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Tensile Response of Epoxy and Glass/Epoxy Composites at Low and Medium Strain rate Regimes

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Abstract

The present research work is to study the effect of low and medium strain rates on tensile behavior of epoxy and glass/epoxy composites. The digital image correlation (DIC) technique is employed for evaluating full-field strain contour plots using high-speed CMOS camera, which captures about 100,000 frames per second. Stress-strain measurements are reported for epoxy and glass/epoxy composites for strain rates ranging from 0.0001 – 450 s^{-1} and the variation of modulus, strength and strain to failure with strain rate is studied. A non-linear regression function is used to predict the tensile properties of epoxy and glass/epoxy composites at both low and medium strain rates regimes. The results reveal that the tensile strength and modulus increases with increase in strain rate for epoxy and glass/epoxy composites. The fracture surfaces of tensile specimens are investigated using scanning electron microscopy (SEM) to understand the influence of strain rate on fracture morphology.

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*Keywords:*Epoxy; glass fibers; strain rate; drop mass test setup; digital image correlation; fractography

1. Introduction

The mechanical properties of most of the polymer and its composites are rate sensitive in nature. For this reason, numerous studies have been carried out to study the variation of strength and stiffness of composites at various strain rates. However, most of the researches have concentrated on the behavior of the polymer matrix composites at

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high strain rates. Split Hopkinson pressure bar (SHPB) technique is widely used to achieve very high strain rate (>1000 s^{-1}) tensile properties. However, the experimental techniques to generate tensile properties in medium strain rates (1 – 100 s^{-1}) are not well established [1]. The high-end servo-hydraulic testing machine and the drop weight impact machine have been widely used to achieve medium strain rates, since the conventional servo-hydraulic machine is restricted to lower strain rates (<10 s^{-1}), due to its inertial effects of the load cell assembly and grips.

Few literatures investigated the effects of strain rate in low and medium strain region for glass/epoxy composites. Saniee et al. [2] investigated the strain rate effect of glass/epoxy composites and observed that the longitudinal strength and modulus has increased to 24.7%, by increasing the strain rate from 0.0001 to 0.1 s^{-1}, respectively. Shokrieh et al. [3] investigated the behavior of unidirectional glass/epoxy composites at quasi-static and intermediate strain rates using servo-hydraulic instrument and found significant increase in tensile properties by increasing the strain rate. The application of drop weight apparatus is introduced by Lifshitz [4] to study the dynamic behavior of angle-ply glass/epoxy composites and it is observed that failure stresses are found to be 20 – 30% higher than the static values; however failure strain and modulus are similar for static and dynamic loadings. Recently, Brown et al. [5] reported the strain rate effects on the tensile, shear and compression behavior of a glass/polypropylene composites over the strain rate range of 10^{-3} – 10^{2} s^{-1} using an electro-mechanical universal testing machine and a modified instrumented falling weight drop tower with specially designed fixtures. The results showed that the tensile and compression modulus and strength increased with increasing strain rate. Perogamvros et al. [6] developed a tensile testing apparatus using drop tower to study the medium strain rate effects in the regime of 1 – 200 $s^{-1}$and also carried out the parametric FEM study for the validation of experimental results.

This paper discusses the application of a drop mass system and digital image correlation (DIC) technique and investigates the effect of strain rate on tensile properties of epoxy and glass/epoxy composites at both low and medium strain rate regime. Fractographic analysis of tested specimens was carried out using scanning electron microscopy (SEM).

2. Experimental Techniques

2.1. Materials

Matrix - Epoxy, a medium viscous diglycidyl ether bisphenol A resin (DGEBA), and the curing agent, a low viscous aliphatic polyamine (TETA) were procured from Huntsman Ltd, (India) and the reinforcement - glass fiber, 610 GSM woven roving mat (WRM) was procured from M/S Sakthi Fibers, India.

Epoxy specimens were prepared by casting epoxy in the mold. The mold was made from two rectangular glass plates having dimensions of 300 mm × 300 mm. Rubber beadings were used to maintain a 3 mm thickness all around the mold plates. Wax was used as a releasing agent. The curing agent TETA was added and the mixture was gently stirred in order to avoid the formation of bubbles. After degassing, the solution was cast in the mold.

Glass/epoxy composite specimens were prepared by hand layup technique followed by compression molding. After adding the required amount of curing agent, a thin layer of epoxy was applied with a brush on an aluminum plate coated with a releasing agent. Then the epoxy mixture was impregnated into the WRM glass fiber with the assistance of hand roller to ensure that all fibers were uniformly wetted. The laminates were cured at room temperature and kept in the compression molding machine for 24 h for complete curing.

2.2. Quasi-static testing

Tensile modulus, tensile strength, and strain to failure were evaluated for both epoxy and glass fiber/epoxy composites as per ASTM: D638-10 standard using universal testing machine. Epoxy tensile specimens having 3 mm thickness and 50 mm gauge length were cut using water jet cutting machine. Thin laminate composed of glass/epoxy, having a laminate thickness of 1 mm and 12.7 mm width were prepared and glass/epoxy tabs of 2.5 mm thick and 35 mm long with tapered ends were locally bonded to each end of the specimens. These tabs allowed a smooth load transfer from the grip to the specimen. The gauge length of the composite specimens was 12.7 mm. The fiber weight fraction of the composites was 50%.

Tensile tests were conducted at cross-head speeds of 0.5, 5, 50 and 500 mm/min for epoxy and glass/epoxy