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Research paper

Torsional Stresses of Composite Fiberglass at High Shear Strain Rate

Fadhel Abbas Abdulla*[1], Waad Adnan Khalaf[2]

Iraq, Baghdad, Al-Mustansiriyah University College of Engineering, Mech. Eng.Dept
**Corresponding Author E-mail: Fadhel975@yahoo.com*

Abstract

Using Torsional-Split-Hopkinson-Bar (TSHB),the dynamic behavior of pure epoxy that reinforced with random (shape) fiberE glass using five twistedangles (4˚, 6˚, 8˚, 10˚ and 12˚) was investigated experimentally. The fiber used in this work was Threads of fiber (140 mmlength).A new clamp system mechanism is used in this work.Using three volume fraction (55, 40 and 25%), the composites samples were prepared. The results show that, the increasing shear strain rate for all types of these samples causes increasing in maximum shear stress, and shear strain. At angles of twist ϴ=12˚, when the volume fraction increased from 25% $V_f$to 40% V_f, the shear strain, shear strain rate and shear stress are increased by 12.4%, 18.9%, and 12.5%respectively, as well when the volume fraction increased from 40% $V_f$to 50% V_f, the shear strain, shear strain rate and shear stress increased by 8.7%, 6.4%, and 5.5% respectively. The shear stress and shear strain for fiber E glass- epoxy composite sample at 55 volume fractionand 594 stain rate are 61 Mpa and 5.1 respectively.

Keywords: *Composite Materials,High Shear Strain Rate,HopkinsonBar.*

1. Introduction

High strain rate shear testing is encountered in several types of processing operations, such as punching operations and grinding operations, machining processes, forming processes and penetration (K. Howard and M. Dana (2000) [1]). Air force massive ordnance air blast bomb and air force delta II rocket are examples of the military applications for the United States Air Force that benefit from testing with split-Hopkinson-torsion-bar (] L. Fuentes, J. Gomez-Leon, and C. Trujillo (2012)[2]). The technique of Hopkinson was first usedin compression test of materials, later on extended to torsion and tension (W. Chen and B. Song (2011)[3]). The torsional Hopkinson bar is a reliable apparatus for testing materials in the 10^2 to $10^4 s^{-1}$ strain rate regime. The torsional Hopkinson bar is consisting of two bars (transmitter and incident bars) propped by bearings which permit them to rotate easily. A specimen is placed between transmitter and incident bars (thin wall tube). By release of the torque which is firstly stored at the bar between loading-end and clamp system, the loading-wave in the incident-bar will begenerated (C, G.-A. Stefan et.al. (2015) [4]).

A. Gilat and C. S. Cheng (2002) [5] worked in the bases of modeling the Hopkinson- split-bar-torsion experiments at rates of strainabove$10^3\ s^{-1}$. Finite-element-methodwas used to investigate the material response by Hopkinson- split-bar-torsion apparatus in which rate of strainabout $10^4\ s^{-1}$ is reached through utilizing samples with very short gage length. Strain-stress curves which are acquired in this method from bars elastic-waves, by assuming pure and uniform shear-stress and deformation in gage length, have some errors but, supply a satisfactory estimation for the response of material. F. Barthelat et al. (2004) [6] presented experimental-methodology for the dynamic torsion and quasi-static tests of nano, and micro-structured coating for (Tungsten carbide cobalt WC-Co, and Aluminum Titanium Oxide Powder Al_2O_3-TiO_2) coating, at aluminum substrates utilizing speckle photograph. The field of displacement given by method ofspeckle correlation permitted the identification of mechanism of deformation, i.e., crack propagation and early crack bridging by ductile aluminum-substrate. There are small changes in strength and modulus are foundedbetween micro, andnano-structured material, but final changes between micro, and nano-structured material are maybe disguised by the first damage in coating, as observed on Scanning Electron Microscope and optical pictures. A. Gilat et al. (2007) [7] carried out a study to investigate the mechanical response for (PR-520 and E-862) epoxy-resin in the shear, and the tensile loading. On two sorts of the loading, two types of resins are experimented at the strain-rate about 450 to 700, 2, 5x$10^{-5}/s$. Results, display that, toughened (PR-520) can carry greater stresses than untoughened (E-862). Toughened (PR-520) has greater maximum-stress in the shear and greater failure-stress in the tension, compared with untoughened (E-862). M. N. Bassim (2007) [8] used Armor materials to evaluate high strain rate. They include Rolled homogeneous armor steel plate, 5083 aluminum alloys and ceramics. It used both direct impact, Hopkinson-compressive-bar, and split-torsional-Hopkinson-bar. Specimens were examined to determine the microstructural evolution during impact. Microstructural evolution in the materials during high strain-rate deformation is also investigated. Occurrence of adiabatic shear bands shows considerable influence on dynamic stress-strain curves for the materials and cause failure at high-strain-rates. Results refers to that the strain-rate in this study in excess of ($10^3 s^{-1}$). High strain rate effect on the shear-properties of (epoxy LY-556) with (hardener HY-951) have been studied by N. K. Naik et al. (2010) [9] used split-torsional-Hopkinson-bar machine for experimental studies in shear-strain-rate range about (385–880/sec). For comparison, investigations are conducted at quasi-static device.

It was observed which, shear-strength is improved below high-strain-rates loading, compared to quasi-static loading. Shear-strength improvement at shear-strain-rates about 880/sec is 45% compared with that, at quasi-static loading. G.-l. Nicolaescu et.al. (2015)[4] studied torsional testing at the high-strain-rate using a kolsky bar.The test specimen is made from CW614N Brass and is a short thin wall tube. The results showed that the shear strain rate is about ($1200\ s^{-1}$), the maximum shear strain in excess of (0.4) and the maximum shear stress in excess of (300 MPa). Also, the maximum strain in excess of (0.2), the maximum stress in excess of (615 MPa) and the strain rate in excess of ($613\ s^{-1}$).The aim of this study is design, and construction the split-Hopkinson-torsion-bar machine, the most important characteristic of the torsional-split-Hopkinson-bar machine is a clamp system responsible of dynamic torsion process. Also, test samples from different types of composite materials and identify the dynamic torsional behavior for these materials when subjected to shear stresses at high shear strain rates. In addition, verify the experimental results by using Johnson- Cook model.

To calculate shear-strain, shear-strain-rate and shear-stress, the analytical relations as a function of time for the specimen are **[8]**:

The expression for the specimen shear stress:

$$\tau_s(t) = \frac{GD^3}{8{D_s}^2 t_s}[\gamma_T(t)] \quad (1)$$

Where G is modulus of shear of the bar, D is the bar diameter, t_s is the gage thickness of the sample, D_s is the mean diameter of gage of the sample and $\gamma_T(t)$ is the shear strain at the transmitter bar.

The expression for the specimen shear strain:

$$\gamma_s(t) = \frac{2C_S D_S}{L_S D}\int_0^t \gamma_R(t)\,dt \quad (2)$$

$$C_s = \sqrt{\frac{G}{\rho}} \quad (3)$$

Here $C_s$is shear wave speed in bar material, ρ is the density of the bar,L_s is the length of gage of the sample, and $\gamma_R(t)$ is the shear strain reflected to the incident bar.

The expression for the specimen shear strain rate:

$$\dot{\gamma}_s(t) = \frac{2C_S D_S}{L_S D}[\gamma_R(t)] \quad (4)$$

Thus, the shear stress- shear strain behavior of specimen is determined simply by measurement made on the elastic wave in Hopkinson torsional-split- -bar. The above equations relate strain gauges measurement to shear-strain -shear-stress behavior in the specimen deformation and require that the wave within the bar must be one dimensional and the specimen must deform uniformly.

2. Experimental Work

2.1 Experimental Set-Up:

In this work, the torsional-split-Hopkinson-bar is designed for the dynamic behavior of various materials at the high-shear-strain-rate. It consists of a clamp system, torque generating mechanism, transmitter, and incident bars, the brackets, fixing and data acquisition system that consist of: four strain gages (foil type, 120 Ω, gage factor=2) bounded on the incident and transmitted bars, Wheatstone bridge, amplifier circuit, digital oscilloscope and personal computer. The TSHB apparatus is shows in figure (1). The calibration was done for data comes from strain gauges.

The clamp system consists of two arms that are held together at the top by a load release pin. The clamp is tightened by two large bolts that pushes the lower ends of the clamp arms together. After the desired torque is loaded between the torque wheel and the clamp, the bolts pressure is increased until the load release pin is broken and the stored torque will be released. The shape of the clamp system was shown in figure (2). The operating of the clamp system depends on the bolts instead of hydraulic pump or linear actuator utilized in most machines. This allows flexibility for the testing, easy operating mechanism and releasing the stored torque for test. The torque generating mechanism consists of a torque wheel is made of cast iron. Cast iron bushing is used to fix the incident bar, is machined and welded into the torque wheel. The torque wheel tightened to the incident bar by ten screws. A shaft is welded on the torque wheel to help in turning it. A two hydraulic jack, the first is used to rotating the torque wheel and the second is used to fixing the torque wheel and prevent it from movement after apply the angle of twist; the shape of the torque generating mechanism. Five angles of twist (4,6,8,10,12°) are used in this work.

The brackets are the structural member that is used in the setup to hold the transmitter bars and incident and to avoid the bending. The brackets are made of two plates (low carbon steel) are welding together, teflon bushing is used to support the bar is machined and fitted into the bracket. To fix the transmitter-bar and stop it from moving, the fixing is used which is made of two plates (low carbon steel) are welding together, low carbon steel bushing is used to fix the transmitter bar, is machined and welded into the fixing. The transmitted-bars and incident are all made of 7075 aluminum-alloy.

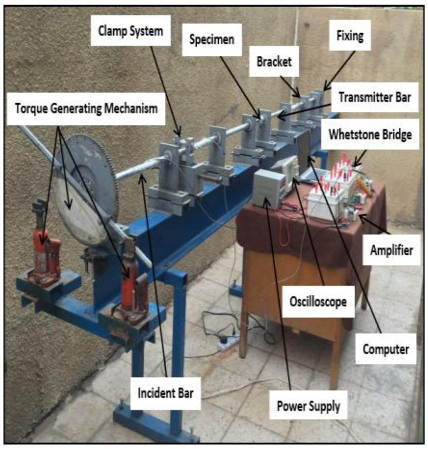


Fig. 1: Photographs of the Torsional Split Hopkinson Bar

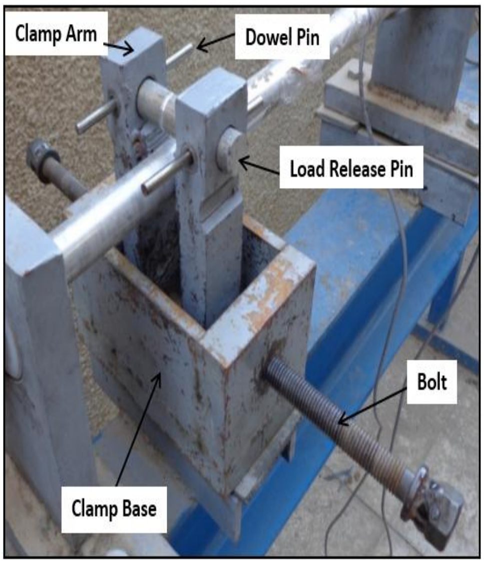


Fig. 2: The Clamp System

2.2 Material Properties:

In present work, random fiber E glass with 25%, 40% and 55% $V_f$with epoxy resin are used to prepared samples. Table (1) describes the experimental properties of epoxy resin and fiber Eglass.

Table 1: List of Epoxy resin Fiber E Glass Properties

Properties	Fiber Eglass	epoxy
Density (gm/cm^3)	2.54	1.1
Tensile strength (MPa)	3450	25

2.3 Specimens Molding:

1. Measuring the epoxy resin by electronically balance.
2. A hollow tube glass mold of (*18 mm diameter and 140 mm length*) with unlocked end is used in this work. Lubricating the tube from inside byoil and placing the fibers (140 mm) in glass-mold in homogenous shape to cover most sample volume, as shown in figure (3).
3. Adding the epoxy with the hardener inside the molding.
4. The composite was left in mold for (6) hours at room-temperature to harden.
5. Lastly, test samples will be submitted to notching, cutting, and drilling processes.

Fig. 3: The Fibers in the Glass Mold

2.4 Specimens Machining:

The specimens are cut, notch and drill by using a lathe machine to get the final shape and dimensions of specimens. The shape of the notch is square and place of the notch in the middle. The dimensions of a composite thin-walled cylindrical sample in this work are 18 mm outer diameter (*Do*), 8 mm inner diameter (*Di*), 12 mm gage mean diameter (*Ds*), 14 mm overall length (*Lt*), 3.5 mm gage length (*Ls*) and 2 mm wall thickness (*ts*); the final shape of specimen is shown in figure (4). In the previous work of TSHB, there are different dimensions of specimen [4,8]. In this work, the dimensions of specimens are based on this different for dimensions of the previous work. Three test was repeated for every test to take the average value.

Fig. 4: The Final Shape of Test Specimen.

3. Results and Discussion

Figure (5) shows the relationship between shear strain and dynamic shear stress at different rates ofshear strain of epoxy samples.From this figure, it can be seen that, increasing twist angle from 4˚ to 12˚ (means increasing$\dot{\gamma}$), causesincreases inthe shear-stress, shear-strain and shear-strain-rate by 27.8%, 42% and 35.9%, respectively. The reason for these increases is due to, the increasing in the stored energy led to increase in transmitted (released after the clamp system) energy to the sample.

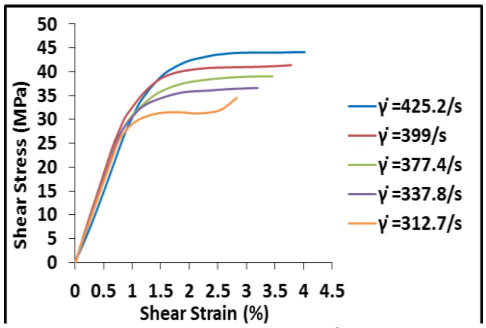


Fig. 5: Stress-Strain Curves of Epoxy

Figure (6) shows the effect of volume fraction of the random fiber E glass-epoxy composite on the shear stress-shear strain behavior at maximum and minimum angle of twist. From this figure at ϴ=12˚, when the volume fraction increased from 25% $V_f$to 40% V_f, the shear strain rate, shear strain, and shear stress are increased by 18.9%, 12.4%, and 12.5%, respectively, as well when the volume fraction increased from 40% $V_f$to 50% V_f, the shear strain rate, shear strain, and shear stress increased by 6.4%, 8.7%, and5.5% respectively. It is evident that, the increase in volume fraction led to increase in magnetic force between atoms, and then the sample became stiffer and possessed higher strength. These indicate that improvement of the properties and the dynamic shear behavior of the materials occur when subjected to dynamic load at high shear strain rates.

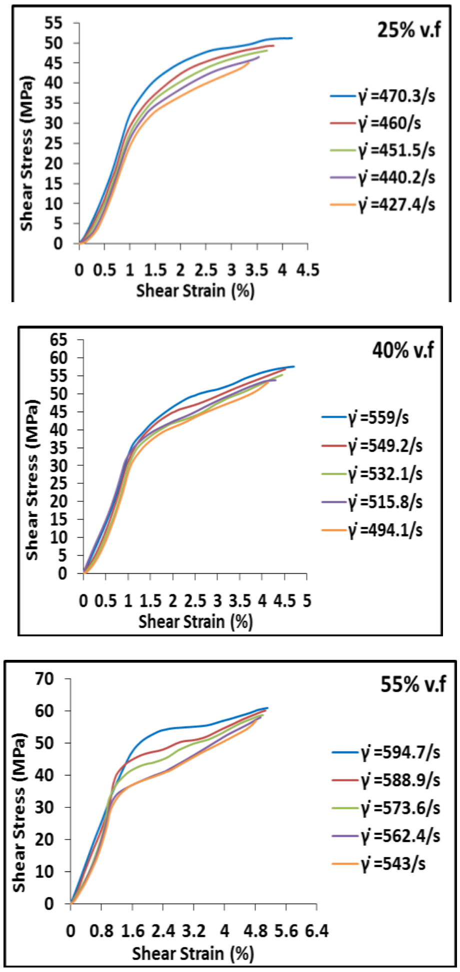
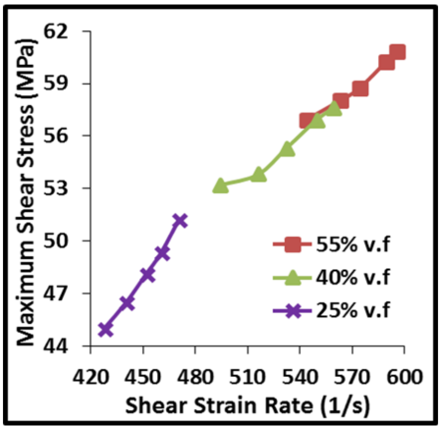


Fig. 6: Stress-Strain curves for Random Fiber E Glass-Epoxy-Composite with different Volume-Fraction

The variations of maximum shear stress and maximum shear strain for random fiber E glass with different volume fraction show similar behavior to those of other cases, as shown in figure (7). The shear strain and shear stress increased with increasingrate of shear strain because the increase in the stored energy led to increase in applied torque to the test specimen. Moreover, the maximum values of shear strain and shear stress at maximum rate of shear strain of 594.7/s, are obtained in the 55% $V_f$random fiber E glass, the maximum shear stress and maximum shear strain are 60.8 MPa and 5.12 %, respectively.



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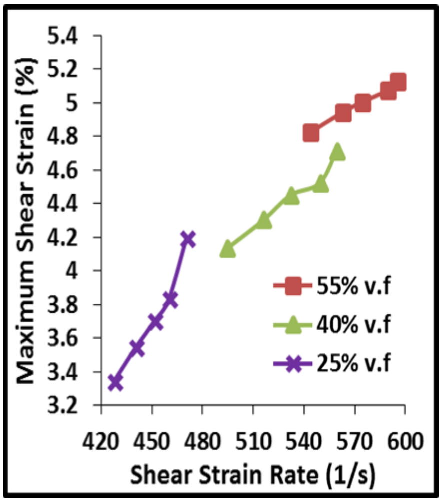

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4. Conclusions

Tests have been carried out with split-Hopkinson-bar machine specially designed for the dynamic torsional tests. The design and construction of the TSHB with its new clamp system mechanism (two bolts) proved to be successful and permitted conducting tests in an easy and simplified method.

The fiber E glass composite samples with 55% volume fraction givesstrain rate,shear stress, and shear strain greater than samples with volume fraction (40 and 25%)

The samples of random fiber E glass composite at volume fraction (55%)improved the shear stress by 37.9% compared with pure epoxy at θ=12˚.

At ϴ=12˚, when the volume fraction increased from 25% $V_f$to 40% V_f, the shear strain rate, shear strain, and shear stress, are increased by 18.9%, 12.4% , and 12.5%respectively, as well when the volume fraction increased from 40% $V_f$to 50% V_f, the shear strain rate, shear strain and shear stress increased by 5.5%, 6.4%, and 8.7% respectively.

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