Université du Québec à Trois-Rivières – Département de Génie Mécanique

Experimental and numerical investigation of the flexural and impact properties of pure Flax/Epoxy and Kevlar/Flax/Epoxy composites

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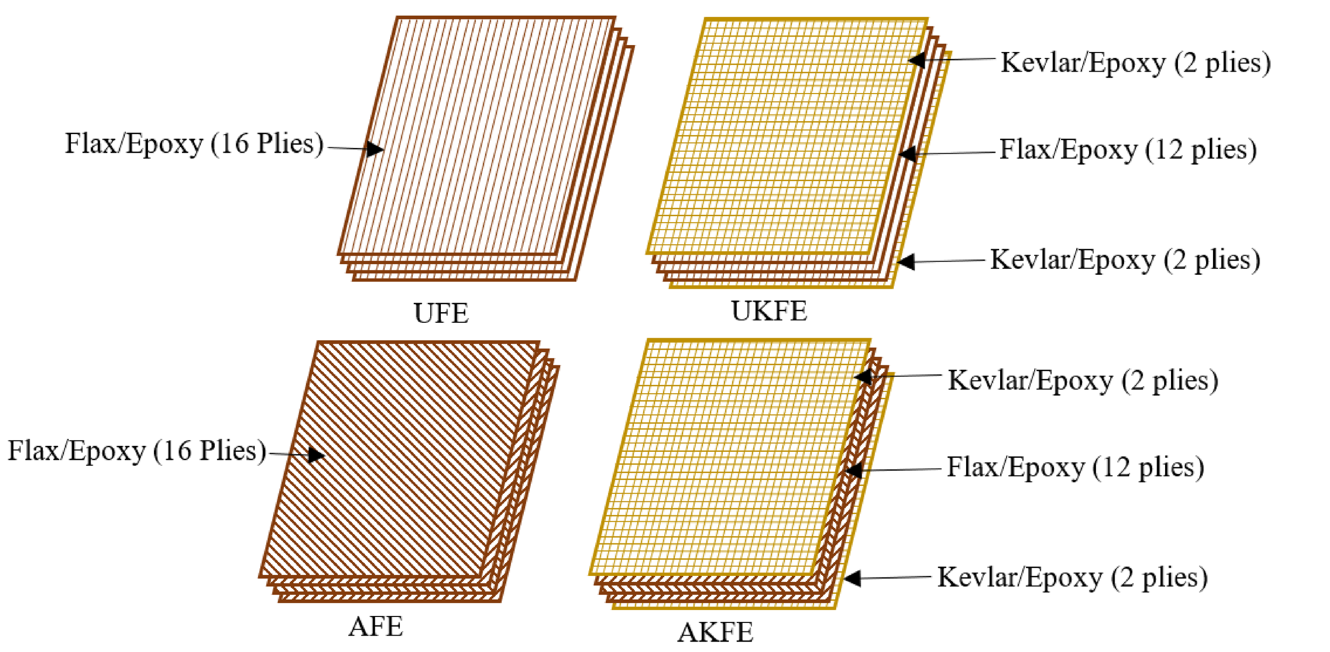
Objective

This study investigated the flexural and impact properties of pure Flax/Epoxy (FE) and hybrid Kevlar/Flax/Epoxy (KFE) composite laminates using three-point bending, Charpy, and drop-weight impact tests. Four main configurations were analyzed, namely unidirectional FE (UFE), unidirectional plain weave KFE (UKFE), angle ply FE (AFE) and angle ply plain weave KFE (AKFE). Three-point bending test results showed that the ultimate strength and the flexural modulus of the UKFE increased by 15% compared to pure UFE and by more than threefold for AKFE compared to AFE laminates. Results of the drop-weight test showed significant increase in the impact force, specifically the impact force increased by 30% for UD and angle-ply laminates configurations. Similarly, the Charpy test results revealed improvement in the impact energies of the flax laminate by more than 60%. The predictions of the FEA model agreed very well with the experimental results. This investigation highlighted the benefits of hybridazation of Kevlar onto flax epoxy composites.

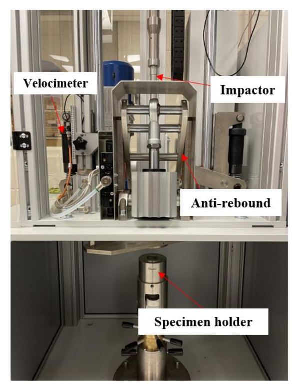
Experimental procedure

Specimens manufacturing

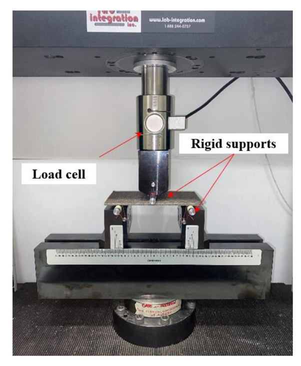
Two sets of composites laminate plates were manufactured using hand lay-up followed by a compression molding process For FE laminates, two stacking sequences were made, the first is unidirectional UF $[0_{F16}]$ and the second is angle-ply AF $[\pm 45_{F16}]$. Regarding the hybrid plates, two configurations are used making the full sandwich structure as follow UKFE $[0_{k2}/0_{F6}]_s$, AKFE $[0_{k2}/\pm 45_{F6}]_s$ where the letter 'F' refers to the flax layer and 'K' for the Kevlar layer.



Mechanical tests



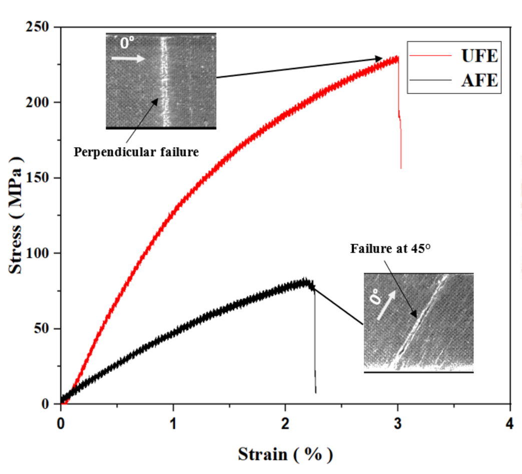
Experimental device for drop impact tests



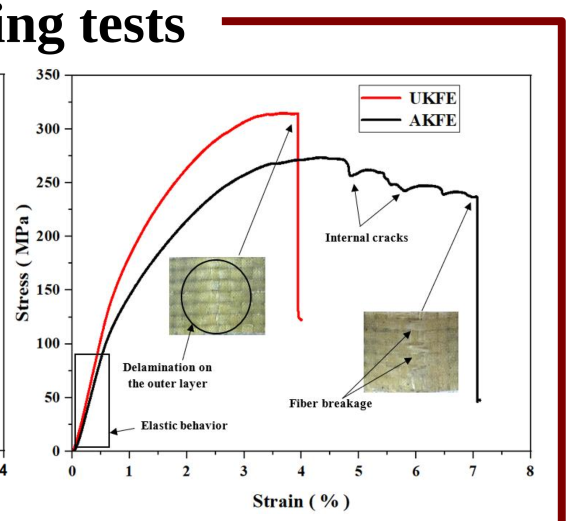
Experimental device for bending tests


Experimental device Charpy tests

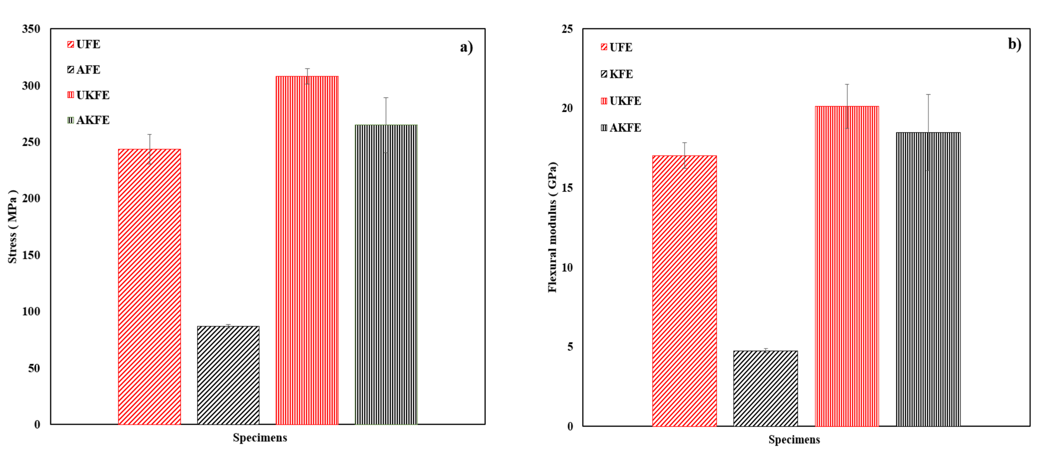
Bending tests



Stress versus strain for the pure Flax/Epoxy configuration

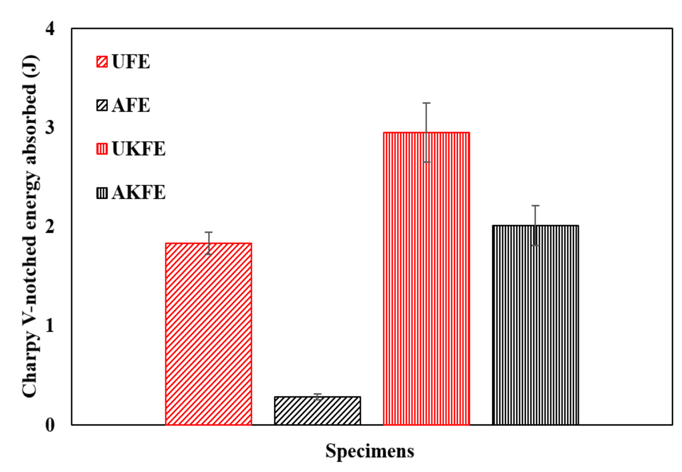


Stress versus strain for the pure Kelar/Flax/Epoxy configuration

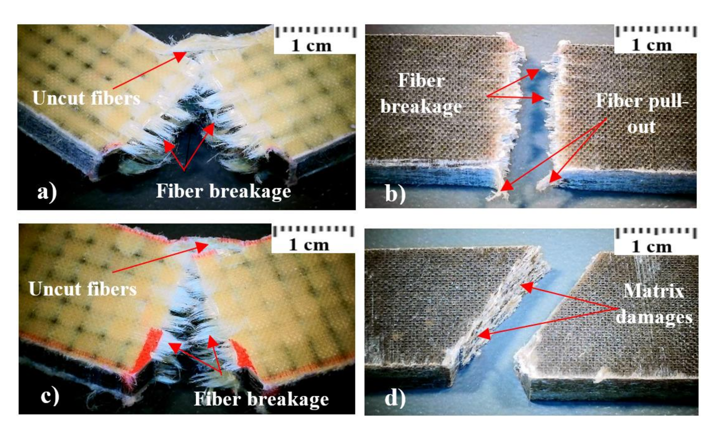


Comparison between the pure flax/epoxy and hybrid Kevlar/flax/epoxy with different laminate configurations. a) Stress. b) Flexural modulus.

Charpy tests

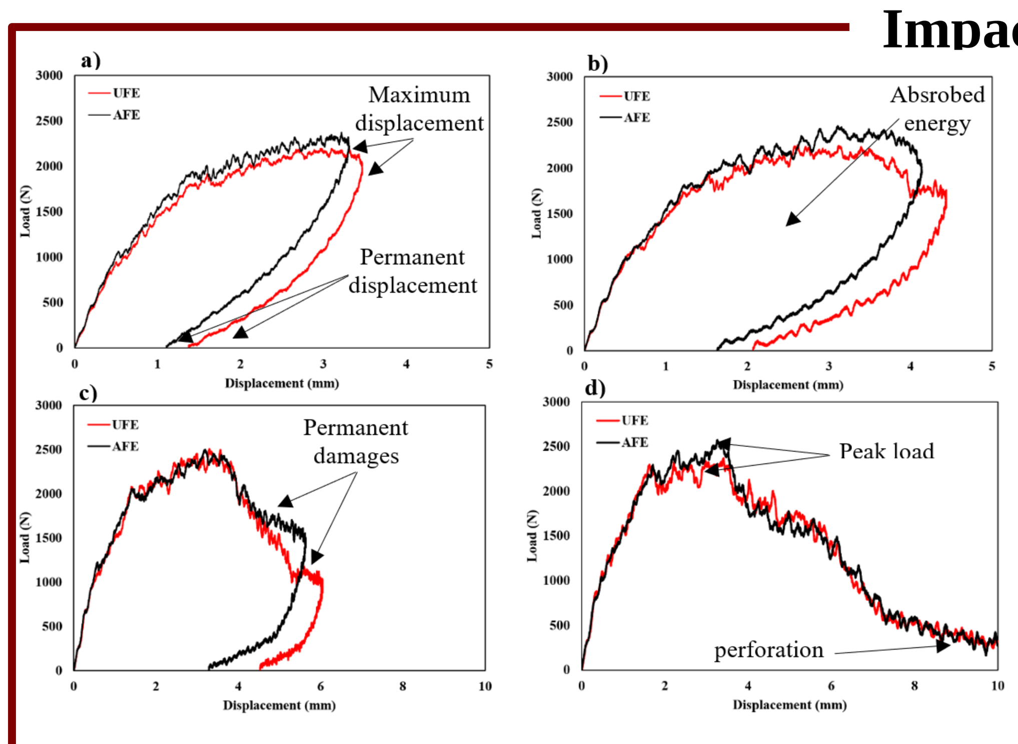


Impact toughness for different configurations

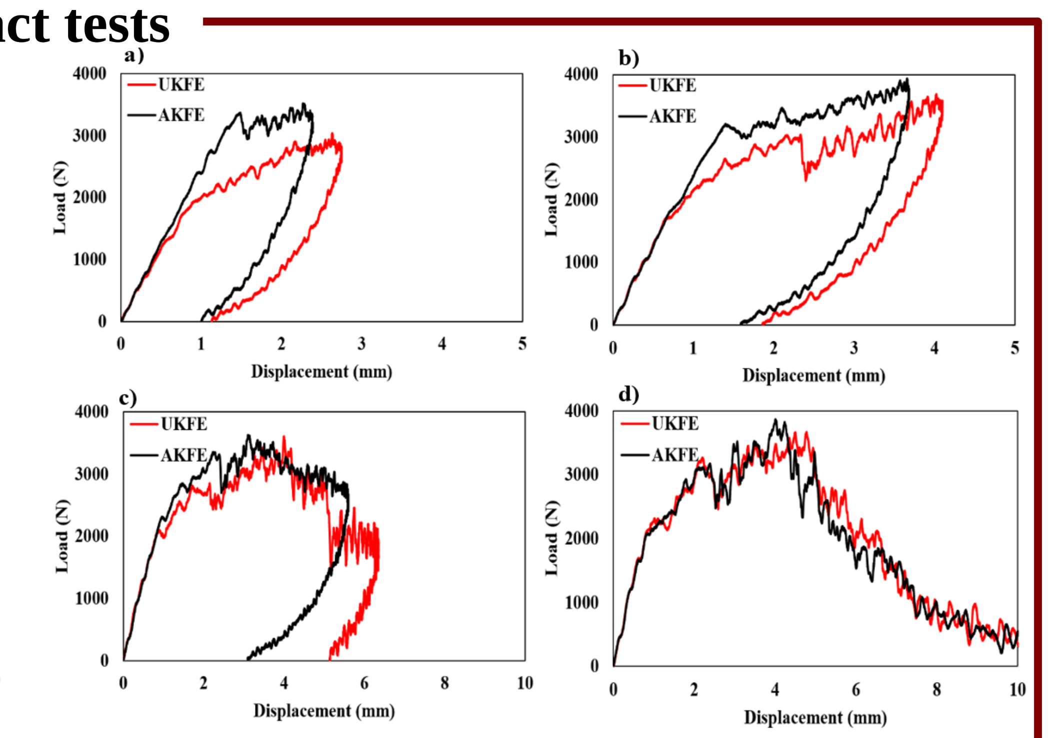


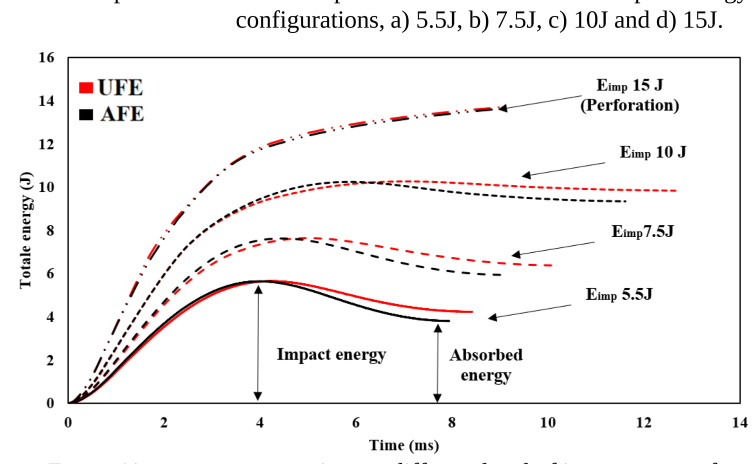
Macroscopic failure mechanisms after impact for the four composite laminate configurations. with a) UKFE. b) UFE c) AKFE and d) AFE

Impact tests

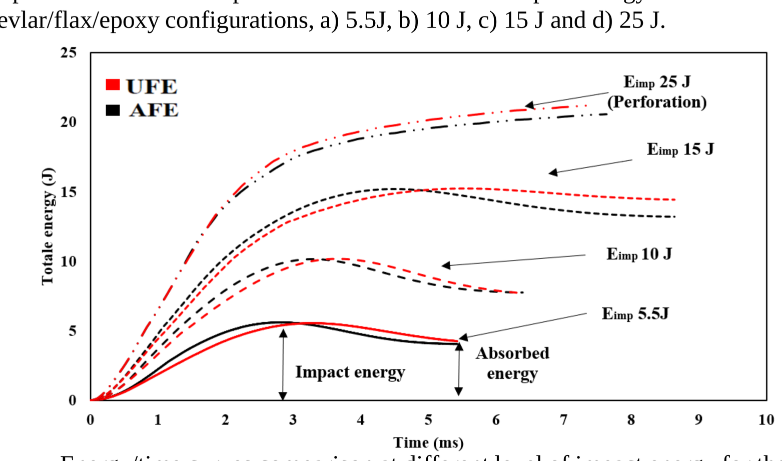


Load/displacement curves comparison at different level of impact energy for the flax/epoxy configurations, a) 5.5J, b) 7.5J, c) 10J and d) 15J.

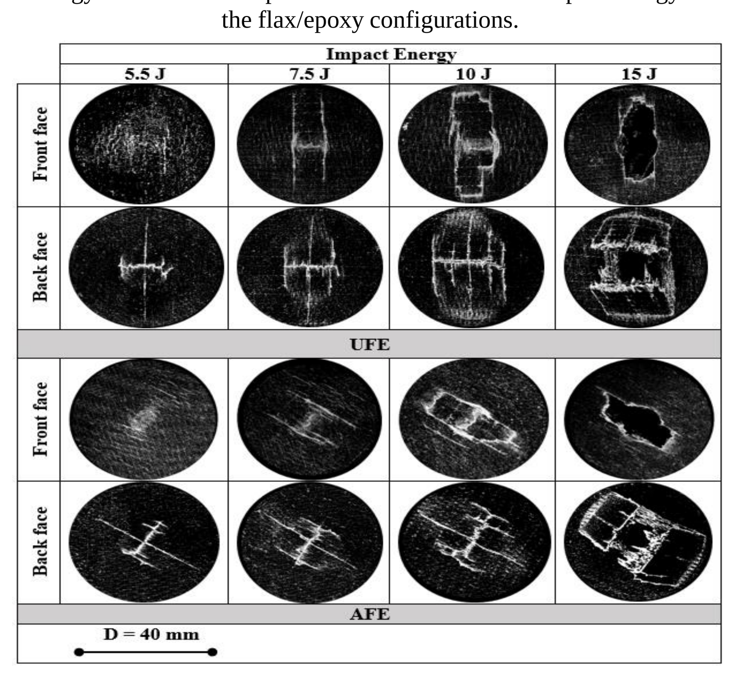

Load/displacement curves comparison at different level of impact energy for the Kevlar/flax/epoxy configurations, a) 5.5J, b) 10 J, c) 15 J and d) 25 J.



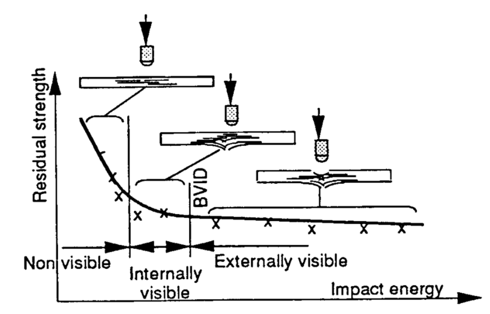
Energy/time curves comparison at different level of impact energy for the flax/epoxy configurations.



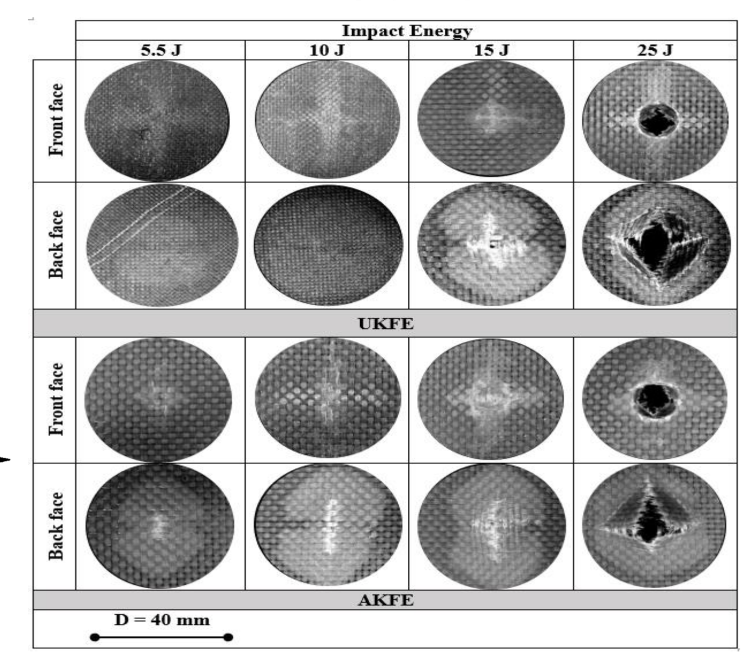
Energy/time curves comparison at different level of impact energy for the Kevlar/flax/epoxy configurations.



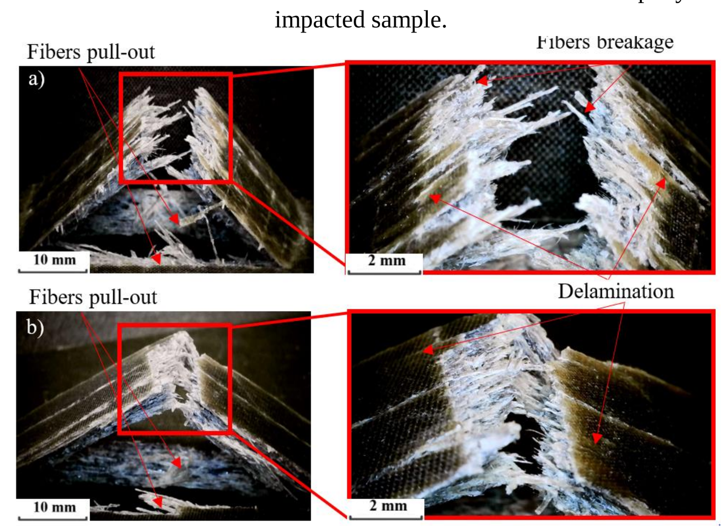
Evolution of the crack in the front and back face of the flax/epoxy impacted sample.



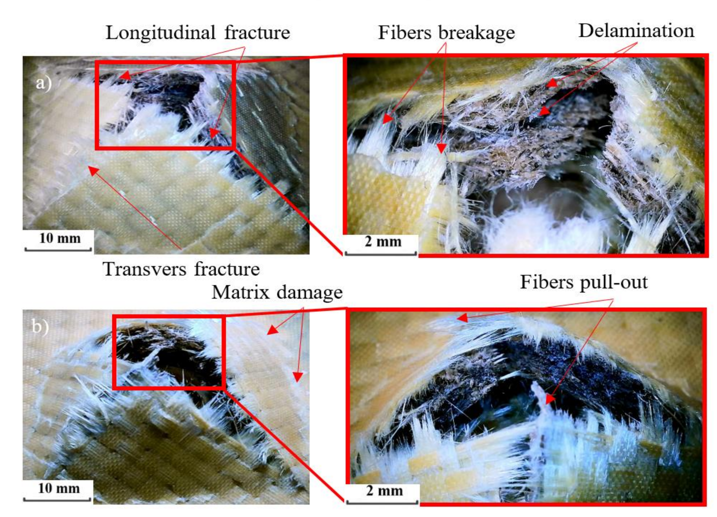
Schematic representation of the damage evolution in impact test



Evolution of the crack in the front and back face of the kevlar/flax/epoxy impacted sample.

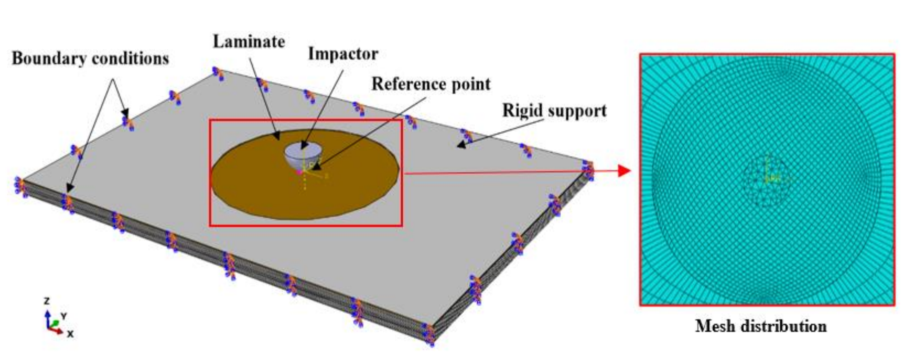


Microscopic damage mechanism for the flax/epoxy configurations with, a) UFE and b) AFE



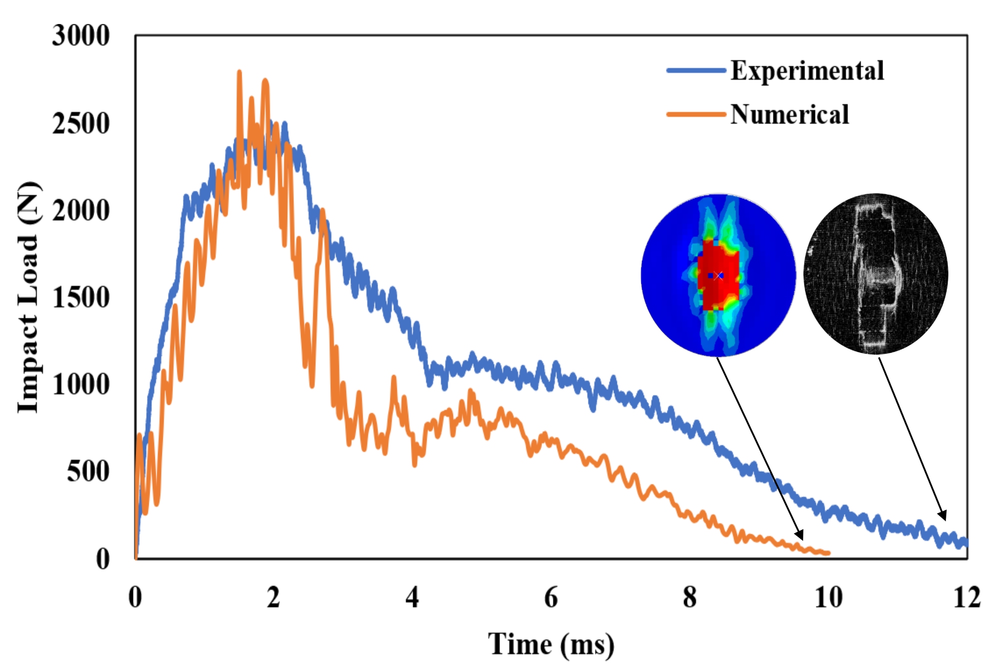
Microscopic damage mechanism for the flax/epoxy configurations with, a) UKFE and b) AKFE

Finite element analysis

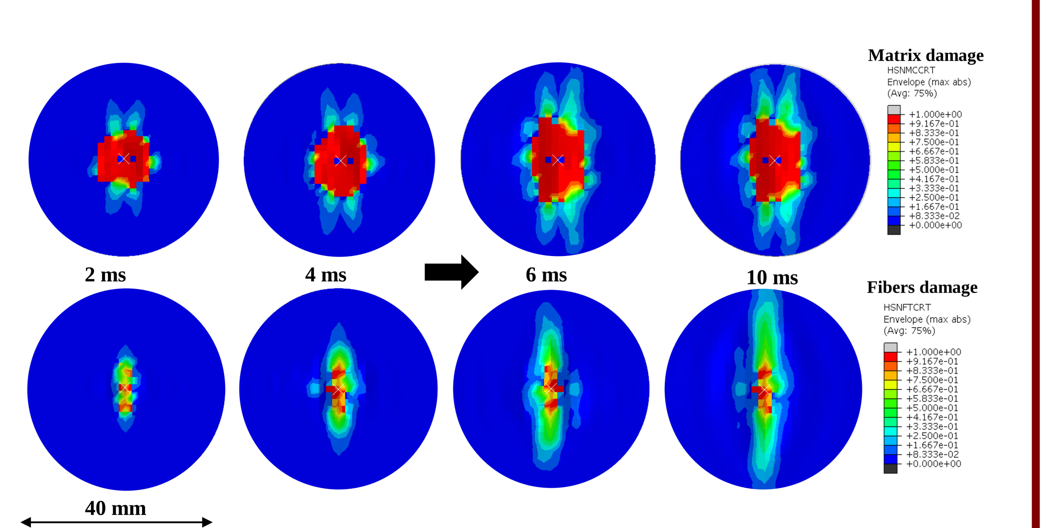


Numerical model for low velocity impact

Failure mode	Failure criterion
Fiber tension failure	$\left(\frac{\sigma_{xx}}{X_T}\right)^2+\left(\frac{\tau_{xy}}{S_{xy}}\right)^2+\left(\frac{\tau_{yz}}{S_{yz}}\right)^2 \geq 1$
Fiber compression failure	$\left(\frac{\sigma_{xx}}{X_C}\right)^2 \geq 1$
Matrix tension cracking	$\left(\frac{\sigma_{yy}}{Y_T}\right)^2+\left(\frac{\tau_{xy}}{S_{xy}}\right)^2+\left(\frac{\tau_{yz}}{S_{yz}}\right)^2 \geq 1$
Matrix compression cracking	$\left(\frac{\sigma_{yy}}{Y_C}\right)^2+\left(\frac{\tau_{xy}}{S_{xy}}\right)^2+\left(\frac{\tau_{yz}}{S_{yz}}\right)^2 \geq 1$
Fiber- matrix shear - out	$\left(\frac{\sigma_{xx}}{X_C}\right)^2+\left(\frac{\sigma_{yy}}{S_{xy}}\right)^2+\left(\frac{\sigma_{yz}}{S_{yz}}\right)^2 \geq 1$



Comparison of the numerical and experimental impact load vs. time at 10 J of impact energy.



Fiber and matrix damage evolution at 2 ms, 4 ms, 6 ms and 10 ms of impact loading on the front face of the impacted UD specimens at 10 J of impact energy.

Conclusion :

- Bending tests showed an increase of 13% for UD and four time for the angle-ply orientations when using the hybrid configuration.
- The results showed that the hybrid structure increased the impact load by 30 % compared the pure flax/epoxy configurations.
- Charpy test results showed that the presence of Kevlar significantly increased the impact energy of flax fiber composites. It was also found that specimens made of unidirectional Kevlar and flax fibers in an epoxy matrix displayed the highest impact toughness.
- The proposed finite element model was able to reproduce the impact event in close agreement with the experimental data and, as a consequence, may become an accurate prediction of the materials behavior under low-velocity impact loadings and assess the damage evolution.

References :

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