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Flexural Properties of Glass Fiber Reinforced Epoxy Composites at Different Strain Rates

Cam Fiber Takviyeli Epoksi Kompozitleri Farklı Yükleme Hızlarında Eğilme Özellikleri

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Abstract

Composite materials are exposed to various loading speeds when considering the application areas. Understanding how strain rates affect the behavior of composite materials and estimating this behavior constitute one of the important work areas. In this work, glass fiber reinforced epoxy composites were produced and their mechanical behaviour under various strain rates (2.5 mm/min, 5 mm/min and 10 mm/min) was investigated. Strain rates was based on crosshead speed. Composite plates were produced by VARIM (Vacuum Assisted Resin Infusion Method). The samples were cut according to ASTM standards and then three-point bending test was applied to understand flexural behaviour of glass fiber reinforced epoxy composites. Composite plates were prepared as three different fiber orientations (0°, 45°, 90°) and the effect of different strain rates on different fiber orientations was investigated. As a result, as strain rate increases, the flexural stress increases and there is no meaningful change in the modulus of elasticity and deflection. In addition, the most affected fiber orientation is 45° fiber orientation for flexural stress.

Keywords: *Polymer, Composite, Flexural properties, Strain rate*

Öz

Kompozit malzemeler, uygulama alanları göz önüne alındığında çeşitli yükleme hızlarına maruz kalmaktadırlar. Farklı yükleme hızlarının kompozit malzemelerin davranışını nasıl etkilediğini anlamak ve bu davranışı tahmin edebilmek önemli çalışma alanlarından birini oluşturmaktadır. Bu çalışmada, cam elyaf takviyeli epoksi kompozitler üretilmiş ve çeşitli yükleme hızları altında (2.5 mm/dak, 5 mm/dak ve 10 mm/dak) mekanik davranışları incelenmiştir. Yükleme hızı olarak piston başlığı hızı baz alınmıştır. Kompozit plakalar VARIM (Vakum Destekli Reçine İnfüzyon Metodu) ile üretilmiştir. Numuneler ASTM standartlarına göre kesilmiş ve cam elyaf takviyeli epoksi kompozitlerin eğilme davranışını anlamak için üç nokta eğilme deneyi uygulanmıştır. Kompozit plakalar, üç farklı elyaf oryantasyonunda (0 °, 45 °, 90 °) hazırlanmış ve belirlenen yükleme hızlarının bu elyaf oryantasyonları üzerindeki etkisi araştırılmıştır. Sonuç olarak, yükleme hızı arttıkça, eğilme gerilmesi artmış fakat elastisite modülü ve çökme sonuçlarında anlamlı bir değişiklik gözlemlenmemiştir. Ek olarak, eğilme gerilmesi için en çok etkilenen elyaf oryantasyonun 45° elyaf oryantasyonu olduğu tespit edilmiştir.

Anahtar Kelimeler: *Polimer, Kompozit, Eğilme özellikleri, Yükleme hızı*

1. Introduction

Fiber reinforced polymer composites have emerged as important materials due to their light weight, high hardness, high strength, excellent fatigue resistance and remarkable corrosion resistance compared to the most common metallic alloys such as steel, aluminum alloys. Composites are preferred to traditional materials where extraordinary physical, thermal and mechanical properties are desirable, especially where weight saving is critical [1].

Today, composite materials are frequently used from aerospace and aviation industries to everyday household goods. The frequency of these uses has led to increased work on fiber-reinforced polymer composites [2-4]. One of these work areas is the changes in the mechanical properties of composites exposed to different strain rates [5].

Dastoorian and Tajvidi [6] investigated the effects of strain rate on the flexural modulus and flexural strength of wood flour and high-density polyethylene composites. Three-point bending experiments were performed using four different strain rates (0.01, 0.02, 0.05, 0.08 min^{-1}). It was found that the mechanical properties of this composite are significantly sensitive to the strain rate. Based on statistical analyzes, it was found that the flexural modulus is more sensitive than the flexural strength.

Okoli and Smith [7] examined the effect of poison ratios under different strain rates of glass-epoxy layer composites produced with different fiber ratios. They produced glass-epoxy composites by using 15.5, 20.7, 26.9, 38.0 and 41.2% fiber volume ratios and subjected them to tensile tests under low and high strain rates (from 0.017 mm/s to 2000 mm/s cross-head speed). They observed that the poison ratios were not dependent on strain rate.

Gurusideswar et al. [8] examined tensile behavior of glass fiber reinforced epoxy composites produced by hand lay-up methods and epoxy produced by casting by exposing them to low and medium strain rates (from 0.0001 s^{-1} to 450 s^{-1}). For epoxy and glass-epoxy composites, they observed that the tensile strength and modulus were sensitive, even at low strain rates, and that these values increased as the strain rate increased.

Perogamvros et al. [9] designed a tensile testing apparatus to enable tensile coupon testing at medium strain rate (from 1 s^{-1} to 200 s^{-1}). They used a drop weight apparatus to do impact tests by utilizing the capabilities of drop tower machines. They observed that this modification was appropriate for the medium strain rate because of the tests they performed.

Ou et al. [10] produced glass fiber reinforced epoxy composites using Vacuum Assisted Resin Transfer Molding method. Using a single ply of glass fabric, they obtained a single layered composite, with 0.52 mm thickness. They have investigated possible changes in mechanical properties of these composites under 4 different strain rates (25, 50, 100 and 200 s^{-1}) and 6 different temperature values (-25, 0, 25, 50, 75 and 100 °C). As a result, it is observed that the increase of the strain rate usually increases the maximum tensile strength. In addition, when the temperature rises from -25 °C to 50 °C there was virtually no change, but the tensile strength decreases sharply (about 18.9%) over a temperature range of 50-100 °C.

Naresh et al. [11] experimentally and theoretically investigated the effect of strain rates between 0.0016 s^{-1} and 542 s^{-1} on mechanical properties of glass / epoxy, carbon / epoxy and hybrid (glass-carbon / epoxy) composites produced by the pressure molding method. For high strain rate tests, Drop weight impact setup was used. Quasi-static tests were carried out on an Instron universal test machine according to the ASTM D638 standard. The results show that as the strain rate increases, the tensile strength and tensile modulus of the glass / epoxy and hybrid composites increase and the percentage of failure strain for glass / epoxy, carbon / epoxy and hybrid composites increases. It has also been observed that as the strain rate increases, the tensile strength and the tensile modulus remain approximately constant for the carbon / epoxy composites.

Li et al. [12] have produced warp-knitted and plain weave carbon fabric reinforced epoxy composites by resin transfer molding method and have studied their tensile and compressive strength under the quasi-static and dynamic strain rates. For the quasi-static test, the strain rate was 0.5 s^{-1}, while for the dynamic test a range of 200 s^{-1} to 2300 s^{-1} was preferred. As a result, for both fabric types, the higher the strain rate, the greater the tensile strength but the effect of the strain rate on the compressive strength was observed at negligible size.

As is known, composite materials are subjected to different speeds according to the areas where they are used. It is important to learn how composites behave under different strain rates. For this purpose, epoxy composites were produced using unidirectional glass fiber with vacuum-assisted resin infusion method and their flexural properties were investigated under different crosshead speeds. In addition, the main purpose of this study is to investigate the effect of different strain rates on different fiber orientations (0°, 45°, 90°).

2. Theory

The three-point bending test is carried out by placing a sample of rectangular cross-section on two supports in a straight line and applying a load from the midpoint of the supports. A support length to width ratio of 16:1 is required for the sample. The samples are deflected until fracture occurs on the outer surface or until a maximum stress of 5.0% is reached (ASTM D790-17). Calculations of flexural stress, flexural strain and modulus of elasticity are shown in Equation 1, Equation 2 and Equation 3.

-Calculation of Flexural Stress

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

- Calculation of Flexural Strain

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (2)$$

- Calculation of Modulus of Elasticity

$$E_B = \frac{L^3 m}{4bd^3} \quad (3)$$

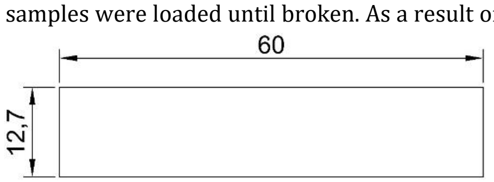
2.1. Nomenclature

σ = stress in the outer fibers at midpoint, MPa (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, mm (in.),
b = width of beam tested, mm (in.),
d = depth of beam tested, mm (in.),
ε = strain in the outer surface, mm/mm (in./in.),
D = maximum deflection of the center of the beam, mm (in.),
E_B = modulus of elasticity in bending, MPa (psi),
m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm (lbf/in.) of deflection.

3. Material and Method

In this study, unidirectional glass fiber (300 gr/m^2) were used as reinforcing materials. Araldite LY 1564 epoxy and Aradur 3487 BD hardener were chosen as thermoset matrix materials. Six layers of uniaxial glass fiber was used in plate production. The ratio of hardener and epoxy for matrix material was 1/3 of the mass. The superimposed reinforcing fabrics were vacuumed at 1 bar pressure. The infusion of epoxy resin to all reinforcing fabrics was accomplished by vacuum sealing. The system was cured at 100 °C for 2 hours in a vacuum environment. These processes were made for 0°, 45°, 90° fiber orientations and the plates produced by vacuum assisted resin infusion method were removed from the workbench. For three-point bending test, a total of 27 samples were prepared, 9 in each direction, according to ASTM D790-17. Samples geometry (mm) are given in Figure 1.

Figure 1. Three-point bending test sample sizes



As shown in Figure 2, prepared samples were subjected to three-point bending test on Shimadzu AGS-X Plus Universal tensile machine. For bending test 2.5 mm/min, 5 mm/min and 10 mm/min crosshead speed were used, and samples were loaded until broken. As a result of this test, Maximum Flexural Stress, Maximum Deflection and Modulus of Elasticity of glass fiber epoxy composites with different fiber orientations were obtained.

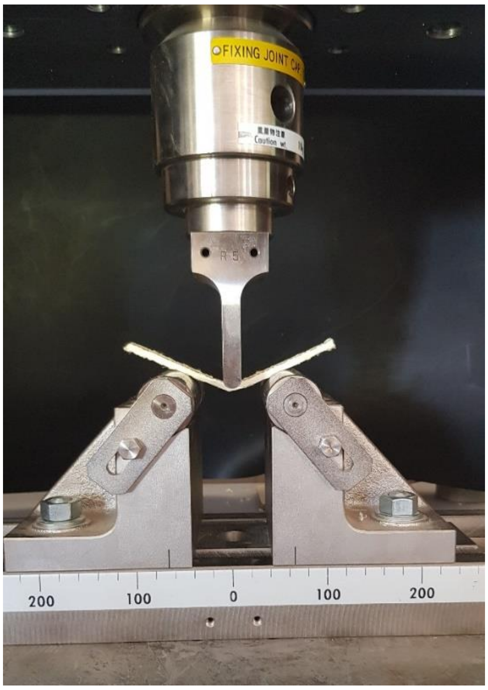


Figure 2. Three-point bending test

4. Results and Discussions

The data obtained by three-point bending test of glass fiber reinforced epoxy composites produced in different fiber orientations under three different strain rates are given in the following Figures. The maximum flexural stress of the specimens shown in Figure 3, the maximum deflection shown in Figure 4 and the modulus of elasticity shown in Figure 5 are indicated respectively.

As the strain rate incresed, an increase in the maximum flexural stress for all three fiber orientations were observed. Looking at the increase rates from 2.5 mm/min to 10 mm/min for each fiber orientations within itself in Figure 3, the highest increase was in 45° fiber orientation with 19.24%. The lowest increase rate was observed at 90° fiber orientation with 1.34%, while the increase rate at 0° fiber orientation was 10.09%. In general, the highest flexural stress values were measured in 0° fiber orientation while the lowest values were measured in 45° fiber orientation. The reason for this is that the maximum shear stress occurs at 45°. In addition, as in the literature, when the strain rates increase, the flexural stress [5,13] and tensile stress [7] increase.

When the results of the maximum deflection shown in Figure 4 were examined, it was seen that the results did not have a certain level of increase and decrease. However, it was observed that the maximum increase is in 45° fiber orientation with 11.06%, a decrease of 6.92% at 90° and an increase of 3.2% at 0°. These ratios were compared between the speed of 2.5 mm/min and the speed of 10 mm/min for each fiber orientations within itself, and as a result, it was seen that the strain rate did not significantly affect the maximum deflection values. In the same way, Adem et al. [14] observed that the flexural stress increased as strain rate increased

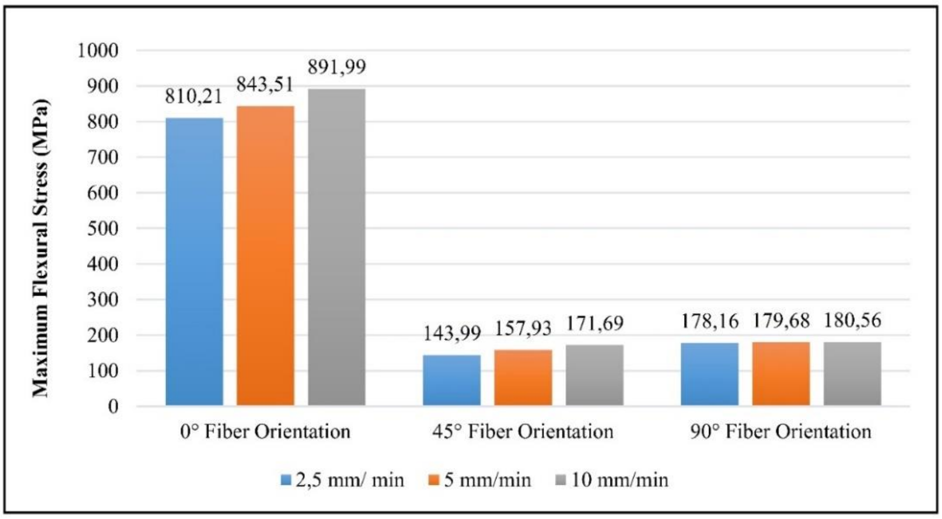


Figure 3. Maximum flexural stress of glass/epoxy composite at different strain rates

in the woven bidirectional E-glass-epoxy composites they produced, and they didn't observe any significant change in the meaning of deflection.

The strain rate did not cause a regular increase or decrease in the modulus of elasticity shown in Figure 5 as in the case of maximum deflection. However, it was observed that the most significant rate of change occurred in the 45° fiber orientation at 11.43% during the transition from 5 mm/min to 10 mm/min.

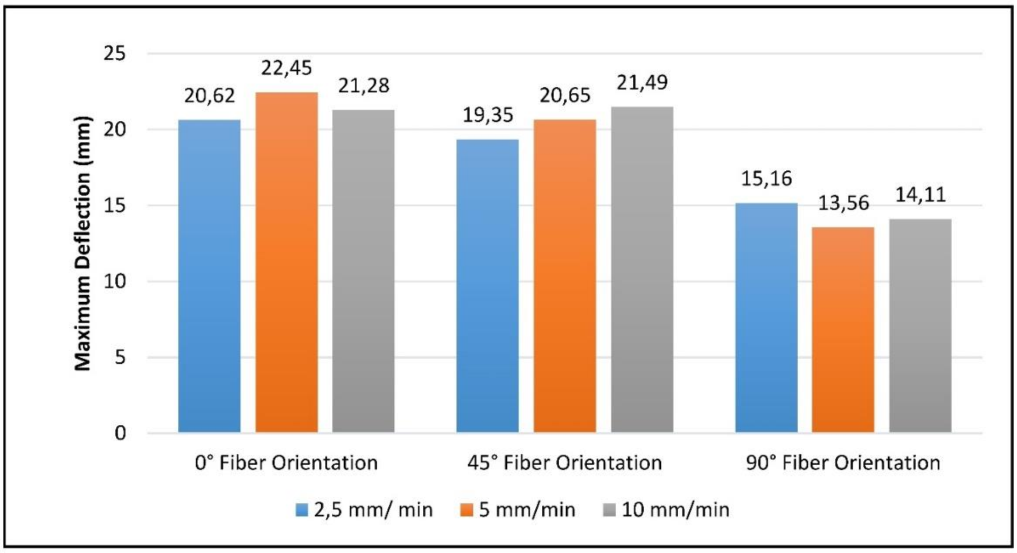


Figure 4. Maximum deflection of glass/epoxy composite at different strain rates

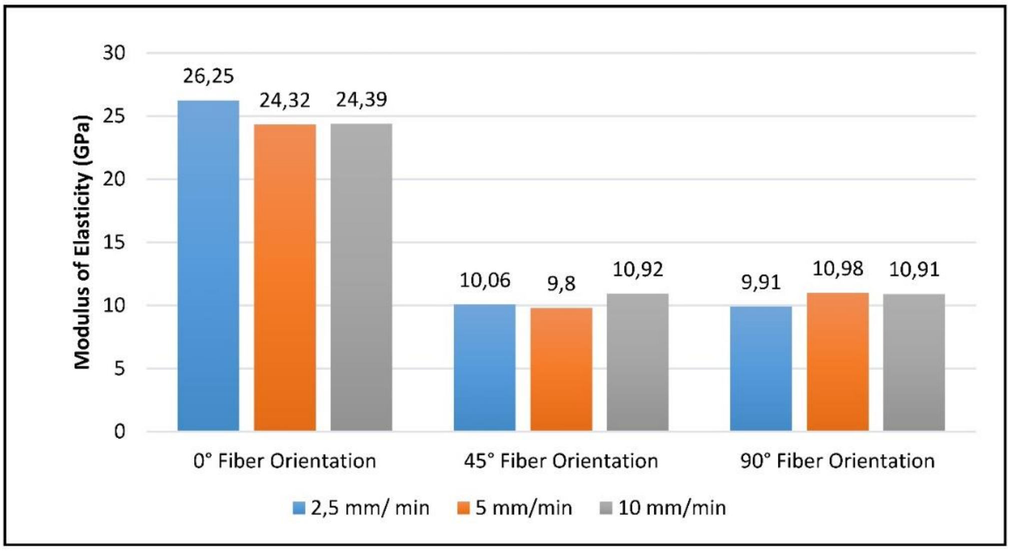


Figure 5. Modulus of elasticity of glass/epoxy composite at different strain rates

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