Journal of Al-Nahrain University **Vol.14 (1), March, 2011, pp.109-114** **Science**

Study Torsion Capacity of Epoxy -Glass Fiber Composites

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Abstract

In this study, torsion test was performed in order to examine the mechanical behaviors of epoxy and an epoxy reinforced by two types of glass fibers (chopped and yarn) composite rod. The stress-strain curves were constituted and examined in order to show the elastic and plastic regions, the yield point was 23.226^o and 34.837^o angle of twist for epoxy and epoxy /fibers respectively which is the same for both chopped and yarn glass fibers epoxy, from this test it was found that the epoxy rod initially yielded first, the cracks propagation in composite rod along the fibers direction, which caused eventually the delimitation of composite chopped and yarn glass fibers from the epoxy matrix. Then the white regions appear in composite rod and finally the fiber breakage and the catastrophic failure took place.

Keyword : Angle of torsion, static torque ,chopped and yarn glass fibers.

Introduction

Interfacial properties between fiber and matrix are very important to control the mechanical performance in composite materials[1]. Modern composites using fiber-reinforced matrices of various types have created a revolution in high-performance structures FRP composites have anisotropic properties i.e. properties apparent only in the direction of the fibers, while other traditional materials have isotropic properties i.e. uniform properties in all directions. The industrial application of composite materials is, generally, specific to the needs of operation and/or the environment, in which that operation takes place. Fiber reinforced composites are widely used in aircrafts, rockets and automotive structures for their advantage in lower weight with high strength and stiffness values. Composite materials such as fiberglass reinforced thermoset plastics have been used in piping systems for over 40 years now[2]. Advanced composite materials offer significant advantages in strength and stiffness coupled with light weight, relative to conventional metallic materials. Along with this structural performance comes the freedom to select the orientation of the fibers for optimum performance. Modern composites have been described as being revolutionary in the sense that the material can be designed as well as the structure .Glass fibers with polymeric matrices both for thermosetting and thermoplastic composites. It have been widely used in various commercial products such as piping, tanks, boats and sporting goods. Glass is by far the most widely used fiber, because of the combination of low cost relative to other composites, corrosion resistance, it has relatively low stiffness, high elongation, and moderate strength and weight, and in many cases efficient manufacturing potential [3].

It is used as a continuous fiber in textile forms such as yarn and as a chopped fiber in less critical applications composites suitable for most methods of resin impregnation and composite fabrication. These structures are designed so that the load is carried by the fibers and provide protection from the operating environment. Depending on the particular application of the composite, the fibers are commonly selected based on either high modulus, or high tensile strength, or a combination of the two [4]. Investigation of the fracture strength and fracture mechanism of the fiber/matrix interface are extremely important, because the mechanical properties of the fiber reinforced composites depend strongly not only on the properties of the fibers and the matrix but also on the an interfacial adhesion is an important factor in determine the mechanical performance of fiber reinforcement composites [5]. This research evaluates the effects of length and direction of glass fiber on the static torsion test of two different categories of structural fibers: chopped and yarn of glass fiber. The most notable test that demonstrates the effects of shearing forces and resulting stresses is the torsion test of a solid circular bar or rod. As a matter of fact, this test generates a state of pure shear stress in the torsional loaded rod. Such a test is used to ascertain all the major shear properties of materials, i.e., the ultimate shear stress, the yield shear stress and the modulus of rigidity or shear modulus.

Torsion Theory

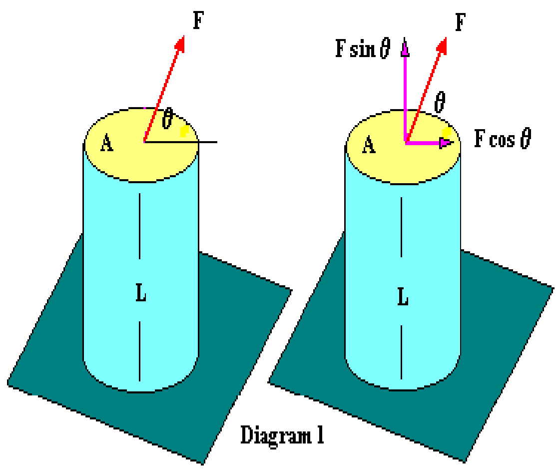
In solid mechanics, torsion is the twisting of an object due to an applied torque. In circular sections, the resultants shearing stress is perpendicular to the radius [6, 7].

ShearStress

In additional to axial (or normal) stress and strain may also have what is known as shear stress and shear strain. In diagram 1shown a rod which is solidly attached to the floor. then exert a force, F, acting at angle theta with respect to the horizontal, on the rod. The component of the force perpendicular to the surface area will produce an axial stress on the rod given by force perpendicular to an area divided by the area, or:

$\sigma = F \sin \theta \; / A$ ....(1)

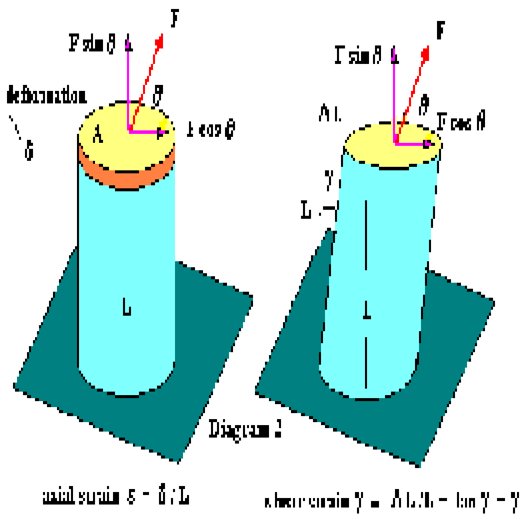
The component of the force parallel to the area will also effect the rod by producing a Shear Stress, defined as Force parallel to an area divided by the area, or: $\tau = F \cos\theta / A$ where the Greek letter, Tau, is used to represent Shear Stress. The units of both axial and shear stress will normally be lb/in^2 or N/m^2 (Pa).



ShearStrean:

Just as an axial stress results in an axial strain, which is the change in the length divided by the original length of the member, so does shear stress produce a shear strain. Both axial strain and shear strain are shown in diagram 2. The shear stress produces a displacement of the rod as indicated in the right drawing in diagram 2. The edge of the rod is displaced a horizontal distance, **ΔL** from its initial position. This displacement (or horizontal deformation) divided by the length of the rod L is equal to the Shear Strain. Examining the small triangle made by **ΔL, L** and the side of the rod, we see that the Shear Strain, **ΔL /L** , is also equal to the tangent of the angle gamma, and since the amount of displacement is quite small the tangent of the angle is approximately equal to the angle itself. Or we may write:

Shear Strain = $\Delta L / L = \text{Tan}\, \gamma = \gamma$



The applied torque (T) to the specimen and resulting deformation (angle of twist θ) are measured during the torsion test. These measured are converted to shear stress (τ) and shear strain(γ) by the following respective equations:

$$\tau = \frac{Tc}{J} \quad \text{...(2)}$$

$$\gamma = \frac{qc}{L_0} \quad \text{...(3)}$$

where c is the radius of the solid circular rod, L_o is the length over which the relative angle of twist is measured (*this angle must be in radians*) and J is the polar moment of inertia defined as follows:

$$J = \frac{\pi}{2} c^4 \quad \text{...(4)}$$

The shear modulus of elasticity is defined as the linear slope, of the shear stress-shear strain relation, between zero shear stress and the proportional limit shear stress (defined below), i.e.,

$$G = \frac{\Delta\tau}{\Delta\gamma} \quad \text{...(5)}$$

Static Torsion Test

The effective torque is recorded with aid of a reference rod equipped with strain gauges. The torque is directly displayed on a digital display of a strain gauge measurement amplifier.

Technical Description:

The apparatus as shown in Fig.(1) consists mainly of:

(1)-loading device with scale and revolution counter for twisting angle measurement.

(2) Torque measurement unit a digital toque meter (6).

(3)-Calibration device.

(4)-The specimen is mounted between the loading device (1) and the torque measurement unit (2) into hexagon sockets. All components are mounted on a track base (5).

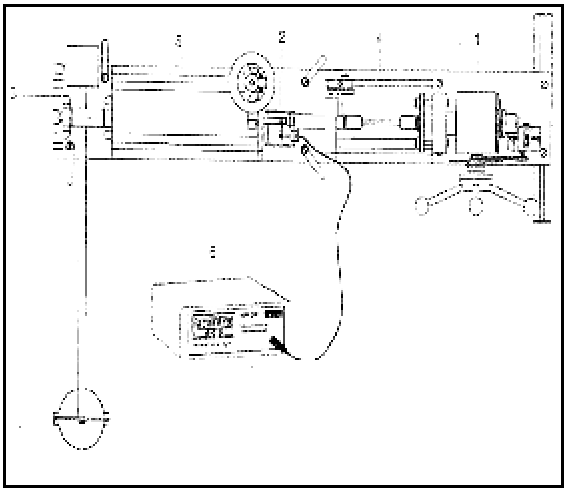


Fig. (1) Installation of Mechanism of Static Torsion Test

Experimental procedure:

Materials and testing procedure

The material used to prepare the test samples were epoxy resin (EPI0 Conbextra) with the hardener aliphatic amine (Hy 956) reinforced by E-glass fiber chopped randomly orientation and yarn types were aligned parallel to the axis of the rod, E-glass fiber density 2.5 g/cm^3. In order to obtain a composite, E-glass a filler should be added to epoxy resin in the filler by hand lay out method was used to prepare specimens as shown in Fig. (2).

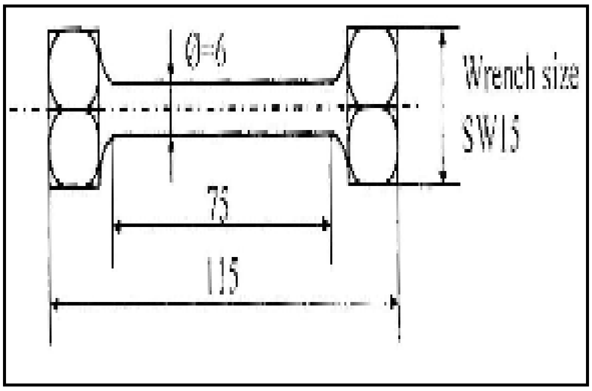


Fig. (2) Configuration and Dimensions of Torsion Test Specimen.

Fig.(3) shows three types of rod specimens were prepared for epoxy and an epoxy composite with chopped and yarn glass fibers before torsion test.

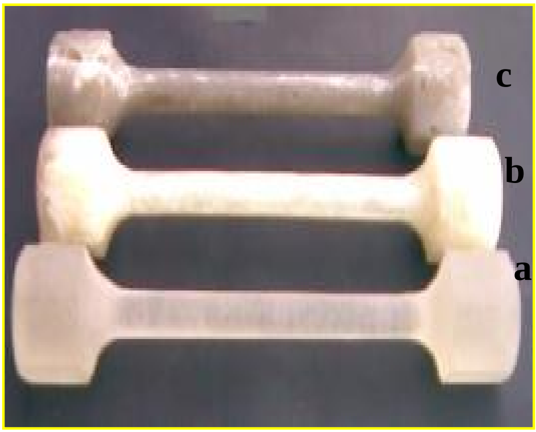


Fig. (3) A-epoxy , b-epoxy /chopped glass fiber composite c- epoxy /yarn glass fiber composite static torsion specimen.

Result and Discussion

Three types of curves were shown in Fig.(4) of the torque as a function of twist angle response of epoxy, an epoxy chopped and yarn glass fiber.

In empirical it was observed that by increase the static torque for epoxy rod until is reach 0.55 N.m , and the corresponding angle of twist from Fig. 4 is approximately 23.226^o, at this region the epoxy rod still in elastic limit and a linear relation between the applied torque and angle of twist, after this point the epoxy rod material enter in non elastic region from this test it was found that the epoxy rod initially yielded first, followed by the crack propagation in composite rod along the fiber direction. The behavior of composite rod till 34.837^{o} angle of twist is the same for both chopped and yarn glass fibers epoxy, with static torque is 0.9 and 1.33 N.m respectively. Fibers are the principal constituent in a fiber-reinforced composite material. They occupy the largest volume fraction in a composite and share the major portion of the load acting on a composite structure. Orientation of fibers is very important and long fibers in various forms are inherently much stiffer and stronger than the same material as a chopped and in neat form. Chopped fiber composites have short fibers randomly dispersed in the matrix, considerably poorer than of long fibers composite [8].

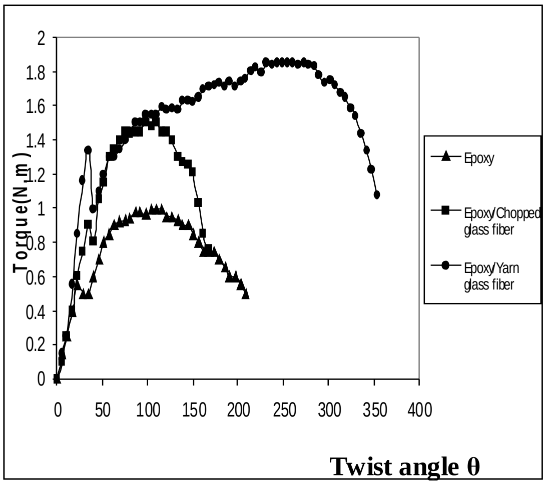


Fig. (4) Shows the torque- twist angle curves of epoxy and an epoxy chopped , yarn glass fiber rod.

Shear stress can result and eventually lead to a crack and fracture. Very short linear elastic stage implies that plastic deformation begins very early from the sample surface where there are maximum normal and shear stress was shown in Fig.(5). From torsion test it was found by increase the shear stress until reach maximum point 2.73 Pa was shown in Fig.(5). That the epoxy rod initially failure first as shown in Fig. (6. a) due to the deformation are the joints of molecular chains of epoxy matrix along the torsion axis and cross link bonds broken. The quick and continual fracture of the epoxy /chopped composite rod results in a sharp drop of increase the stress after maximum point 2.57 Pa as shown in Fig. (5). Once rupture occurs on one or several chopped, the neighbor chopped glass fiber will be loaded with higher stress. This must lead to quick fracture of the neighbor chopped glass, followed by the crack propagation in epoxy /chopped composite rod catastrophic failure took place as shown in Fig. (6. b).

The plastic deformation results from the rods stretching, rotating and moving in the mesh structure for epoxy yarn glass fiber as shown in Fig. (6. c). The obstacles for the deformation are the joints of molecular chains of epoxy matrix, adhesion between epoxy and fiber, the friction between fibers, and the deformation resistance of the fibers. Once a twisted yarn is completely stretched and oriented towards the torsional direction, further torsion strain needs the yarn plastically to be elongated, which also contributes to the ‘‘work-hardening” effect work hardening is a consequence of plastic deformation, a permanent change in shape. Due to the stress gradient across section, the plastic deformation begins from the surface and spreads towards the center progressively as torsion. With the yielding progressing, the mesh structure deformation in above mechanism (rod stretching, rotating and moving) will repeatedly occur. The strain resistance described above will play an effective role in the progressing deformation.. The sample’s failure begins when the maximum normal stress on the surface reaches the fracture strength of the glass fiber. Since almost all the yarn on the surface are stretched and oriented towards the torsion direction at the late stage, each yarn will bear similar stress. This eventually caused the delimitation of composite layers from the epoxy rod, then the white regions appear in epoxy/yarn composite layers and finally the fiber breakage along the fiber direction. It might be due to reduced interfacial adhesion between E- glass fiber and epoxy and micro cracks were growth and prorogate along the direction of fiber [9, 10].

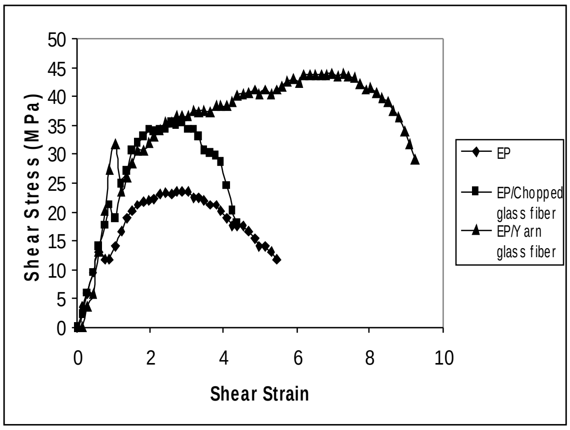


Fig. (5) Shear Stress as a function of Shear strain for epoxy and an epoxy chopped, yarn glass fiber rod.

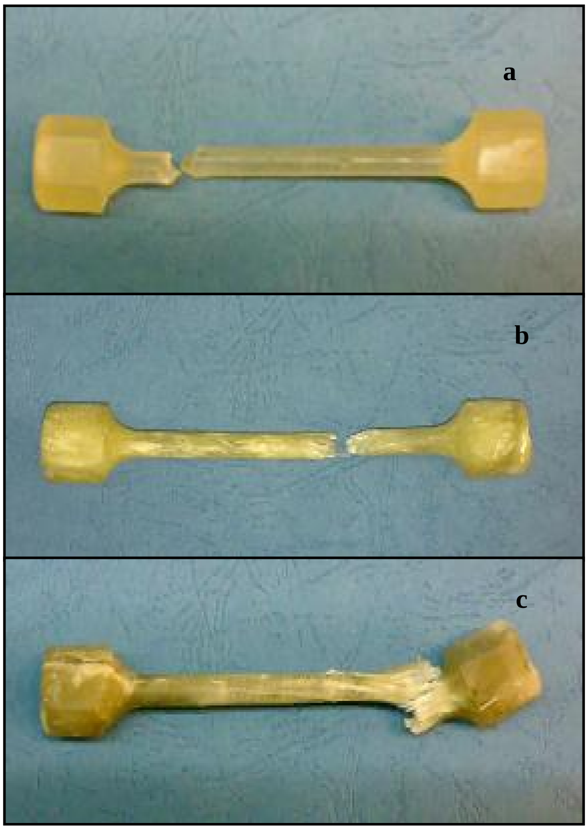


Fig. (6) Failure Modes of(a) epoxy rod (b) Ep/Chopped rod (c) Ep/Yarn rod.

slipped shape as shown in Fig. (6) was indicates that the fractured plane is not perpendicular to the fiber but declined with an angle, which would affect the stress transfer from one fragment to another respond less strain for epoxy compared to the same applied load means can withstand more load.

The shear modulus G capability of epoxy respond less strain compared to the epoxy chopped glass fiber and for epoxy yarn glass fiber as shown in Table (1) for same applied load .

Table (1)
Shear modulus of epoxy and epoxy/chooped and yarn glass.

Sample	*G(MPa)*
Ep	20
Ep/choppe glass	22
Ep/yarn glass	30

Reference

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الخلاصة

تم في هذه الدراسة انجاز فحص عزم الالتواء لفحص السلوك الميكانيكي للايبوكسي ومتراكباته المدعمة بنوعين من الياف الزجاج (مقطع وخيوط), وتبين من انجاز منحيات الاجهاد- الانفعال كل من المناطق اللدنة والمرنة وكانت نقطة الخضوع23.2260و34.8370 للكل من الايبوكسي ومتراكباته على التوالي حيث انها متشابهة لايبوكسي-الياف زجاج مقطع وخيوط, ومن هذا الاختبار وجد ان قضيب الايبوكسي يخضع اولا وان الشقوق تاخذ بالانتشار على طول وباتجاه االالياف في القضيب المتراكب مما يتسبب انفصال الياف الزجاج المقطع والخيوط من الايبوكسي وبالتالي تظهر مناطق بيضاء في قضيب المتراكب ثم ينكسر الليف وبذلك يحل الفشل.