SOME ISSUES ON THE SHEAR MODULUS DETERMINATION BY USING THE 10° OFF-AXIS TENSILE TEST

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Abstract: The shear properties of long-fiber reinforced composite materials can be studied on the basis of some tension tests, on the condition, for the reinforcement, to be oriented at an certain angle in respect with the load direction. The most frequently used, at this aim, are the values of 10° and ±45°.
The present paper focuses on the experimental results obtained from some 10° off-axis tensile tests, on a unidirectional carbon/epoxy composite. One can consider that the resulted shear modulus values are consistent with those obtained, for the same material, using the Iosipescu shear test.

Keywords: unidirectional composite materials, off-axis tensile test, shear modulus.

1. INTRODUCTION

The knowledge of composite materials shear properties can be very important, for the engineering design, in numerous practical situations. Their study can be made using various types of mechanical tests, most of which been developed especially to be applied for non-homogeneous materials [Ref. 4]. It must be emphasized that, besides the specific shear tests, one can also use at this aim some tension tests, with the limitation that the studied composite must be reinforced with long fiber. In fact, the loading forces that are used in experiment must be oriented at an angle, in respect with the reinforcement direction (see Fig.1). As a consequence, the complexity of the stress state which is induced into the composite specimen is increasing, together with the experimental results interpretation manner.

2. EXPERIMENTAL METHOD

Chamis and Sinclair introduced, in 1977 [Ref. 1], the ten-degree off-axis shear test, as a specific method for testing thin fibrous composites. In principle, the method consists in a uniaxial tensile test of a unidirectional laminate (see Fig.2) with fibers oriented at an angle (θ) in respect with the loading direction (see Fig. 2). As a result of the method appliance experience, the angle value of 10° was chosen in order to minimize the effects of longitudinal and transversal stress components, σ_1 and σ_2, on the material shear response [Ref. 2].

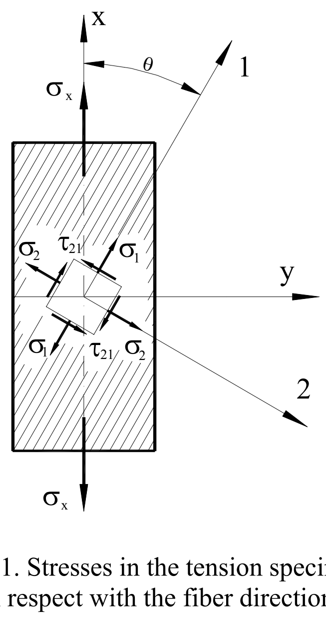

Fig. 1. Stresses in the tension specimen in respect with the fiber direction.

It must be noted that a simmilar method exists for the composite materials that are reinforced with double-oriented long fiber: their shear propeties are studied using the ±45° off-axis tension test, which was adopted as a standard shear test method by ASTM Standard D 3518 (in fact, it can be emphasized that it is the only off-axis tension test that was defined as a standard method).

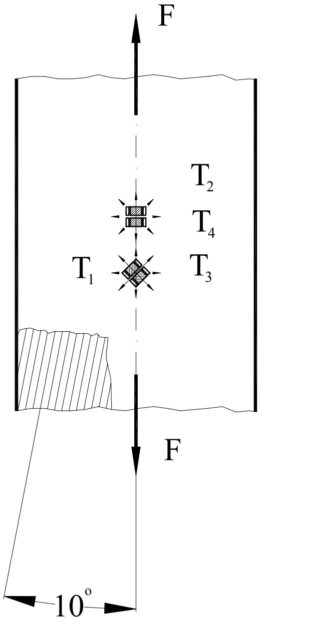

Fig.2. Transducers positioning and loading orientation.

It is also important to note that the specimen is not properly placed into a state of pure shear stress, but under the action of a combined state of stresses. The stress on the tensile direction can be calculated from the loading force (F) and the transverse section area (A) of the specimen, as:

$$\sigma_x = \frac{F}{A} \tag{1}$$

so the stress components, when reporting to the principal material axes, are:

$$\begin{aligned} \sigma_1 &= \sigma_x \cdot \cos^2\theta \\ \sigma_2 &= \sigma_x \cdot \sin^2\theta \\ \tau_{12} &= -\sigma_x \cdot \cos\theta \cdot \sin\theta \end{aligned} \tag{2}$$

For the present experiment, the basic component is the in-plane shear stress $\boldsymbol{\tau_{12}}$, and it can be obtained, as a numerical value, from the above relation, using the actual value of θ = -10°, as follows:

$$\tau_{12} = 0{,}171 \cdot \sigma_x \tag{3}$$

On the other hand, in order to study the shear response of the tested material, the corresponding value of shear strain is necesary to be known, and it can be calculated [Ref. 6] from the theoretical extensional strain values (on the three strain gages positioning direction), as:

$$\gamma_{12} = \varepsilon_x (\sin 2\theta - \cos 2\theta) - \varepsilon_y (\sin 2\theta + \cos 2\theta) + 2\,\varepsilon_{45} \cos 2\theta \tag{4}$$

As a consequence, the real value of shear strain is obtained from the indications of the bridge instrument and its final calculus relation is:

$$\gamma_{12,TS} = -0.620295\hat{\varepsilon}_1 + 1.950524\hat{\varepsilon}_2 - 1.330228\hat{\varepsilon}_3 \tag{5}$$

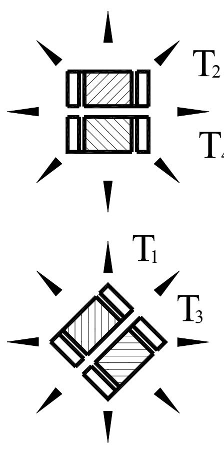

Fig.3. The structure and the orientation of the strain gages.

The strain values $\varepsilon_{1,\,2,\,3}$ are obtained from three of the four strain gages of the rosettes that are placed on the longitudinal axis of the specimen (see Fig. 3), as follows:

- T_1 and T_3 are, respectively, parallel and normal to the loading direction;
- T_2 is oriented at 45° from the same direction.

It must be noted that the values $\varepsilon_{1,\,2,\,3}$ that are introduced in relation (5) are strictly those that are reading to the Wheatstone bridge, during the corresponding stage of the experiment. On the other hand, the coefficients values from the relation (5) are obtained by considering two particular experimental aspects, as follows:

- the real electrical supply of the bridge was U_A=2V, lower then the standard one (4V), in order to limit the heating of composite material, into the vicinity of transducers;
- as the producer of strain gages rosettes recommends, a transverse sensitivity correction factor of transducers must be applied, for any value of extensional strain that is read on the bridge instrument.

The above-cited correction factor is determined [see Ref. 7], for the present strain gages, as:

$$C_{s-tr} = \frac{1-\nu_0 K_t}{1+K_t} = \frac{1-0,285 \cdot 0,019}{1+0,019} = 0,97604 \tag{6}$$

Finally, the shear modulus of the studied composite is determined as the slope of the straight line which approximates the shear stress-strain curve, in the loading stage of the experiment. That fact can be formulated as:

$$G_{12} = \frac{\Delta\tau_{12}}{\Delta\gamma_{12}} \tag{7}$$

where, $\Delta\tau_{12}$, $\Delta\gamma_{12}$ are the increments of shear stress and strain, respectively, for two precise levels of loading force.

3. MATERIALS AND EXPERIMENTAL DEVICES

A specimen of general shape (Fig. 4) for tension testing is used (cutted with respect to the corresponding orientation of the reinforcement), including some aluminum strenghtning end tabs.

The strain gage rosettes were EA-13-062TV-350 type, from Micro-Measurements (Vishay), and it were bonded as it is indicated in Figure 5. The tension voltage supply was chosen at the level of 2V, in order to prevent the local heating into the composite, near the transducer zone [Ref. 4]. The experiments were made on a "Textenser" testing machine, with 500N as the maximum loading force.

The studied composite is based on an epoxy resin, reinforced with unidirectional long carbon fiber, having a volume fraction of 68%. The specimen has l=15.8mm in wide, g=3.3mm in thickness, and its gage length was L=90mm. The aspect ratio of the specimen was L/h=11,39, which is a sufficiently high value for neglecting the clamping influence on the stress state in the gage zone of the specimen.

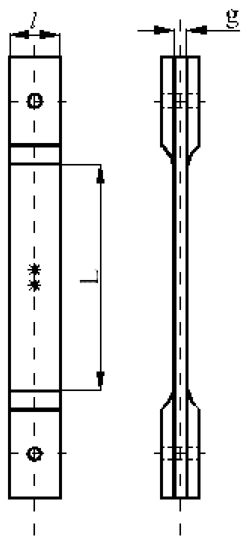

Fig.4. The tension specimen.

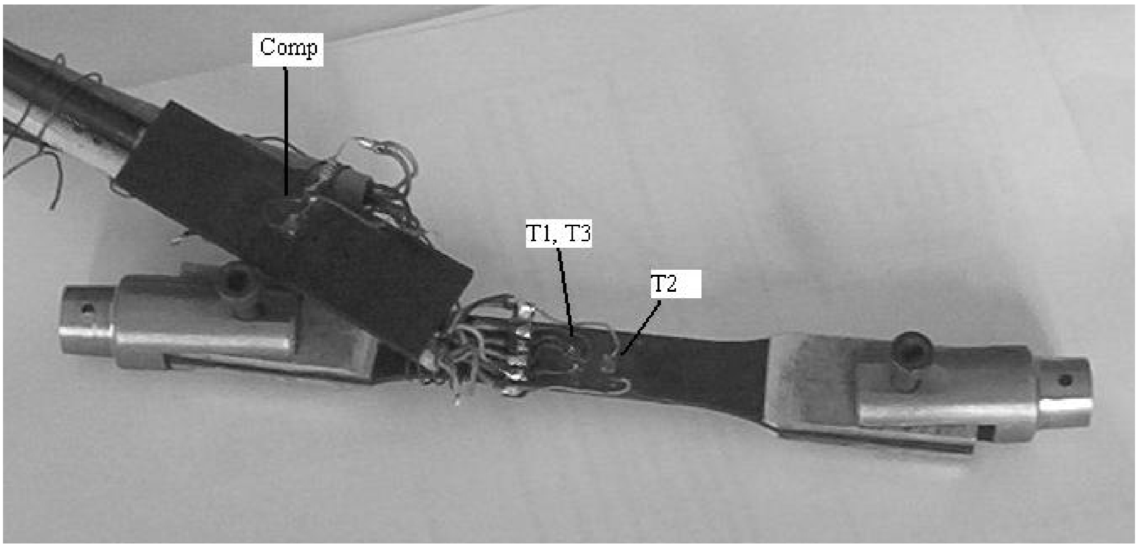

Fig. 5. The instrumented off-axis tension test specimen.
("Comp." is the compensation strain gage.)

4. RESULTS AND CONCLUSIONS

Using the calculated values from the above-cited relations (3) and (5), corresponding to certain levels of loading force (F), one can plot the variation of shear stress-strain dependence for the studied composite material. (see Fig. 6). The trend line of that curve indicates an approximate value of the in-plane shear modulus (G_{12}), representing the slope of that line. In fact, the resulted shear modulus values are G_{12}=5472.2MPa and G_{12}=5306.8MPa, respectively.

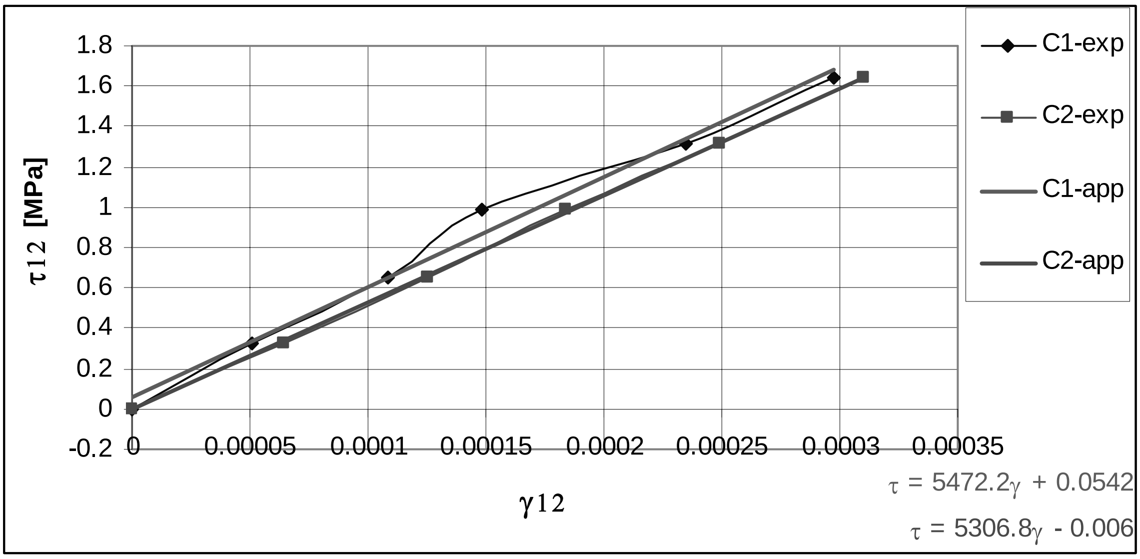

Fig. 6. Typical aspect of the trend line, for the shear-stress-strain response of the studied composite.

The cited values are in good agreement with experimental data that are presented in literature for shear modulus of unidirectional carbon/epoxy composites, and also with the results previously obtained, by the present authors [see Ref. 5]. On that basis, one can conclude that the off-axis tension test method leads to an accurate determination of shear modulus of composite materials, on condition of using a precise specimen processing and respecting the experimental parameters requested by the test method.

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