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ARRESTING PROPAGATING KINKBANDS: FAILURE MECHANISMS UNDER LONGITUDINAL COMPRESSION OF CARBON-BORON FIBRE HYBRIDS

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ABSTRACT

The use of Fibre Reinforced Polymers (FRPs) in structural applications has been steadily growing, thanks to the continuous improvements in their performance and to the ever-increasing understanding of their mechanical behaviour. However, one long-standing weakness of these materials, still limiting their potential, is their performance under longitudinal compression. This is due to compressive failure being most often caused by a material instability phenomenon leading to kinkband formation and propagation, causing compressive strength to be typically much lower than the tensile one [1]. Among FRPs, boron-fibre composites have unmatched compressive strength. Typically, due to high production cost of boron fibre, these composites are used in high-performance specialty applications. Nonetheless, advanced design strategies optimizing material adoption, like the use of fibre-hybrid composites and *material-by-design* approaches (which are gaining more and more traction in the field [2]), could pave the way to a more widespread adoption. Carbon/boron fibre hybrids are reported to have exceptional compressive performances [3], but, as of today, the literature on the subject is scarce. An in-depth understanding of the mechanisms governing failure under compression of these materials will clarify the motives of their strength; furthermore, it will lay the grounds for the development of the next generation of composite materials and structures, surpassing current limitations.

In view of this, we present a detailed experimental study on the failure mechanisms of carbon/boron fibre hybrid under compression. We used IM7/8552 prepreg from Hexcel and HyBor 52 from Specialty Materials Inc. HyBor 52 is a second-generation carbon/boron fibre hybrid prepreg; it has a boron content of 52 fibres-per-inch, while the resin material and the carbon fibre used in it are Toray TG275-1E (double cure epoxy, allowing wide cure cycle compatibility with other epoxies) and T1100G, respectively. We designed cross-ply hybrid small-scale notched specimens having the carbon/boron fibre-hybrid material, HyBor 52, in the 0° plies. We then tested under compression the specimens using a Deben micromechanical testing device; specifically, we performed in-situ Scanning Electron Microscope (SEM) tests, to directly observe failure mechanisms under load, and in-situ optical microscope tests with speckled specimens for subsequent Digital Image Correlation (DIC) analysis.

The results of one sample test are illustrated in Fig. 1, which reports the load displacement plot of one of the tests we performed, along with SEM pictures taken at different load levels. A kinkband is seen to develop from the notch tip and to reach the first boron fibre on its path; there, the kinkband is arrested, while the test continues and the load increase steadily. After a subsequent load drop occurring at a much higher load level, no further propagation of the initial kinkband is observed. Rather, multiple disjointed kinkbands are observed in the carbon fibre regions of the composite at different locations, while boron fibres remain mostly intact, justifying the still impressive load carrying capability of the specimen.

The results of this study shed light on the reasons for the impressive performance of carbon-boron fibre hybrid under longitudinal compression. Most importantly, they reveal, for the first time, the possibility of arresting propagating kinkbands in Carbon FRPs, in this case thanks to the adoption of boron fibres, that act as arresters and promote damage diffusion. They also provide important hints on

how future composite materials with improved longitudinal compressive performance could be obtained.

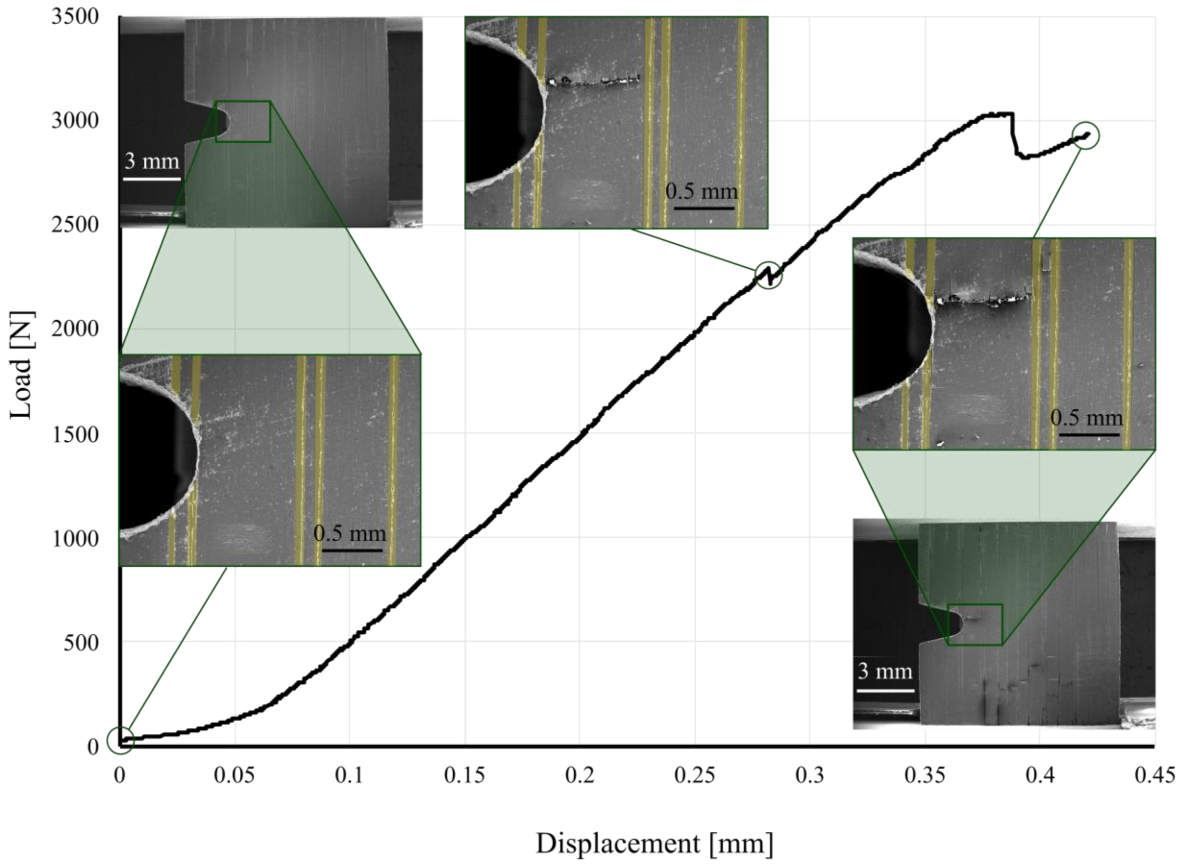

Figure 1: results of one in-situ SEM test performed: load displacement curve and SEM pictures taken at different load levels (in the high magnification pictures, boron fibres have been highlighted with a semi-transparent shading to improve visibility).

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REFERENCES

[1] Pinho, S. T., Gutkin, R., Pimenta, S., De Carvalho, N. V., Robinson P. *On longitudinal compressive failure of carbon-fibre-reinforced polymer: from unidirectional to woven, and from virgin to recycled*, Philosophical Transactions of the Royal Society A, **370**, 2012, p. 1871–1895.

[2] Swolfs, Y., Verpoest, I., Gorbatikh, L. *Recent advances in fibre-hybrid composites: materials selection, opportunities and applications*, International Materials Reviews, **64**, No. 4, 2019, p. 181-215.

[3] Gen 2 Hy-Bor® (https://www.specmaterials.com/gen-2), Specialty Materials website, accessed 10/01/2023.