Composites Part B 100 (2016) 125–135

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Effect of high strain rate on glass/carbon/hybrid fiber reinforced epoxy laminated composites

K. Naresh [a], K. Shankar [a], B.S. Rao [b], R. Velmurugan [c, *]

[a] Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India
[b] Aeronautical Development Agency, Bangalore, India
[c] Department of Aerospace Engineering, Indian Institute of Technology Madras, Chennai, India

ARTICLE INFO

Article history:
Received 30 January 2016
Received in revised form
25 May 2016
Accepted 3 June 2016
Available online 6 June 2016

Keywords:
Polymer-matrix composites (PMCs)
Mechanical properties
Fractography
Compression moulding
Digital image correlation technique

ABSTRACT

Composites are efficient to deal with tensile loads than metals. Now-a-days, metals are replaced with composites owing to their higher strength to weight ratio and are extensively used in aircraft wing and fuselage structures. These structures are subjected to high strain rates during impact loadings, such as bird hit or run-way debris impact. In order to design robust composite structures, it is important to understand the strain-rate-dependent behavior of composite materials. In this study, influence of strain rate on the tensile properties of glass/epoxy, carbon/epoxy and hybrid (glass-carbon/epoxy) composites are experimentally and theoretically investigated in the range of strain rates from 0.0016 s^{-1} to 542 s^{-1}. Drop mass setup is used for high strain rate tests. Quasi-static tests are performed on Instron universal testing machine in accordance with ASTM D638. The results indicate that the tensile strength and tensile modulus of GFRP and hybrid composites increase and percentage of failure strain for GFRP, CFRP and Hybrid composites decreases with the increase in strain rate, whereas tensile strength and tensile modulus of CFRP composites remains approximately constant. The scanning electron microscopy is used for analyzing the failure modes of the failed region (surface) of the tested specimens. Non contact DIC system is used to capture the strain field with the help of high speed camera.

1. Introduction

Now-a-days, the use of composite materials is increasing very rapidly and particularly their use in aerospace, defense and automotive applications are inevitable, because of their superior structural properties. At the same time, many accidents occurred because of structural failures of components due to a bird hit on the aircraft, runway debris hit on gas turbine blades and many accidents in road and rail vehicles. Therefore a complete characterization of composite materials is very much required for the reliable design of structural components. Some of the experimental techniques are helpful to characterize the rate dependent behavior of the composite materials. The experimental techniques for dynamic loading are mainly categorized based on the final parameters to be tested which include, tensile, compression and shear loading and the range of strain rate experienced during testing. Koerber et al. [1] presented experimental study of the strain rate effect on unidirectional carbon/epoxy composites for strain rates up to 350 s^{-1} using SHPB. The in-plane strain field of the specimen was obtained by the digital image correlation technique by using a high speed camera. Brown et al. [2] studied the tensile, compression and shear behavior of commingled, woven E-glass/polypropylene composites for the strain rate range of 10^{-3} s^{-1} to 10^{2} s^{-1} using the universal testing machine and falling weight drop tower. It was observed that there was an increase in the compressive and tensile modulus and strength with increase of strain rate. However, the shear modulus and shear strength decreased with increasing strain rate. Okoli et al. [3] worked on high strain rate characterization of glass/epoxy composites under tensile and shear loading. It was reported that there was an increase in the mechanical properties such as tensile strength, shear strength, tensile modulus and shear modulus for the increase of strain rate. Duan et al. [4] investigated the mechanical properties of continuous, Glass Fiber Reinforced Polypropylene composites for the strain rates of 0.001 s^{-1} to 50 s^{-1}. They observed that ultimate strength and failure strain increase with the increase of strain rate. Ochala et al. [5] compared the

* Corresponding author.
E-mail address: ramanv@iitm.ac.in (R. Velmurugan).

http://dx.doi.org/10.1016/j.compositesb.2016.06.007
1359-8368/

dynamic compression response of GFRP and CFRP composites for the strain rates of 10^{-3} s^{-1} and 450 s^{-1} by using servo hydraulic machine and SHPB, respectively. It was observed that the compressive strength for GFRP increased with increasing strain rates and not much change of CFRP. The failure strain for both GFRP and CFRP decreased with increase in strain rates. Gilat et al. [6] investigated the strain rate effect on the tensile properties of carbon/epoxy material by using modified SHPB. The identical specimens with different orientation (90°,10°, 45°, $[\pm 45°]_s$) were tested at strain rates of 10^{-5}, 1 and 400–600 s^{-1}. It was observed that in all the configurations stiffness increased with increasing strain rate. Elanchezhian et al. [7] studied the mechanical behavior of CFRP and GFRP composites for different temperatures and strain rates. They observed that the CFRP composites have better tensile and flexural properties compared to GFRP composites. Guedes et al. [8] have used unidirectional laminates for uniaxial compression tests on a universal testing machine at the strain rates of 0.07, 0.001 and 0.0001 s^{-1} and developed a 3-parameter constitutive viscoplastic model to describe the mechanical behavior. Experimental studies on the strain rate effect of glass/epoxy/clay nanocomposites, in the strain rate ranges from 0.0016 to 450 s^{-1} were studied [9]. It is found that the glass/epoxy composite is strain rate sensitive and reveals that the tensile modulus and strength increase as the clay loading increases. Alemi-Ardakani et al. [10] have conducted experiments on twill woven glass/polypropylene composite laminates under the impact energy of 200 J using the drop weight machine and Abaqus/Explicit was used for modeling the laminate through Hashin progressive damage criterion and showed reasonably accurate results. Rotem and Lifshitz [11] studied the effect of strain rate ranges from 10^{-6} to 30 s^{-1} on the tensile behavior of unidirectional glass/epoxy composites. They found that the dynamic strength and modulus increased by 3 times and 50%, respectively, with respect to the static strength and modulus. Our studies [12,13] show that with the addition of clay the tensile modulus and strength increase even at low strain rates as strain rate increases for both epoxy and glass/epoxy nanocomposites. Naik et al. [14] described hybrid composites (glass-carbon/epoxy) reduced notch sensitivity and improved impact resistance. Zweben [15,16] has used hybrid (“Kevlar” 49 aramid – “thornel” 300 graphite/epoxy) composites for his study and found that the tensile failure strain and fracture toughness have increased for the hybrid effect. Hybrid composites are mainly used to obtain the combined advantages of two or more types of fibers or matrices or both and at the same time mitigating their less desirable properties [17]. There are only few studies on the strain rate effect of hybrid (glass-carbon/epoxy) composites. Carbon/epoxy composite is stiffer material and less sensitive to strain rate, but glass/epoxy composite is more sensitive to strain rate. The combination of these two fibers will make a laminate which is sensitive and stiffer to impact loading. Hence, in the present study in addition to glass/epoxy and carbon/epoxy composite we have used hybrid (glass-carbon/epoxy) composite material to characterize the tensile behavior for different strain rates.

The present research work is to investigate the influence of strain rate, in the range of 0.0016 s^{-1} to 542 s^{-1}, on the tensile strength, tensile modulus, and failure strain of glass/epoxy, carbon/epoxy and hybrid composites. The results obtained in this investigation show that the percentage of failure strain for GFRP, CFRP and hybrid composites decreases and the tensile strength and tensile modulus of GFRP and hybrid composites increase with the increase in strain rate, whereas tensile strength and tensile modulus of CFRP remains approximately constant. Theoretical studies show good correlation with experiments. The DIC system is useful to get the strain field at different levels of deformation.

2. Experimental setup

2.1. Drop mass setup

Drop weight impact machine is used for dynamic testing to produce strain rates from 10 to 1000 s^{-1} [18,19]. In this technique the weight is dropped from a pre-determined height to strike the test specimen located in the fixture. Height of falling weight along with the specimen geometry is responsible for achieving different strain rates. Load cells and non-contact strain measuring methods are used for calculating stress and strain respectively. The drop mass setup mainly consists of a base plate, a drop mass tower, an elevator, a magnetic holder and a fixture for holding specimen as shown in Fig. 1. The guide rods, which are made of hard chrome plated steel, are used to guide the falling mass. The falling mass is set at heights of 0.25, 0.5, 0.75, 1, 1.25 and 1.5 m to attain velocities of 2.21, 3.13, 3.83, 4.43, 4.95 and 5.42 ms^{-1} respectively. These velocities are responsible for nominal strain rates of 221, 313, 384, 443, 495 and 542 s^{-1} on the specimen. The schematic diagram of the drop mass tower and the specimen fixture is shown in Fig. 1.

The piezoelectric load cell (PCB 208C04) of capacity 5 KN is used to measure the applied load. The stress data is calculated by dividing load data with the cross section area of gauge portion. A high speed camera (Phantom V611) with a maximum resolution of 1280 × 800 is used for capturing images. At full resolution, we can achieve a speed of 6246 frames per second and at lower resolutions it can deliver up to 1, 00,000 fps. Due to the smaller area of interest, a high frame-rate of 100,000 fps is achieved at a resolution of 128 × 128 pixels with exposure time of 9.81 μs? The data acquisition system, NI PXI 1042 along with the lab view, is used for acquiring the load data from the load cell. Light emitting diode (LED) panel lights of 30 W capacity is used as a lighting system. Proper lighting is required to ensure better quality pictures.

3. Material selection and laminate preparation

Three types of composite laminates, viz glass/epoxy, carbon/epoxy and hybrid (glass-carbon/epoxy) are considered for the study. The E-Glass fibre, woven roving mat, plain weave, 610 gsm, from Shakthi fibre glass, Chennai, India and carbon fibre of plane weave type, 450 gsm and woven roving mat from Hindustan mills Pvt Limited, Pune, India are used. Epoxy (Araldite (LY556)) and Hardener (HY951) are used as resin system. The mixing ratios by weight for fibre to resin and resin to hardener are maintained as 1:1 and 10:1, respectively. The laminates of 300 × 300 mm with thickness of 2 mm are made by compression moulding technique. All the laminates are made with a layup of [0°/90°] orientation. Each layer of the laminate has an average thickness of 0.4 mm. The spacer of 2 mm thickness is used for maintaining thickness of the laminate and the straight fibre direction is ensured by taking proper care.

4. Specimen preparation and geometry

There are no specific data available on geometry of the high strain rate specimen for laminated composites, however, based on literature survey and by trial and error, the new specimen geometry (Fig. 2) is designed and validated by using the drop weight dynamic test.

It consists of a central zone with a constant width of 3 mm, gauge length of 10 mm and both ends with a hole of 4 mm diameter. Width from the central zone to ends increases gradually with a circular curve of radius 5 mm. The dimensions of reference geometry are established by trials and the dimensions are in accordance with ASTM D638.