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Test method

# Dependency of dynamic interlaminar shear strength of composites on test technique used

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ABSTRACT

Studies are presented on dependency of dynamic interlaminar shear (ILS) strength on the experimental technique used for a typical plain weave E-glass/epoxy composite. Dynamic ILS strength was determined based on two experimental techniques, namely torsional split Hopkinson bar (TSHB) apparatus using thin walled tubular specimens and compressive split Hopkinson pressure bar (SHPB) apparatus using single lap specimens. The results obtained from these techniques are compared. In general, it is observed that dynamic ILS strength for composites obtained by TSHB testing using thin walled tubular specimens is lower than the dynamic ILS strength obtained using single lap specimens in compressive SHPB. The issues involved in TSHB testing of thin walled tubular specimens made of composites are discussed and the reasons for reduced dynamic ILS strength using thin walled tubular specimens are highlighted. Finite element analysis (FEA) of thin walled tubular specimens made of composite and resin subjected to quasi-static torsional loading is presented. Using FEA results, the reasons for lower ILS strength of composite thin walled tubular specimens are substantiated.



## 1. Introduction

Laminated composites are widely used in many structural applications. Aerospace and automobile structures, windmills, defense equipment and ship hulls are typical examples. The wide usage of these materials is because of their unique architectural features, ease of handling, low fabrication cost and excellent mechanical properties.

Laminated composites are orthotropic materials. These materials exhibit two types of shear properties, one along the plane of lamina, which is termed the in-plane shear and the other along the thickness of the laminate, which is termed the interlaminar shear (ILS). The ILS strength is one of the most important parameters in determining the ability of a composite material to resist delamination damage.

Composites are subjected to a variety of loads during service life. These loads can be classified as quasi-static and dynamic. Material response varies significantly with quasi-static and dynamic loading conditions. Dynamic loading is also referred to as high strain rate loading.

The relationship between the magnitude of the load applied and the time over which it acts plays an important role in deciding the system response. Response of laminated composites under high strain rate shear loading is an important engineering requirement. It is used in applications like composite shaft design and design of external panels of aircraft etc.

In theory, mechanical properties of a material are unique. They should not change with the test technique or the specimen used. This behavior is observed in metals/alloys as well as many the other materials. However, composites tend to display variations in dynamic interlaminar shear strength with the test technique employed.

The focus of the present study is to establish the reasons for variation in dynamic ILS strength with the test

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technique used, and validate the reasons established with finite element analysis (FEA) simulation results. Studies are performed on a typical plain weave E-glass/epoxy composite.

There are several methods for the determination of shear properties under dynamic loading [1]; those available for the evaluation of dynamic shear properties of composites are:

- TSHB test [2–9].
- Compressive SHPB test [10–14].
- Tensile SHPB test [15].
- Drop-weight test [16].
- Hydraulic/Pneumatic machine test [17].

There are only limited studies on high strain rate ILS properties of composites. Leber and Lifshitz [3], Dai et al [4,5], Hu and Feng [6] and Naik et al [7] are among the few researchers who have studied ILS properties of composites on TSHB using thin walled tubular specimens.

Researchers have also used single lap specimens for determining dynamic ILS properties of composites. Bouette et al [10], Dong and Harding [11] and Hallet et al [12,13] used compressive SHPB apparatus with single lap specimens for ILS characterization of composites.

Apart from thin walled tubular specimens and single lap specimens, researchers have also used double lap specimens [18,19], V-notched specimens [20] and short beam specimens [21] to evaluate the dynamic shear properties of composites. However, TSHB testing with thin walled tubular specimens and compressive SHPB testing with single lap specimens are the most widely used techniques.

In the present study, dynamic ILS strength for a typical plain weave E-glass/epoxy was evaluated on TSHB apparatus using thin walled tubular specimens, and compressive SHPB apparatus using single lap specimens. The results obtained are compared. The reasons for variation in dynamic ILS strength obtained from TSHB apparatus using thin walled tubular specimens and compressive SHPB apparatus using single lap specimens are considered. FEA of thin walled tubular specimens made of composite and resin subjected to quasi-static torsional loading is presented.

## 2. Test apparatus and calibration

TSHB apparatus [7,9,22] was used to evaluate dynamic ILS behavior of a typical plain weave E-glass/epoxy using thin walled tubular specimens. Compressive SHPB apparatus [10,11,23,24] was also used to evaluate dynamic ILS behavior of a typical plain weave E-glass/epoxy using single lap specimens. In both TSHB and compressive SHPB apparatus, strain gauges were mounted on the incident as well as the transmitter bar. The strain gauges were connected in half bridge configuration.

Before the commencement of actual experiments, calibration was performed. Details regarding calibration of TSHB and compressive SHPB apparatus are presented in [9] and [23,24], respectively.

## 3. Specimen design and dimensions

Specimens for the tests were made from plain weave E-glass/epoxy laminates. Balanced layers of thickness 0.25 mm were used for making the laminates. The laminates were made such that warp direction of all the layers was along direction 1 and fill direction of all the layers was along direction 2 (Figs. 1 and 2). Epoxy resin LY556 with hardener HY951 was used for making the laminates. The fiber volume fraction of the laminates was 0.54.

### 3.1. Thin wall tubular specimen

A schematic arrangement of laminate configuration used for thin walled tubular specimen is presented in Fig. 1a. The axis of the specimen was along the thickness direction of the laminate. Thin walled tubular specimens with wall thickness ($t_S$) of 3 mm and gage length ($L_S$) of 3 mm were used. Other specimen dimensions were $D_i$ = 10 mm, $D_o$ = 16 mm and D = 22 mm. The overall length of the specimens (L) was 9 mm and radius of edge, R, was 0.5 mm. For bonding the specimens to the incident and transmitter bars of the TSHB apparatus, Araldite adhesive was used with room temperature curing. Fig. 1b shows photograph of a fractured specimen tested on the TSHB apparatus. It can be seen that the fracture surface has a zigzag appearance.

### 3.2. Single lap specimen

A schematic arrangement of laminate configuration and single lap specimen is shown in Fig. 2a. The dimensions of the specimen are: a = 5 mm, b = 27.5 mm and width (c) = 20 mm, d = 8.66 mm, e = 12 mm. The axis of the specimen was along the warp direction (direction 1) of the laminate. Overall length, width and thickness of specimen were 51.5 mm, 20 mm and 10 mm, respectively. Loading was along direction 1 on the flat surfaces on either side of the specimen. Fracture plane area is ‘a x c’. Fig. 2b shows a photograph of a failed single lap specimen. It can be seen from the photograph that the fracture surface has a zigzag appearance. Specially designed specimen holders for specimen gripping in compressive SHPB apparatus can also be seen. Inner dimension of the fixture is 10 mm. For bonding the specimens to the fixture, Araldite adhesive was used with room temperature curing.

## 4. Test methods

### 4.1. TSHB testing

TSHB apparatus was used to evaluate the ILS properties of WF E-glass/epoxy thin walled tubular specimens [7]. Tests were carried out over a shear strain rate range of 192–457 per second with at least five specimens under identical test conditions. Signals from strain gauges mounted on the incident and transmitter bars of TSHB were obtained on an oscilloscope and are presented in Fig. 3. With the help of incident (I), transmitted (T) and reflected (R) strain gauge signals, torque histories of incident and transmitter bars were obtained. Starting with the signals