity, higher hardness and fatigue resistance [12]. Telli et al. [13] examined the damage analysis of hybrid Carbon/Glass-Epoxy pipe elbows under bending and pressure loading. They noted that for a hybrid composite, the position of the plies has a large impact on the behavior, especially on the resistance of the tubular structure. Wang et al. [14] investigated the mechanical properties of fiber-reinforced hybrid composite pipes in their study. They observed that the innermost layer was exposed to the highest stress under axial tensile load. They concluded that increasing the proportion of fibers with high modulus of elasticity in the hybrid composite structure could improve the tensile properties of these structures. The reason for this is that the effect on the mechanical behavior of fiber-reinforced hybrid composite pipes is mainly attributed to the axial tension of the fibers.

The aim of this study is to investigate the effect of glass/carbon fiber stacking sequences under tensile load in hybrid composite pipes made of glass and carbon fiber fibers. The behavior of interlayer hybrid composite pipes with eight different stacking sequences under tensile load was examined by the finite element method. In the hybrid structure consisting of a total of eight layers, four layers of glass fiber and carbon fiber were used. In addition, composite pipes consisting of pure glass and pure carbon fiber were also analyzed for reference. Thus, hybrid structures were compared and interpreted both with pure fiber reinforced composites and among themselves.

2. Materials and Method

In this study, the behavior of interlayer hybrid composite pipes under tensile load was investigated by finite element analysis. Hybrid composite pipes are modeled as shell elements in SpaceClaim. Next, the model was transferred to the ACP (Pre) module in the Ansys. In the ACP (Pre) module, the materials are defined for the model. Unidirectional carbon fiber/epoxy and glass/epoxy were chosen as materials. Some properties of the selected materials are given in Table 1.

Table 1. Some properties of the materials used in the analysis

	Carbon Fiber	Glass Fiber
Tensile Strength (MPa)	1632	780
Tensile Strain	0,0143	0,0244
Modulus of Elasticity (GPa)	123	35
Poisson's Ratio	0,27	0,28
Shear Modulus (GPa)	5	4,7

After the selected materials were introduced to the model, the interlayer hybrid structure of the pipe was created. The models are designed to have eight layers in total. The designs and stacking sequence of the layers are shown in Figures 1. The part shown in green in Figure 1b is the layers of the section. The bottom layer in Figure 1c shows the innermost layer of the composite pipe, and the top layer shows the outermost layer. The blue-colored layers represent the glass fiber layers, and the dark gray-colored layers represent the carbon fiber layers. While samples 3–10 are composite pipes between layers formed in various ways, samples 1 and 2 are reference models consisting of only glass fiber and only carbon fiber, respectively.

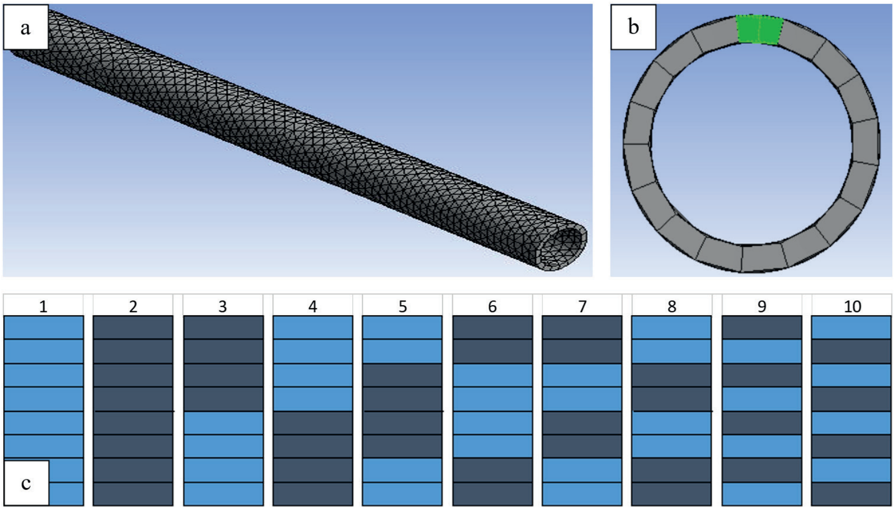


Figure 1. (a) design of interlayer hybrid composite pipes, (b) cross-sectional view and (c) layer sequences of the green area in the cross-section and numbering of the models (Blue color shows glass fiber layers, dark gray color shows carbon fiber layers)

The thickness of each layer is 0.25 mm, and the wall thickness of the composite pipes is 2 mm. The outer diameter of the model is 20 mm, and the length is 200 mm. The orientation of the unidirectional fibers is designed in the direction of the force. The triangle method was chosen as the mesh method. Improvements were made in the quality of the mesh structure, considering the solution times over the mesh size. The model is fixed supported at one end to prevent rotation and translation. From the other end, tensile force was applied and support was applied against translation (except in the direction of force) and rotation (see Figure 2). Models were analyzed according to the Tsai-Wu damage criteria.

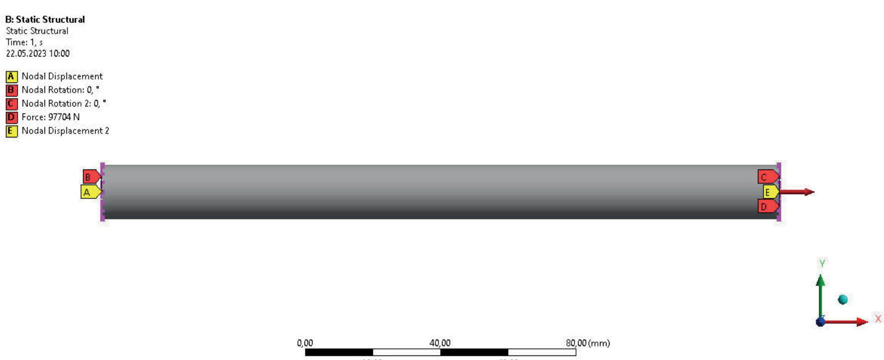
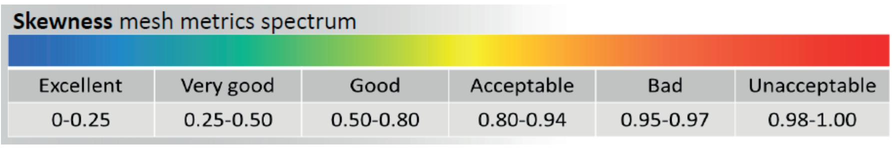


Figure 2. Loading and boundary conditions

3. Results and Discussion

Before determining the behavior of composite pipes under tensile forces, the quality of the mesh was checked, and improvements were made in the mesh size, taking into account the analysis solution times. The skewness values were examined to measure the quality of the mesh. Experimenting with different mesh sizes is aimed to optimize the skewness value in the skewness scale ranges of the Ansys program (see Figure 3). According to this scale, skewness values of 0.94 and below are acceptable.



Skewness mesh metrics spectrum

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Figure 3. Scaling of Ansys program showing network structure quality due to skewness [15]

The effect of the mesh structures formed in different sizes of the composite pipe model on the skewness is given in Figure 4. All the mesh structures of various sizes created on the model are in the "very good" range according to the scale in Figure 3. It has been observed that the mesh size gives the lowest skewness for 3 mm and the values greater than 8 mm. Larger mesh sizes were not preferred because they may cause convergence problems in the analysis. When the mesh size decreased below 1 mm, it caught a downtrend. However, the mesh structure created on the model with dimensions less than 0.5 mm extends the analysis time considerably. Therefore, taking into account the analysis times, it was decided that the most appropriate mesh size was 3 mm. The highest skewness value finding is 0.27 in this mesh size. According to the scale in Figure 3, this value is close to the lower limit of the "very good" range.

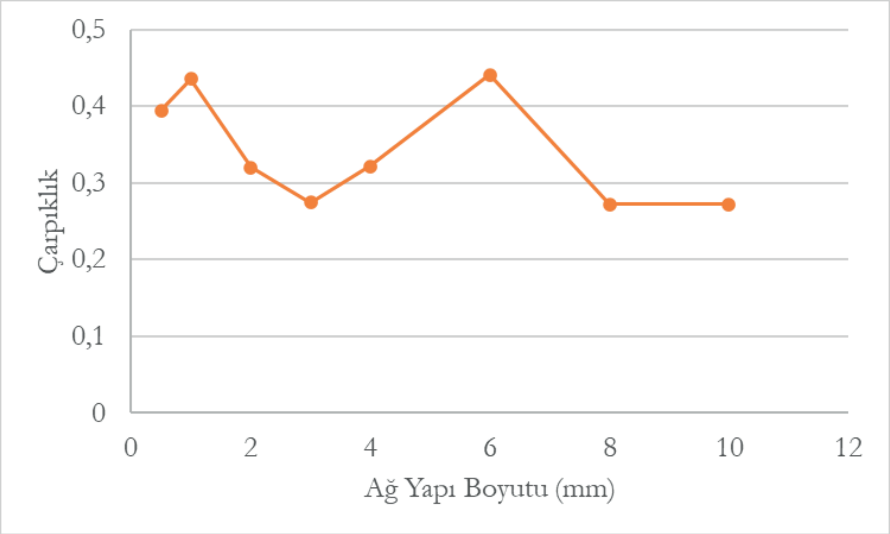


Figure 4. Change of maximum skewness depending on mesh structure size

Figure 5 shows the maximum forces that composite pipes can withstand according to the Tsai-Wu criterion. As expected, the reference samples consisting of only glass fiber and only carbon fiber were the samples with the lowest and highest strengths, withstanding 46 kN and 98 kN forces, respectively. The average of the maximum forces that the two reference samples can withstand is shown in the figure with a straight blue line (72 kN). The remaining samples are interlayer hybrid composite samples, and all of them use four layers of glass fiber and four layers of carbon fiber. In other words, the use of expensive carbon fiber has been halved. When the results were examined, it was seen that sample number 4 gave the highest value of 86 kN among the interlayer hybrid composites. Following this, samples 8, 5 and 10 withstood forces of 80 kN, 78 kN and 76 kN, respectively. When these samples are examined, it is seen that there is glass fiber in their outermost layers. Sample number 4, which has the four glass fiber layers at the outermost layers, had the highest strength among the mixed composites. As the use of carbon fiber in the innermost layer increased, the maximum force increased. In other words, as the use of glass fiber in the inner layers increased, the maximum force decreased. The highest load that sample number 3 could withstand was the lowest with 69 kN. Sample number 4 withstood 17 kN more load than sample number 3, just by changing the stacking sequences. This value, which means approximately 25% more load, shows how important the stacking sequences is, even though the usage of glass and carbon fibers are the same.

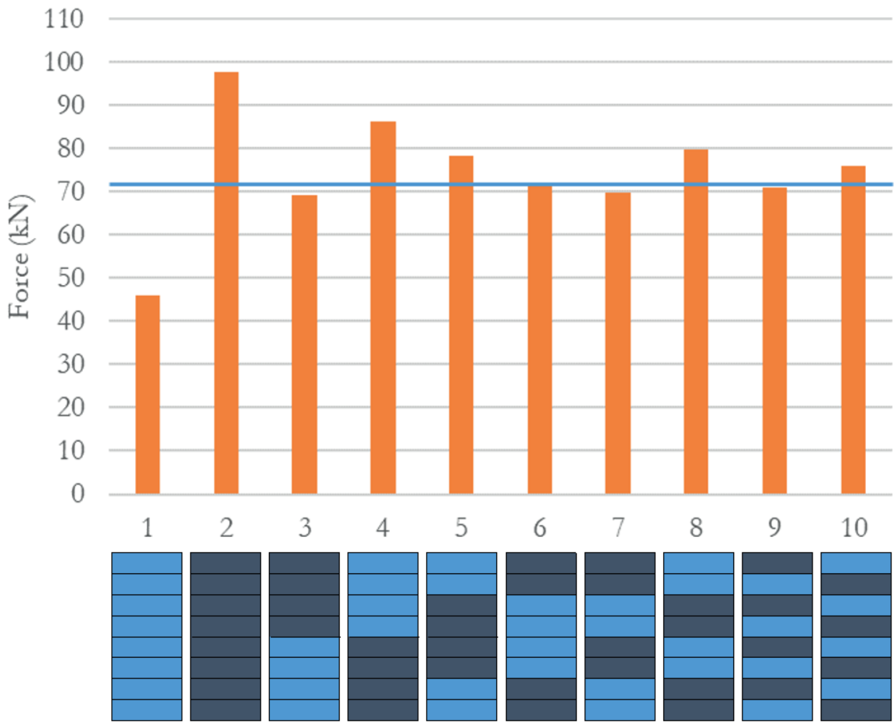


Figure 5. Maximum force that composite pipes can withstand (Blue layers show glass fiber, dark gray layers show carbon fiber)

Sample no. 4 withstood an 87% higher force than sample no. 1, just by converting 50% of the layers from glass fiber to carbon fiber. Although the use of carbon fiber was halved compared to sample no. 2, sample no. 4 only withstood a force approximately 12% lower than sample no. 2. Thus, while the use of carbon fiber, which is much more expensive, was reduced by half, there was only a 12% decrease in maximum force, but an 87% increase in maximum force was achieved compared to the glass fiber sample alone.

4. Conclusions

In this study, the behavior of interlayer hybrid composite pipes under tensile load was investigated. Fixed support was applied to the models from one end and tensile force was applied from the other end. According to the Tsai-Wu criterion, the highest forces it can withstand have been found. In hybrid composites, the samples that withstood the highest forces were the samples with glass fiber in the outermost layers. While the sample with glass fibers in the outermost layers and carbon fibers in the innermost layers withstood 87% higher force than the sample with all layers consisting of glass fibers, it could withstand only 12% lower force than the sample with all layers composed of carbon fibers. Therefore, with mixed composites, greater reductions in cost can be achieved with lower compromises in strength. Among the interlayer hybrid composites, 25% increases in maximum force were obtained with the effect of the stacking sequences. Thus, by simply changing the stacking sequences of the fibers, higher forces resistance can be achieved even using the same ratio of glass and carbon fiber.

References

[1] Prashanth S, Subbaya K, Nithin K, Sachhidananda S. Fiber Reinforced Composites - A Review. J Mater Sci Eng 2017;06. https://doi.org/10.4172/2169-0022.1000341.

[2] Brown KR, Harrell TM, Skrzypczak L, Scherschel A, Wu HF, Li X. Carbon fibers derived from commodity polymers: A review. Carbon N Y 2022;196. https://doi.org/10.1016/j.carbon.2022.05.005.

[3] Xian G, Guo R, Li C, Hong B. Mechanical properties of carbon/glass fiber reinforced polymer plates with sandwich structure exposed to freezing-thawing environment: Effects of water immersion, bending loading and fiber hybrid mode. Mech Adv Mater Struct 2023;30. https://doi.org/10.1080/15376494.2021.2024927.

[4] Lal HM, Uthaman A, Li C, Xian G, Thomas S. Combined effects of cyclic/sustained bending loading and water immersion on the interface shear strength of carbon/glass fiber reinforced polymer hybrid rods for bridge cable. Constr Build Mater 2022;314. https://doi.org/10.1016/j.conbuildmat.2021.125587.

[5] Kaya G. Hibrit Dokunan Karbon/E-Cam/Polipropilen Termoplastik Prepreg Kompozitlerin Mekanik Özellikleri. Tekst ve Mühendis 2018;25. https://doi.org/10.7216/1300759920182511103.

[6] Yanen C, Solmaz MY. Tabakalı Hibrit Kompozitlerin Bireysel Zırh Malzemesi Olarak Üretimi Ve Balistik Performanslarının İncelenmesi. El-Cezeri Fen ve Mühendislik Derg 2016;3. https://doi.org/10.31202/ecjse.264200.

[7] Karacor B, Özcanlı M. Evaluation of Mechanical Properties of Intraply Hybrid Carbon/Aramid Composite Materials. Uludağ Üniversitesi Mühendislik Fakültesi Derg 2022;27:537–56. https://doi.org/10.17482/UUMFD.978721.

[8] Aydın MR, Acar V, Yapıcı F, Yıldız K, Topcu MV, Gündoğdu Ö. Inter-ply Hibrit Kompozit Yapılarda Elyaf Diziliş Sıralamasının Mekanik ve Dinamik Özelliklere Etkisi. Iğdır Üniversitesi Fen Bilim Enstitüsü Derg 2018;8. https://doi.org/10.21597/jist.458649.

[9] Rajan V V, Muruganandhan R. Impact Analysis of Carbon/Glass/Epoxy Hybrid Composite Pipes. Int J Recent Technol Eng 2019;8:6002–3.

[10] Supian ABM, Sapuan SM, Zuhri MYM, Zainudin ES, Ya HH. Hybrid reinforced thermoset polymer composite in energy absorption tube application: A review. Def Technol 2018;14. https://doi.org/10.1016/j.dt.2018.04.004.

[11] Alabtah FG, Mahdi E, Eliyan FF. The use of fiber reinforced polymeric composites in pipelines: A review. Compos Struct 2021;276. https://doi.org/10.1016/j.compstruct.2021.114595.

[12] Tüzemen MÇ. Cam ve Karbon Elyaflar ile Oluşturulan Karma Kompozitlerin Çekme Dayanımlarının Analitik ve Nümerik Araştırılması. Afyon Kocatepe Univ J Sci Eng 2023;23. https://doi.org/10.35414/akufemubid.1202306.

[13] Telli F, Mokhtari M, Khiari MEA, Habib B, Slamene A, Abdelouahed E. Damage analysis of hybrid carbon/Glass-Epoxy pipe elbows under bending and pressure loading. Mech Adv Mater Struct 2023. https://doi.org/10.1080/15376494.2023.2226953.

[14] Wang L, Ma W, Deng L, Liu S, Yang T. Mechanical model and mechanical property analysis of fibre-reinforced hybrid composite pipes. Mar Struct 2023;89. https://doi.org/10.1016/j.marstruc.2023.103396.

[15] Adam NM, Attia OH, Al-Sulttani AO, Mahmood HA, As'arry A, Rezali KAM. Numerical Analysis for Solar Panel Subjected with an External Force to Overcome Adhesive Force in Desert Areas. CFD Lett 2020;12:60–75. https://doi.org/10.37934/CFDL.12.9.6075.