Composites Communications 3 (2017) 7–10

Contents lists available at ScienceDirect

Composites Communications

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

Effect of loading rates of severely thermal-shocked glass fiber/epoxy composites

Kishore Kumar Mahato*, Dinesh Kumar Rathore, Krishna Dutta, Bankim Chandra Ray

Composite Materials Group, Metallurgical and Materials Engineering Department, National Institute of Technology, Rourkela 769008, India

A R T I C L E I N F O

Keywords:
Thermal-shock
Loading rate
Residual stresses
Fractography

A B S T R A C T

Present investigation is aimed to study the effect of short term exposure of thermal-shock conditioning on the mechanical properties of glass/epoxy (GE) composites. The specimens were conditioned at −60 °C temperature for 36 h followed by further conditioning at +70 °C temperature for the same duration. In order to assess the effect of thermal-shock on the mechanical properties, tensile tests of the conditioned and unconditioned specimens were done with various loading rates viz. 1, 10, 100, 500 and 1000 mm/min. The ultimate tensile strength (UTS) as well as strain to failure were found to increase with increase in the loading rates at room temperature; the thermal-shocked conditioned specimens exhibited even higher UTS and failure strain as compared to the unconditioned specimens. It can be stated that different coefficients of thermal expansion during thermal-shock conditioning and significant amount of pre-existing residual stresses govern the stress distribution and ultimately the mechanical properties of glass/epoxy composite. Various dominating modes of failures in the composites were analyzed under scanning electron microscope.

1. Introduction

Fiber reinforced polymeric (FRP) composite materials are nowadays globally one of the main counterparts of the historic metallic materials used over various structural and construction field. FRP Composite possess excellent properties such as high strength to weight ratio, low density, high specific stiffness, high endurance limit, high fatigue resistance, high corrosion resistance over conventional metallic materials. These materials have an extensive field of applications in various sectors such as sporting goods, automotive, aerospace, marine, low temperature applications include cryogenic fuel distribution lines, cryogenic fuel tanks, cryogenic wind tunnels and different portions of the cryogenic turbo-pumps due to their ease of handling, lower fabrication cost and superior mechanical properties [1].

However, the effects of thermal-shock conditioning with loading rate, which are encountered in real service conditions, are more vulnerable on the overall properties of composites than reacted separately. In aircrafts and spacecrafts, the body parts are exposed to range of temperatures starting from troposphere region to the mesosphere region where temperature exists in between – 60 °C to + 30 °C. Also, during vertical take-off and landing (VTOL) aircrafts are highly subjected to temperature gradient during take-off and landing. Therefore, a comprehensive understanding is highly required in-service condition to access the mechanical behavior and various modes of failure in such safety critical applications. During fabrication, storage and in-service conditions these composites are subjected to different nature of stresses. The stresses acting on the FRP composite materials may be constant load or dynamic loading. Dynamic loadings can generate multi-axial stresses [2]. Under these multiaxial stresses, the failure circumstances and design aspects based on uniaxial strength criterion are not favourable and entirely reliable for woven fabric reinforced polymer composites [3]. The thermal mismatch between fiber and matrix phase leads to development of residual thermal stresses around the fiber/matrix interface or interphase regions when there temperature goes below the fabrication temperature [4]. Numerous studies have been carried out on the loading rate sensitivity of the glass/epoxy composites in room temperature as well as at different elevated and low temperature environments. There are also limited studies which shows the effects of thermal shock on the mechanical properties of glass/epoxy composites [4,5]. But, there is dearth of literature on the loading rate sensitivity of thermal shock conditioned glass/epoxy composite. The sudden change in the in-service environment may possibly modify the polymer matrix and/or the fiber/matrix interphase and how these modifications alters the bulk mechanical performance of glass/epoxy composites under various rates of loadings have been presented in the present investigation. The situation becomes relatively more complex when the composite contains woven fabric reinforcement, which under uni-axial loading

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* Corresponding author.
E-mail addresses: kishorepce@gmail.com, 514MM1002@nitrkl.ac.in (K.K. Mahato).

http://dx.doi.org/10.1016/j.coco.2016.11.001
Received 25 August 2016; Received in revised form 4 November 2016; Accepted 18 November 2016

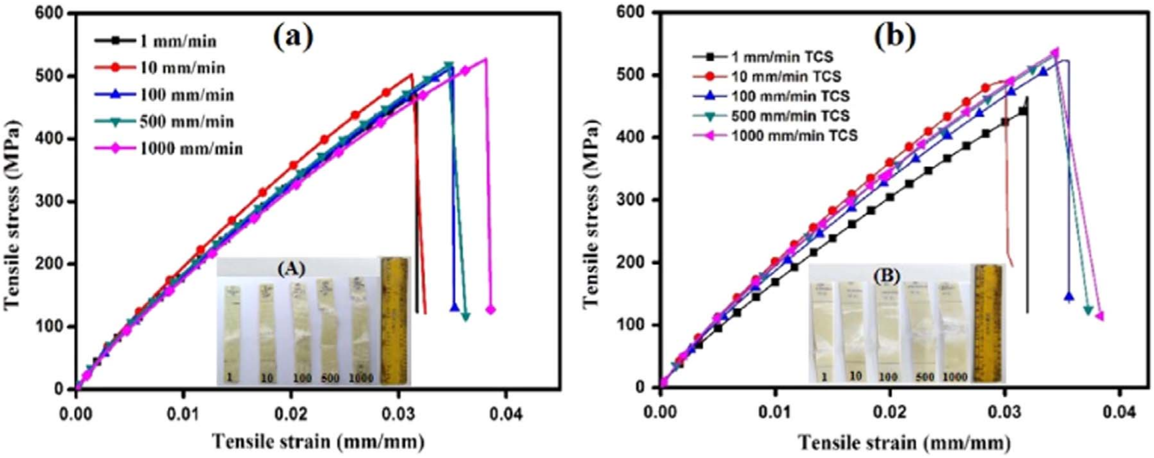

Fig. 1. Tensile stress Vs Tensile strain curve with 1, 10, 100, 500 and 1000 mm/min loading rates tested at (a) RT (30 °C) (b) Thermal-shock conditioned specimen.

experiences stresses in different directions. The thermal stresses develops in the FRP composite depends on the volume fraction of reinforcement, the amount of voids present and lack of adhesion between the polymer matrix and the reinforcement phase. The repetition of these non-reversible phenomena like thermal cycling causes permanent deformation. Thus, the reinforcement geometry stimulates the degree of thermal stresses in the matrix region would increase thermal fatigue resistance [5]. The current investigation is highlighted on the effects of thermal-shock conditioning and loading rates on the mechanical behavior of GE composite exposed to thermal shock environment (i.e. −60 °C for 36 h and then further conditioned to +70 °C for 36 h) with various loading rates.

2. Material and experimental

2.1. Materials

The experimental study comprises of fabrication of GE composite. The epoxy resin used having trade name Diglycidyl Ether of Bisphenol A (DGEBA) was used as matrix material and hardener having the trade name triethylene tetra amine (TETA). The reinforcement used in the experiment was woven fabric E-glass fibers supplied by Owens corning. As per the manufacturer standard the epoxy to hardener weight ratio was taken as 10:1.

2.2. Preparation of glass/epoxy laminates and conditioning of specimens

The laminated GE composite was fabricated with woven fabric E-glass fibers having 9 layers. The weight fraction of glass fibers and epoxy was taken 50:50 respectively. The laminates were fabricated using hand layup technique. The curing of GE laminates were carried out in hot press compression moulding machine at 60 °C temperature for 20 min at a pressure of 5 kgf/cm^2. The GE laminates were cut using diamond cutter as per the ASTM D3039 to obtain the specimens. Further, the specimens were post cured in an oven at 140 °C for 6 h [6]. Initially, the specimens were conditioned in the ultra-low chamber at −60 °C for 36 h and then further conditioned to +70 °C for 36 h in an oven.

2.3. Testing methods of glass/epoxy composite

2.3.1. Tensile test

The test was carried out in Instron 8862 Universal testing machine (equipped with hydraulic pressure grip) in accordance to the ASTM D3039 to assess the tensile properties. Flat rectangular specimens of dimension (L×W×T) 250×25×2.5 mm^3 were used with 150 mm gauge length. The specimens were tested with various loading rates viz. 1, 10, 100, 500 and 1000 mm/min at room temperature. Also, the conditioned specimens were tested in the tension mode with the aforesaid loading rates. For each loading rate minimum five specimens were tested. The strain values were measured from the extension based on crosshead displacement of the machine. However, the strain measurement is more accurate when strain gauges are employed but at higher loading rates (100, 500 and 1000 mm/min in the present study), most of the times the strain measurement by video extensometer became invalid in our case. Hence, in order to compare the results at all loading rates the strain was measured from the crosshead displacement. Based on the degree of sizing of fibers (Surface treatment) the strain varies in case of glass fibers. The interfacial bond strength (33 MPa for E-glass, 49 MPa for E-glass + silane) of the glass fiber is based on sizing leads to little bit higher failure strain [7].

2.3.2. Scanning electron microscopy (SEM) analysis

The post-failure observation of fractured surfaces of the tested samples were carried out using scanning electron microscope (SEM) for identifying the different leading modes of failure mechanisms using JEOL-JSM 6480 LVSEM at 20KV.

2.3.3. Differential scanning calorimetry (DSC) measurements

DSC measurements were done using a DSC 821 (Mettler-Toledo, STAR software) with intra cooler. The heating rate used was 10 °C /min. DSC was done to know the in-service temperature of the polymer phase of composite material.

3. Results and discussion

3.1. Evaluation of glass/epoxy composite at various loading rates

The specimens were tested at room temperature (RT, 30 °C) with the aforesaid loading rates. Fig. 1 shows the stress-strain behaviour of both control as well as thermal-shock conditioned GE composites. It can be seen from the Fig. 1(a) that with increase in loading rate i.e. from 1 mm/min to 1000 mm/min the value of maximum tensile stress is increasing. At lower loading rates more time is available and thus small microcracks propagates to potential cracks that leads to substantial reduction in tensile stress of the composite system. But, at the higher loading rates, the time availability to propagate these microcracks is very less. Hence, the load carrying capacity of the GE composite is found to be more. The Failed glass/epoxy composites at different loading rates (A) Without conditioning and (B) Thermal shock conditioned are shown in Fig. 1.