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# Carbon Fabric-Reinforced Polymeric Composites Produced by Hand Lay-Up and Investigation of the Tensile Behavior

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**Abstract:** Composite materials are recognized as advanced materials, which can be formed by combining different constituents, excellent mechanical properties can be achieved by chosen appropriate elements and processing. This paper describes that Carbon Fabric Reinforced Epoxy Composites (CFRPs) are produced using twill weave carbon fibers with CR-80 epoxy resin through hand lay-up method. The composite laminates are designed with 10th layers of stacking [0/0/0/0/0]s in with 3.0 mm thickness. Tensile tests are carried out at longitudinal orientation and transverse orientation of the samples in addition to analytical analysis models. A comparison is made between the experimental results of tensile tests data and evaluated statistical point of view. Experimental results indicated that average tensile strength of the composites was obtained around 427 MPa for the longitudinal orientation [0o], while for transverse orientation [90o] sample, average tensile strength was 359 MPa, which is lower than that of the sample. Further, it was concluded that analytical analysis is a good agreement with experimental data.

**Keywords:** Carbon twill fiber, CR-80 epoxy resin, Hand lay-up, Fiber orientation, Tensile Strength, Elongation rate, Analytical analysis

## Introduction

Composite materials are materials that are aimed to exhibit superior properties by combining the characteristics of materials from different classes. A composite material is formed by the combination of at least two different materials. This combination must occur without dissolution. At least one of these materials is a reinforcement material, and the structure surrounding the reinforcement is called the matrix (Çakır and Berberoğlu 2018). Synthetic fiber-reinforced composites such as aramid and carbon, as well as glass and carbon fibers, are widely used in many industries, particularly in automotive, construction, and aerospace, due to properties such as high strength and lightness (Tasgın and Kandemir 2023).

With the development of fiber technology in recent years, the use of technical fibers with superior properties such as carbon fiber, which are advantageous due to being lightweight and having corrosion resistance, has become widespread as reinforcement materials in composites in various forms in order to increase their strength. Although carbon fiber–reinforced polymeric composite materials have high in-plane strength and stiffness, they require strengthening due to their low interlaminar performance properties determined by the characteristics of the matrix, their high sensitivity to damage especially against impact and fatigue, and the fact that they cannot be repaired once damaged (Korkmaz et al. 2016; Cakır and Berberoglu, 2018). Carbon fibers/fabrics are selected as reinforcements in making composites because the chemical resistance, higher tensile/hardness, toughness and wear resistance increase while epoxy resin is chosen as matrix due to having excellent mechanical properties, having good adhesion behavior with fibers, but it is brittle (Sirinivas and Bhagyashekar, 2021). More importantly, they have a high strength to density ratio for use in demanding polymer processing operations for various applications.

Composite materials store damage within their structure, and damage does not always occur as macroscopic failure. Types of damage such as fiber damage, delamination, transverse ply cracking, and matrix cracking may occur. Therefore, application of tensile tests and the determination of the durability of composite materials are of great importance (Irmak et al. 2016). Salviato et al. (2016) investigated the effect of specimen size and the presence of notches on the fracture behavior of twill-woven carbon/epoxy composites using both experimental and numerical methods, demonstrating that size effects played a critical role in understanding material strength. Similarly, Niutta et al. (2023) performed tensile and flexural tests on twill-woven carbon composites produced with epoxy and bio-based epoxy matrices, comparing the results with numerical models to establish modeling accuracy. In addition, Yan et al. (2024) showed, through combined experimental and numerical analyses, that the loading rate had a pronounced influence on the tensile property at the carbon fiber/epoxy interface. Other studies showed that the mechanical behavior of twill-woven carbon/epoxy composites could be evaluated reliably not only with experimental data but also through numerical modeling. Therefore, the combined use of experimental tensile tests and numerical analyses contributed to the accurate prediction of the material's strength and elastic properties (Ashby & Jones, 2012).

Mechanical and physical properties of the polymer based composites are very important because many variables such as type of fiber/matrix, volume fraction of fiber, diameter of fibers, and distribution of fibers, processing, consolidation, and interface bonding between the constituents affect the output (Sahin, 2022). Tensile tests are among the most commonly used methods for determining the mechanical properties of materials. These tests enable the calculation of parameters such as tensile strength, elastic modulus, and yield strength. The literature indicates that when fiber-reinforced composites and anisotropic materials are subjected to tensile testing along different directions, the material behavior varies significantly (Ashby & Jones, 2012). It is also emphasized that the repeatability of the data obtained from the tests depended largely on specimen preparation and test conditions (ASTM, 2015). In this study, low cost epoxy based composites have been produced by hand lay-up method using carbon fabrics with twill types of reinforcements. Then, the effects of orientation on mechanical property like tensile strength are determined according to ASTM standard by tensile tests.

## Material and Method

### Manufacturing of Composites

In manufacturing of composite materials, carbon fiber fabric with a Twill weave structure was used, which it has a 245 g/m² areal weight with a thickness of 0.25 mm, and a density of 1.76 g/cm³. According to the COC document provided by the manufacturer of this fabric, its tensile strength is 3800 MPa and its elastic modulus is 240 GPa. In the production of the composite, Sika Biresin CR-80 epoxy and its hardener were used as the matrix. CR-80 is a low-viscosity epoxy resin system suitable for the production of high-performance reinforced composite parts. CH80-1 hardener was used as the hardener. The density of this resin after mixing is 1.15 g/cm³, the tensile strength is 88 MPa, and the elastic modulus is 3000 MPa. The data obtained from the COC documents for the fiber and resin are listed in Table 1 below.

The composite material to be produced was targeted to have dimensions of 400 × 400 × 2.5 ±0.5 mm, and accordingly, since the fiber thickness is 0.25 mm, it was planned to be 10 layers with 0° orientation. Based on the selected fiber and resin, the hand lay-up method was chosen as the production method. The production process includes the following steps: (a) Preparation of mold surface: A flat mold surface was used for composite production. A polyvinyl alcohol-based release agent was applied to the surface to prevent the resin from adhering to the mold. (b) Cutting of layers: Twill 245 carbon fiber fabric was cut into 10 layers of 400 × 400 mm. Each layer was arranged according to 0° orientation. (c) Preparation of resin and hardener: CR-80 epoxy resin and CH80-1 hardener were weighed and adjusted at a ratio of 30 grams of hardener per 100 grams of epoxy resin. (d) The mixture was stirred at low speed until it achieved a homogeneous consistency and was degased under vacuum to prevent air bubbles. (e) Impregnation of layers: Each carbon fabric layer was placed on the mold surface and fully impregnated with resin using a brush and roller. This process was repeated for each layer. (f) Curing process: After placing the layers, the plate was left to cure for 24 hours at room temperature (23–25 °C).

Table 1. Data obtained from COC documents for fiber and resin

| | Fiber | Matrix |
|---|---|---|
| Material Name | *Twill 245 Carbon Fiber* | *SikaBiresin CR-80 Epoxy* |
| Type | Woven Fabric (Twill 2/2) | Thermoset Epoxy CH80-1 Hardener |
| Density (g/cm³) | 1.76 | 1.15 (Blend) |
| Tensile Strength (MPa) | 3800 | 85–88 |
| Elastic Modulus (GPa) | 240 | 3000 |
| Thickness (single layer) | 0.25 mm | — |
| Areal Weight (g/m²) | 245 | — |
| Elongation at Break (%) | — | 6.3 |
| Glass Transition Temperature (°C, Tg) | — | 98 |
| Hardness | — | Shore D85 |

**Cutting/Tensile Testing**

After the plate production was completed, 10 specimens, each with dimensions of 180 × 25 mm, were cut using a CNC machine in accordance with ASTM D3039 standard. Five of these specimens were cut parallel (0°) to the fiber direction, while five of others were cut perpendicular (90°) to the fiber direction from the plate. Each specimen was numbered sequentially from 1 to 10, with the first five parallel to the fiber direction and the next five perpendicular. At the ends of these specimens, tabs with a length of 50 mm and a width suitable for grips of the testing machine were bonded. These tabs were cut from a high-strength composite plate prepared with CR-80 epoxy resin and CH80-1 hardener. Prior to application, both the specimen end surfaces and tab surfaces were sanded to roughen them and then cleaned with acetone. The resin mixture was applied as a thin layer to both surfaces, and the tabs were aligned and pressed onto the specimen ends manually, as shown in Figure 1. This procedure was carried out to prevent end failures during testing and to distribute the load uniformly.


Figure 1. The composite specimen with twill pattern prepared for tensile test

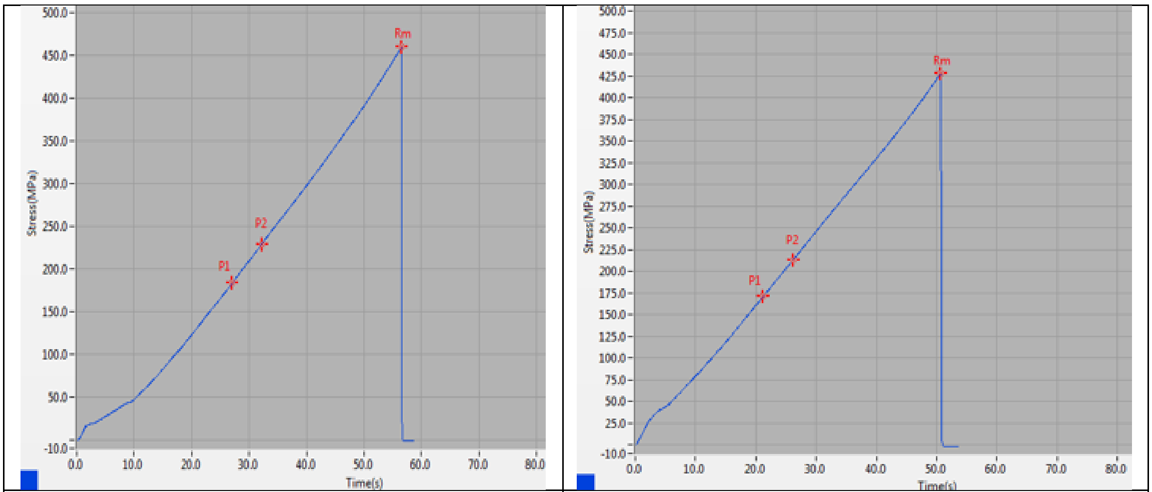
Tensile tests were applied to the prepared specimens in accordance with the ASTM D3039 standard. The tensile test was carried out with a MITECH brand, DW-CN-2008 model, at 22 °C ambient temperature and 51% humidity. The tensile cross-speed of the device was set at 2 mm/min, and the test was performed separately for 10 specimens.

## Results and Discussion

For the tensile test conducted, at least five measurements have been obtained from the different composite specimens, the values recorded for each specimen and the average values longitudinal and transverse orientations are presented in the Table 2 and 3, respectively. Average ultimate tensile stress and strain at break values are obtained about 426.9 MPa and 1.72 mm during the tensile test, shown in Fig.1. Whereas, average maximum force to break the composite specimens was 33.4 kN. In the case of tensile test results perpendicular to the fiber axis and their averages as indicated in Table 3 and Fig. 2, lower mechanical properties were obtained. For example, average values for tensile strength and elongation rate were about 359 MPa and 1.52 mm, respectively. The maximum force to break the samples was reached to 27.0 kN.

Table 2. Tensile test results parallel to the fiber axis and their averages

| Data | 1st test | 2nd test | 3rd test | 4th test | 5th test | Average value |
|---|---|---|---|---|---|---|
| F-max (kN) | 36.10 | 32.84 | 30.26 | 32.21 | 35.35 | 33.35 |
| Crosshead speed (mm/min) | 2.00 | 2.00 | 2.0 | 2.00 | 2.00 | 2.00 |
| Thickness (mm) | 3.06 | 3.04 | 3.09 | 3.07 | 3.11 | 3.07 |
| Width (mm) | 25.60 | 25.25 | 25.60 | 25.32 | 25.25 | 25.40 |
| Length (mm) | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 |
| Cross-sectional area (mm²) | 78.34 | 76.76 | 79.10 | 77.73 | 78.53 | 78.09 |
| Duration (s)/Extension (mm) | 56.45 | 50.71 | 46.31 | 50.21 | 53.87 | 51.51/1.72 |
| Tensile strength (N/mm²) | 459.69 | 427.83 | 382.53 | 414.37 | 450.16 | 426.92 |

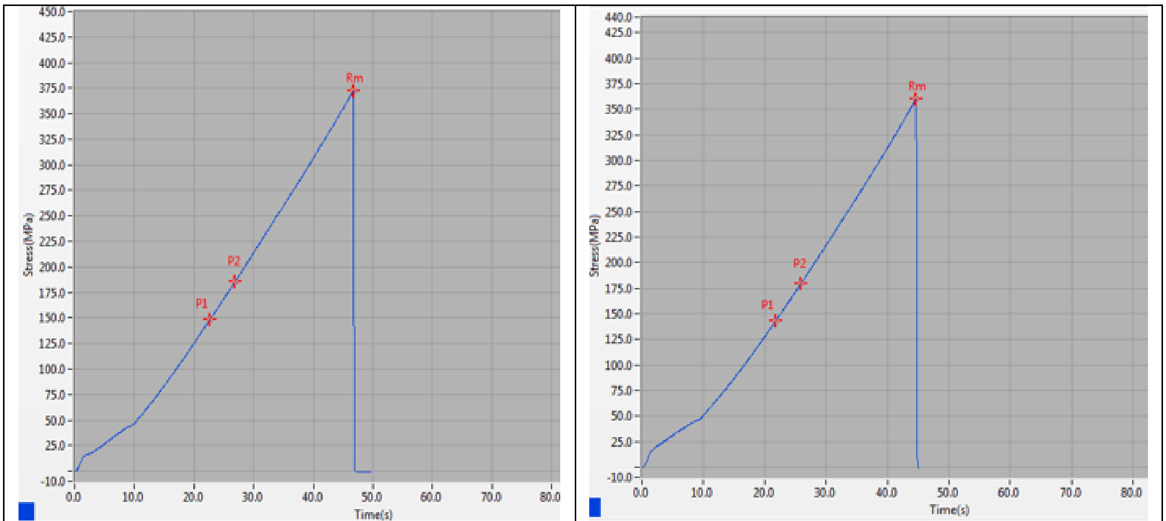



Sample 1 | Sample 2

Figure 1. Tensile stress vs. time in longitudinal orientation (0 degree)

Table 3. Tensile test results perpendicular to the fiber axis and their averages

| Data | 1st test | 2nd test | 3rd test | 4th test | 5th test | Average value |
|---|---|---|---|---|---|---|
| F-max (kN) | 28.14 | 27.67 | 28.16 | 24.15 | 27.09 | 27.04 |
| Crosshead speed (mm/min) | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Thickness (mm) | 2.98 | 2.92 | 3.00 | 3.01 | 3.00 | 2.98 |
| Width (mm) | 25.48 | 26.26 | 25.2 | 25.19 | 25.1 | 25.45 |
| Length (mm) | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 |
| Cross-sectional area (mm²) | 75.93 | 76.68 | 75.6 | 75.82 | 75.3 | 75.87 |
| Duration (s)/Extension (mm) | 46.86 | - | 47.04 | 45.3 | 44.71 | 45.9/1.52 |
| Tensile strength (N/mm²) | 370.6 | 375.14 | 372.49 | 318.51 | 359.76 | 359.30 |




Sample 1 | Sample 2

Figure 2. Tensile stress vs. Time in perpendicular orientation (90 degree)

Upon evaluation of the specimen measurements, the average tensile strength of the specimens cut parallel to the fiber direction was determined as 426.9 N/mm². The coefficient of variation for these values was approximately 7.2%, indicating an acceptable level of consistency. Similarly, for the specimens cut perpendicular to the fiber direction, the average tensile strength was 359.3 N/mm² with a coefficient of variation of approximately 6.6%, which likewise confirms the consistency of the measurements. Statistical analysis showed that the difference between the two groups was significant ($p \leq 0.05$). This result confirms that the load-carrying capacity of carbon fiber is markedly higher along the fiber direction (Table 4).

Table 4. Descriptive statistics and statistical comparison of tensile strengths

| | | Average | Standard Deviation | Min. | Mak. | Coefficient of variation (CV) | P-Value |
|---|---|---|---|---|---|---|---|
| Tensile Strength (N/mm²) | Parallel to the fiber axis | 426.92 | 30.58 | 382.53 | 459.69 | 7.17 | ≈0.05 |
| | Perpendicular to the fiber axis | 359.3 | 23.54 | 318.51 | 375.14 | 6.55 | |

In this study, analytical predictions were generated using algorithms developed in MATLAB, with the mean values obtained from tensile tests as inputs. The algorithms performed calculations based on Classical Laminate Theory (CLT), taking into account parameters such as ply thickness, fiber orientation (0°/90°), elastic modulus, Poisson's ratio and matrix-reinforcement properties (Kav, 2006). As a result, a prediction of the maximum tensile strength was obtained. The summary of findings are presented in Table 5.

Table 5. Average tensile test and analytical analysis results

| | Parallel to the fiber axis | Perpendicular to the fiber axis | Analytical Analysis | Analytical Analysis |
|---|---|---|---|---|
| | Average Tensile Test | Average Tensile Test | X0 | Y0 |
| Tensile Strength (N/mm²) | 426.92 | 359.3 | 427.09 | 356.38 |

Based on the data we obtained, the results of the measured tensile strength and the analytical tensile results are similar. Comparing the specimens in the parallel direction with the analytical analysis result, the difference is 0.17 N/mm² and a negligible deviation of about 0.04% is observed. Comparing the specimens in the perpendicular direction with the analytical analysis result, the difference is 2.92 N/mm² and a small deviation of approximately 0.8% is observed. In both cases, the results obtained by analytical analysis and the experimentally determined average tensile strength strongly corroborate each other. It is argued that as the percentage of filler material increase, the hardness value of the material increases, while the amount of deformation under bending decreases (Bal, 2022). The increase in the glass fiber ratio in glass fiber–reinforced composites, the mechanical properties of composites (tensile strength, elongation, and elastic) improved with increasing glass fiber content (Çakır and Berberoğlu, 2018). For various fiber orientations like 0°/0°, 0°/90° and 0°/±45°/90°of tested samples, the main cause of damage was the compressive failure occurring in the ply with 0° orientation (Irmak et al. 2016). Similar work carried out on 0°, 90° and 45°direction, the elastic modulus varied with fiber orientation. The highest deformation occurred in specimens with 45° orientation, while the lowest deformation occurred in specimens with 0° orientation (Ozen, 2017), which is consistent with the current results.

## Conclusion

In this study, the tensile performance of the twill-woven carbon reinforced epoxy composites produced by the hand lay-up method was investigated experimentally and analytically using the CLT. The findings are summarized as follows:

(1). Average maximum force to break the composite specimens tested at longitudinal orientation produced by hand-lay-up method was 33.4 kN while the maximum force to break the composite samples tested at perpendicular orientation was reached to 27.0 kN.
(2). The experimental mean tensile strengths were measured as 426.92 MPa and 359.30 MPa for the 0° and 90° direction, respectively. Coefficient of variations for these values were approximately 7.2%, 6.6% respectively.
(3). It was determined that there was no statistically significant difference between the analytical and experimental values. Elongation values were at a similar level between the experimental and numerical models. However, the

experimental mean elongations measured were larger in the parallel direction than that of the perpendicular direction.

## Recommendations

Numerical analysis will be applied for such carbon fibers reinforced composites and compared to the experimental results.

## Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

## Conflict of Interest

* The authors declare that there is no conflict of interest.

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## References

Ashby, M. F., & Jones, D. R. H. (2012). *Engineering materials 1: An introduction to properties, applications and design*. Butterworth-Heinemann.

ASTM International. (2015). *Standard test method for tensile properties of plastics* (ASTM D638-15).

Aziz, S., Rashid, S., & Mohd Salleh, M. A. (2013). Theoretical prediction of CNT-CF/PP composite tensile properties using various numerical modeling methods. *Fullerenes, Nanotubes and Carbon Nanostructures, 21*(5), 411-416.

Bal, B. C. (2022). Lineer düşük yoğunluklu polietilen (LDYPE) ve odun unu ile üretilen kompozit malzemenin bazı teknolojik özellikleri üzerine bir araştırma. *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, 5*(1), 40-49.

Campos, C. A., Soufen, M. P., & Bueno, M. P. (2014). Comparative study of mechanical properties of woven carbon fiber twill and plain weave in laminates with epoxy matrix. *2nd Brazilian Conference on Composite Materials*, 1-5.

Cakir, M., & Berberoglu, B. (2018). E-Cam elyaf takviyeli epoksi matrisli kompozit malzemelerin elyaf oranındaki artış ile mekanik özelliklerindeki değişimlerin incelenmesi. *El-Cezerî Fen ve Mühendislik Dergisi, 5*(3), 734-740.

Erdogan, I., Kisa, M., Ozen, M., Demircan, G., & Kaya, A. I. (2023). Cam elyaf takviyeli epoksi nanokompozitlerin dinamik davranışlarının incelenmesi. *Harran Üniversitesi Mühendislik Dergisi, 8*(2), 78-90.

Hu, H., Wei, Q., Wang, T., Ma, Q., Pan, S., Li, F., Wang, C., & Ding, J. (2025). Theoretical prediction method for tensile properties of high-strength steel/carbon fiber-reinforced polymer laminates. *Polymers, 17*, 846.

Imak, A., Solmaz, M. Y., & Topkaya, T. (2016). Tabakalı hibrit kompozit malzemelerin yorulma davranışlarının analizi. *ECJSE, 3*(3).

Kav, K. (2006). *Mechanics of composite materials* (2nd ed.). Taylor & Francis Group.

Korkmaz, N., Cakmak, E., & Dayik, M. (2016). Dokuma karbon elyaf takviyeli karbon nano tüp-epoksi kompozit malzemelerin mekanik ve termal karakterizasyonu. *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 20*(2).

Lafranche, E., Martins, C. I., Oliveira, V. M., & Krawczak, P. (2013). Prediction of tensile properties of injection moulding flax fibre reinforced polypropylene from morphology analysis. *Key Engineering Materials, 554*, 1573-1582.

Li, X., Zhang, Y., Shi, C., & Chen, X. (2020). Experimental and numerical study on tensile strength and failure pattern of high performance steel fiber reinforced concrete under dynamic splitting tension. *Construction and Building Materials, 259*, 119796.

Niutta, C. B., Ciardiello, R., & Paolino, D. S. (2023). Epoxy and bio-based epoxy carbon fiber twill composite: Comparison of the quasi-static properties. *Polymers, 16*(4), 1601.

Ozen, M. (2017). E-Cam/Epoksi kompozitlerde lif doğrultularının gerilme gevşeme davranışı üzerindeki etkisi. *Fırat Üniversitesi Mühendislik Bilimleri Dergisi, 29*(1), 219-224.

Pant, M., & Palsule, S. (2024). Prediction of tensile properties of natural fiber reinforced pp hybrid composites by facca-kortschot-yan (fky) and palsule equations. *Journal of Physics: IOP Conference Series, 2837*(1), 012005.

Salviato, M., Kirane, K., Esna Ashari, S., Bazant, Z., & Cusatis, G. (2016). *Experimental and numerical investigation of intra-laminar energy dissipation and size effect in two-dimensional textile composites* (SEGIM Internal Report No. 16-05/707E). Northwestern University, McCormick School of Engineering and Applied Science.

Srinivas, K., & Bhagyashekar, M. S. (2021). Prediction of mechanical properties of epoxy composites containing mono and hybrids particulate fillers. *IOP Conference Series: Materials Science and Engineering, 1189*(1), 012003.

Tasgin, Y., & Kandemir, S. (2023). Doğal elyaf takviyeli (jüt-keten-kenevir) kompozit malzemelerin mekanik ve metalografik olarak incelenmesi. *International Journal of Pure and Applied Sciences, 9*(2), 240-249.

Uzay, C., Cetin, A., Geren, N., Bayramoglu, M., & Tutuncu, N. (2024). Düz dokunmuş karbon fiber/epoksi laminatların çekme sertliği ve mukavemet özelliklerinin tahmini: Pratik bir analitik yaklaşım ve deneysel doğrulamalar. *İleri Malzeme ve Yapıların Mekaniği, 31*(12), 2619-2634.

Yan, K., Jiang, Z., Tang, J., Xie, X., & Suo, T. (2024). Experimental and numerical study on the loading rate effect on tensile behavior of carbon fiber/epoxy composite interface. *Composites Part B: Engineering, 284*, 111732.

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