DYNAMIC TESTING OF HIGH PERFORMANCE COMPOSITE MATERIALS

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Summary
This paper presents work-in-progress in the area of tensile split Hopkinson bar testing of high performance composite materials and their constituents. Improvements in the design of yarn grips for dynamic tensile testing are presented. Examples of contactless measurements, such as strain measurement directly from the specimen, showed that 2D Digital Image Correlation can be used to extract strains from very small areas, however a number of problems have to be solved in order to obtain qualitative data.

1 Introduction

Dynamic tensile testing of yarns using a tensile Split Hopkinson Pressure Bar (SHPB) requires designing some type of gripping system. It is known that regardless of the grip design the grips always affect the incident wave delivered to the specimen through the grip; and the reflected wave measured by the strain gauges. Therefore, ideally, it is desirable to take the measurements directly from the specimen using a contactless measurement method.

This paper presents initial results of SHPB experiments during which 2D Digital Image Correlation was used to extract strains directly from the surface of thin prepreg tapes.

2 Testing equipment

The experimental setup of the tensile SHPB consisted of a 2.7 m long steel input bar, a 1.5 m long bronze output bar, and a 0.4 m long steel striker bar. Both the input and the output bar had 19 mm diameter, whereas the striker bar had 50 mm outer diameter. EN24 steel was used for the input and the striker bars and the anvil. The anvil was attached via thread to one of the ends of the input bar. Based on the outcomes of the study described in the reference [1], the striker bar was redesigned so that the mechanical impedance between the striker and the input bar was substantially reduced, towards Z = 1. The strain gauges were positioned at the input and the output bars 0.6 m away from the specimen.

3 Improved gripping system for a tensile SHPB testing

Testing yarns in a tensile split Hopkinson pressure bar requires designing some type of gripping system. Having found that the grip design proposed by Tan et al. [2] provides the most reliable type of gripping for yarn testing, the original design was improved in order to; solve problems outlined in the reference [2], extend the testing capability of the grips and to make the grips more contactless-measurement-friendly.

Tan et al. [2] tested fibres of 30 mm gauge length, where the gauge length was the length of the unclamped region of the fibre between the grips. They mentioned that installation of shorter specimens resulted in misalignment and twisting of fibres, which would have influenced the test results. However, due to the selected gauge length and due to their SHPB setup the maximum achieved strain rates were not higher than 480 s^{-1}. We found that it is possible to install fibres in the grips without twisting if an appropriate installation method is used. Nevertheless, it was found also that regardless of the researcher's efforts the yarn mounted in the yarn grips is almost always misaligned, although it may look aligned by a naked eye. This is due to the nature of the grips themselves, due to the fibre installation procedure (governed by the grip design again), and due to small misalignments present in SHPB setups. It is believed that the best way to solve this problem is to rule out any misalignments statistically by conducting a large number of tests.

Figure below shows a cross-section view of the original grips and the improved design. The grips consist of four main elements: the holder, two clamping pieces, and the retainer.

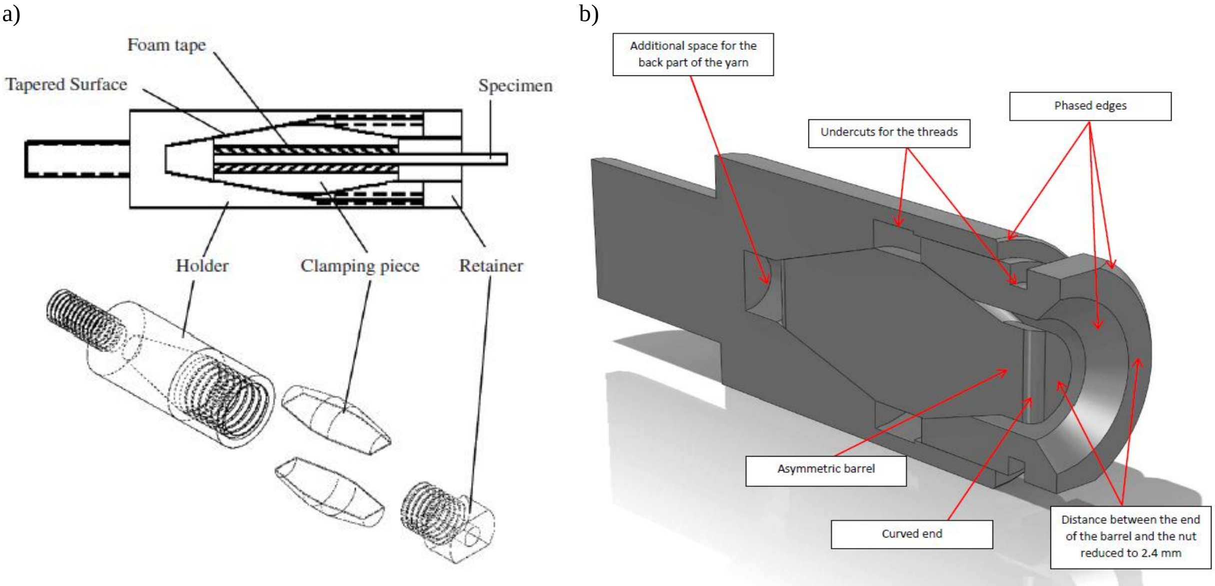

Figure 1. SHPB tensile yarn grips: a) Original design [2]; b) Improved design.

The following changes were made to the original design of the grip:

a) Addition of round edges to the clamping pieces.
Tan et al. [2] placed a high-density urethane foam tape between the yarn and the clamping pieces in order to prevent premature failure caused by the clamping pieces [2]. Compared to the original design, the clamping pieces in the improved grips have round edges. No premature failure at the edge of the clamping pieces has been ever noticed (high speed video used) during any tests. Also, no foam tape is used in the improved grips as the fibres are in direct contact with the clamping pieces.

b) Additional cylindrical space was added behind the clamping pieces.
Tan et al. [2] placed the yarn as shown in Figure 1a, i.e. the yarn does not go beyond the end of the clamping piece inside the grip. In the proposed improved grip design the tested yarn always overhangs between 2-5mm inside the grip. This is done in order to be able to verify whether there was a slippage in the grip. High performance yarns such as Dyneema, Spectra, or Kevlar are typically white or yellow. Once the yarn is inserted between the clamping pieces onto the retainer, the overhang end of the yarn is painted with a marker, and then the holder is mounted. After the test, once the holder

and one of the clamping pieces is removed, it is possible to observe whether the painted region of the yarn is inside the clamping region showing whether there was a slippage.

c) General clamp geometry optimization.
The retainer, the holder, and the clamping pieces were redesigned in order to minimize the distance between the end of the clamping pieces and the surface of the retainer. The distance in the modified grip is only 2.4 mm. This was done in order to minimize length of the yarn within the grip that is invisible to the high speed camera recording the experiment. In this setup it is possible to tests specimens of 5-6mm gauge length, thus obtain very high strain rates.
Two undercuts in the holder and in the retainer were made in order to maximize the length of the thread while minimizing the overall length of the retainer. This also allows for a greater compression force to be applied to the clamping pieces.

d) Asymmetric clamping pieces.
The clamping pieces were made asymmetric in order to maximize the clamping area and to minimize the distance between the clamping pieces and the retainer surface. This modification also enhances the testing capabilities of the grips as it is not only possible to test yarns but also thin tapes (6mm maximum width).

e) Modification of the thread.
It is always assumed that the entire grip remains perfectly together during the tests. However, a motion tracking analysis of the grip movement showed (not presented in here) that in some cases the retainer experiences large inertia forces that cause it to lag behind the already moving holder. However, a posteriori inspection within the grips does not indicate presence of the slippage, which indicates that probably the retainer, the clamping pieces and the tested yarn move together. Alternatively, it is possible that a micro slippage, not visible to a naked eye, might be occurring during some of the tests. In response to this problem a finer thread was made on the retainer and the holder.

f) Other minor modifications.
A number of edges were phased out in order to change angle of reflections created by light illuminating the grips during the tests involving a high speed camera. Well-defined edges are preferred for contactless measurements made using high speed camera software or motion tracking software.

4. Measurement of strain directly from the specimen using 2D Digital Image Correlation

4.1. Materials and measurement setup

In order to investigate the performance of the improved grips and the feasibility of using 2D Digital Image Correlation for measurement of strain directly from the specimen mounted in a tensile SHPB, five different Ultra High Molecular Weight Polyethylene (UHMWPE) tapes were tested. The materials tested included: Dyneema HB26, Dyneema HB50, Spectra Shield II SR-3124, Tensylon 30A and Tensylon 31D. All materials were unconsolidated i.e. in a prepreg form. The specimen size was 5x60 mm, while its thickness was the thickness of a single ply of a given prepreg. It is known that most of the UHMWPE have very low interlaminar shear strength (ILSS). In some cases the ILSS is so low that the plies of the prepreg easily split when rubbed. The low ILSS of the specimens can possibly cause slippage in the grip. Therefore, in all cases where it was possible to make the prepreg thinner (split the plies) without damaging the adjacent plies, the prepreg was split. The specimen gauge length was approximately 15 mm, however the area of interest recorded by the high speed camera had 5mm length.

The experiments were recorded using Phantom V12 high speed camera with 100 mm F2 Carl Zeiss lens with 20mm extension tube. The images had 128x152 pixels resolution and were recorded at 160k fps. Aramis software was used for the DIC analysis. The initial facet size was set to 12x12 pixels, whereas the initial facet step was 4 pixels.

4.2. Results

The experiments showed that the grips are capable of withholding thin tapes loaded in tension in the SHPB. No slippage occurred in tests involving prepregs that were split. In some of the tests involving prepreg that had not been split the slippage was present.

Figure 2 shows snapshots from DIC analysis of Spectra Shield specimen. The strain field (Epsilon X, where x runs in the horizontal direction) is overlapped with the images from the high speed video. Figure 3 shows true strain measured at two different points selected from the strain field (one is shown in the Figure 2 as the yellow cross).

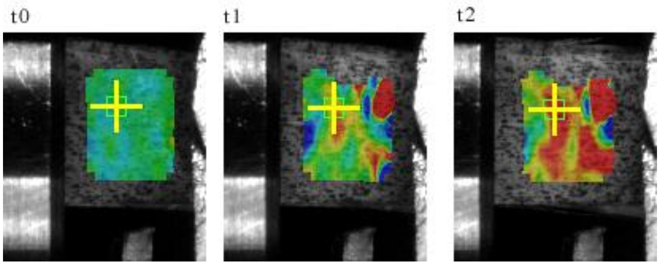

Figure 2. Snapshots from DIC analysis of Spectra Shield II specimen.

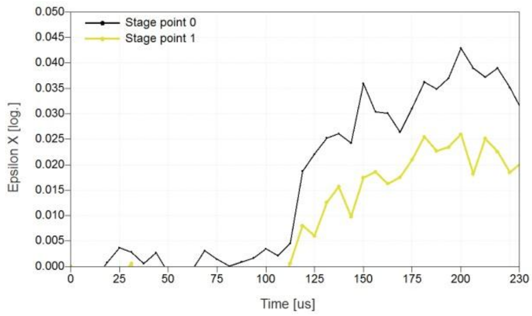

Figure 3. True strain vs. Time plot for two measurement points from the Spectra Shield test.

The above figures show that although it is possible to measure dynamically changing strain field in the specimen, it is difficult to obtain qualitative data from the measurement using this DIC setup. First, the presence of strains presented in the Figure 3 that occur before 75 µs indicate that there is substantial noise in the measurement (as the specimen was not loaded at this time span). This is most likely the result of a sub-optimal illumination setup. Second, the strain field, showed in Figure 2, is highly non-uniform within the specimen, although the specimen seemed to be well aligned when judged by a naked eye. The micro misalignments caused some parts of the specimen to strain more than the others, which created the non-uniformity.

In order to minimize the influence of the point selected for the measurement and to average readings from multiple facets, a number of facet sizes were selected for the DIC analysis. The facet step was set as close to half of the facet size as possible. Figure 4 presents true strain measurement for a point selected in the middle of the Spectra specimen.

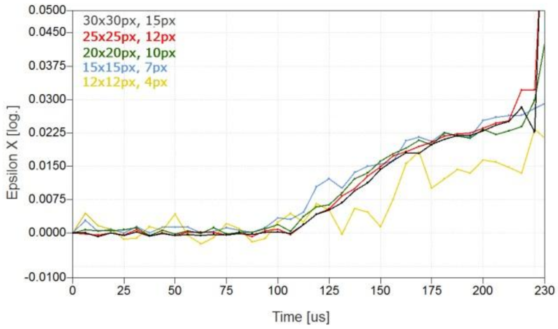

Figure 4. Influence of the facet size on the measurement of strain in the Spectra Shield specimen.

It was observed that as the facet size was increased, the noise was reduced. The influence of the selection point on the strain readout was pronounced for the two smallest facet sizes, while the facet sizes of 20x20 pixels and larger showed relatively similar readings. The maximum recorded DIC strain experienced by the Spectra specimen was 2.86%. This however does not mean that 2.86% was the maximum strain experienced by the specimen before failure. The DIC measurement breaks down once the specimen starts to fail due to blurring of the speckle pattern. The obtained DIC measurement allows us to conclude that the Spectra Shield specimen experienced no less than 2.86% strain before failure.

Similar measurements were made for all the other aforementioned materials.

5 Conclusions

The presented research showed that the redesigned grips allow to test in tension both yarns and thin composite tapes. The study showed that it is possible to obtain strain measurements directly from specimen tested in a tensile SHPB by using 2D Digital Image Correlation. It was highlighted however that careful consideration has to be given to the post processing of the data in order to obtain reliable results. Moreover, it was emphasized that the maximum measured strains are not final strains to failure but final strains measured using the DIC. Also, it was shown that the micro misalignments are almost always present in the discussed experiment, although the specimen might seem to be perfectly aligned when observed by a naked eye.

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References

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