# Tailoring the damage mechanisms in flax/silk hybrid composites for improved ductility

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**Publication date**
2025

**Document Version**
Final published version

**Citation (APA)**
Prapavesis, A., Wu, W., Mosleh, Y., & Van Vuure, A. W. (2025). *Tailoring the damage mechanisms in flax/silk hybrid composites for improved ductility*. Abstract from 7th International Conference on Natural Fibers 2025, Lisbon, Portugal.

# Tailoring the damage mechanisms in flax/silk hybrid composites for improved ductility

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## ABSTRACT

This study focuses on interlayer hybridisation of flax with silk fibres and the resulting damage mechanisms controlled by the hybrid composite configuration, can lead to an improved balance between stiffness, strength and toughness/ductility. The results demonstrate that a sandwich design configuration with flax layers at the outside of the laminate exhibit the highest increase in (pseudo-)ductility compared to monolithic flax fibre composites. X-ray computed tomography (XCT) revealed that fragmentation and debonding of the flax fibre layers can be achieved by optimising the hybrid laminate configuration and the volume fraction ratio between the two fibres, explaining the increased toughness of the hybrid composites.

## INTRODUCTION

The stiff (order of 60GPa) and strong (order of 700MPa) flax fibre composites dominate the academic and industrial natural fibre sectors when the aim is placed on high-performance structural applications. However, because of their intrinsic brittleness, with a strain-to-failure typically around 1.4%-1.5%, these composites perform poorly when impact resistance or high ductility is required. On the other hand, silk fibre composites are highly ductile with a strain-to-failure level above 10% but are significantly more compliant (16GPa) than flax [1]. Therefore, hybridisation between flax and silk is a promising strategy to achieve a better balance between properties enhancing the flexibility during the design phase of a composite material with more application tailored performance and without compromising the bio-based content of the reinforcement [2]. Furthermore, the combination of the two fibres in an intelligent design results in the appearance of pseudo-ductility which were absent in each individual monolithic composite due to the (potential) synergistic effect between the fibres.

## RESULTS AND CONCLUSIONS

The tensile results show that a sandwich configuration with flax on the outside the highest increase in toughness and strain-to-failure. In Figure 1, the XCT images reveal that the flax fibres on the outer layers of the specimen are fragmenting during loading in an alternating pattern between each outer flax layer and the fracture of the specimen occurs when saturation of the fragments is reached at 4.7mm ± 0.5mm distance between each two fragments. Furthermore, Figure 2b shows large debonding areas, as well as some fibre pull-out, which were identified near the fragmented flax layer. Debonding and pull-out are typically dominant damage mechanisms in terms of energy absorption and impact resistance. These described damage mechanisms are absent from the monolithic composites which points towards a synergistic damage behaviour in this hybrid configuration explaining the observed increased toughness & ductility.

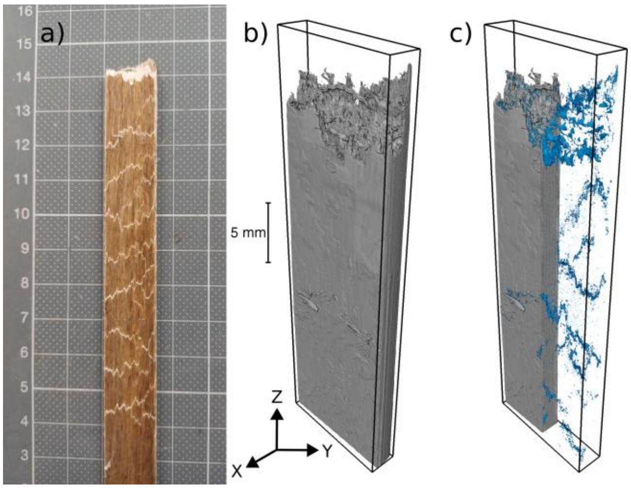


Fig.1 a) Optical inspection of the fragmentation followed by XCT visualization of the b) 3D specimen and c) the internal damage patterns

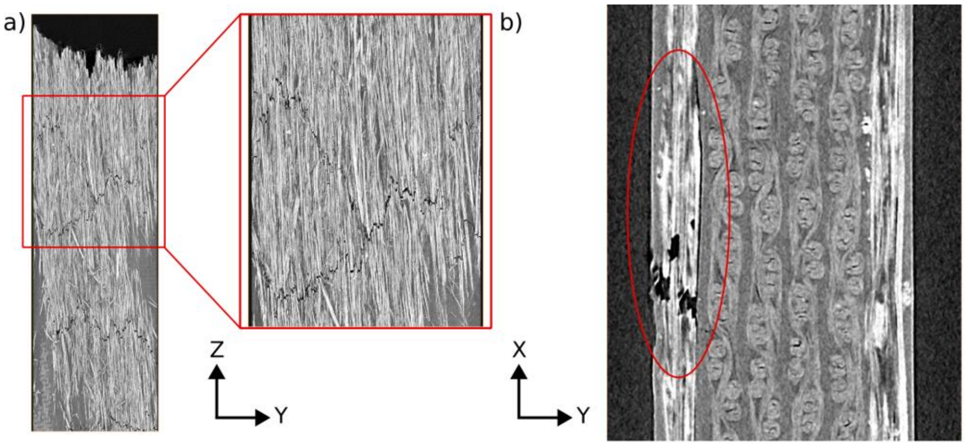


**Fig.2 XCT internal damage patterns a) fragmentation of flax layers and b) debonding regions near the fragments**

## ACKNOWLEDGMENTS

Weijing Wu expresses his gratitude to the China Scholarship Council (CSC) for the financial support during the visiting research period in KU Leuven.

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