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Statistical analysis of the tensile strength of GFRP, CFRP and hybrid composites

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ABSTRACT

Glass/epoxy, carbon/epoxy and hybrid (glass-carbon/epoxy) composites are subjected to quasi-static to high strain rate (542 s^{-1}) studies to obtain the tensile strength. The two-parameter Weibull distribution is employed to measure the variability of the tensile strength of cross ply laminates. The Weibull parameters are obtained using the linear curve fit method. The theoretical tensile strength values are determined for the GFRP, CFRP and hybrid composites. The experimental and theoretical strength values are in good agreement. Using Hitachi scanning electron microscope instrument, the failure mechanisms are investigated in the fracture surfaces of glass/epoxy, carbon/epoxy and hybrid specimens, and discussed.

1. Introduction

Now-a-days, aerospace and automotive industries are extensively using fiber reinforced laminated composites due to their light weight and better mechanical properties. Laminated composites are used as primary and secondary structural members in aerospace and automotive vehicles [1,2]. The degree of variation of mechanical properties is high for these composites due to their heterogeneity and anisotropic behavior and there is a need to improve their safety margins by employing failure analysis approaches [3]. In the recent years, the Weibull statistics [4] has been widely used to investigate the accuracy of the mechanical properties of fiber reinforced polymer matrix composites [5,6]. Using this approach, the failure analysis of static and dynamic mechanical properties are carried out [7]. Flaws occur in brittle fibers (glass and carbon) due to misalignment and handling of fibers during fiber cutting and laminate preparation [8–10]. As a consequence, the strength properties are generally scattered. To measure the accuracy of the tensile strength values, two-parameter Weibull statistic analysis is used based on the difference between theoretical and experimental cumulative probability density (cumulative failure probability) values. The tensile strength values are accurate when the theoretical and experimental cumulative probability density values are closer to each other. Ou and Zhu [11] have used Weibull statistics to find the tensile strength distribution of GFRP composites for the strain rates of 1.6×10^{-3} to 160 s^{-1} and observed that the cumulative failure probability vs. strength curves move towards higher strength direction with the increase of strain rate. Dirikolu et al. [12] have tested 19 samples of $[0°]_3$ carbon/epoxy sheets at a crosshead speed of 0.02×10^{-3} ms^{-1} using an Instron universal testing machine and got an average tensile strength of 496 MPa. The variation in fracture strength of $[0°]_3$ carbon/epoxy sheets were modelled using the two-parameter Weibull distribution and observed that the distribution provided reliable results. Alqam et al. [13] analyzed pultruded composite mechanical properties (Tensile, compressive and shear) using two and three parameter Weibull distribution. It is observed that both distributions are useful to characterize the mechanical properties of FRP composites and not much variation between the distributions. Recent studies show that the tensile strength values of unidirectional 0° and woven roving (0°/90°) carbon/epoxy composites are less sensitive to the strain rate or strain rate insensitive whereas glass/epoxy composites are sensitive to the strain rate [14–17]. In order to make carbon/epoxy composites as strain rate sensitive either orientation effect is required [18] or hybrid effect is employed. The failure strain and toughness of CFRP composite are increased by making a hybrid (incorporating glass and carbon fibers in an epoxy matrix) composite [19–22]. The strain rate sensitivity of hybrid composites is increased by adding more amount of glass fibers and fewer amount of carbon fibers in the epoxy matrix, since glass/epoxy composites are higher sensitive to the strain rate and carbon/epoxy composites are less or insensitive to the strain rate. Therefore, to increase the strain rate effect on hybrid composites, glass fibers of 610 gsm and carbon fibers of 450 gsm are used for this study.

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Nomenclature

V_0 impact velocity
α tensile strength
$\overline{\alpha}$ mean tensile strength
$\dot{\varepsilon}$ strain rate
F cumulative probability density (cumulative failure probability)
ω scale parameter
ϕ– *shape parameter*
Γ – *gamma function*

Fig. 1. Compression molding machine.

In this work, an effort is made to determine the theoretical tensile strength values for glass/epoxy, carbon/epoxy and hybrid composites from quasi-static ($8.3\times10^{-3}\,s^{-1}$) to high strain rate ($542\,s^{-1}$), by employing the two-parameter Weibull statistic analysis. The results obtained from this analysis reveal that the tensile strength of glass/epoxy and hybrid composites is strain rate sensitive, whereas it is less sensitive in carbon/epoxy composites.

2. Materials selection and specimen fabrication

Fiber materials viz glass fibers woven roving mat of 610 gsm and carbon fibers woven roving mat of 450 gsm and epoxy resin (Araldite LY 556) and hardener (Aradour HY 951) as matrix material, are used for the study. Using compression molding technique (Fig. 1), the (0°/90°) GFRP, CFRP and hybrid laminates are prepared. For each laminate, four layers are used and thickness of each layer is 0.4 mm. The thickness, gauge width and length of the specimen used for both quasi-static and high strain rate tests are 2 mm, 3 mm and 10 mm, respectively.

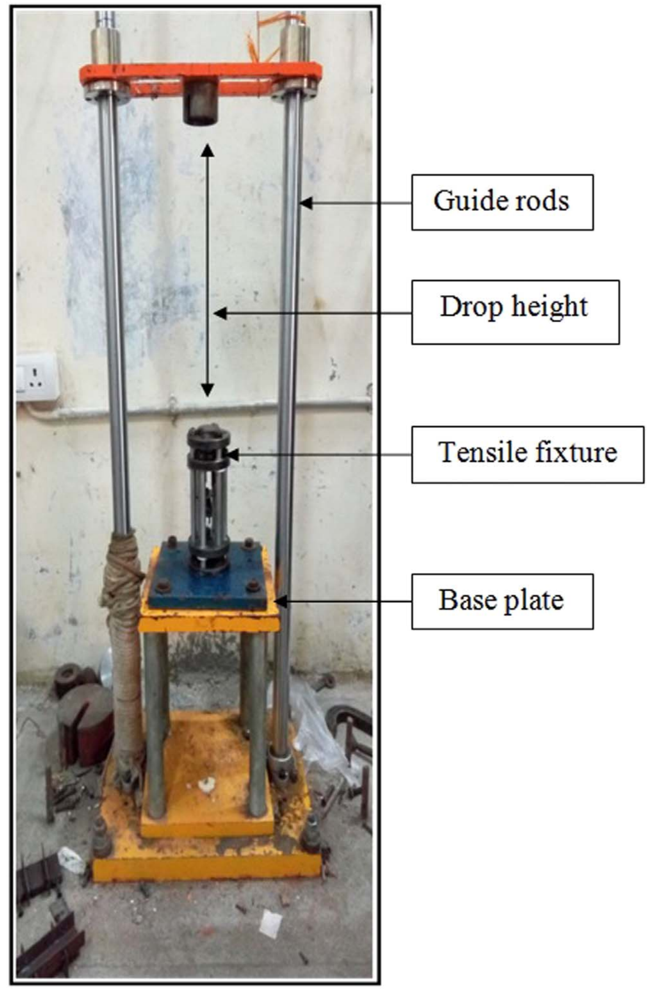

Fig. 2. Drop-weight experimental setup.

3. Experimental setup and procedure

Using an Instron universal testing machine (UTM) of capacity 30 kN and the drop-weight setup, quasi-static and dynamic tests are conducted, respectively. Using the drop-weight setup, medium to high strain rate experiments are carried out in the strain rate ranges from $10\,s^{-1}$ up to $1000\,s^{-1}$ [23,24]. In this technique, mass is dropped vertically downward with the help of guide rods from the required height to strike the tensile fixture and break the specimen. The drop-weight test setup is shown in Fig. 2.

The piezoelectric load sensor (PCB208C04) is connected to the National instruments data acquisition system to obtain the dynamic load data through LabVIEW software. The displacement fields are obtained using Digital Image Correlation (DIC) technique through Phantom V611, CMOS high speed camera with a resolution of