COMPRESSIVE FAILURE OF BORON-CARBON FIBRE HYBRID COMPOSITES: A DETAILED EXPERIMENTAL STUDY

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ABSTRACT

Hybridising carbon fibre reinforced polymers (CFRP) with boron fibres offers the potential of improving the compressive response of CFRP. In this work, a small compressive translaminar fracture specimen was designed, manufactured and tested in a scanning electron microscope environment to obtain detailed information on how the presence of the boron fibres affects the typical kinkband formation and propagation within CFRP. It is shown that the boron fibres successfully stop propagating kinkbands in CFRP, and that, as the kinkband approaches a boron fibre, a large split tends to form which protects the subsequent CFRP material.

1 INTRODUCTION

Fibre reinforced polymers (FRPs) are widely used in structural applications due to their excellent specific stiffness and strength. Most of them, however, have poor properties under longitudinal compression, when compared to tension, due to failure being triggered by material instability, leading to kinkband formation and propagation [1]. Boron fibre composites are one notable exception, exhibiting outstanding compressive performance [2]. They have however only been used in high-performance applications due to their high cost. The use of boron fibre-hybrid composites [3] and the possibilities they open in terms of *material-by-design* solutions represent possible paths for cost reduction. Furthermore, the need for improved compressive performance provides a strong case for their consideration. Despite their excellent mechanical properties [4], the literature on boron/carbon fibre hybrids is very limited. In particular, the mechanism by which the presence of boron fibres affects the failure mechanism of carbon-boron hybrids has never been investigated. A fundamental understanding of the mechanisms involved in the failure of these fibre-hybrid composites under compression would provide not only quantitative data about their excellent properties but also invaluable insights into how to design the next generation of composite materials and structures, with the aim of overcoming current barriers on compressive performance.

The work conducted in this paper presents the fundamental compressive failure mechanisms associated with hybrid carbon and boron fibre, polymer matrix composites. Typically, failure of carbon-fibre composites under compression is dominated by in-plane and out-of-plane kinking due to the local shear effects. This study aims to analyse the corresponding failure patterns in boron/carbon fibre hybrids. The following Sections outline the materials used in the study, the bespoke specimen utilised to capture qualitative information on the failure mechanisms, resulting fractographic observations, and conclusions.

2 MATERIALS AND METHODS

For this experimental study, second-generation HyBor (boron/carbon fibre hybrid) prepregs from Specialty Materials [4] were used; specifically, three grades of HyBor having a different content of boron fibres-per-inch (FPI): 52, 104, and 152 FPI. The epoxy system and the carbon fibres used in the HyBor prepreg were Toray TG275-1E (double cure epoxy, allowing cure compatibility with many other epoxies) and T1100G carbon fibres. Additionally, as explained in the following, an IM7/8552 prepreg from Hexcel for baseline specimens was also used. Cross-ply hybrid plates were designed and manufactured whereby the HyBor prepreg was used for the 0° plies and IM7/8552 prepreg for the 90° plies: $[90/0_{HyBor}/90_9]_S$. Figure 1 shows micrographs obtained from the plate manufactured using the HyBor 52 FPI. From these plates, bespoke Small Sharp Notched Compression (SSNC) specimens (as motivated by [5-7]) were manufactured using a waterjet cutter whose geometry is shown Figure 2. The notches were cut using a diamond tipped circular saw and the top and bottom faces of the specimens (loading faces) were then ground to be flat and parallel. The specimens were loaded initially (denoted as ‘initiation’ on the load versus displacement curves) using a Deben micro-testing device (5 kN load cell) until the onset of non-linearity in the load reading. Subsequently, each specimen was polished by hand to expose one of the two outer HyBor layers. Each specimen was then coated with a thin (2-5 nm) layer of gold and further tested in compression inside a Hitachi SM-1700 Scanning Electron Microscope using the same Deben micro-testing device. A nominal compressive crosshead displacement rate of 0.1 mm/min was applied throughout. This in-situ testing approach allowed the loading to be paused at each noticeable load drop for fractographic interrogation of the resulting damage. In addition to the HyBor specimens, a corresponding baseline carbon-epoxy specimen of IM7/8552 prepreg containing no boron was tested under the same procedure.

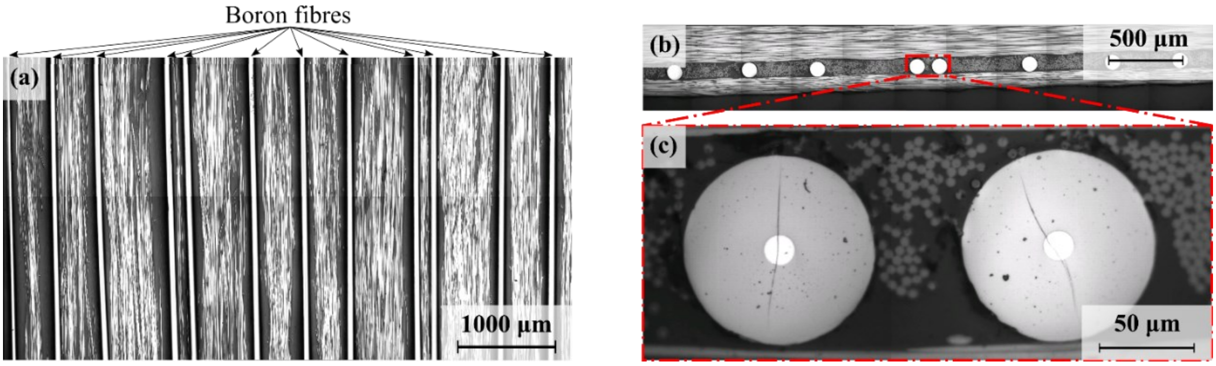

Figure 1: Micrographs from the HyBor 52 FPI plate: (a) front view of a polished HyBor 52 FPI ply, (b) cross-section view and (c) high-magnification detail of a duplet of boron fibres.

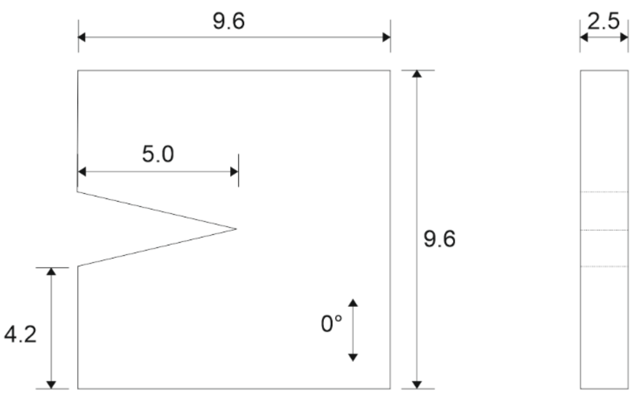

Figure 2: Small Sharp Notched Compression specimen dimensions (dimensions in mm).

2.1 RESULTS

Figure 3 shows results from one baseline test specimen with no boron content. Figure 4 shows results from one test specimen with HyBor 52 FPI, Figure 5 shows results from one test specimen with HyBor 104 FPI, and Figure 6 shows results from one test specimen with HyBor 152 FPI.

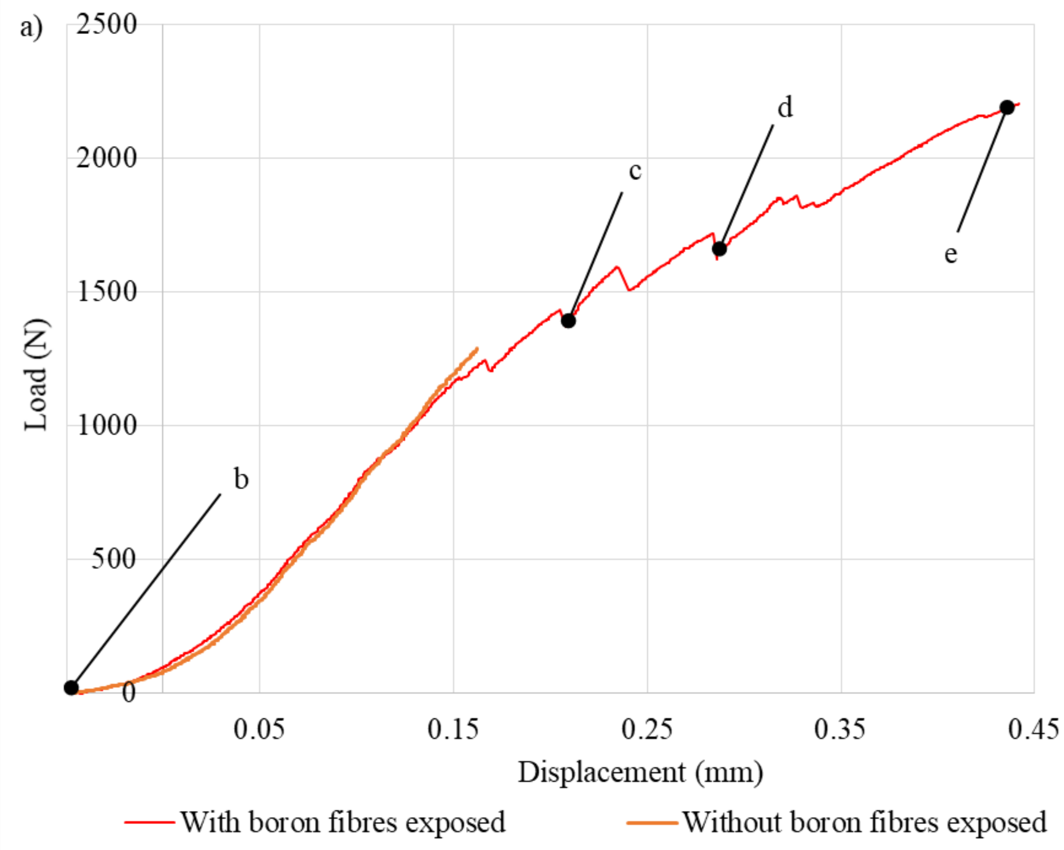

Figure 3: Baseline (no boron fibres), SSNC test results: a) Load versus displacement (continued on next page).

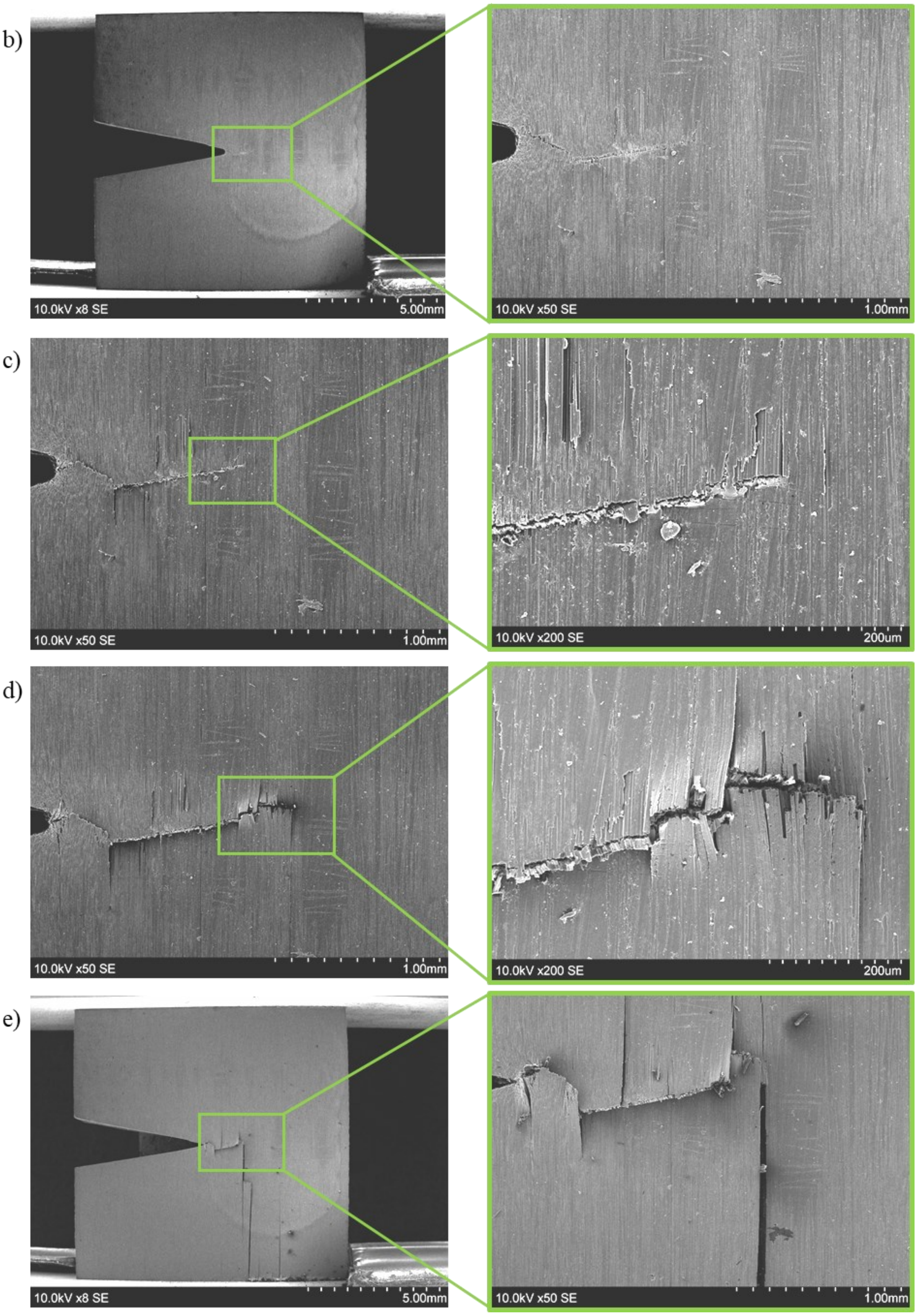

Figure 3: (continued): Baseline (no boron fibres), SSNC test results: b) initiation of kinkband, c) kinkband progressing, d) in-plane kinkband migrating out-of-plane, e) ultimate failure, splitting along height of the specimen.

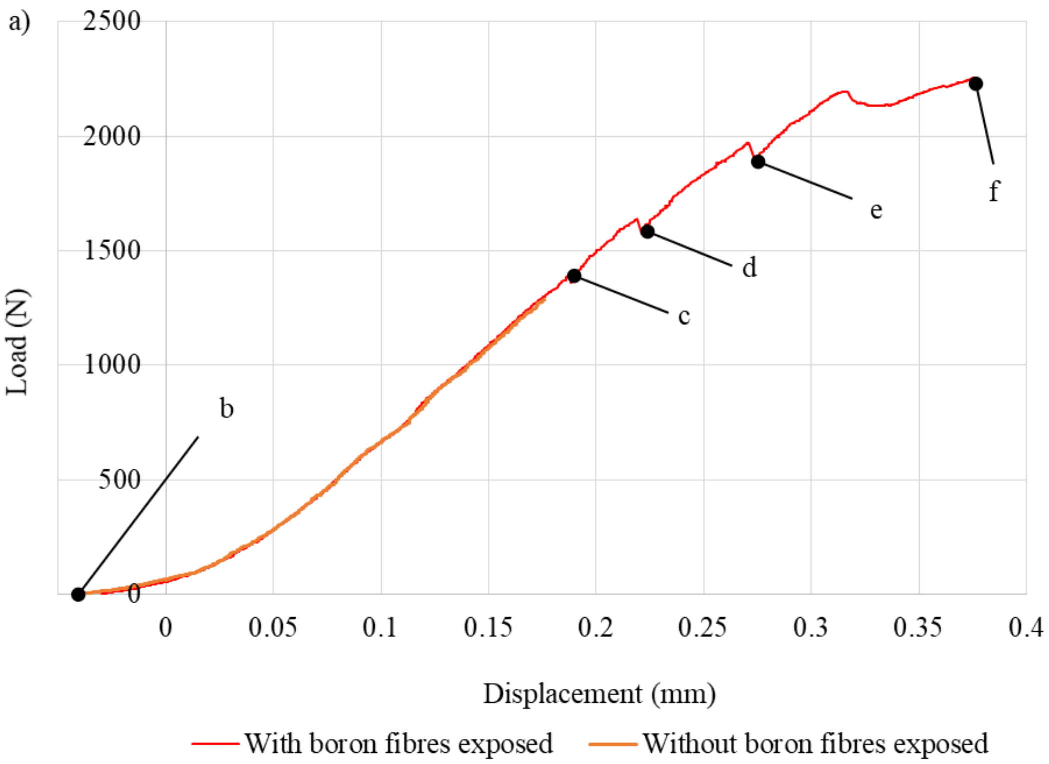

Figure 4: HyBor 52, SSNC test results: a) Load versus displacement (continued on next page).

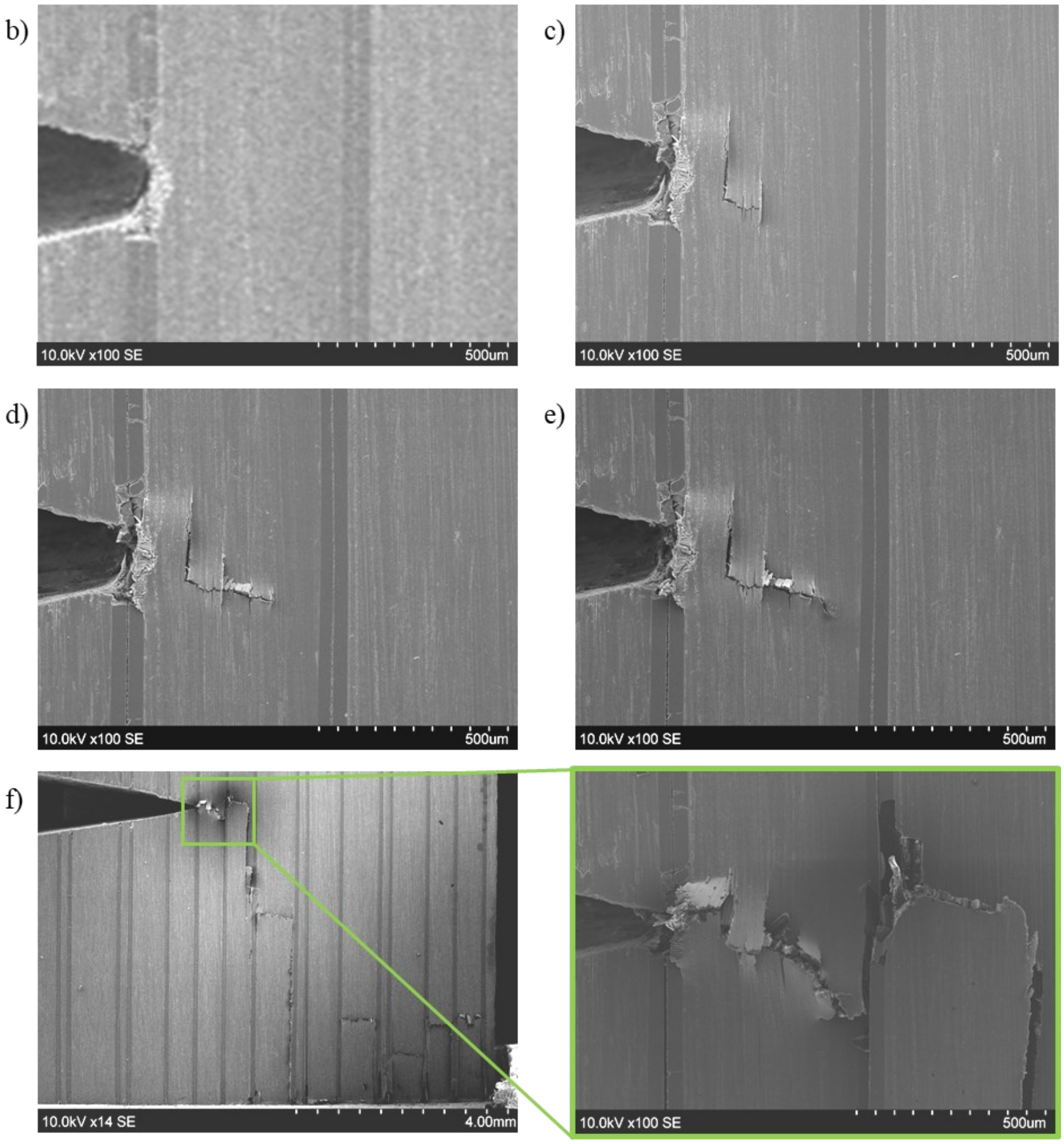

Figure 4: (continued): HyBor 52, SSNC test results: b) initiation of fracture, c) kinkband initiation, d) kinkband progressing out-of-plane, e) kinkband progressing, boron fibre seen to 'protect' subsequent carbon fibres from deformation, f) splitting at the carbon/boron interface, damage is dissipated away from the notched region followed by further splits and out-of-plane kinking.

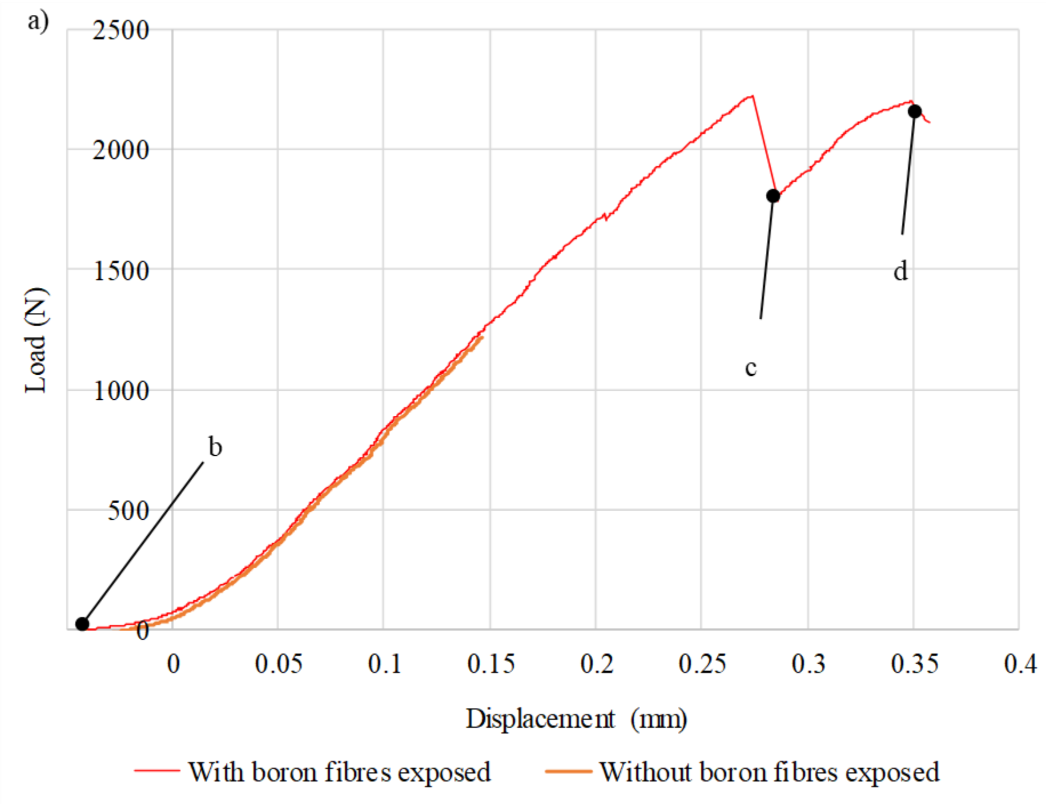

Figure 5: HyBor 104, SSNC test results: a) Load versus displacement (continued on next page).

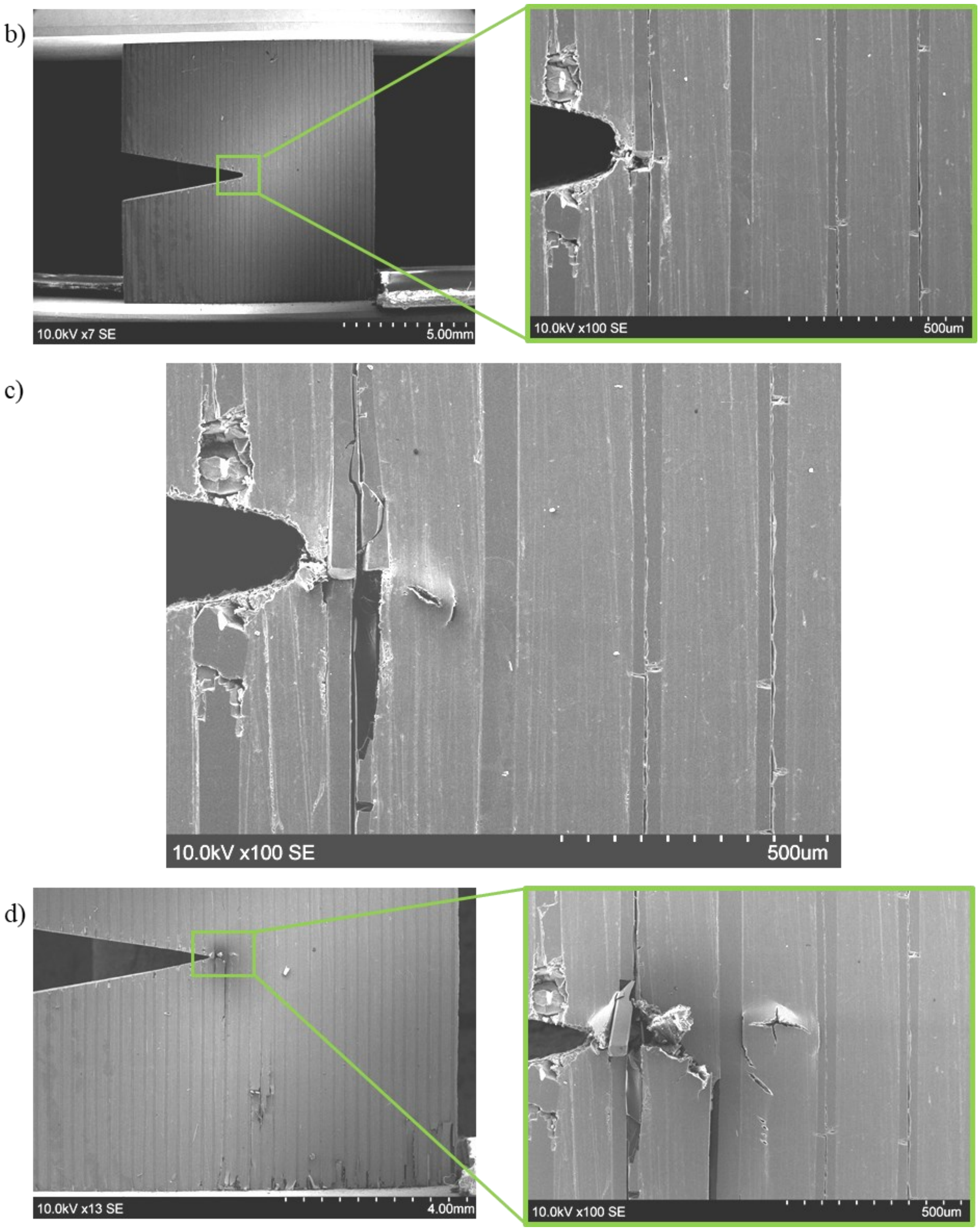

Figure 5: (continued): HyBor 104, SSNC test results: b) kinkband initiation, c) kinkband progressing, boron fibre seen to 'protect' subsequent carbon fibres from deformation, d) splitting at the carbon/boron interface followed by further out-of-plane kinking. Third boron fibre from the notch seen to 'protect' subsequent carbon fibres from deformation.

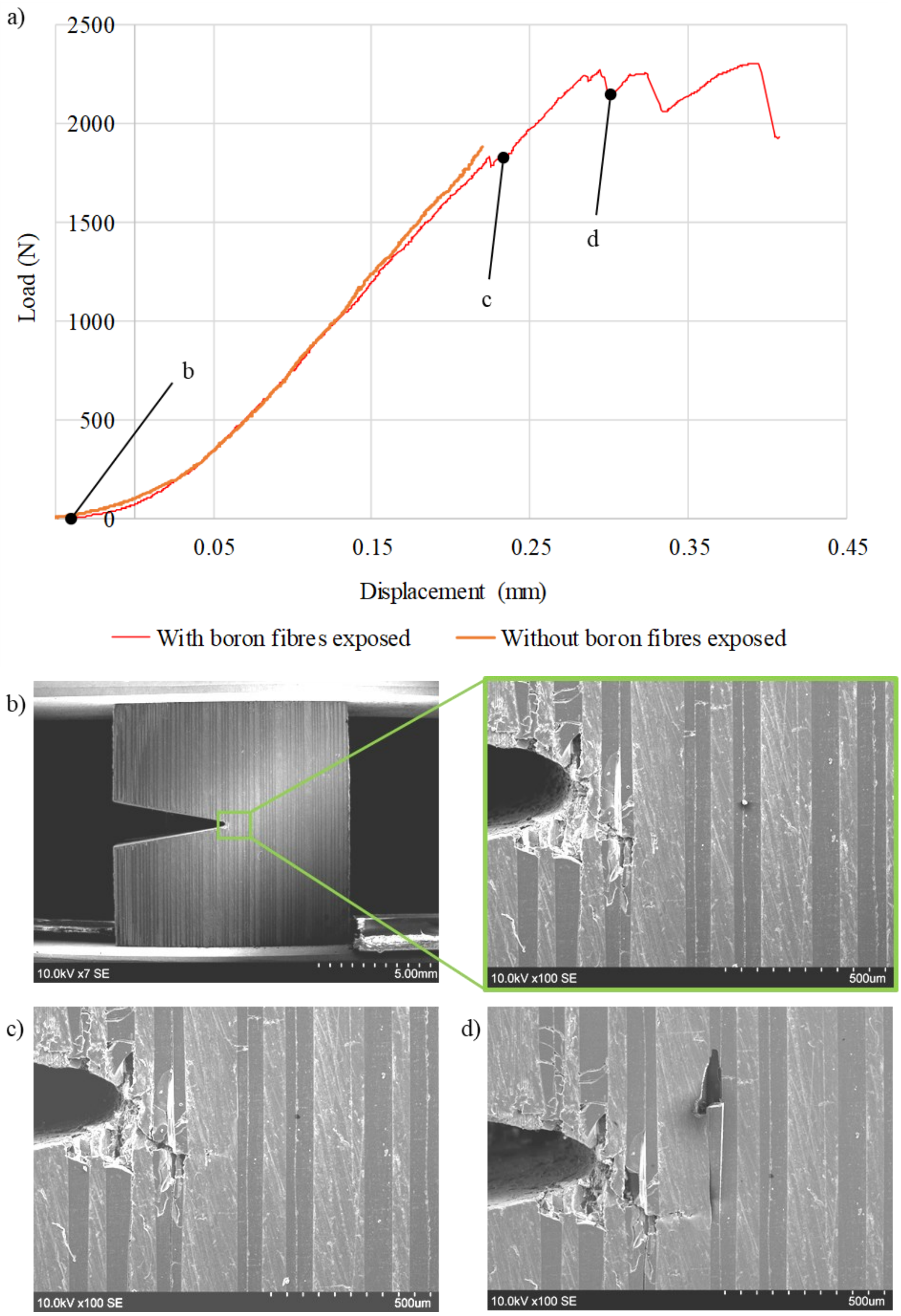

Figure 6: HyBor 152, SSNC test results: a) Load versus displacement, b) initiation of kinkband, c) progressive damage of kinkband, d) splitting at the carbon/boron interface, boron fibre seen to 'protect' subsequent carbon fibres from deformation.

3 CONCLUSIONS

From the tests conducted in this work the following conclusion can be drawn: The presence of boron fibres with CFRP composite plies loaded under compression were seen to arrest both in-plane and out-of-plane kinking of the carbon fibre layers in the form of splitting at the boron/matrix interface.

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