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Torsional fatigue behaviour of solid carbon/epoxy composite rods

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Research motivation and objectives

Carbon composites have tremendous applications in aerospace structures. These composite structures are subjected to various loading applications. These structural components often fail over a period of time due to fatigue failure. Yet, the torsional fatigue behaviour of carbon composites has barely been studied. Cylindrical geometry is known to be ideal to study the torsional behaviour of the structural components, as it allows uniform stress distribution. However, mostly dog-bone or rectangular plate geometries have been used in the literature, owing to the absence of a standard fixture, testing standards and difficulties involved around the torsion testing of cylindrical composite rods. The use of rectangular specimens leads to maximum stress occurrence at the closest point near the centroid. Hence, it leads to non-uniform stress distribution and might further lead to misinterpretation of failure behaviour. There is no data available in the literature for the fatigue behaviour of carbon composite cylindrical rods under torsional loading. This paper presents the experimental test data based study for carbon/epoxy composite specimens subjected to pure torsional static as well as fatigue loading. The cylindrical carbon/epoxy composite rods of 60% fibre volume fraction are used as test specimens. A customized fixture for torsional testing of composite rods is designed and fabricated. The failure modes of the test specimens are analysed using optical microscopy and scanning electron microscopy (SEM). The shear modulus of the specimens is also obtained using strain gauge data.

Brief literature survey

Yerramalli [1] studied the in-situ matrix shear response for carbon/vinyl ester and glass vinyl ester composites using static torsion test data, where cylindrical composite rods were used as test specimens. The response of the specimens under pure compression and combined compression and torsional loading has also been studied [2]. Davidson [3] has also presented in-situ matrix behaviour using torsion test data. Pristine dog-bone specimens are used as test specimens. The compression behaviour under static and fatigue loading is also examined. Liu [4] provided a novel approach to test torsional behaviour of single carbon fibre filament. Ogasawara [5] presents the torsional fatigue behaviour of carbon/epoxy composites to investigate its feasibility as a helicopter flex beam material. Rectangular panel specimens were used test materials. The response of glass/epoxy composites was also studied. Capela [6] deployed dog-bone shaped tubular specimens to test fatigue behaviour of woven biaxial carbon/epoxy composite subjected to bending, torsion and combined bending and torsion loading.

Experimental methodology

The cylindrical carbon/epoxy composite rods are selected as a test specimen. The rods have a diameter of 6.5 mm and an average fibre volume fraction of 60 %. The carbon fibres have

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an average diameter of 5 μm. An average initial fibre misalignment of 2.3 degrees exist is observed in the rods using scanning electron microscopy (SEM) and optical microscope images. A tapered chuck design is used for gripping the cylindrical rods. The specimen is inserted inside the chuck and the threaded nut is tightened. The tightening of the nut applies clamping force on the specimen. The schematic of the chuck design is shown in **Figure 1** and **Figure 2**. INSTRON 8800 universal testing machine is used to carry out the experiments. The machine has a maximum torque capacity of 1 kN-m and a maximum travel of 90 degrees is permissible (-45 degrees to +45 degrees). The samples have an average gauge length of 10.5 mm. The test is conducted in rotation control mode at a constant strain rate of 3.6 degrees/min and are loaded for a maximum rotation of 88 degrees (-44 degrees to +44 degrees).

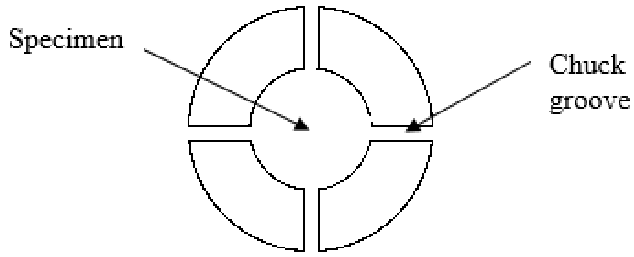

Figure 1: Schematic top view of the chuck design

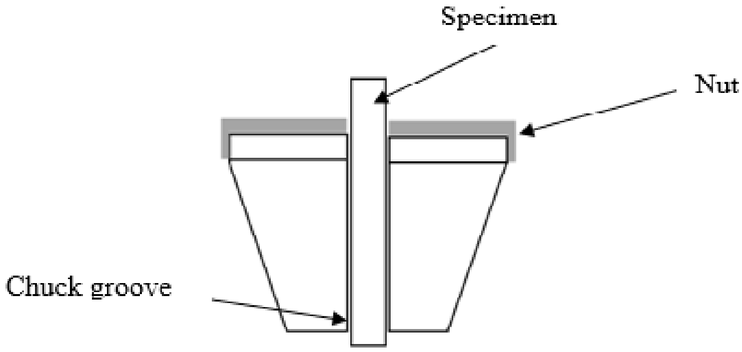

Figure 2: Schematic section view of the chuck design

Results and observations

The specimens do not undergo complete rupture even after total angular displacement of 88 degrees. Although, delamination is visible at the surface of the specimen, since maximum shear stress occurs at the surface (see **Figure 3**) The shear stress vs strain plot illustrates three different regions of the torsional characteristics of the composite rods. The region I is the elastic region shear stress and shear strain are linearly proportional. The shear modulus of the specimen is calculated in this region. The average shear modulus obtained was 8.814 GPa. The average shear stress at the end of region I was observed to be about 72 MPa, which can also be referred to as the elastic limit. Region II is the transition phase, where the curve starts plateauing after a slight drop in shear stress. In this region the matrix begins to deform and the shear stress is observed to remain almost constant, while the shear strain is increasing. The length of the region II is subject to change with rods of different volume fraction. The matrix deformation stops at the end of region II and the specimen regains strength in region III. The regaining of shear strength of the rod in region III might be occurring due to stiffening of the fibres due to the increasing twisting moment. Since the matrix has deformed in region II, the application of further twisting moment might be enabling braiding of the fibres together. Hence, increasing its torsional strength. The shear stress vs strain plot is shown in **Figure 4**

The fatigue properties of the composite are obtained for the elastic range of the composite. The specimens are loaded at stress ratio, R = 0.1 and 3 Hz frequency.

Figure 3: Carbon/epoxy fibre subjected to static torsion

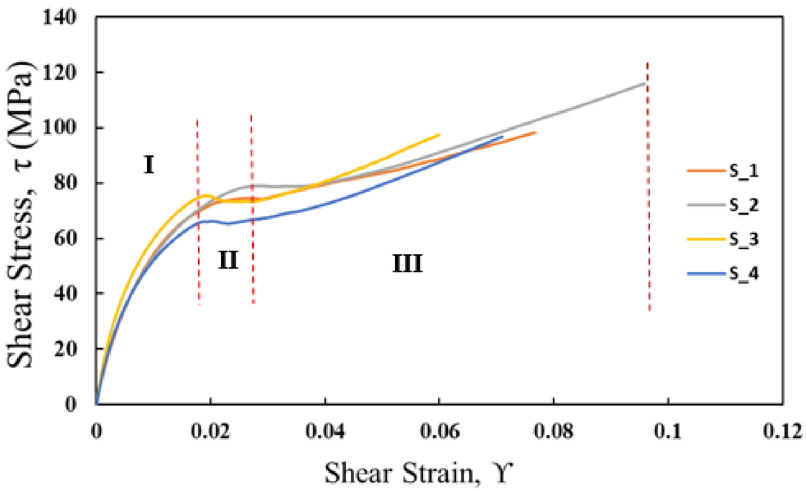

Figure 4: Shear stress vs shear strain for carbon/epoxy rods

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