



Chapter 5

Novel Experiment Design to Investigate High-Rate Shear Fracture of Composites

Elias Gerstein, Tyler Robertson, Andrew Baumgardner, Paul Custodio, and Nathan Spulak

Abstract Fiber reinforced composites are extremely desirable materials for aerospace applications due to their inherent high strength to weight ratios. For safe application of these materials in such structures, it is important to understand their mechanical behavior during high-rate loading. High-rate shear testing of fiber reinforced composites provides important data for understanding the material's high-rate mechanical response. However, there is no generally accepted standardized method for performing high-rate shear tests on fiber reinforced composites. Existing high-rate shear methods typically result in mixed mode loading, rather than deformation and fracture under pure shear conditions. Therefore, a novel unnotched high-rate shear test method for composite materials is investigated. This test method utilizes specialized fixtures to induce direct shear loading on an unnotched test coupon using a split-Hopkinson pressure bar and special high-rate shear fixtures to secure the unnotched test coupon. The novel experiment is designed and simulated using finite element analysis with Ansys LS-DYNA, and preliminary validation tests are performed. The simulation and test results demonstrate a promising concentration of pure shear deformation on the fiber reinforced composite material.

Keywords Fiber reinforced composite · High-rate testing · Shear · Finite element analysis

Introduction

Due to the high strength-to-weight ratios of fiber reinforced composites (FRC's), they have become a desirable material of choice for structural components in the automotive, aviation, and defense industries. The applications FRC's are used for commonly result in them being subject to complex loading conditions across a wide variety of strain rates, such as during vehicle crashes. To safely apply these materials to such conditions, it is therefore important to understand the high strain rate shear behavior of FRC's. However, the current ASTM standard for determining shear properties of composite materials is designed for low rate loading, and does not produce pure shear loading when adapted for use high strain-rate testing (on the order of $10^3 s^{-1}$) [1]. Furthermore, existing non-standardized tests tend to produce mixed mode loading rather than pure shear loading, or they require complex specimen geometries that that can result in damage during the machining process [2]. Therefore, a novel unnotched shear test method is proposed. This method utilizes a simple and easily machinable unnotched specimen and custom fixtures to directly induce pure shear loading at high-strain rates. The high-rate test method utilizes a tensile split-Hopkinson pressure bar (SHPB) to induce the high-rate shear loading desired. The feasibility of this test is initially investigated via finite element analysis (FEA) simulations using Ansys LS-DYNA. Preliminary validation testing for comparison is also performed at low loading rates utilizing a hydraulic load frame, and demonstrate that pure shear deformation is successfully induced on the specimen. This indicates the unnotched shear test is a feasible method for performing pure shear loading at high-strain rates in future testing. Successful production of high-rate shear stress vs strain data obtained from the designed test method can be implemented into the deformation sub-model of LS-DYNA material model MAT_213 to further increase accuracy of FRC material simulations [4].

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Experimental Design and Methods

The proposed test procedure for achieving pure shear loading utilizes a specially designed slotted fixture to hold an unnotched FRC shear specimen. The unnotched shear specimen, shown in Figure 1 (a) is secured within both sides of the slotted test fixture, as illustrated in Figure 1 (b). Then, the grip sections of the fixture are secured within the specimen grips of the hydraulic load frame.

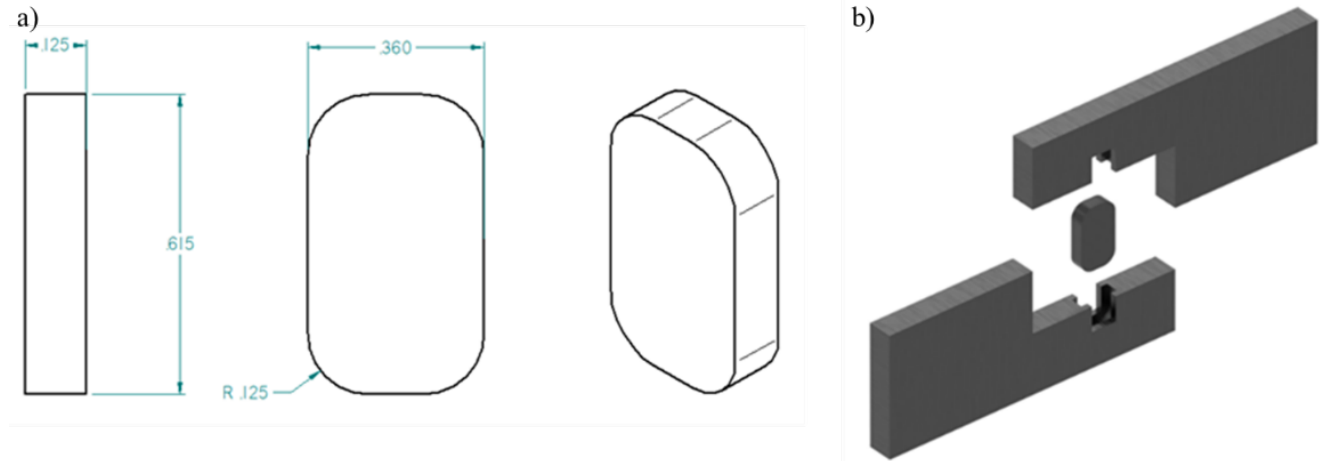


Fig. 1 (a) Unnotched FRC shear specimen (dimensions in inches), and (b) schematic of slotted shear test fixtures with unnotched specimen

Initial FEA simulations of the proposed test setup were done using LS DYNA. One fixture was modeled as a fully constrained rigid material while the other fixture was modeled as rigid material with a prescribed motion. The specimen itself is modeled as a Toray T700S carbon fiber and G83-CM prepreg laminate [2] using the LS DYNA orthotropic elastic material model, MAT_002 [5]. The specimen was then modeled as a solid mesh with a mesh size of 0.305 mm. The purpose of this simulation is to demonstrate the test setup's ability to produce pure shear loading in the test specimen; therefore, the simple orthotropic elastic material model suffices.

Initial low-rate tests are performed on a hydraulic load frame to assess the feasibility and accuracy of the designed test technique. The experiments are performed at the UAH Experimental Mechanics and Multiphysics Modeling (E3M) lab. The specimen material used for the low-rate tests is a polymeric-carbon unidirectional laminate in a quasi-isotropic layup. Low-rate tests are carried out using the fixture from Figure 1 and a hydraulic load frame. To allow for three-dimensional digital image correlation (DIC) analysis, images are taken using two 5 MP cameras, and the specimen and fixtures are covered in a black and white spray paint speckle pattern. The low-rate test is run until fracture of the specimen is observed.

Experimental Results

A comparison of the simulated shear strain and the experimentally observed shear strain prior to specimen fracture is shown in Figure 2. Additionally, the simulated shear strain across along the vertical centerline of the specimen is graphed at various stages as the deformation progresses in Figure 3. The simulation shows the specimen experiences clear shear strain concentration at the center, and this is verified in the preliminary test DIC data which aligns well with the design simulation response. The strain data along the centerline shown in Figure 3 illustrates that the specimen has a highly localized shear strain concentration in the center, with the strain rapidly decreasing towards the outer edges of the specimen.

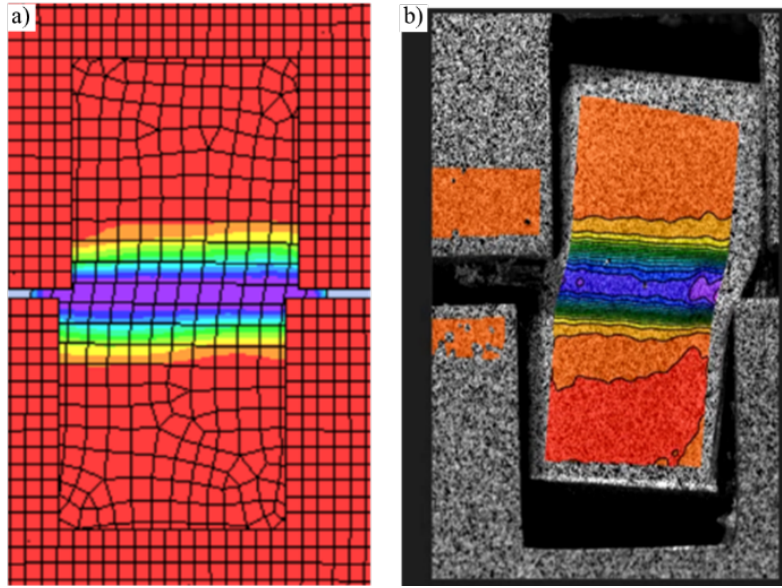


Fig. 2 Shear strain concentration of novel unnotched shear test: (a) LS-DYNA simulation and (b) DIC data from preliminary low rate test

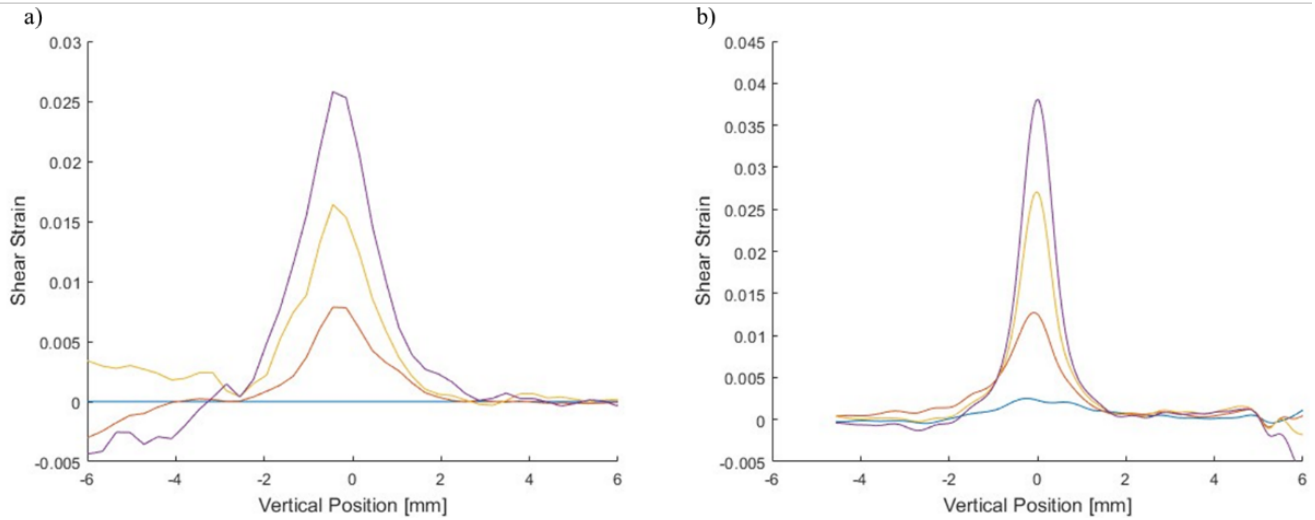


Fig. 3 Shear strain at various stages of deformation along specimen vertical centerline for (a) LS-DYNA simulation and (b) preliminary low rate test

Conclusion

Simulations and low-rate shear testing of a composite material are performed to provide validation of the proposed shear test method. The purpose of the test method is to induce pure shear loading on an FRC specimen. Initial simulations performed using LS-DYNA show the feasibility of this test method, as an obvious concentrated shear strain band is developed within the specimen over the course of the simulation. Low-rate tests are also completed to further provide validation. Through DIC analysis of the low-rate tests, the shear strains are determined over the surface of the FRC specimen. Once again, an obvious concentrated shear band is developed in the specimen, and the shear distribution found is very similar to what was determined in the LS-DYNA simulation. Furthermore, shear strain waterfall plots developed from both the simulation and

test match very closely in shape and progression. Thus, the shear concentration proceeds through the course of the test as desired. Future work for this test method will involve carrying out high-rate split-Hopkinson bar testing and will utilize other material systems.

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