167 The off-axis IBII test for simultaneous characterisation of the transverse and shear moduli of composites at high strain rates

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Abstract. Limitations with the Split Hopkinson Bar (SHB) technique restrict the achievable strain rates to a few $100\ s^{-1}$ when testing composite materials. The Image Based Inertial Impact (IBII) test can be used to evaluate the mechanical properties of composites at high strain rates. The IBII test does not have the requirement for quasi-static equilibrium in the specimen, making it an ideal test method for dynamic material property identification. This paper presents a new off-axis IBII configuration to obtain the transverse and shear moduli for a unidirectional carbon fibre reinforced polymer composite. The transverse modulus was identified as $E_{22} = 7.8\ GPa$ and the shear modulus as $G_{12} = 3.5\ GPa$ at a strain rate of $\dot{\epsilon} \approx 1000\ s^{-1}$.

Introduction

Composite materials utilised in automotive, aerospace and defence applications experience dynamic loads. Due to their anisotropic nature, composites have different longitudinal, transverse and shear material behaviour, of which the transverse and shear properties are generally considered strain rate sensitive. The SHB apparatus has been used to obtain the high strain rate properties of composites [1]. When using the SHB the state of stress in the specimen is inferred from the input and output bar strain gauge signals. To do this, there is a requirement that the forces on both faces of the specimen must be equal *i.e.* the specimen is in a state of quasi-static equilibrium. This requirement is difficult to achieve in low wave speed, brittle and low failure strain materials such as composites, because the specimen can fail before quasi-static equilibrium has been achieved. If the specimen does achieve quasi-static equilibrium, the time required for inertial effects to dissipate is usually longer than the elastic material response time and therefore, the elastic modulus cannot be obtained [2].

The continued requirement to characterise composite material properties at high strain rates has called for new test methods with less restrictions on the test conditions. The IBII test utilises full-field displacement measurements together with the Virtual Fields Method (VFM) to calculate high strain rate material properties, without the requirement of quasi-static equilibrium. In [3] the IBII test was used to obtain the in-plane transverse modulus and failure strength in carbon fibre composite specimens impacted in the 90˚ transverse configuration (2-axis). This work extends the method to obtain both the transverse and shear moduli with the specimen impacted in the 45˚ off-axis configuration.

Test Description and Theory

The IBII test utilises a gas gun to accelerate a cylindrical projectile onto a waveguide and impart a compressive pulse into the specimen. Fig. 1 shows a schematic of the main components used in the IBII test. During the test, images of the impacted specimen are used to calculate displacement fields. The displacement fields are differentiated with respect to space to obtain the strain fields and twice differentiated with respect to time to obtain the acceleration fields.

In [3] the 'stress-gauge' equation was derived using a rigid body virtual field describing a translation in the 'x' direction. The stress-gauge equation relates the average stress in a cross section of the sample to the surface average of the accelerations. The goal here is to extend this concept to an off-axis configuration by using rigid body virtual fields that describe translations in the material coordinates. The off-axis specimen configuration is shown in Fig. 1, where the 1-axis from the material coordinate system (1,2) is rotated at an angle θ to the x-axis from the global coordinate system (x,y). Here a slice l is taken at the angle θ. The average stress over l transverse to the fibres, $\overline{\sigma_{22}}^l$ and the average shear stress, $\overline{\sigma_{12}}^l$ are given by:

$$\overline{\sigma_{ij}}^l = \rho \frac{S}{l} \overline{a_i}^S \ for\ i = 1,2\ \ j = 2 \quad (1)$$

where ρ is the material density, S is the area of a trapezoid (blue shaded area in Fig. 1) and $\overline{a_i}^S$ is the average acceleration over S. The off-axis transverse and shear moduli are obtained by taking a line of best fit from plots of $\overline{\sigma_{22}}^l$ vs. $\overline{\epsilon_{22}}^l$ and $\overline{\sigma_{12}}^l$ vs. $\overline{\gamma_{12}}^l$, respectively.

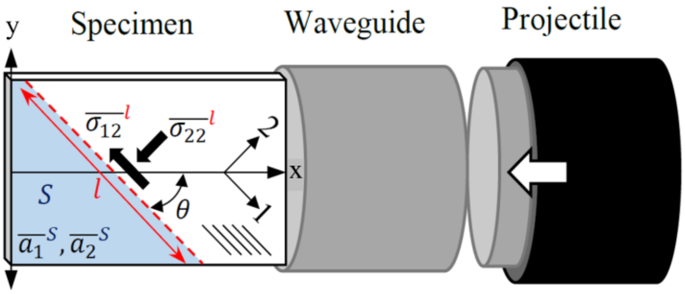

Figure 1. Schematic showing the main components of the IBII test with an off-axis composite specimen.

Experimental Method

A specimen with dimensions 70 x 43 x 3.72 mm was cut from an autoclave cured composite plate, manufactured from Gurit SE70 pre-preg containing unidirectional carbon fibres. The specimen was cut using a diamond saw, such that the fibre angle was at 45˚ to the impact direction. The gas gun, camera and data processing details are given in [3].

Results and Discussion

Fig. 2 shows the kinematic fields and stress-strain response in the transverse (a) and shear (b) directions. The stress – strain response is shown along the slice indicated by the dashed line in the kinematic fields shown in Fig. 2. The modulus components were obtained from a linear fit of the stress – strain data, computed over the initial compressive portion of the test where the material response was linear. The modulus was calculated at each slice and averaged. The average transverse modulus was $E_{22} = 7.8\ GPa$ and the average shear modulus was $G_{12} = 3.5\ GPa$. The peak transverse strain rate was $\overline{\dot{\epsilon}_{22}}^l_{max} = 820\ s^{-1}$ and the peak shear strain rate was $\overline{\dot{\gamma}_{12}}^l_{max} = 1300\ s^{-1}$. The identified transverse modulus conforms well to that identified in [3], but limited data is available to make comparison with the shear modulus.

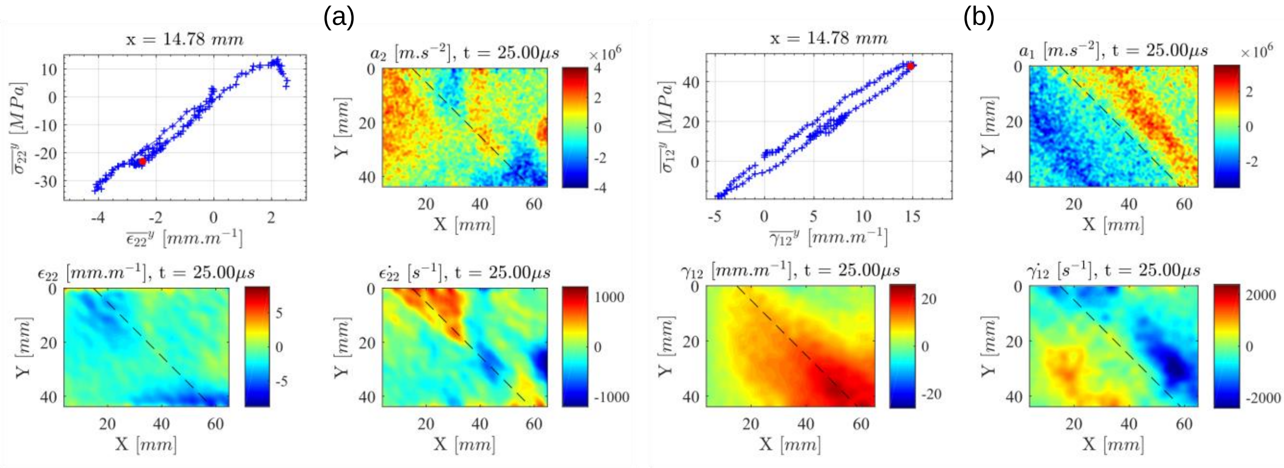

Figure 2. Kinematic fields and stress-strain response for the (a) transverse component and (b) shear component.

Conclusion and Future Work

The IBII test was used to identify the in-plane transverse and shear moduli of a carbon fibre reinforced polymer composite tested in the 45˚ off-axis configuration at $\dot{\epsilon} \approx 1000\ s^{-1}$. Future work will include testing at different off-axis angles and developing local strength identification methods similar to the linear stress-gauge presented in [3]. Testing at several different angles will allow for the investigation of the tension/shear, compression/shear failure envelope at high strain rates.

References

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