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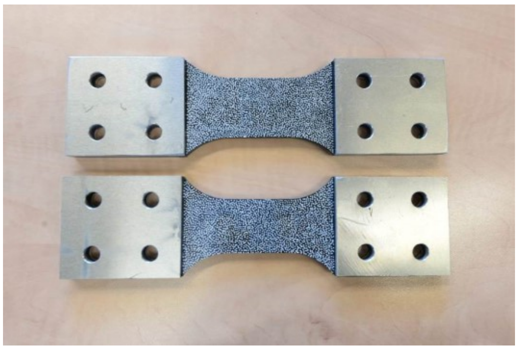
Hopkinson tensile testing on large specimens: application to Advanced Placed Ply AFP composites

Marco Peroni[a]*, Rutger Kok[b], Francisca Martinez-Hergueta[b], Antonio Pellegrino[c]

[a]*European Commission, Joint Research Centre, Ispra, Italy*
[b]*School of Engineering, Institute for Infrastructure and Environment, The University of Edinburgh, William 4 Rankine Building, EH9 3FG, Edinburgh, UK*
[c] *Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK*

Extended Abstract

High strain-rate mechanical testing play a key role to achieve reliable data essential in components design subjected to impacts or explosions using FEM methodology. In this context, Hopkinson bar methodology is largely adopted, both in compression and tension, to obtain material stress-strain curves in the range of strain-rate between 10^2 to 10^4 s^{-1}. Since Hopkinson techniques works properly for ductile materials (i.e. metals, plastics, etc.) several problems arise with two main material classes: brittle and coarse structure materials.
Typically, brittle materials (characterized by elastic behaviour until fracture) are difficult to test by means of Hopkinson bars because traditional setups and data elaboration accuracy in small strains regime are not adequate to correctly evaluate material Young modulus. In addition, for the reduced test duration, force equilibrium is not always reached and this prevents to correctly evaluate the specimen stress field using global measurements (i.e. measured forces at specimen ends). Coarse structure materials (for example foams, geo-materials or composites) point out another limitation of conventional Hopkinson techniques related to specimen sizes. In fact, typical Hopkinson facilities have bars diameters of about 10 to 20 mm which are not adequate to test materials with structural unit cells of more than 10 mm (the specimen is no more representative of material behaviour).
In this context, this work develops the experimental methodology to characterise the dynamic response~~presents an example of characterization at high strain-rate~~ of a series of brittle material with a coarse structure of more than 10 mm (Advanced Placed Ply AFP composites [1]) emphasising testing technique and design instead of material properties discussion. Tests have been performed at the large Hopkinson bar of the HopLab laboratory of European Commission [2]. HopLab is probably the largest existing Hopkinson bar equipment with a length of more than 200 m and a bar diameter of 72 mm made of high strength steel. Differently from a classical Hopkinson bar the loading pulse (with a maximum amplitude of 1.5 MN) is generated statically pre-tensioning and suddenly releasing a portion of the input bar (using an explosive bolt).



* Corresponding author. Tel.: +39 0332789775
E-mail address: marco.peroni@ec.europa.eu

Figure 1 Clamping system designed for composite material (left) and tabbed specimen of AP-PLY composites (Right)

Figure 1 shows on the left the ad-hoc friction based clamping system designed for the test campaign and on the right the specimen geometry adopted. Specimens (extracted from plate using CNC machining) have a gage section of 30÷40 mm with a thickness of about 4÷6 mm and they have been reinforced with aluminium tabs at the clamping ends. To avoid slipping between clamp and specimen four M10 high-strength bolts have been used and clamping surface have been knurled to improve friction coefficient. Specimen geometry and clamps have been designed with several iterations to reduce the risk of premature fracture outside the gage section.
Figure 2 presents on the left typical signals acquired during a test (3 measurement points for each bar, ohmic and semiconductor strain-gages, amplifier with 500 Hz bandwidth and sampling rate of 5 MHz) and on the right elaborated waves at specimen ends using a deconvolution algorithm (input wave is largely longer than input and output bar) able to compensate for wave dispersion distortions [3].

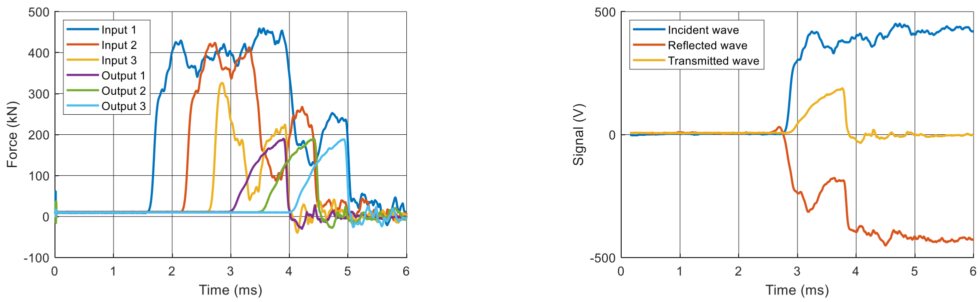


Figure 2 Raw acquired signals in Hopkinson tests (left) and waves reconstructed with deconvolution algorithm (Right)

With the adopted setup force equilibrium is rapidly achieved as reported in Figure 3 (left) since the input side velocity is about 5 m/s. Small oscillations in the input side force are due to a small propagating error of the deconvolution algorithm and to additional masses introduced with the specimen clamps. To further improve data accuracy (especially in small strains regime) with additional and independents measurements, DIC has been ~~largely adopted~~used to directly evaluate the specimen strain field (adopted speckle is visible on the specimen surface in Figure 1).

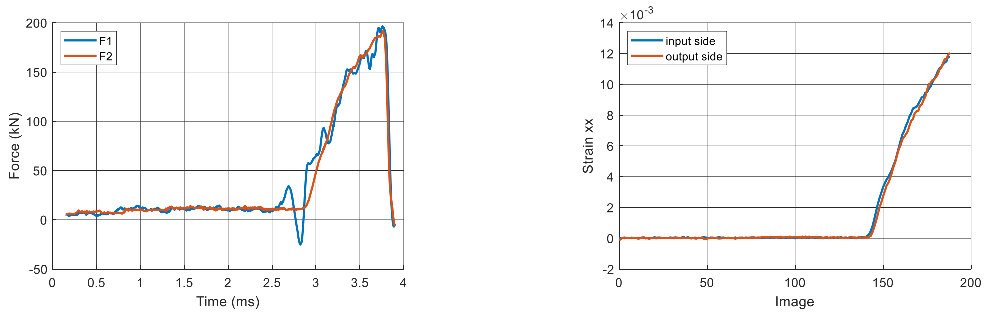


Figure 3 equilibrium check using farce reconstructed at specimen ends (left) and using DIC (Right)

Using DIC an accurate evaluation of material Young modulus can be achieved simply averaging the strain on the specimen gage section (high speed camera and Hopkinson transient recorder have to be finely synchronized). In addition, it is possible to check specimen equilibrium (alternatively and independently from Hopkinson measurement) using the right and left specimen shoulder as load cell as reported in Figure 3 (right).
The proposed equipment and methodology ~~just proposed~~represents ~~is currently~~ one of the few alternatives to perform highly demanding tests to characterize the tensile high strain-rate behaviour of brittle material with coarse structure, like AP-PLY composites, maintaining the specimen sizes representative of global material behaviour (and thus reducing data scattering).

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