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IOSIPESCU SHEAR TEST FOR ADHESIVE MATERIALS AND BONDED FRP ELEMENTS

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Abstract: *The Iosipescu or the V-notch shear test is an experimental method capable of determining the interfacial shear strength and the shear modulus of fibre reinforced polymer (FRP) composite materials. Although this method has been found convenient and adapted to a large variety of composite materials, it remains significantly underutilized for composite bonded joints samples and adhesive specimens. These paper presents some of the latest developments of the Iosipescu testing method, highlighting several implementation concerns, like specimen manufacture and fixture arrangement for FRP bonded joints and adhesive specimens.*

Key words: *fibre reinforced polymer adhesively bonded joints, Iosipescu shear test, fixture arrangement.*

1. Introduction

The specific manufacturing technologies of fibre reinforced polymer (FRP) composite materials enable the development of unique structural assemblies that minimize the amount of individual parts and, thereby significantly reduce the number of structural joints [2]. However, despite these potential advantages, the structural joining of FRP composite elements remains an unavoidable necessity, which arises from the technological and transportation constraints. The most common methods that are currently utilized in connecting two or more elements made of FRP composite materials are the mechanical fastening and the adhesive bonding or a combination of the two (hybrid connection) [11,12,14]. Adhesively bonded joints are more structural efficient than the mechanical joints since the load is distributed over a larger area. Also, the manufacturing methods for bonded connections do not require intrusive processes such as drilling holes, machining or dressing. Therefore, they do not create local stress concentrations that can cause structural deficiencies and in some cases may lead to the collapse of the joint by delamination through the thickness of the adherend [10],[13], [15].

The design approaches for FRP adhesively bonded joints can be divided into two main

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categories, based on the failure predictions that are assumed for the analytical or the numerical model. The first assumes a linear elastic behaviour for the adhesive, while the latter considers that the joint strength is governed by a critical strain value in the bond line, and the adhesive has a nonlinear behaviour. Nevertheless, for both linear and nonlinear analysis approaches, the adhesive joint should be designed by assuming that the failure will occur by reaching the shear strength of the adhesive. This type of failure (also referred as cohesive) is the optimum one, since it has been proven that it enables the most efficient use of the mechanical properties of the adhesive [13,18].

The adhesive shear stress – strain behaviour is an essential input for the design of structural adhesive joints. The distributions and the ultimate values of the effective shear stresses and strains of the adhesive can be determined through various experimental methods, such as: V-notch beam test, Arcan test, the two and three rail shear tests, the asymmetric four-point bending test, etc. [8]. However, it is difficult to guarantee an ideal uniform shear stress state for adhesive specimens.

The V-notch test was originally proposed by N. Iosipescu in 1967 to quantify the shear strength for concrete and was later adapted for testing the shear strength of metals and welds. Nevertheless, more recent developments of the Iosipescu test method transitioned from a predominantly concrete and metal specimens protocol into a test heavily targeted towards FRP composite and adhesive samples, [9]. This paper provides an update on the current status of the Iosipescu testing method, highlighting several implementation concerns, like specimen manufacture and fixture arrangement for FRP bonded joints and adhesive specimens.

2. Specimen Preparation

The Iosipescu shear test method can be applied to adhesives, both in bulk form and as joint specimens. The bulk specimens can be manufactured by injecting or by pouring the adhesive into a mould that is designed to guarantee the geometrical features of the final specimens. For the adhesive products, that are obtained by mixing two distinct components (resin and hardener agent), the injection method usually provides better results. In case of one-part adhesive products, due to their lower viscosity, the pouring method is more appropriate [6]. In standard geometrical configuration, angular notches are cut in bulk samples, usually inclined at $\pm 45^0$ to the specimen axes (Figure 1), [19]. In this manner a region of uniform shear stress is ensured in the central section of the specimen.

One of the most important concerns related to the Iosipescu shear test approach consists in avoiding the premature failure that may develop due to the tensile stress concentrations in the notch region. ASTM D5379 specifies several manufacturing methods to reduce the tensile stress concentrations. The most used method consists in machining a radius of 1.3 mm around the edges of the notch [19]. However, in some particular cases, machining is not allowed, and this radius can be obtained only by pouring the adhesive in special jigs and moulds, such as those described by Wycherley et. al. [17].

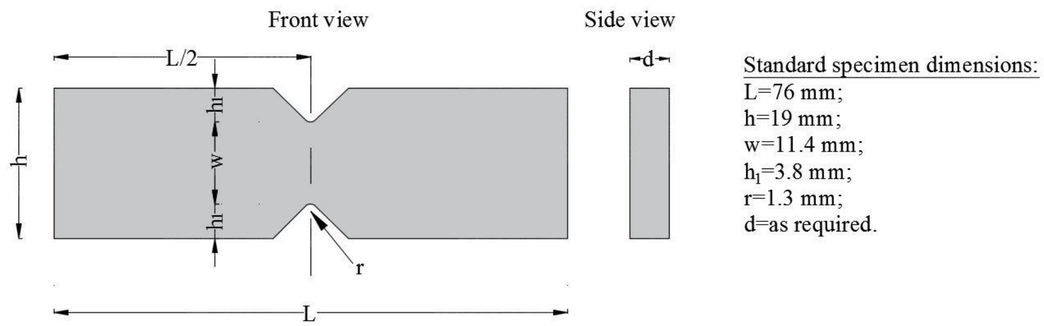

Fig. 1. *Standard geometry of Iosipescu specimen [19]*

The geometry of the specimens as specified in ASTM D 5379 consists in beams that are 76 mm long and either 19 or 20 mm deep. The optimum depth of the notches is considered to be one-fourth of the depth of the specimen. For rigid adhesive specimens (*i.e.* epoxy) the ASTM D5379 specifies a minimum width of 4 mm. The recommended and the most often used width for the Iosipescu adhesive and joint specimens is 20 mm, since exothermic heating is less of an issue for wide and thin bond areas [19].

Variations of the notch geometry were also investigated, and, for some particular cases of Iosipescu joint specimens, notch angles wider than 90^0 were found to be more suitable. Asymmetric notches with a skewed angle of 126^0 were experimentally studied by Ding et al, and the results show that the tensile stress concentrations are significantly diminished compared to the ones developed for the standard configuration with 90^0 notches [4].

2.1. Specimen instrumentation and loading conditions

The key advantage of the Iosipescu test consists in a specific loading pattern that provides a relatively uniform region of shear dominated stress across the central area of the specimen. The loading conditions are obtained by applying a compressive load to one end of the specimen while the opposite end is fixed (Figure 3d). For the analytical approach, the loading can be idealized as asymmetric flexure, as it is shown by the shear force and bending moment diagrams (Figure 2) [19].

The ASTM D5379 recommends that the shear strain distributions should be determined for bulk samples, using strain gauges attached to the specimen's central section at ±45° to its central axis. The effective shear strain, γ, is determined as the sum of the strains recorded by the gauges.

The specimen instrumentation can be achieved by using two distinct gauge configurations. The first consists in two individual linear strain gauges attached at ±45° to the specimen axis. However, this instrumentation method may provide altered results due to alignment errors. The second configuration uses biaxial shear strain gauges with orthogonally oriented sensing elements (Figure 2b) [6]. These devices provide more reliable results, since the longitudinal and the horizontal sensing units are pre-aligned. The most common biaxial shear strain gauges are the rectangular / rosette gauges (having stacked or side-by-side sensing elements) and the rosette gauges (having overlapping sensing elements).

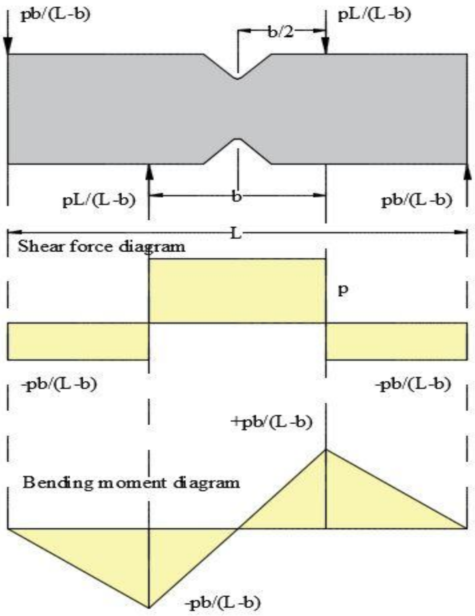

Fig. 2. *Idealized shear force and bending moment diagrams [19]*

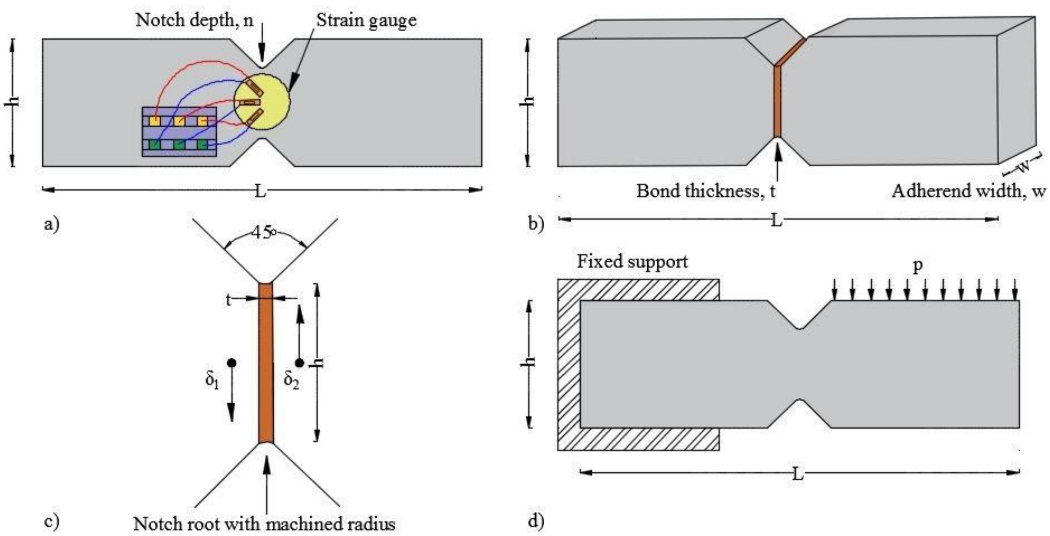

Fig. 3. *Instrumentation and loading conditions for Iosipescu specimen [6]*

The strain gauges should be small enough to fit within the central section of the specimen. Thus, the maximum length of the rectangular strain gauges should be bellow

12 mm. However, these recommendations are valid only for bulk adhesive specimens. For joint specimens (Figure 3b) it is difficult to record the strain variations with strain gauges since the sensing elements need to be smaller than the bond thickness (usually 1 mm). Due to this constraint, for this type of specimens the instrumentation is done only with shear extensometers. Thus, the shear strain, γ, is determined by dividing the shear extension (relative vertical motion of two points on either side of the centre line of the specimen) to the thickness of the adhesive, t (Equation 1) [6].

$$\gamma = \frac{(\delta_1 - \delta_2)}{t}. \quad (1)$$

3. Test Fixture

3.1. Wyoming fixture

The Iosipescu shear test method works by loading a V-notch specimen using a special design fixture. The loading device described in ASTM D5379 is generally referred to as the Wyoming fixture. It consists of a sliding grip that is connected to the clamps of the testing machine and a fixed grip that is attached to its base plate. (Figure 4). Also, by using several adjustable supports, the Wyoming fixture allows for different specimen depths to be accommodated [6,19]. The efficiency of the Wyoming device was experimentally studied by various research teams that concluded that the system provides satisfactory and reliable results for a large number of specimens tested in shear or under various combination of shear, compression and transverse tension [1,7].

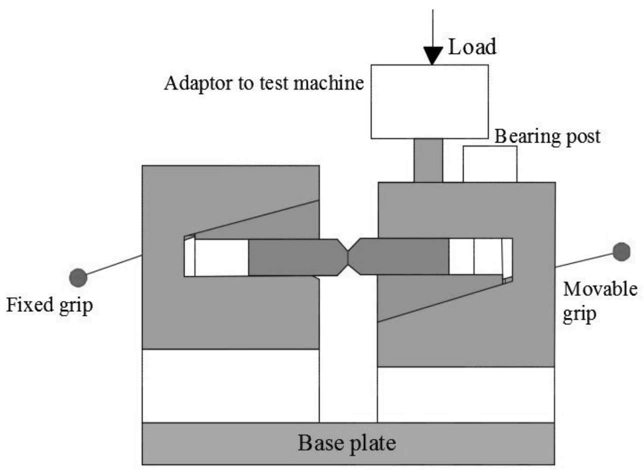

Fig. 4. *Wyoming fixture [6]*

However, Walrath and Adams [16] reported several issues that may be encountered when testing composite samples and may finally alter the test results. One of the most important issues refers to the specimen twisting, which results in unequal shear strain distribution on the front and the rear faces of the specimen. These concerns were addressed by Conant and Odom [3] by designing several improvements to the Wyoming fixture, such as the addition of clamps, side bearings and centring adjustments.

3.2. Arcan fixture

The improved Wyoming fixture required a considerable amount of additional bearings and centring adjustments. Therefore, a more compact fixture, easier to manufacture and set up was developed (Figure 5) [5]. The compact V-notch fixture (Arcan fixture) is also referred to as ''butterfly'' because of its unique shape.

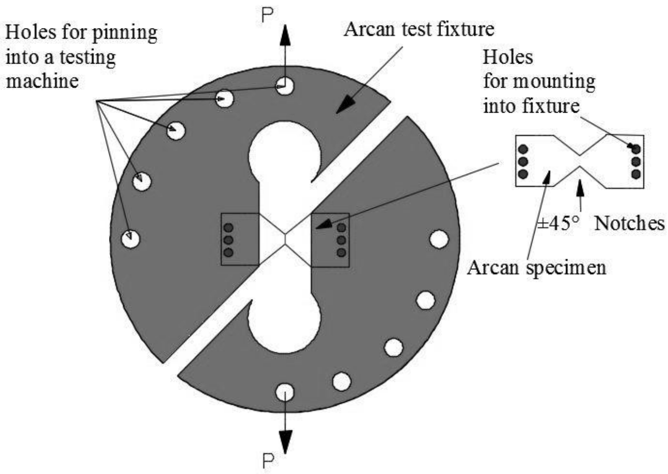

Fig. 5. *Arcan fixture [5]*

The Arcan fixture is very adaptive and has been used to assess the shear properties of a large number of materials, including metals, plastics, FRP composites and adhesives. In the case of the adhesive testing, due to the convenient installation method, the same system can be used to determine the distribution of the shear stresses and strains for both bulk and joint specimens.

As it can be observed in Figure 5, the Arcan fixture consists of two distinct semi-circular metal supports that have a central pattern of holes for mounting the specimen and an outer array of holes used to connect the fixture to the clamps of the testing machine. The geometry of the specimen is similar to the one designed for the Wyoming fixture, but it requires additional predrilled holes. The bolts passing through these holes secure the specimens to the fixture.

Although the Arcan shear test method insures the fast and efficient mounting of the specimen with insignificant alignment errors to the loading direction, it is difficult to be applied to bulk adhesive specimens. Several difficulties arise when the bolts mounting holes are drilled into the bulk specimens, such as the development of stress concentrations in the region of the hole or insufficiently processed regions that may lead to grip loss. In order to overcome these issues, for most of the adhesive products, it is recommended to drill the bolts mounting holes with a computer numerically controlled (CNC) machine. This manner also ensures that the holes are correctly positioned [5].

Another unique feature of the Arcan fixture is that it can be rotated and connected to the test machine through any opposite pairs of holes. In this manner, the specimen can be loaded through various combinations of shear and tensile forces. For example, if the Arcan fixture is rotated at 90^o, a butt tension load can be applied.

4. Conclusions

This paper has outlined and discussed several concerns that may have deterred researchers from applying the V-notch test method for determining the effective shear properties of adhesive products. One of the most common concerns associated to the Iosipescu shear test approach, relates to the high stress concentrations that may develop in the region of the specimen notches. Various specimen manufacturing methods (for both bulk and joint samples) were presented and studied. Furthermore, the most frequently utilized loading fixtures were described and their advantageous and disadvantageous characteristics were outlined.

The most advantageous feature of the Iosipescu test method consists in the possibility of providing a relatively pure shear stress state, condition that most shear tests do not provide. Thus, the Isopescu approach can be considered to be more representative to the real loading conditions of FRP adhesively bonded joints. By completing this short and comprehensive review on the developments of the Iosipescu method, the authors bring to attention the relevance of this test within the methods of investigation of the interfacial adhesion for FRP bonded joints.

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