168 Simultaneous identification of the transverse and shear moduli of a UD composite at high strain rates with the IBUS test

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Abstract

A recently developed test called the 'IBUS' (Image-Based Ultrasonic Shaking) made the material behaviour characterisation at high strain rates possible. Here a new development of this technic to characterise an orthotropic behaviour is presented. UD composites with four different off-axis configurations are tested. By using the Virtual Fields Method, we were able to identify the average stress for the transverse and shear components along a slice following the fibre direction. This method provides a simple way to measure the transverse and shear moduli of UD composites simultaneously at strain rates in the 10s to 100 s^{-1}.

Introduction

The new experimental set-up called IBUS (Image-Based Ultrasonic Shaking) [1] allows for the characterisation of the Young's modulus of materials and its dependency to the strain-rate and the temperature. This test consists in bonding a thin rectangular sample onto the horn of a sonotrode. On one side of the sample a grid is printed in order to get the displacement fields via the grid method [2]. The grid method is chosen for its better spatial resolution than Digital Image Correlation (DIC), and for its accuracy concerning small strains. The sonotrode's horn harmonically imposes a displacement to the sample at a frequency of 20 kHz. The kinematic fields enable the material parameters identification at different strain-rates along the test sample. In order to maximise the displacements and to minimise debonding stresses at the interface between sample and horn, the samples' length is adjusted so that the system is resonant at the sonotrode frequency. This device can be used for different materials and for different purposes. When considering an orthotropic material the need is not any more to characterise two material parameters (E and ν) but four (E_{11}, E_{22}, G_{12} and ν_{12}) in the 2D case to fully characterise the material behaviour. Here a unidirectional Carbon Fibre Reinforced Polymer (CFRP) composite material is studied. This kind of material is widely used in the transportation industry; indeed its mechanical properties in association with its low density make it a wise choice as a substitute for metallic alloys. Nevertheless its dynamic behaviour is difficult to characterise and the different data found in the literature are quite confusing about its strain-rate sensitivity [3].

The IBUS test

The IBUS test needs the different samples to be resonant with the excitation frequency. In the case of the 90° specimens, the determination of the resonance frequency is similar to that of an isotropic material. The length of the sample is adjusted according to the analytical solution for isotropic materials, so to be resonant at 20k Hz. In an off–axis configuration, such analytical solution does not exist and the length has to be determined using finite element modal analysis. In this case the stress field is not uni-axial anymore. In order to identify the material behaviour the classic 'stress gauge' method can be applied in the 90° configuration [4]. But in the case of an off-axis configuration this relation does not stand. Instead, with the help of the Virtual Fields Method, it can be shown than the average stress for components σ_{12} and σ_{22} along a slice *l* parallel to the fibre direction (see Figure 1), can be determined with the help of both acceleration components. The relations are:

$$\overline{\sigma_{12}} = \frac{S}{l}\rho\overline{a_1} \quad ; \quad \overline{\sigma_{22}} = \frac{S}{l}\rho\overline{a_2} \qquad (1)$$

Since the full-field technique also provides the mean strains, it is possible to identify the shear and the transverse moduli simultaneously.

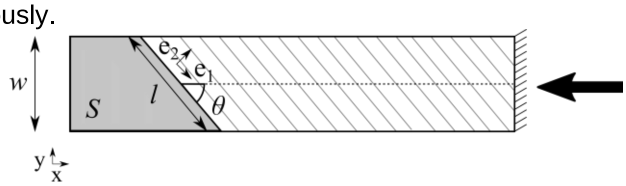

Figure 1: Off-axis IBUS test configuration

Experimental procedure and results

IBUS tests have been performed on unidirectional samples of Gurit SE70 carbon fibre at four different angles to the loading direction (45°, 60°, 75° and 90°). The samples were simply bonded to the tip of the sonotrode horn. A grid was printed on the sample to measure displacements using the grid method. The experiments were recorded with an ultra-high speed camera, a Shimadzu HPV-X, at 500 kHz. At this framerate, because the camera only records 128 images, a bit more than 5 cycles were captured. The displacements were spatially differentiated to obtain strain, while acceleration was obtained by double temporal differentiation of displacements. Both stress (from Eq. 1) and strain were then fitted with sine functions over time to allow for the identification of both moduli (and phase lag relating to dissipation, though this was quite small here). Stress-strain curves (fitted and unfitted) are shown in Figure 2 for the 60° case. Because the strain state is not the same in each direction. The value of the strain rate will depend of the component. In the case shown the strain rates are respectively 63 and 116 per second regarding to shear and transverse components.

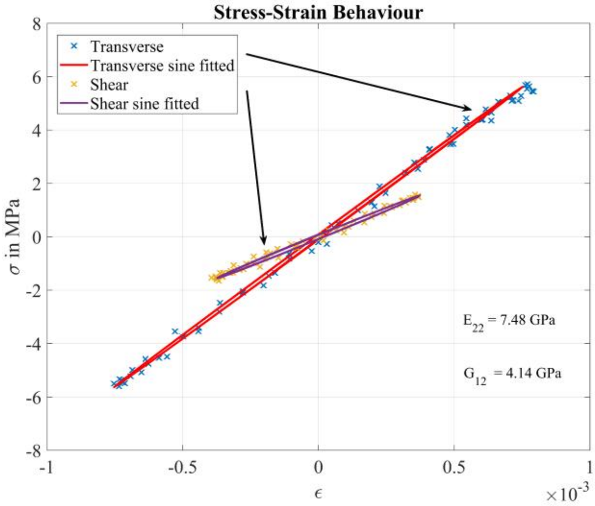

Figure 2: Experimental stress-strain curves for the 60° case

Conclusion

This work brings to light the possibility of using the IBUS test to identify both transverse and shear moduli of unidirectional composites, here a CFRP. The main advantages of this procedure are its low cost (provided a UHS camera is available), compared to, for instance the use of a high-speed hydraulic machine; and the high quality of the derived data. The strain rates are lower than those obtained for the Image-Based Inertial Impact (IBII) test [5], so both tests are complementary. While the IBII test also provides a strength information, the IBUS test cannot reach large enough stresses to fracture the specimen, though this may be achievable in the future by designing dogbone shapes. Finally, another advantage of the IBUS test is that the strain rate is heterogeneous in time at a given location in the specimen, and in space at a given time. This rich experimental database may make it possible to identify a strain-rate dependence model with a single test, particularly for highly strain rate dependent materials like thermoplastic matrix composites. This will be investigated in the future.

References

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