125 Advancing the image-based inertial impact test for high strain rate interlaminar properties using synchronised ultra-high-speed-cameras

J. Van Blitterswyk[1a], L. Fletcher[1] and F. Pierron[1]

[1]University of Southampton, University Road, Southampton, SO17 1BJ, UK

[a]j.van-blitterswyk@soton.ac.uk

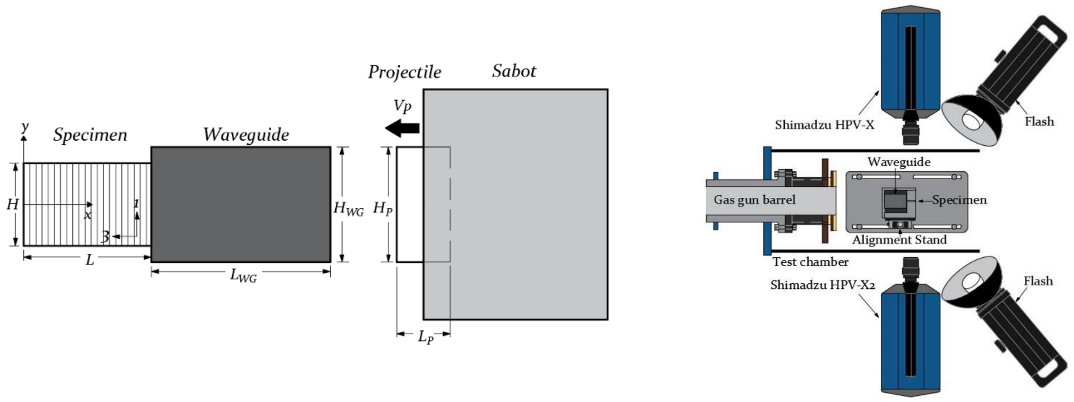
Abstract. This work explores the effects of the specimen geometry and test configuration (i.e.: specimen mounting, alignment, etc.) to more rigorously quantify the accuracy of interlaminar stiffness measured using the IBII. Two ultra-high-speed cameras are used to measure dynamic kinematic fields on the front and back faces of samples. These fields are processed using the VFM to identify stiffness from both sides of the sample. This provides a means to assess the suitability of the assumptions of plane stress, and through-thickness uniformity. On all samples the unloading response of the material differs between the front and back surfaces. It is suspected that slight misalignments of the projectile or sample may cause this behaviour.

Introduction

Characterisation of the effect of strain rate on the interlaminar stiffness is important for the design of fibre-reinforced polymer (FRP) composites that are subjected to dynamic loading. The strain rate effect is currently not well understood due to limitations of existing techniques (i.e.: high-speed load frames, split-Hopkinson pressure bar, etc.). The limited information used in these tests makes it is very challenging to obtain reliable measurements above a few 100/s where transient stress waves cause heterogeneous states of stress and strain [1]. Recently, an image-based inertial impact (IBII) test has been successfully developed to measure in-plane [2], and interlaminar [3] stiffness and strength for unidirectional FRP composites at strain rates above 1,000/s. The next step in the development of the interlaminar IBII test is to more rigorously investigate the accuracy of measured stiffness values using measurements from a single side of the sample. Single-sided measurements are suitable so long as: 1) the material is loaded in a state of plane stress, and 2) the measured fields on the surface of the sample are constant through the thickness. The objective of this study is to assess the appropriateness of the above assumptions for the configuration presented in [3] using synchronized ultra-high-speed cameras to measure the response on the front and back surface of interlaminar IBII specimens.

Experimental Approach

The material used in this study is a unidirectional carbon/epoxy pre-preg (AS4-145/MTM45-1). A plate having a nominal thickness of 18 mm was used to provide a long enough specimen in the through-thickness direction for the tests to be successful. The thickness of the samples were 3.0 mm and the specimen height was fixed at 12 mm to maximize the camera spatial resolution (Shimadzu HPV-X, 400 x 250 pixels). The proposed test configuration (Fig. 1a) is designed to indirectly load the specimen in tension through the application of a compressive pulse from a projectile traveling at speed, $\boldsymbol{V_P}$. The following experimental parameters were selected based on the optimization study in [3]: $\boldsymbol{L_P}$ = 10 mm, $\boldsymbol{V_P}$ = 50 m·s-1, $\boldsymbol{H_P} = \boldsymbol{H_{WG}}$ = 25 mm, and $\boldsymbol{L_{WG}}$ = 50 mm. Two Shimadzu ultra-high-speed cameras were used to image front face (HPV-X model) and back face (HPV-X2 Model) of the sample. The dual camera arrangement is shown schematically in Fig.1b.



a) b)

Figure 1: a) Schematic of interlaminar IBII test and b) schematic of the experimental setup with back-to-back cameras used to image the front and back surfaces of the sample.

Reconstructing Stress from Acceleration

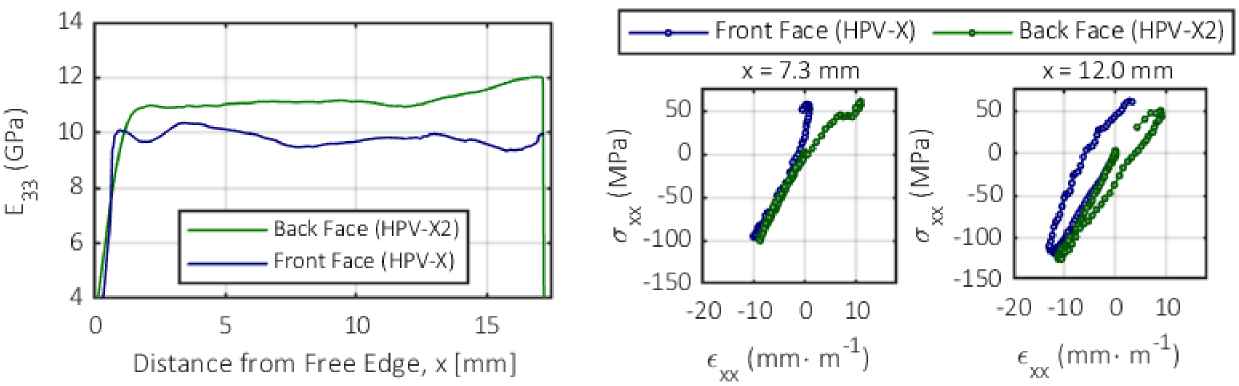
From equilibrium, the average axial stress, $\overline{\sigma_{xx}}^{y}$, at any position, x, and time, t, can be expressed as a function of the measured surface accelerations (`stress-gauge equation' Eq. (1)) [4].

$$\overline{\sigma_{xx}(x,t)}^{y} = \rho x \overline{a_x(x,t)}^{S} \tag{1}$$

In Eq. (1), ρ is the material density, the superscripts y and s, coupled with the overline, respectively denote the line average at x, and the average surface acceleration between the free edge and x. Using the stress-gauge equation (Eq. (1)), the average stress ($\overline{\sigma_{xx}}^{y}$) was reconstructed and plotted against average axial strain ($\overline{\epsilon_{xx}}^{y}$) at each axial cross-section to identify the stress-strain behaviour of the material. A linear regression fitting to the compressive loading of the stress-strain curve at each cross-section to identify the modulus (E_{33}).

Results

Fields measured from both sides of the sample were processed using Eq. (1) to identify the stress-strain response and interlaminar stiffness at each cross-section. The spatial identifications from each side of one sample are shown in Fig. 2a. The modulus was systematically greater on the back side of the sample (by approximately 10%). The stress-strain curves at two cross-sections on both sides of the sample (Fig. 2b) show that near the free edge the measured compression loading and unloading behaviour is very similar, as illustrated by the stress-strain curves at x = 7.3 mm. However, the tensile loading behaviour are different between the two sides. This divergence happens earlier at cross-sections nearer to the impact edge (*i.e.:* stress-strain curve at x = 12.0 mm in Fig. 2b. Simulations of the test with an angled input pulse show a similar trend in the stress-strain response from the front and back faces as a result of a bending wave which follows the axial wave. It is suspected that misalignment (projectile or specimen) may be responsible for the measured differences between the front and back faces, however, further investigation is required to confirm this.



a) b)

Figure 2: a) Spatial distribution in identified interlaminar stiffness from reconstructed stress-strain curves using the stress-gauge equation (Eq. (1)), and b) sample stress-strain curves reconstructed on from front and back face measurements at two positions on the sample.

Conclusions and Future Work

Two synchronized ultra-high-speed cameras were used to characterize the interlaminar stiffness of a carbon/epoxy composite using the image-based inertial impact (IBII) test. Measuring the stress-strain behaviour on the front and back faces of the IBII specimens enabled a quantitative assessment to be made regarding the uniformity of the behaviour through the thickness. This study showed a systematic difference between the two sides of the specimen, resulting in a 10% mismatch in stiffness between the front and back faces. It is suspected that this is a result of misalignment of the input pulse, which causes some out-of-plane bending of the sample. Future work involves experimental and numerical studies to quantify the alignment of the current setup and the effect of any misalignment on the measured fields. The objective is to establish tolerances for the experimental parameters to improve the accuracy of material property identifications.

References

[1] Van Blitterswyk J., Fletcher L., Pierron F., Adv. Exp. Mech., 2:3-28, 2017.
[2] Fletcher L., Van Blitterswyk J., Pierron F., J. Dynamic Behavior Mater., 2019.
[3] Van Blitterswyk J., Fletcher L., Pierron F., J. Dynamic Behavior Mater., 4:453, 2018.
[4] Pierron F., Zhu H., Siviour C. R., Philos. T. R. Soc. A, 372: 20130195, 2014.