

Low Velocity Impact Behaviour of Mechanochromic Sandwich Composites

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Abstract. This paper studies the mechanochromic response of carbon/flax sandwich composites equipped with hybrid thin-ply glass/carbon composite sensors when exposed to the low velocity impact load. Also, the pre-cut carbon sensing layer is investigated as a potential strategy for improving the self-reporting function. The effectiveness of the mechanochromic sensor is studied through analysis of impact test results, visual inspection and dent depth measurements. The results showed a successful implementation of hybrid glass/carbon sensing technology for impact damage monitoring in flax/carbon sandwich structures. Furthermore, it was observed that the self-reporting function could be modified by introducing discontinuities (cuts) in the sensing layer.

Introduction

Natural fibres such as flax have high moisture absorption, limiting the number of suitable applications for their composite products. Research has shown that the poor environmental response of flax can be improved by adding carbon layers within the composite. Improvements include a reduction in the deterioration of mechanical properties and moisture absorption with environmental exposure [1]. Dhakal et al. [2] reported the most significant improvements when the carbon fibre plies were placed on the external layers. This is intuitive as the carbon layers protect the flax from the environment. Moreover, the hybridisation of flax and carbon fibres enhances flexural strength and modulus, increasing their suitability for a wide range of structural applications, while retaining the environmental benefits that natural fibres offer.

Despite all the advantages above, sandwich structures often exhibit a more complex damage mechanism compared to conventional composites. This can be attributed to significant differences between the thermo-mechanical properties of the various materials within a sandwich structure. In most cases, damage occurs in the interface between the skin and the core materials [1,2]. Structural health monitoring (SHM) techniques have been developed to improve the sandwich structure's inspection, maintenance and lifetime. Mechanochromic composites that can provide a visual signal after experiencing damage are recent progress in SHM practice. There are different approaches to designing and manufacturing mechanochromic composites; herein, we focus on hybrid thin-ply glass/carbon composite sensors [3]. The proposed sensor consists of a carbon/epoxy sensing layer and an outermost glass/epoxy layer bonded to a substrate material/component, allowing the sensor to undergo comparable strains. The addition of this sensor may be through, either co-curing with, or retrofitting onto, the material/component. The possibility of using this hybrid sensing layer is first mentioned by Czél and Wisnom [4] in a report investigating the pseudo-ductile failure of glass/epoxy composites hybridised with thin-ply carbon prepreg. In that report, a change of appearance was noted when hybrid specimens were subjected to tensile loading, as the translucent nature of the outer glass layer allows the visual detection of delamination. These authors further explored this concept in a 2019 report, retrofitting the sensing layer onto the handlebars of a carbon fibre composite mountain bike. This demonstrated its suitability in a real-life application [5].

There is a gap in the literature on the possibility of implementing the sensor concept on different substrate materials beyond carbon. Expanding the range of materials to which the sensor can be applied would increase the number of potential applications. The opportunity to combine this thin hybrid composite sensing layer with a flax/carbon sandwich could be beneficial for several reasons. For instance, adding SHM techniques to flax materials may facilitate their use in structural applications. The ability to observe and repair the damage could reduce the need to overdesign with excessive damage tolerance. Additionally, the sensors can be easily applied to the sandwich, as the outer layers of the sandwich are carbon. Flax/carbon sandwich structures offer improved damage tolerance compared to pure carbon composites, making them desirable for applications where impact is likely. In these applications, barely visible impact damage (BVID) detection could be of significant benefit. This could facilitate the use of flax as an alternative to pure glass and carbon fibre composites and bring with it the environmental benefits linked with the use of natural fibres.

Experiments, Results and Conclusions

Sandwich composite specimens were manufactured by hand lay-up with a [0C/90C/45F/0F/90F/-45F]_s lay-up configuration. To examine the mechanochromic response under low velocity impact, a sensor composed of an outer S-glass layer and a YS-80 carbon sensing layer was attached to the both sides of some of the sandwich composite specimens [6]. Moreover, a cut pattern was made in YS-80 carbon layer of some specimens to study the influence of discontinuities on the mechanochromic performance (Fig. 1). Next, drop weight impact tests were conducted at two different impact energies, 12J and 18J. These energies were chosen based on pre-liminary quasi-static indentation tests, ensuring that the impact-induced damage is within

the BVID range. Finally, two different non-destructive evaluation (NDE) methods were used to analyse the BVID and mechanochromic response. The first method was measuring the dent depth via an Alicona Infinite Focus G4 3D Surface Profilometer, and the second method was post-impact visual inspection by taking high-quality images of the impacted and non-impacted surfaces.

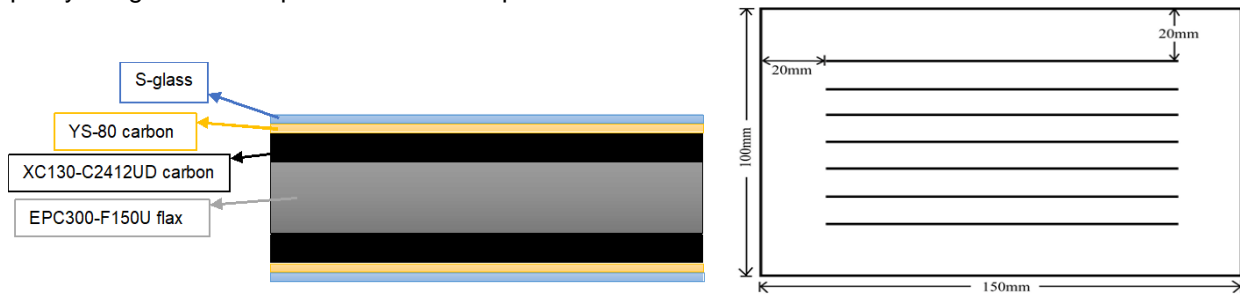


Fig. 1: Schematic of a sandwich composite specimen (left), and the cut pattern in the sensing layer (right)

Impact test results show that adding a glass/carbon sensor on both sides of a flax/carbon sandwich sample does not significantly change its mechanical properties, while improving BVID inspection to a great extent. Surface profilometer images show different damage mechanisms in the reference and sensor-integrated specimens. It also confirms that damage is within the BVID range. Another interesting result is that introducing discontinuities can provide better damage detection, particularly on the back face, and this is more effective at higher impact energies. The proposed sandwich composite system is lighter, more sustainable, and easier to inspect than conventional carbon fibre reinforced polymer (CFRP) composite structures.

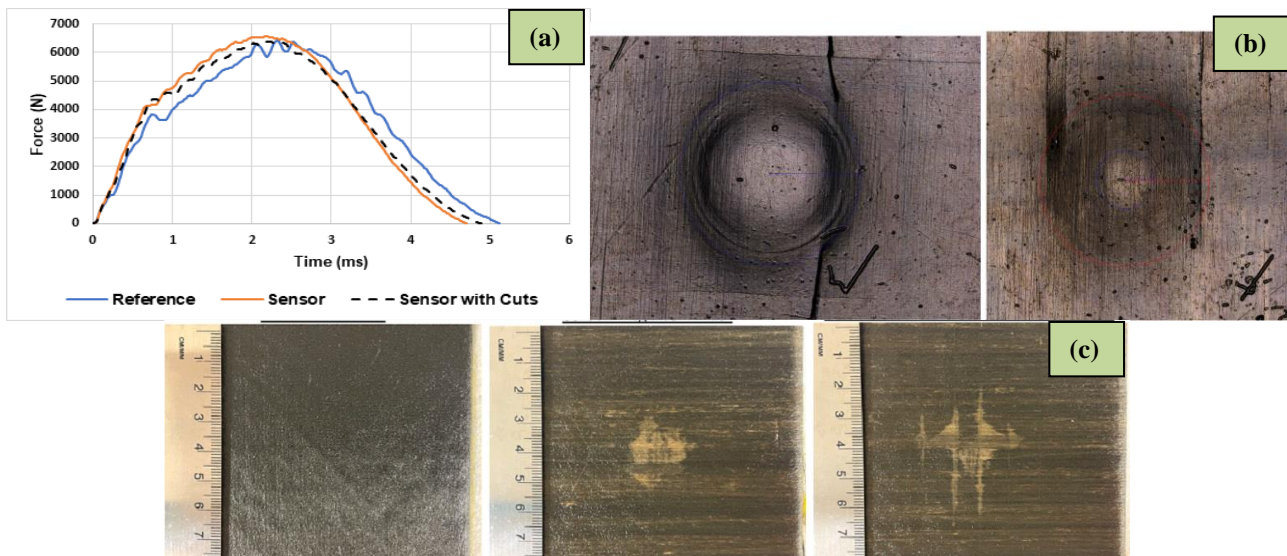


Fig. 2: a) Impact test results (18J), b) dent depth measurement of reference (left) and sensor-integrated (right) samples (12J), c) visual inspection of the back face of specimens under 18J impact, from left to right: reference, sensor-integrated and sensor-integrated with cuts in the sensing layer samples

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