

How do we measure Shear Strength of composites and the factors affecting it?

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In our first workshop, we defined strength as the maximum stress that the material can sustain under uniform uniaxial loading and in the absence of other stress components [1]. A second workshop discussed UD tensile strength [2] and a third one discussed UD compressive strength [3]. We now move to shear strength and the factors affecting it. This is probably the most complicated property to determine, due to the difficulty of obtaining a uniform shear stress state with no other stress components.

Many different tests have been proposed historically, five of them being initially considered in this presentation. The aim is to describe briefly each of them emphasizing their advantages and drawbacks.

The “rail-shear” test, proposed by Floeter & Boller in 1967 [4] and standardized in the ASTM D 4255 (83), is one of the first proposals, and probably the most intuitive, to try to generate a uniform and pure shear stress state. It has some problems related to the holes needed to mount the specimen (Fig. 1a). In 1999, Hussain & Adams [5] proposed a test configuration which holds the specimen by friction, avoiding the presence of the holes and minimizing stress concentration issues. A variant of this configuration, with three rails, was developed by De Baere et al. [6] in 2008. Adams et al. [7], in 2003, proposed the “v-notched rail shear” test substituting the rectangular specimen by a double-notched one and gripping by friction, which was standardized in ASTM D 7078 (05) (Fig. 1b). Despite many improvements over the years, this test still struggles with stress concentrations and a lack of uniform shear stress.

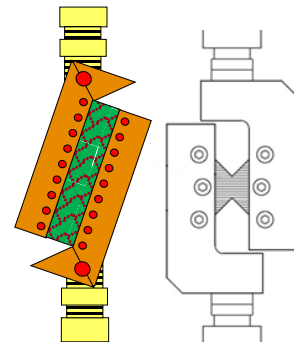


Fig.1. a) Rail shear test fixture, b) V-notched rail shear test



Fig.2. Tube torsion test.

The tube torsion test, proposed by Whitney & Halpin [8] and standardized in ASTM D 5448 (93), introduces a torsion moment in a tube made of unidirectional plies (Fig.2). While it generates a reasonably uniform and pure shear stress state, this configuration has the drawback of its cost and complexity. In addition, the quality of a tube and hence its shear behaviour may not be representative of flat laminates.

The “off-axis” tension test is, maybe, the simplest test to induce indirectly shear stresses. It consists of a tension test on a rectangular specimen, obtained from a unidirectional laminate with the fibre direction at a certain angle, typically 10°, with respect the loading direction (Fig.3).

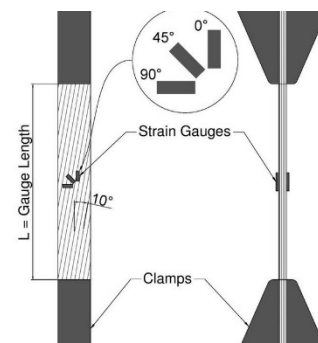


Fig.3. Off-axis tension test.

Problems associated with the coupling of normal and shear stress components [9], as well as the ways to minimize them, have been extensively reported in the literature. These solutions include correction factors from experimental results [10, 11], modification of the test configuration to reproduce the ideal test configuration, the use of oblique tabs [12] and the optimal choice of the tab angles depending on the mechanical properties of the tested material [13]. Proposals to avoid premature failures associated with the singular stress states appearing at the tabs have also been reported in the literature [14].

A tension test of a $\pm 45^\circ$ laminate is one of the most used techniques to characterize, in shear, a composite material, and it is described in several international standards: ASTM D 3518 (76), EN 6031: 2015, or ISO 14129: 1997. In this test, a symmetric $\pm 45^\circ$ laminate (not a unidirectional laminate) is subjected to tension. This is good for measuring the non-linear stress-strain response, but the stress state is not pure shear and the failure is influenced by the stacking sequence, the number of plies, free edge effects and large rotations. ASTM D 3518 suggests a minimum of 16 plies, while EN 6031 allows a laminate of just 8 plies to be used. Kellas et al [15] observed a significant scale effect in strength, and reported a transition in failure mode in scaled specimens for certain laminate stacking sequences.

In 1967, N. Iosipescu [16] proposed a test on a v-notched specimen to quantify the shear strength of metals (Fig.4). Subsequently, the test was extended in the 1980's to determine the shear modulus and shear strength of composites using the modified Wyoming specimen [17]. Recently, Stojcevski et al. [18] provided an update on the current status of this test method. The main advantages of the test are related to its simplicity and the creation of a region dominated by shear stresses that has been validated by experimental and numerical investigations. The disadvantages concern premature failure due to stress concentrations, misalignment of the specimen, twisting and irregular load distribution and the need to apply a correction factor for non-uniform stress.

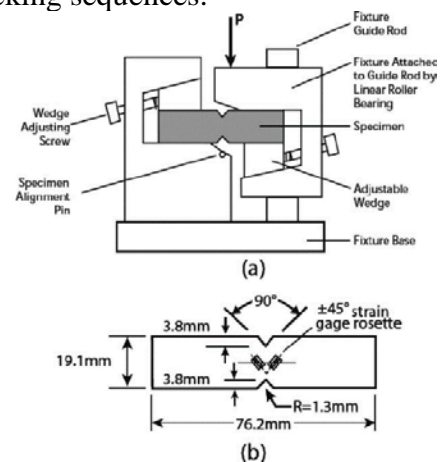


Fig.4. Iosipescu test device (a) and specimen (b).

In general terms, it is clear that different values can be obtained using different procedures to estimate shear strength, as different damage mechanisms are involved in each type of test used for the experimental determination of this value. In other words, this implies that different things are being measured in the different tests. A comparison between shear strength values obtained from different tests can be found in Adams and Lewis [19].

More recently, alternative proposals, such as the “shear frame” test [20], Figure 5, and the tension-compression biaxial test [21], Figure 6, have been also considered to determine shear strength.

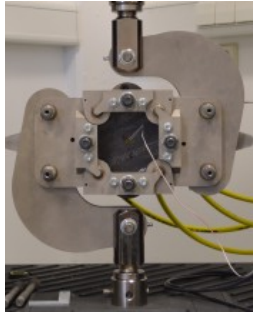


Fig.5. Shear frame test

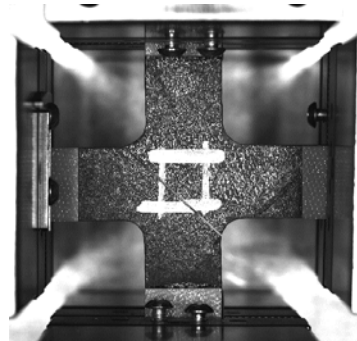


Fig.6. Biaxial tension-compression test

Although a special emphasis has been put on the advantages and drawbacks of each test, it is obvious that there is a long list of concerns, particular for each test or common to all of them, when talking about factors affecting the measurement. Thus, specimen size, 0° vs 90° ply orientation, voidage, loading rate, environmental conditions, effect of other stress components, presence of nominally singular stresses, are with no doubt on this list. This paper has primarily addressed in-plane shear strength, although some of the methods can also be applied to measure interlaminar shear strength. The relation between these two properties is another interesting question. Further research with reliable test methods is required to fully understand the factors affecting the determination of the shear strength of composites.

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