Dispersion Effects on High Speed Tension Testing – SHPB

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1. Introduction

When designing with polymeric fiber reinforced composites, properties such as the elastic moduli and failure strength are of principal interest. Compression strength is affected by end conditions and result from a combination of end conditions [1]. In the other hand, tensile strength is regarded as one of the most important intrinsic material properties needed by a designer.

Characterizing the behavior of composites under dynamic loading is not an easy task. The majority of dynamic testing techniques introduce complex stress and strain fields which prevent a fundamental formulation of strain-rate effects on material properties. The Split Hopkinson Pressure Bar (SHPB) provides with a uniaxial homogeneous state of stress. However, contact surfaces conditions are very critical and specimens must be short to minimize wave propagation effects [2]. On in-plane compression testing the specimen is sandwiched between two pressure bars. It sits flat against each bar without being fixed or gripped to the bars. In contrast, several difficulties arise when tensile testing is at hand. Mechanical interfaces between specimen, fixture, and bars hinder the stress wave transmission. Such interfaces introduce additional dispersion into the signals recorded from the pressure bars.

Dispersion is the result of a bar's phase velocity dependence on frequency [3]. There are different sources of dispersion on pressure bar apparatus, e.g., dispersive nature of the bar, radial inertia, friction, mechanical joints, specimen geometry, etc. Load and strain measurements are distorted through oscillations, which include rigid body accelerations of the system and shock waves resulting from the impact event.

2. Experiments, Results, and Discussion

The Split Hopkinson Pressure Bar principle requires that the specimen reaches quasi-static equilibrium at an early stage during the test [1]. For this requirement to be satisfied, the stress distribution on the specimen and the failure process expected to predominate need to be well understood. Failure strengths knowledge aided estimating specimen dimensions. Specimen geometry was carefully designed to allow for a smooth load transmition minimizing stress concentration (see Figure 1).

With the goal of minimizing the mechanical interfaces between load transmition components and the testing coupon, several gripping mechanism were discarded, e.g., clamping, bearing, etc. A common procedure on metal testing constitutes the use of threaded specimens. However, this is not feasible on composite materials. Therefore, the proposed gripping mechanism adhesively bonds the specimen to an aluminum cap, which is then threaded to the end of the pressure bars (see Figures 2 and 3).

The tensile SHPB apparatus and the load path interface are simplified for testing reliability. After carefully evaluating the qualities and deficiencies of current high speed testing apparatus for material evaluation, a tensile SHPB apparatus is implemented (see Figure 4).

The dispersion correction procedure is based on numerical results of the first mode of vibration of Pochhammer-Chree elastic wave equations. The high-frequency components introduced by dispersion sources in strain gage data are eliminated by using a low-pass filter. The Nyquist frequency is used in the data analysis as the cut-off frequency for dispersion correction. High-frequency components are identified transforming the data into the frequency domain using a FFT (Fast Fourier Transform). The unwanted frequency components are eliminated by multiplying the FFT values at these frequencies by zero. The modified frequency domain data is then transformed back into time-domain with IFFT (Inverse FFT). Figure 5 shows an incident pulse before and after high-frequency components were eliminated. A significant noise reduction is observed without compromising the shape of the pulse. A dispersion correction technique is developed to reduce the magnitude of the oscillations of the stress-strain plot (see Figure 6).

3. Conclusions

A tension specimen was designed minimizing stress concentration and satisfying quasi-static equilibrium conditions. The tensile SHPB apparatus and the load path interface were simplified for testing reliability. The current work quantified the amount of dispersion and identified influential parameters. Strain gage raw data was filtered from high-frequency content. A dispersion correction technique was developed to reduce the magnitude of the oscillations of the stress-strain plot.

[1] Ruiz, C. and Harding, J., Modeling Impact of Composite Structures Using Small Specimens, Chapter 3, *Impact Behavior of Fibre-reinforced Composite Materials and Structures, Journal of Composite Materials*, ed. Reid, S. R. and Zhou, G., CRC Press, 2000.
[2] Hsiao, H. M. Strain Rate Effects on the Transverse Compressive and Shear Behavior of Unidirectional Composites, *Journal of Composite Materials*, pp. 1620-1642, 1999.
[3] Kaiser, M. A., Advancements in the Split Hopkinson Bar Test, *Master Thesis*, Virginia Polytechnic Institute, 1998.
[4] Hsiao, H. M. Strain Rate Effects on the Transverse Compressive and Shear Behavior of Unidirectional Composites, *Journal of Composite Materials*, pp. 1620-1642, 1999.

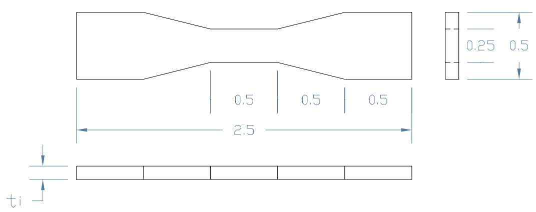

Figure (1): Test specimen geometry.

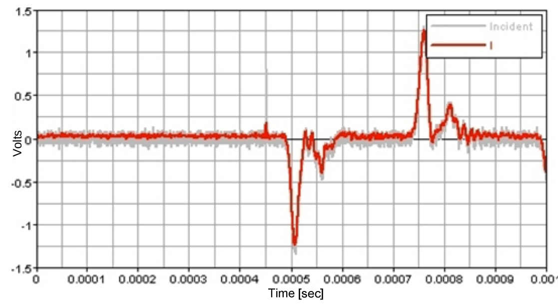

Figure (5): Incident pulse before and after dispersion correction.

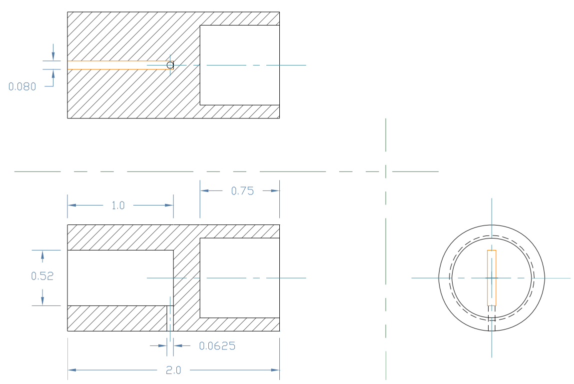

Figure (2): Test gripping mechanism.

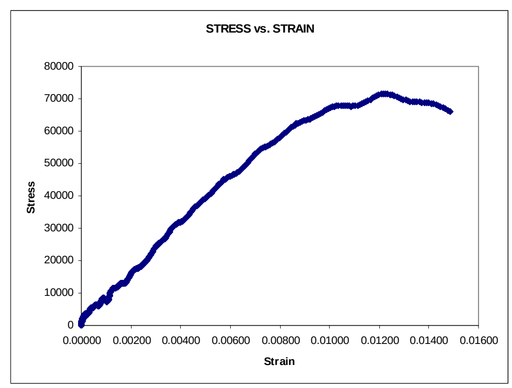

Figure (6): Corrected stress-strain plot.

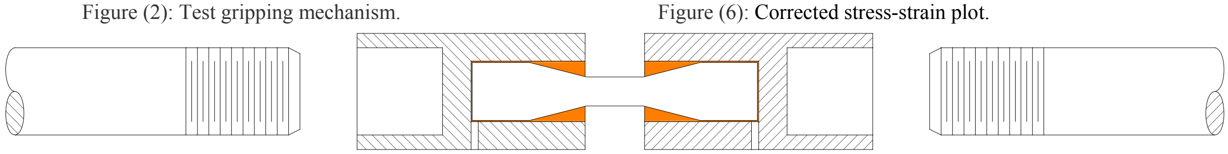

Figure (3): Test gripping mechanism set up.

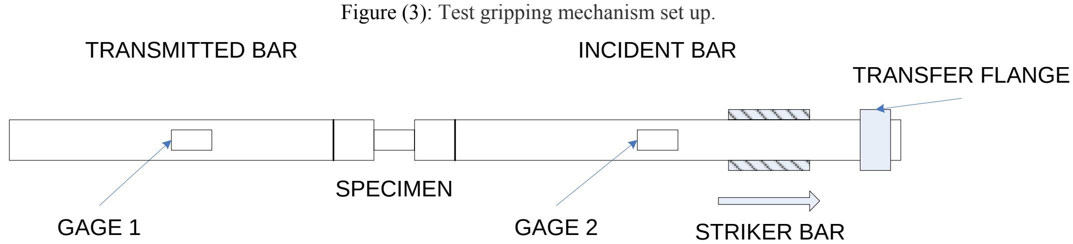

Figure (4): Tension Split Hopkinson Pressure Bar Apparatus.