Mondragon Unibertsitatea
Faculty of Engineering

Impact performance of out of die UV cured pultruded profiles for vessel structures

I. Ruiz de Eguino, I. Saenz-Dominguez, I. Tena, A. Arruti, M. Sarrionandia, J. Aurrekoetxea

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ECCM20

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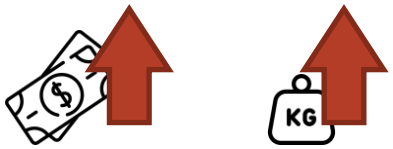
Index

Composites in Shipbuilding

Composites → Lightweight

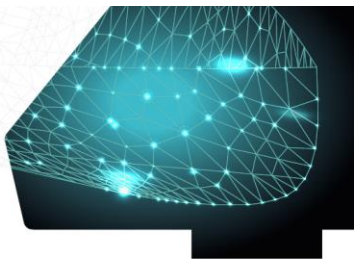
Source: RTVE Fabricando Made in Spain - Barcos.

- Labour intensive
- Low productivity
- Lack of robustness



FIBRE4YARDS
SHIPYARD FOR THE FUTURE

FIBRE composite manufacturing technologies FOR the automation and modular construction in shipYARDS

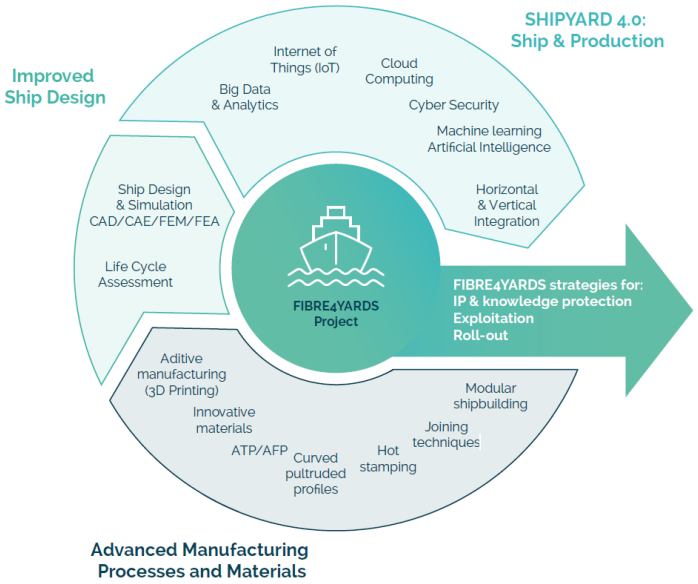


Grant Agreement No. 101006860

MAIN OBJECTIVE

The main objective of **FIBRE4YARDS** is to maintain European global leadership in ship building and ship maintenance, through implementation of the Shipyard 4.0 concept.

FIBRE4YARDS focuses on the entire value chain of the shipyards and their ecosystem, cooperatively working on small and medium length fibre-based ships in a digital environment.



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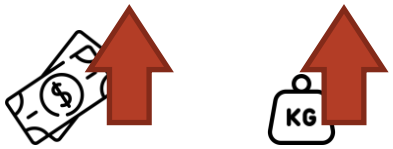

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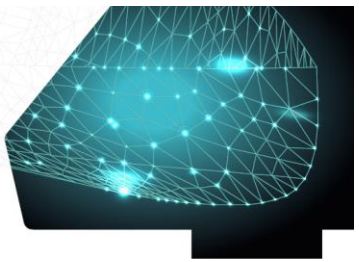

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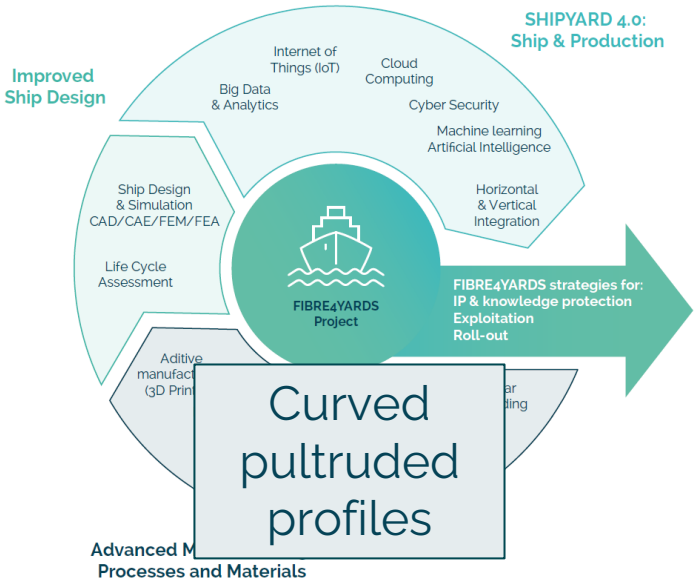
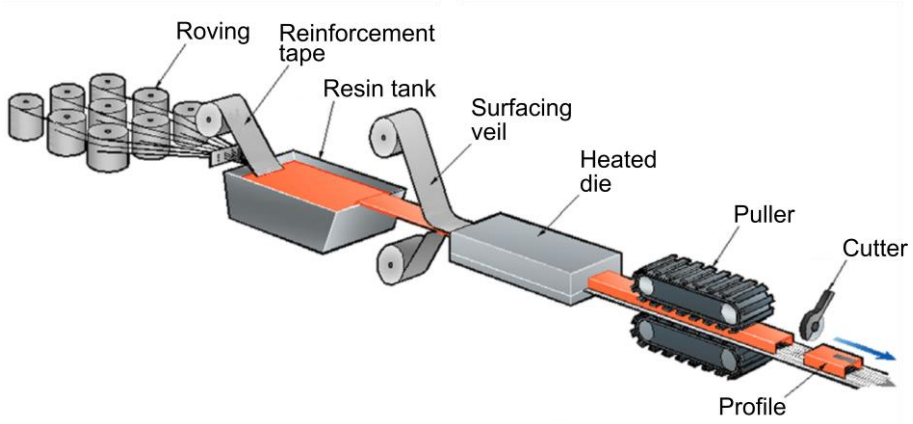


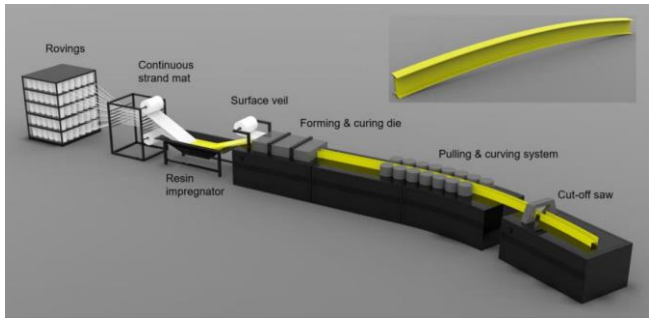
Out of die UV cured pultrusion



Source: A. Landesmann, C. A. Seruti, and E. d. M. Batista, "Mechanical Properties of Glass Fiber Reinforced Polymers Members for Structural Applications," Materials Research, vol. 18, no. 6, pp. 1372–1383, Nov. 2015, issn: 1516-1439. doi: 10.1590/1516-1439.044615.

Source: Jamco Advanced Pultrusion Process. [Online]. Available: https://www.jamco.co.jp/en/business/jco/adp/adp_process.html.

Source: ShapeCORP. [Online]. Available: https://www.shapecorp.com/manufacturing/composites/.



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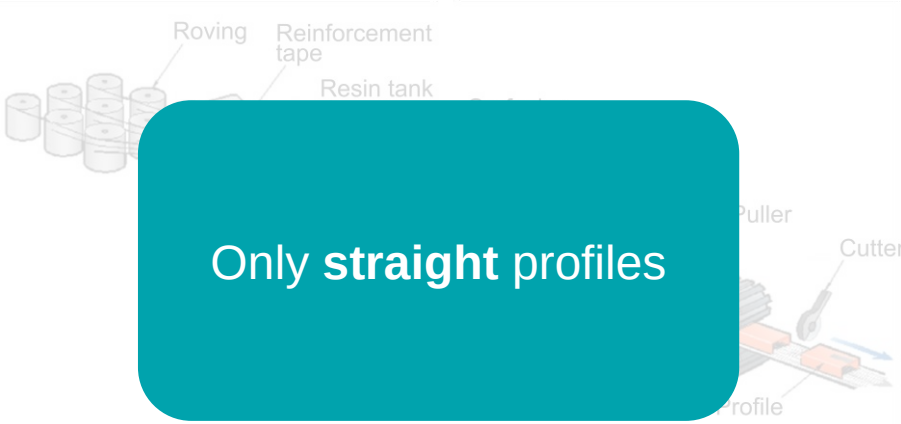
- ✓ Continuous process
- ✓ Automated operation of the line
- ✓ High productivity
- ✓ High mechanical properties in the longitudinal direction
- ✓ High flexibility

- × Constant cross section
- × High pulling forces
- × High investment on machinery
- × Limited to shapes with a constant curvature

Out of die UV cured pultrusion



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Only **straight** profiles

Source: Jamco Advanced Pultrusion Process. [Online]. Available: https://www.jamco.co.jp/en/business/jco/adp/adp_process.html.

No **variable** curvatures

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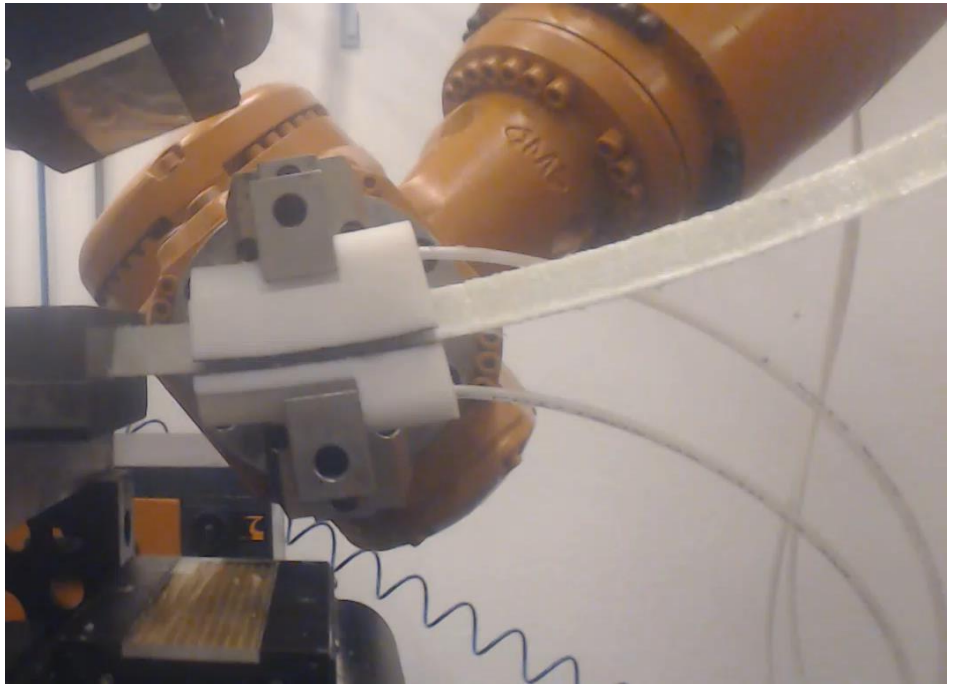
Curing inside the die

Out of die UV cured pultrusion

Ultraviolet (UV) curing

To cure the profile **out of the die** and change the paradigm of conventional pultrusion technologies

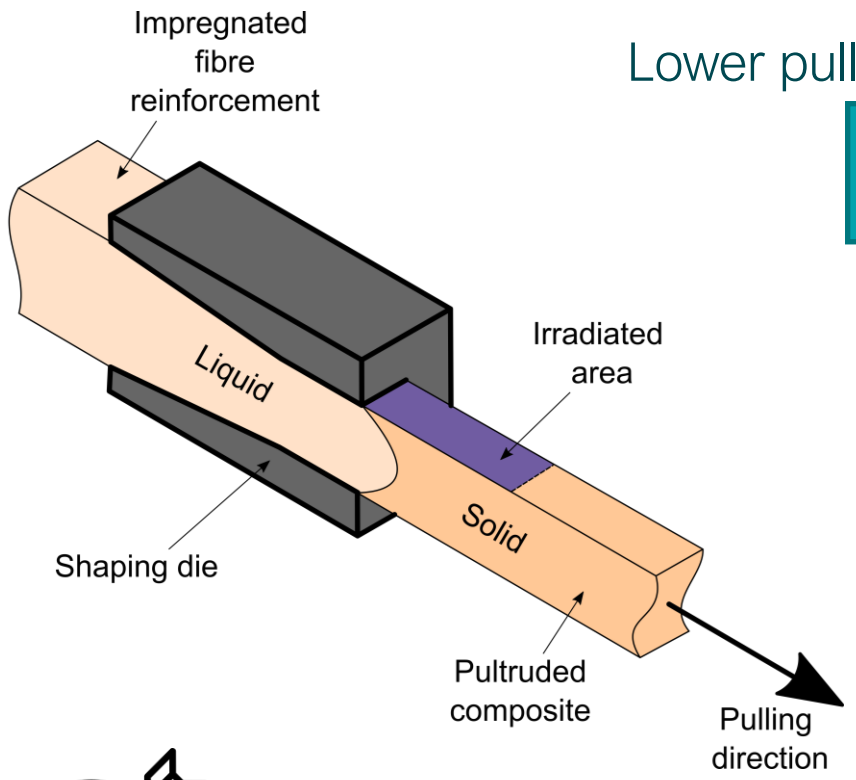


- ✓ Continuous process
- ✓ Automated operation of the line
- ✓ High productivity
- ✓ High mechanical properties in the longitudinal direction
- ✓ High flexibility

- × Constant cross section
- ✓ **Low pulling forces**
- ✓ **Moderate investment in machinery**
- ✓ **Shapes with variable curvatures**
- × No opaque reinforcements
- × Profile thickness limited by radiation penetration

doi: 10.1016/j.compstruct.2020.113111

Transversal mechanical behaviour



Lower pulling forces

↳ Less longitudinal fibre reinforcement

↳ Enhanced transversal mechanical behaviour

↳ Improvement against complex loading conditions

Objective

Analyse how the **impact response of stiffeners** could be improved by taking advantage of the **greater freedom for defining the reinforcement configuration** on profiles manufactured by **out of die UV cured pultrusion**.

Materials and physical characterization

Matrix

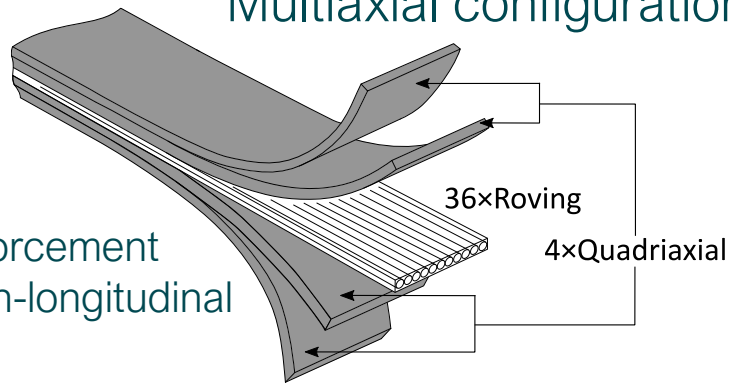
Vinyl ester acrylate resin formulation

IRUCRIL GFR-30 LED

Provided by:

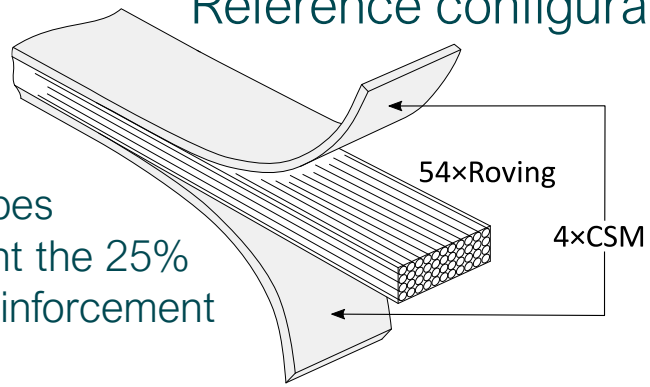
Fibre Reinforcement

Multiaxial configuration

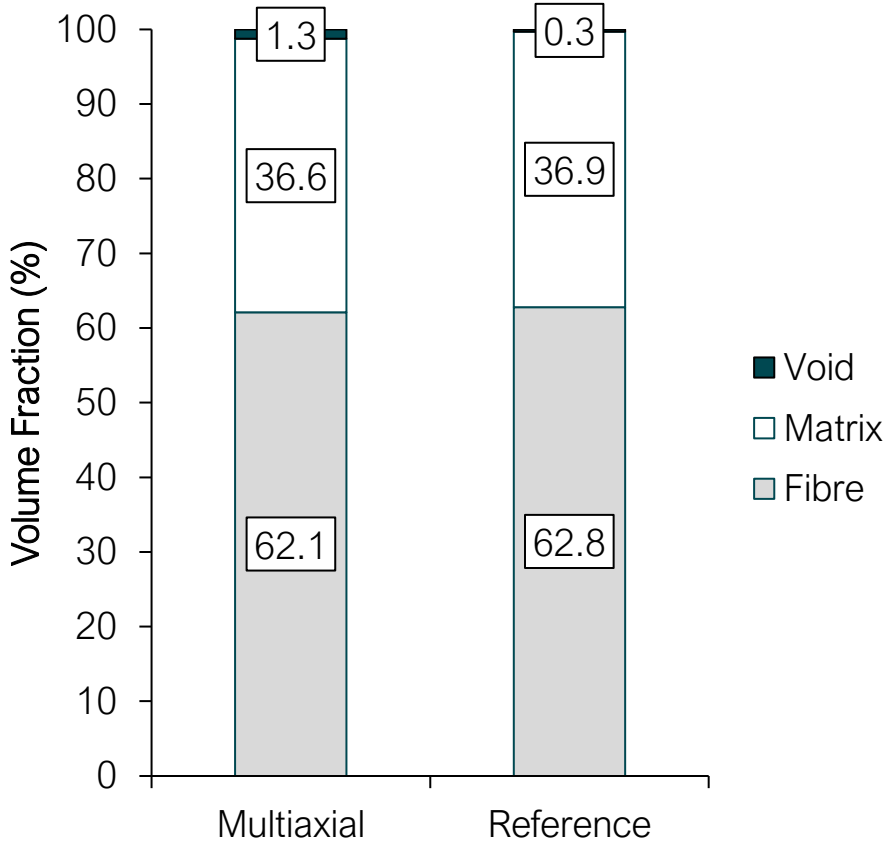


40% of reinforcement placed in non-longitudinal orientations

Reference configuration

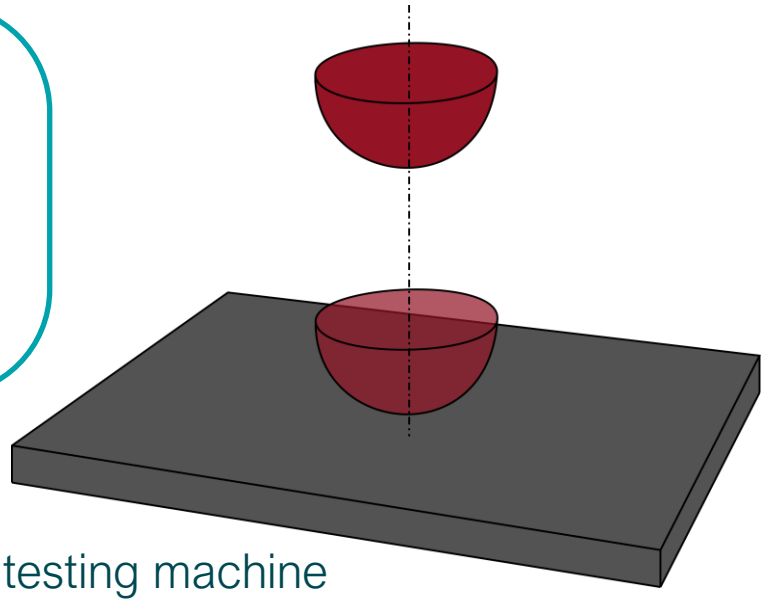


CSM tapes represent the 25% of the reinforcement



Experimental techniques

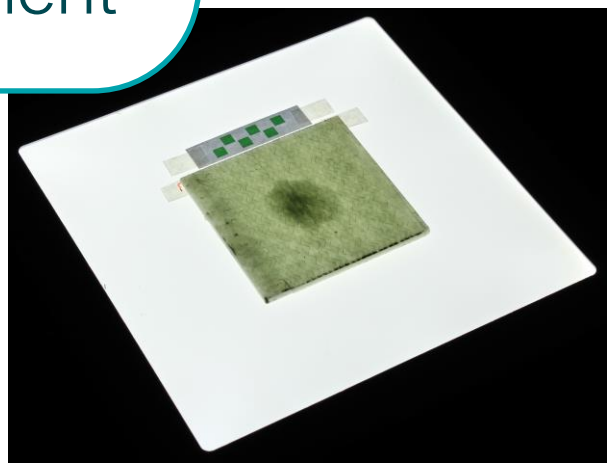
Drop weight low velocity impact test



Fractovis-Plus (CEAST) testing machine

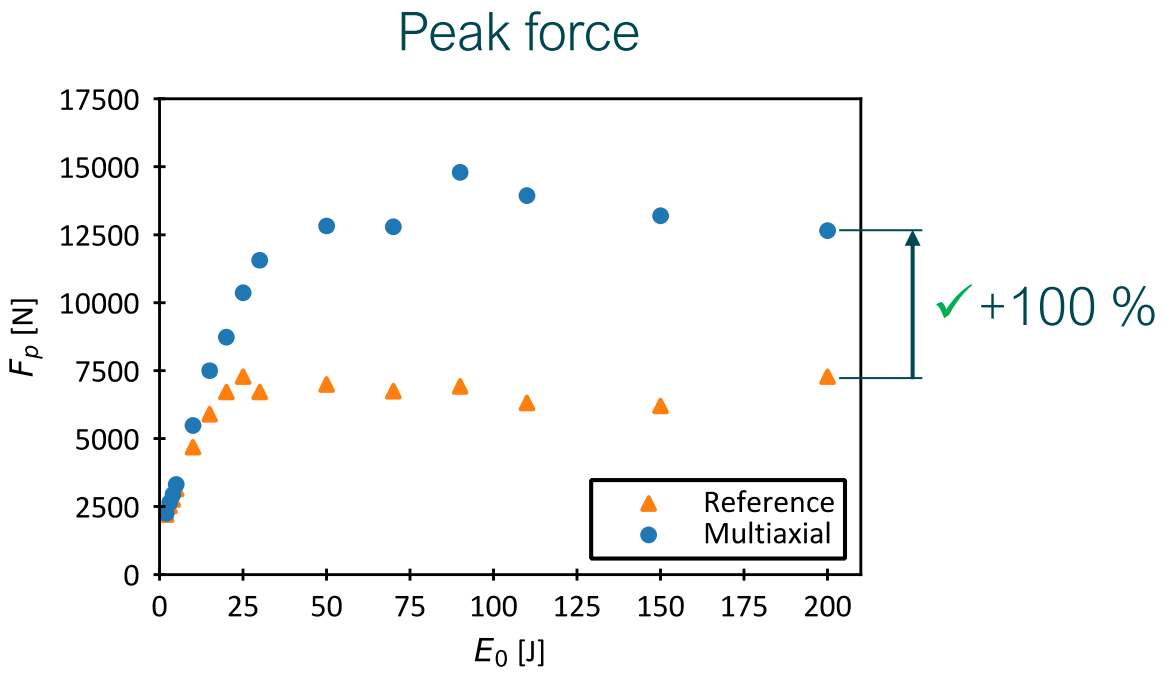
- Flat square specimens (3 mm thick and 75 mm wide)
- Clamping ring (Ø 40 mm inner and Ø 60 mm outer)
- Initial drop heights 50 - 1000 mm
- Striker masses 2 - 20 kg
- Incident impact energies 1 - 200 J
- Hemispherical instrumented striker (Ø 20 mm) with a 20 kN load cell

Backlighting delamination assessment

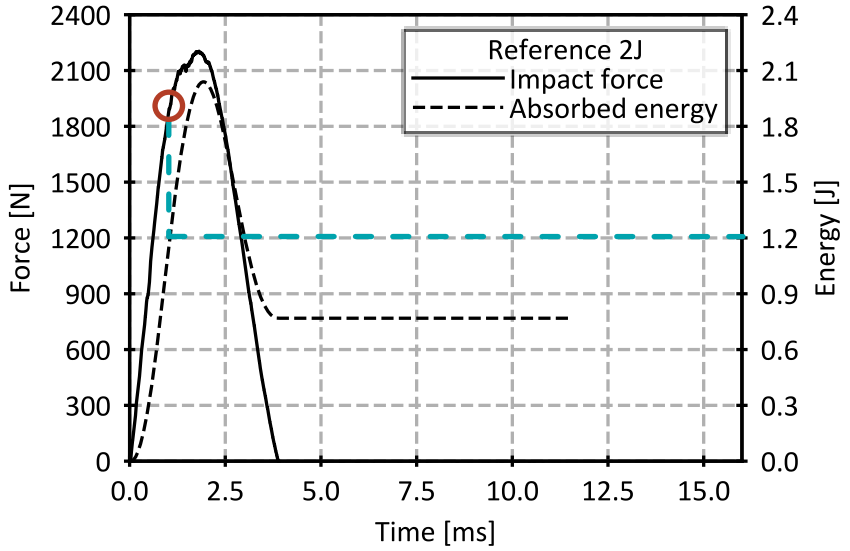


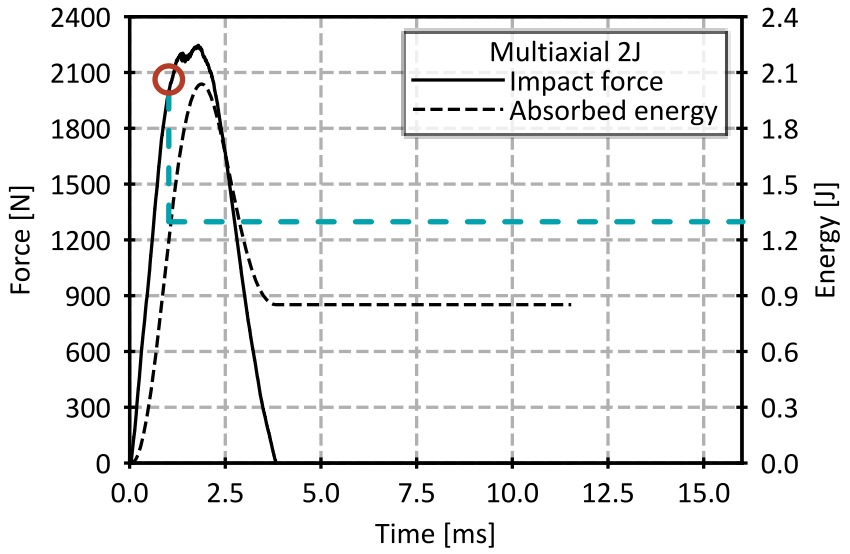
Computer vision aided delamination contour recognition

Impact resistance



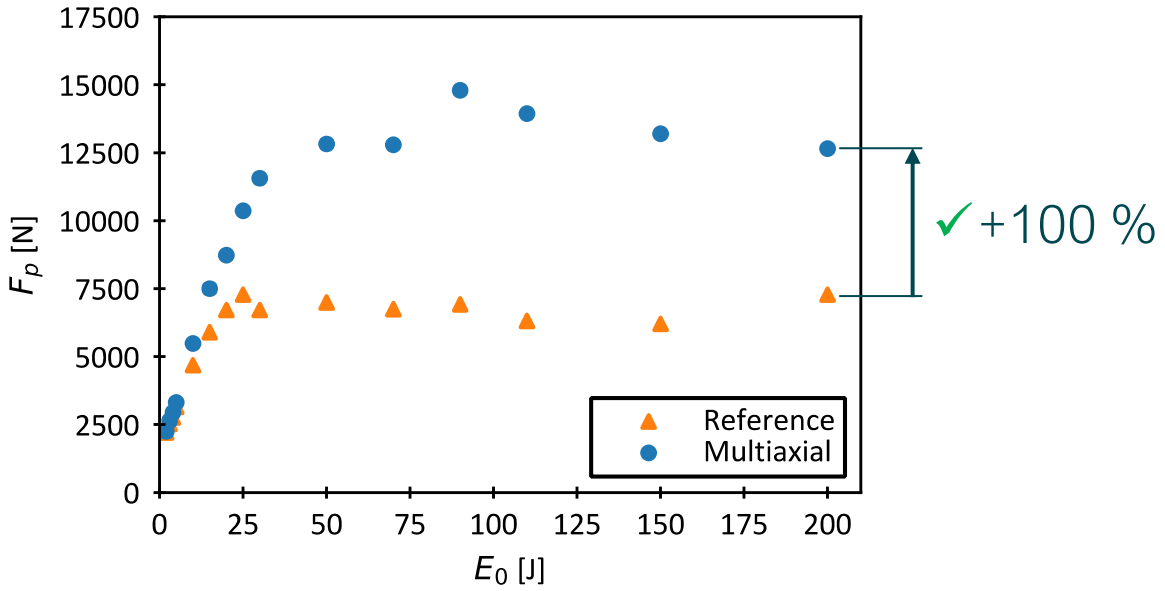
Pultruded composite	Critical energy [J]
Reference	1.2
Multiaxial	1.3



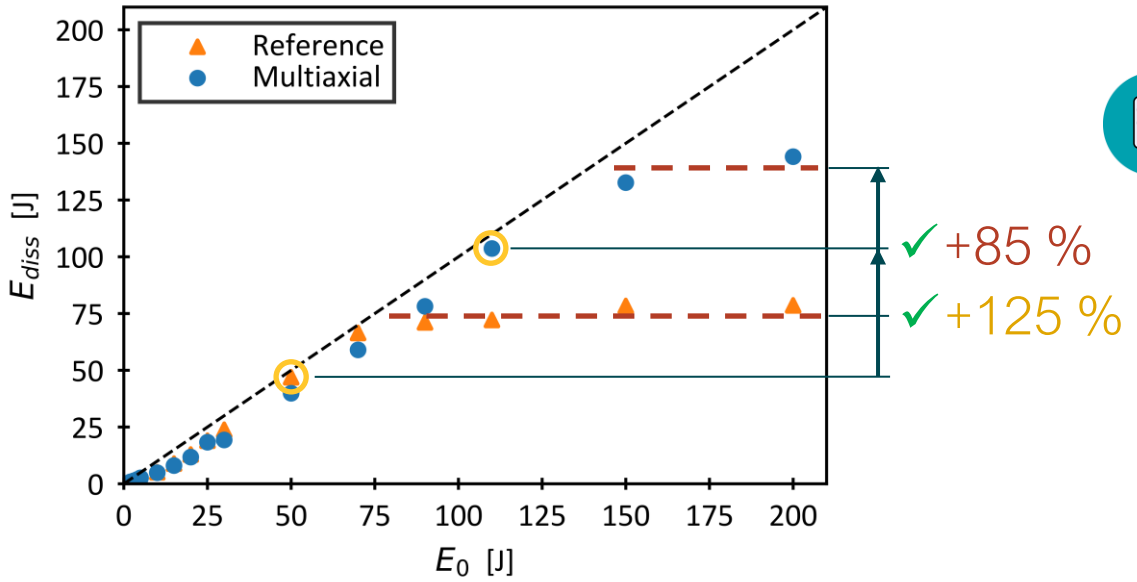


Impact resistance

Peak force



Dissipated energy

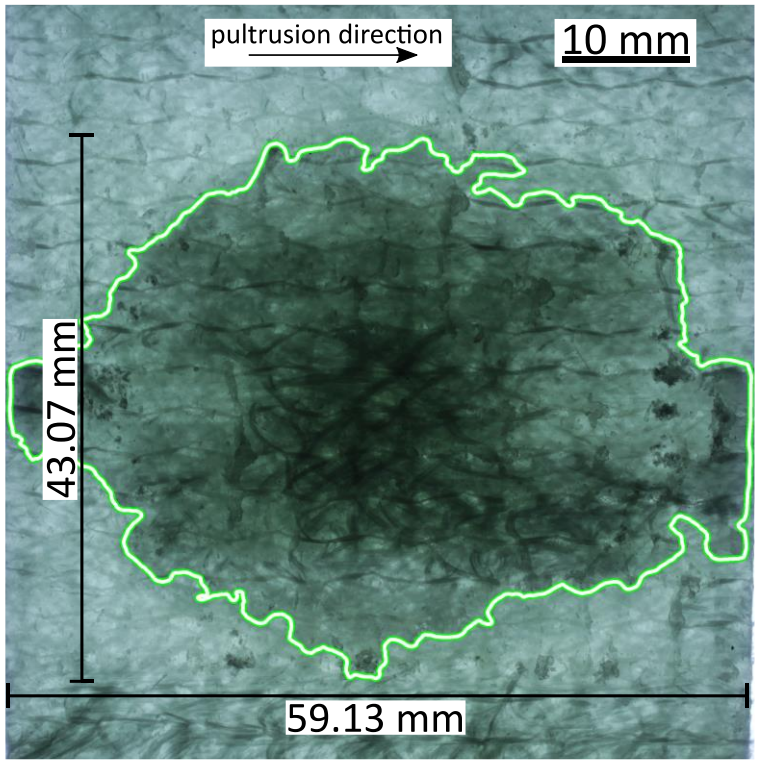


Pultruded composite	Critical energy [J]	Penetration threshold [J]		Perforation threshold [J]	
Reference	1.2	50		75	
Multiaxial	1.3	115	✓+125 %	140	✓+85 %

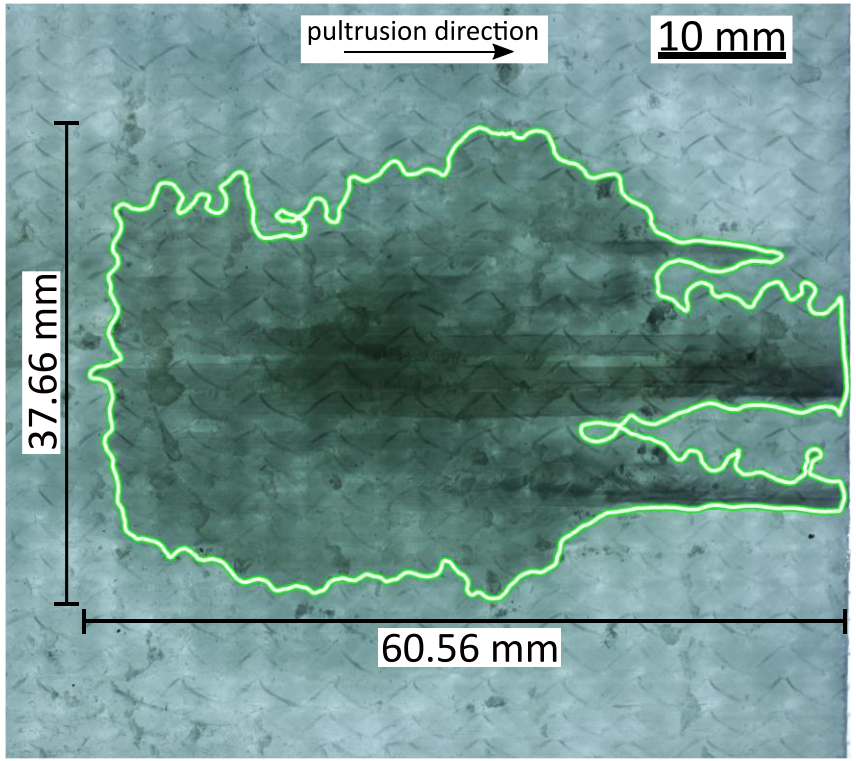
Delamination assessment

Delamination contours after a 25 J impact event

Reference configuration



Multiaxial configuration



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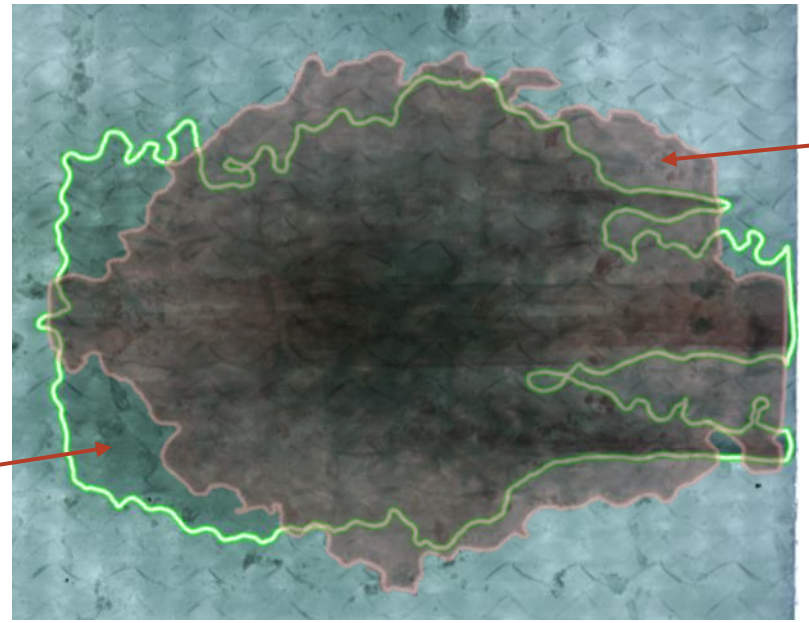


✓ The multiaxial configuration **restrains the extent of the delaminated area** in the transversal direction.

Damage tolerance

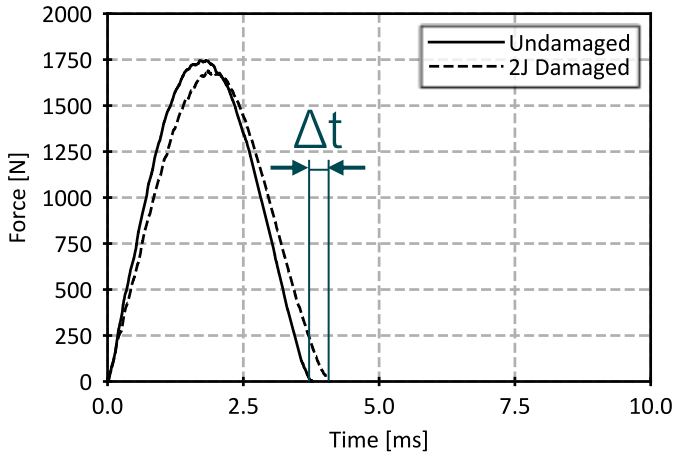
Feraboli et al.

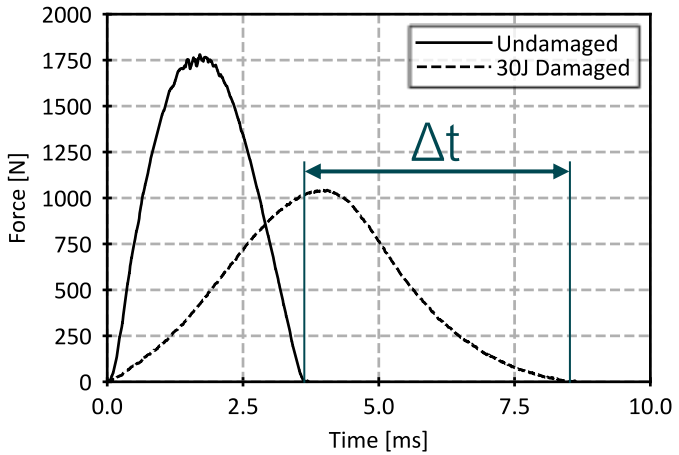
Composites Science and Technology 66 (2006) 10:1336-47

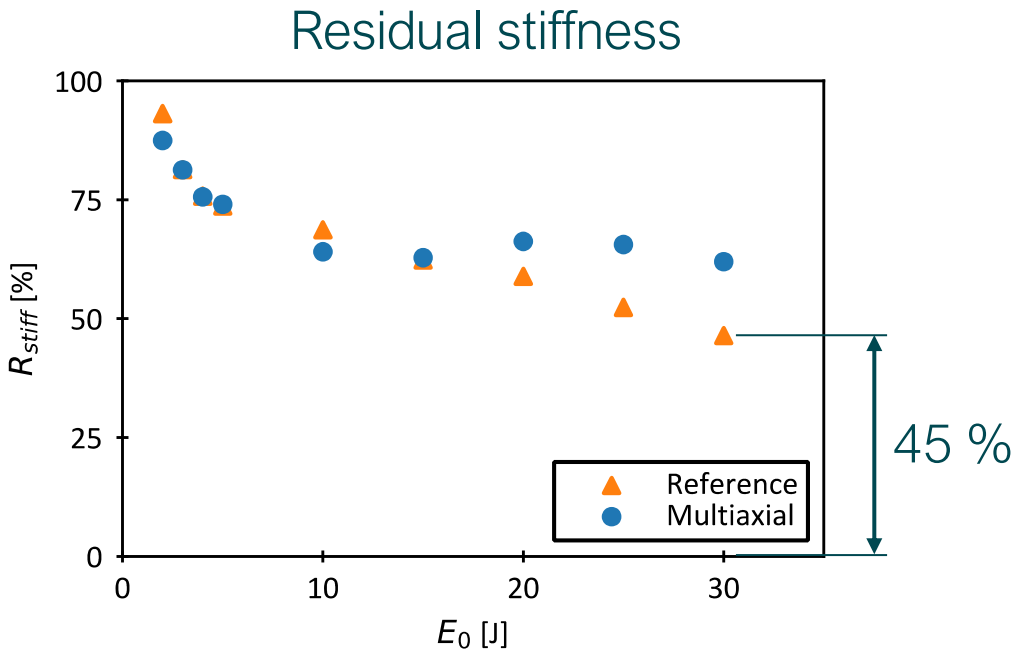
Subcritical impact

Critical impact

Subcritical impact







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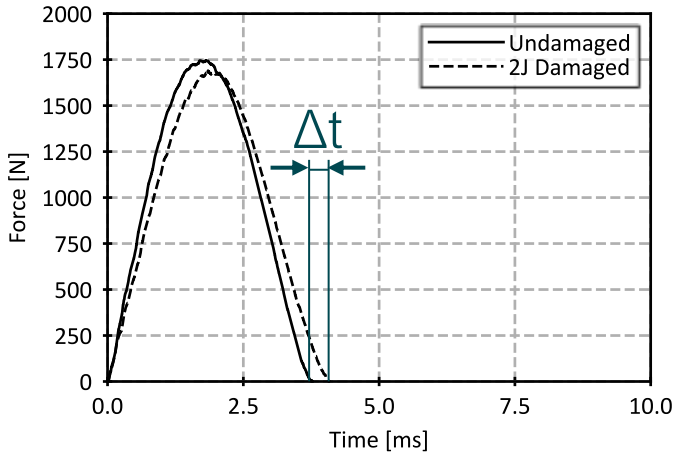
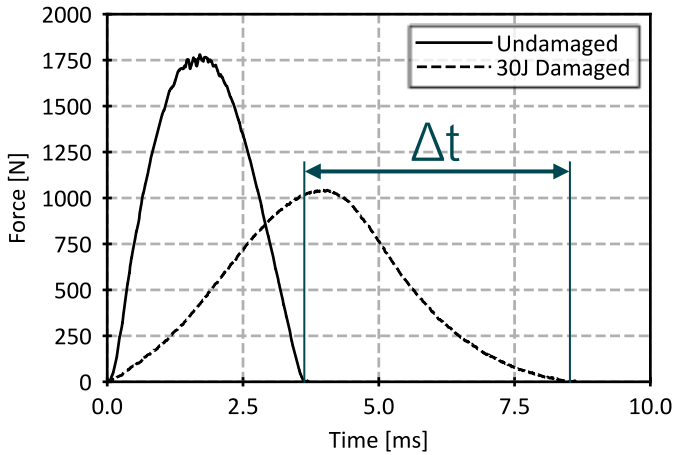
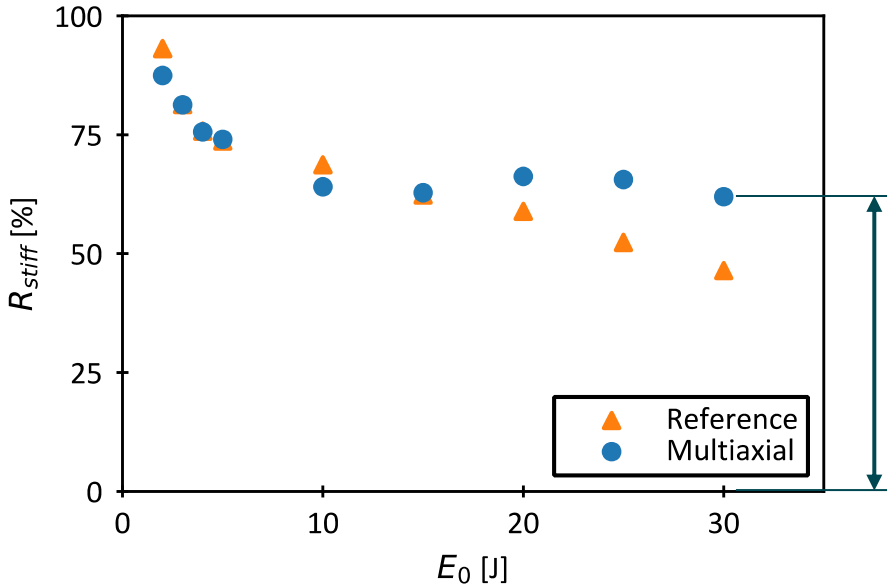




Residual stiffness

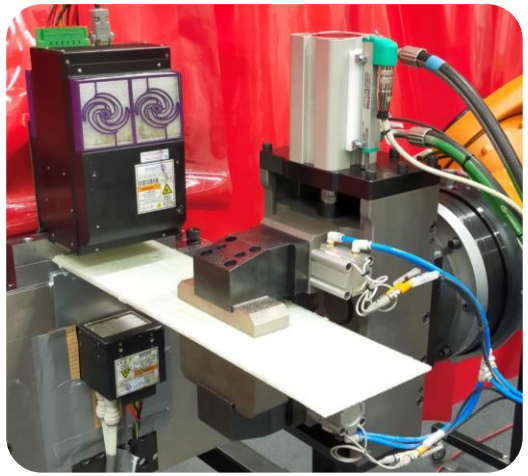


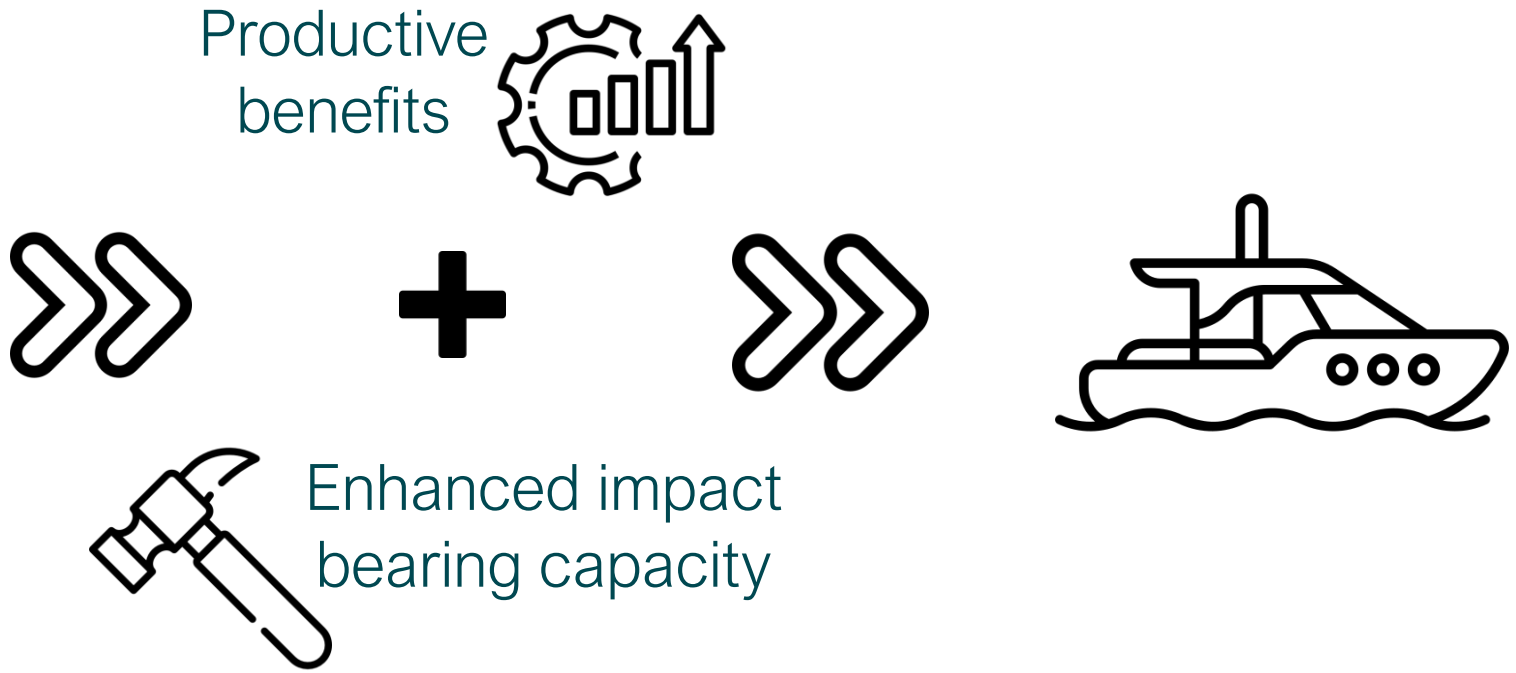
✓60 %

✓ The multiaxial configuration retains a **60 % of its original stiffness,** even when presenting delamination of a considerable extent due to a 30 J impact event.

Conclusions

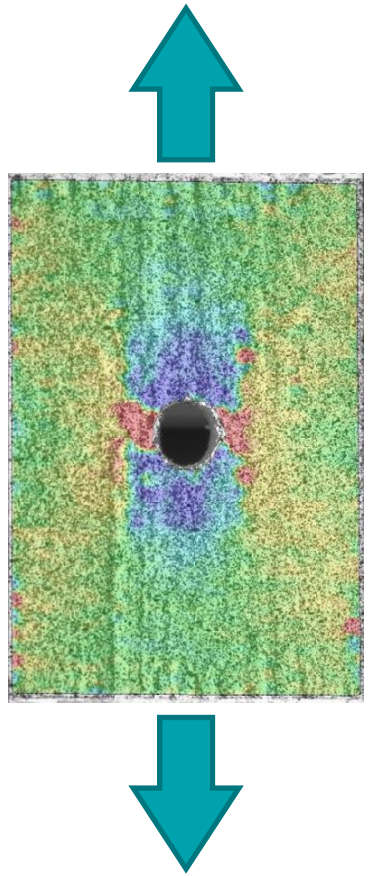
- ✓ The **impact response** and **damage tolerance** of vessel structures stiffeners could be enhanced with the **reinforcement configurations** that can be manufactured by **out of die UV cured pultrusion**.



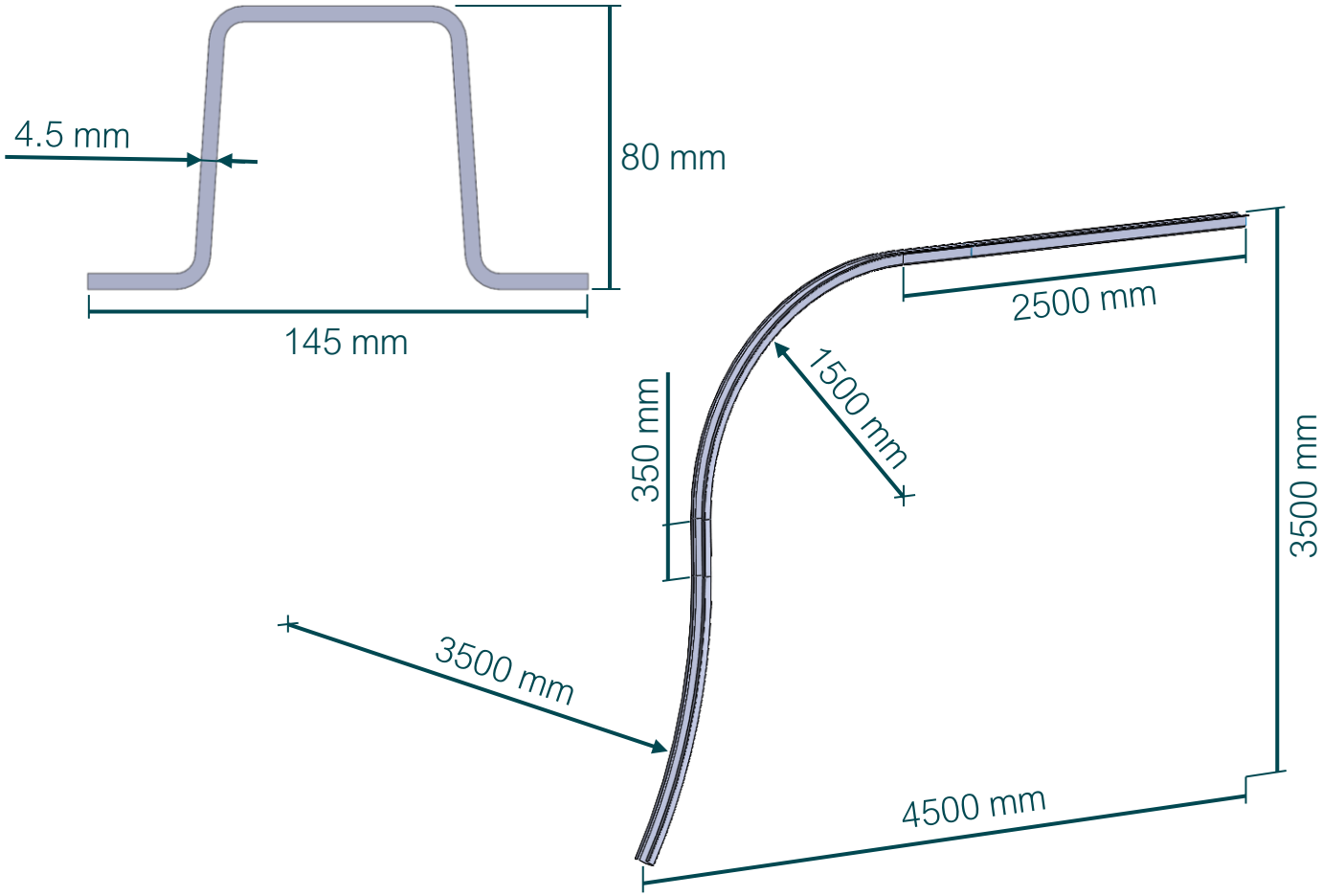


Future lines

- **Open Hole** tensile strength tests on the same analysed **reinforcement configuration.**



- **Top-hat stiffener profiles** for the F4Y demonstrator superstructure with a **variable curvature.**



Acknowledgements

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Faculty of Engineering

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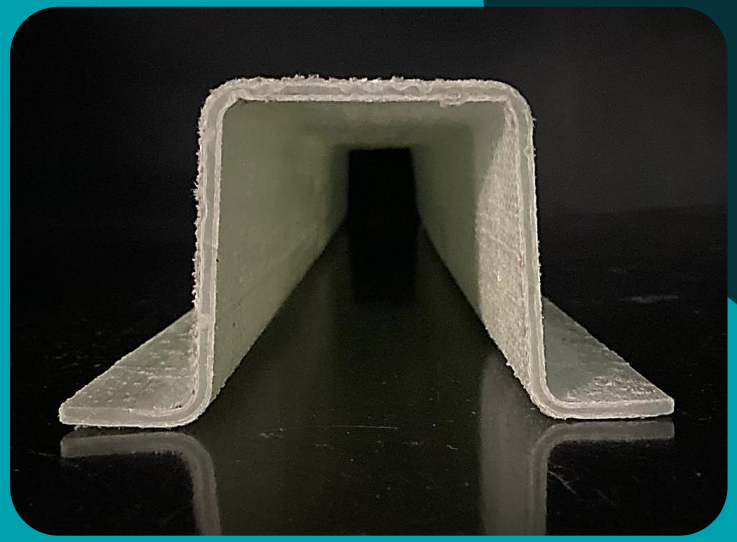

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