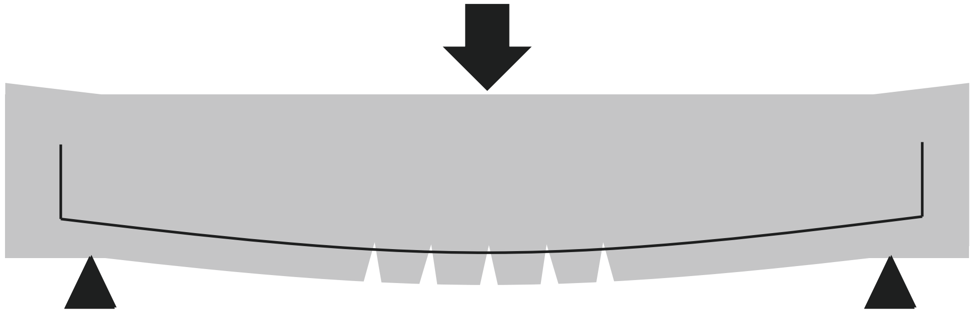
Post-tensioning method for Prestressed Fiber-Reinforced Vitrimer Laminates

L. Carreras, D. Sánchez-Rodríguez, P. Maimí, A. Ruiz de Luzuriaga, J. Farjas, A. Rekondo and J. Costa

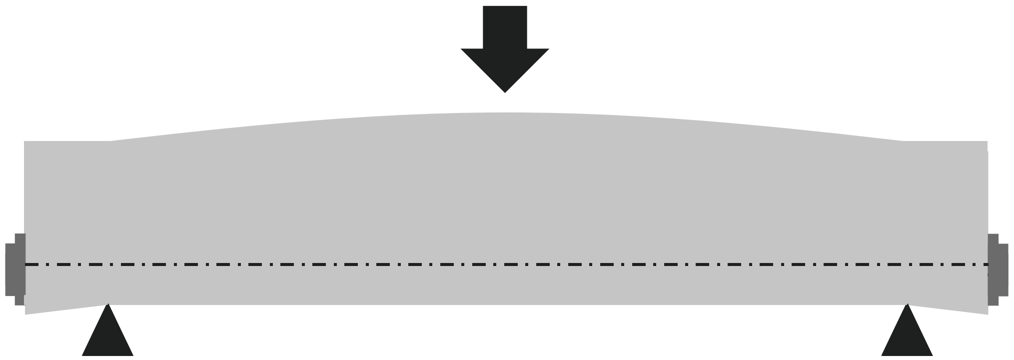
Prestressed concrete: a revolutionary invention

Reinforced concrete



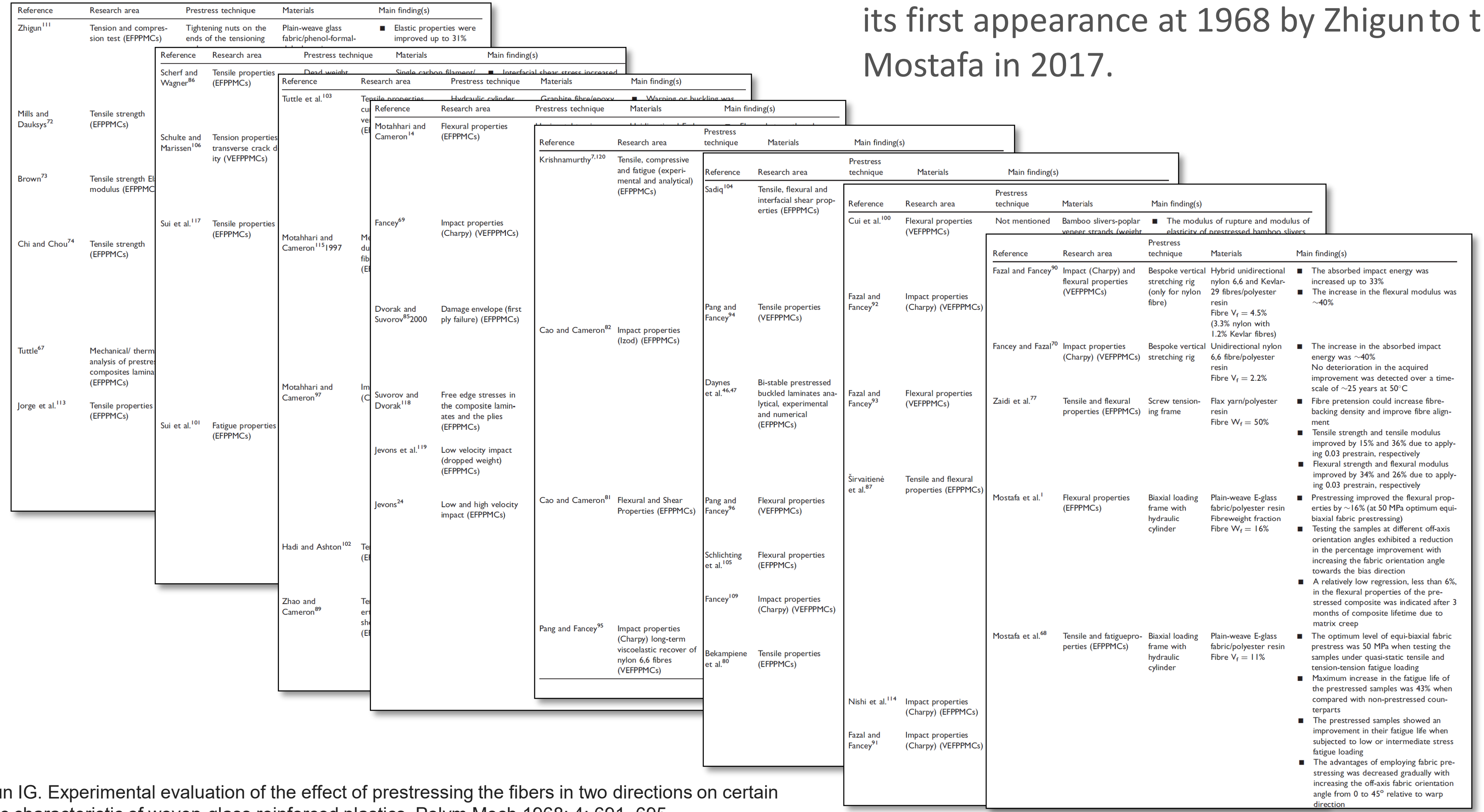
Prestressed concrete: a revolutionary invention

Prestressed concrete



The Role of Prestressing in Fiber Reinforced Polymer Composites

43 available studies related to fibre pre-tension methods from its first appearance at 1968 by Zhigun to the review done by Mostafa in 2017.

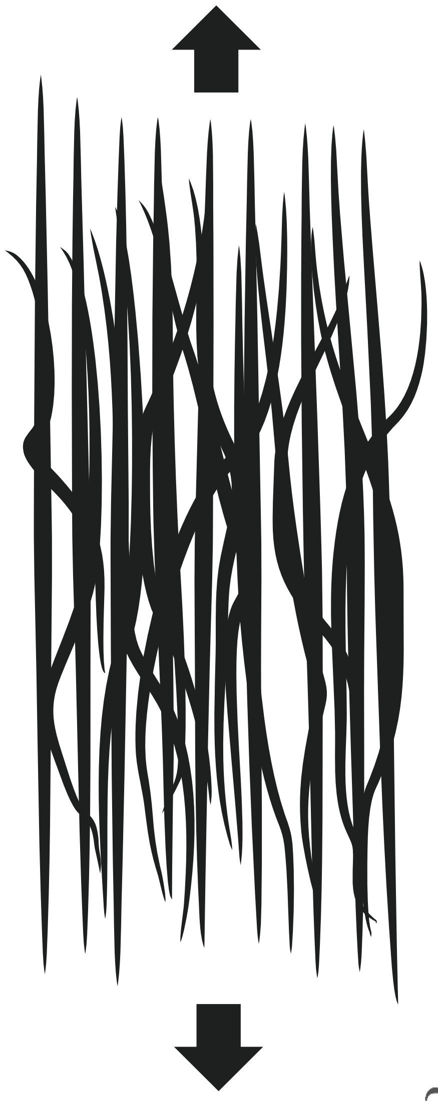


Reference	Research area	Prestress technique	Materials	Main finding(s)
Fazal and Fancey[90]	Impact (Charpy) and flexural properties (VEFPPMCs)	Bespoke vertical stretching rig (only for nylon fibre)	Hybrid unidirectional nylon 6,6 and Kevlar-29 fibres/polyester resin Fibre $V_f = 4.5\%$ (3.3% nylon with 1.2% Kevlar fibres)	■ The absorbed impact energy was increased up to 33% ■ The increase in the flexural modulus was ∼40%
Fancey and Fazal[70]	Impact properties (Charpy) (VEFPPMCs)	Bespoke vertical stretching rig	Unidirectional nylon 6,6 fibre/polyester resin Fibre $V_f = 2.2\%$	■ The increase in the absorbed impact energy was ∼40% No deterioration in the acquired improvement was detected over a time-scale of ∼25 years at 50°C
Zaidi et al.[77]	Tensile and flexural properties (EFPPMCs)	Screw tensioning frame	Flax yarn/polyester resin Fibre $W_f = 50\%$	■ Fibre pretension could increase fibre-backing density and improve fibre alignment ■ Tensile strength and tensile modulus improved by 15% and 36% due to applying 0.03 prestrain, respectively ■ Flexural strength and flexural modulus improved by 34% and 26% due to applying 0.03 prestrain, respectively
Mostafa et al.[1]	Flexural properties (EFPPMCs)	Biaxial loading frame with hydraulic cylinder	Plain-weave E-glass fabric/polyester resin Fibreweight fraction Fibre $W_f = 16\%$	■ Prestressing improved the flexural properties by ∼16% (at 50 MPa optimum equi-biaxial fabric prestressing) ■ Testing the samples at different off-axis orientation angles exhibited a reduction in the percentage improvement with increasing the fabric orientation angle towards the bias direction ■ A relatively low regression, less than 6%, in the flexural properties of the prestressed composite was indicated after 3 months of composite lifetime due to matrix creep
Mostafa et al.[68]	Tensile and fatigueproperties (EFPPMCs)	Biaxial loading frame with hydraulic cylinder	Plain-weave E-glass fabric/polyester resin Fibre $V_f = 11\%$	■ The optimum level of equi-biaxial fabric prestress was 50 MPa when testing the samples under quasi-static tensile and tension-tension fatigue loading ■ Maximum increase in the fatigue life of the prestressed samples was 43% when compared with non-prestressed counterparts ■ The prestressed samples showed an improvement in their fatigue life when subjected to low or intermediate stress fatigue loading ■ The advantages of employing fabric prestressing was decreased gradually with increasing the off-axis fabric orientation angle from 0 to 45° relative to warp direction

Zhigun IG. Experimental evaluation of the effect of prestressing the fibers in two directions on certain elastic characteristic of woven-glass reinforced plastics. Polym Mech 1968; 4: 691–695.
Mostafa, N. H., Ismarrubie, Z. N., Sapuan, S. M., & Sultan, M. T. H. (2017). Fibre prestressed polymer-matrix composites: a review. *Journal of Composite Materials*, *51*(1), 39-66.

The Role of Prestressing in Fiber Reinforced Polymer Composites

- Making the fiber yarns to become straighter and tighter

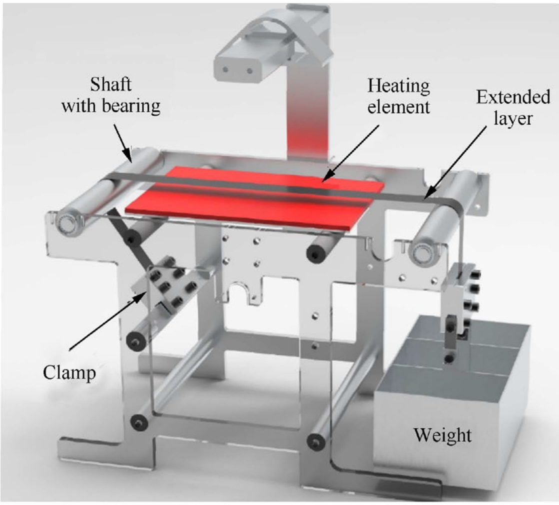


The Role of Prestressing in Fiber Reinforced Polymer Composites (FRPC)

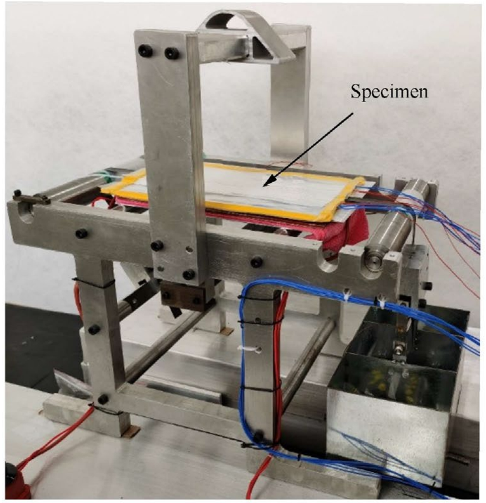
- Making the fiber yarns to become straighter and tighter

- Inducing residual stress "on demand"
  - Making the matrix more resistant to cracks initiation and propagation
  - Minimizing the generated residual stresses during fabrication processes

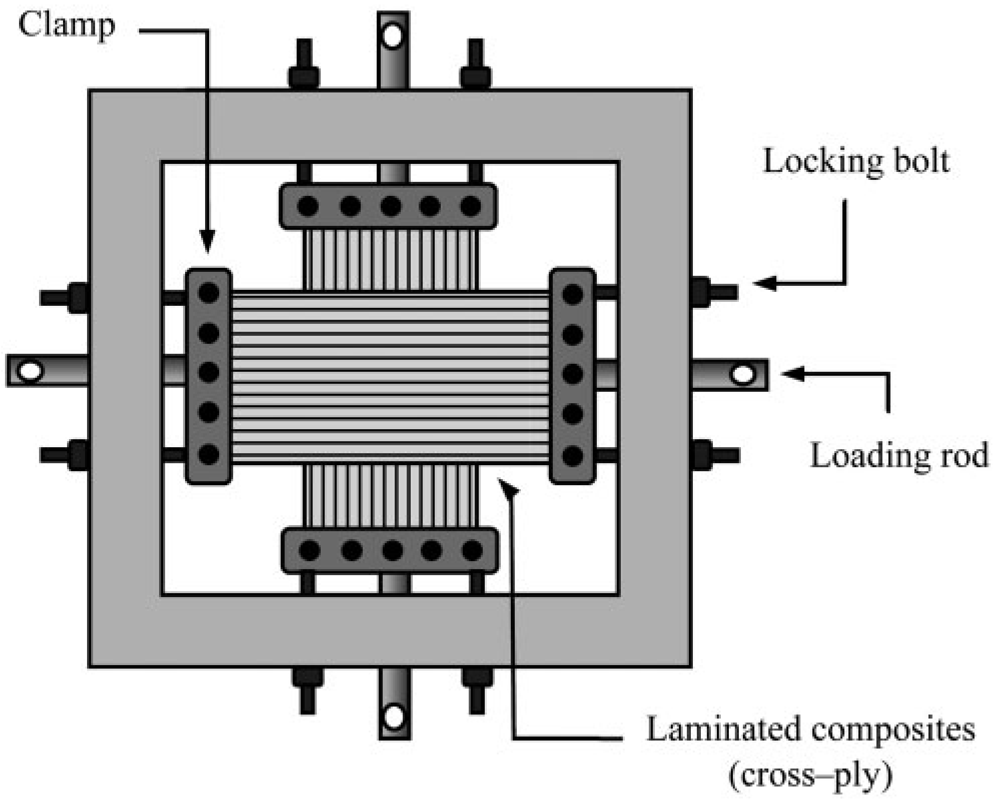
The Role of Prestressing in Fiber Reinforced Polymer Composites



(a) Prestress loading frame



(b) Experimental setups

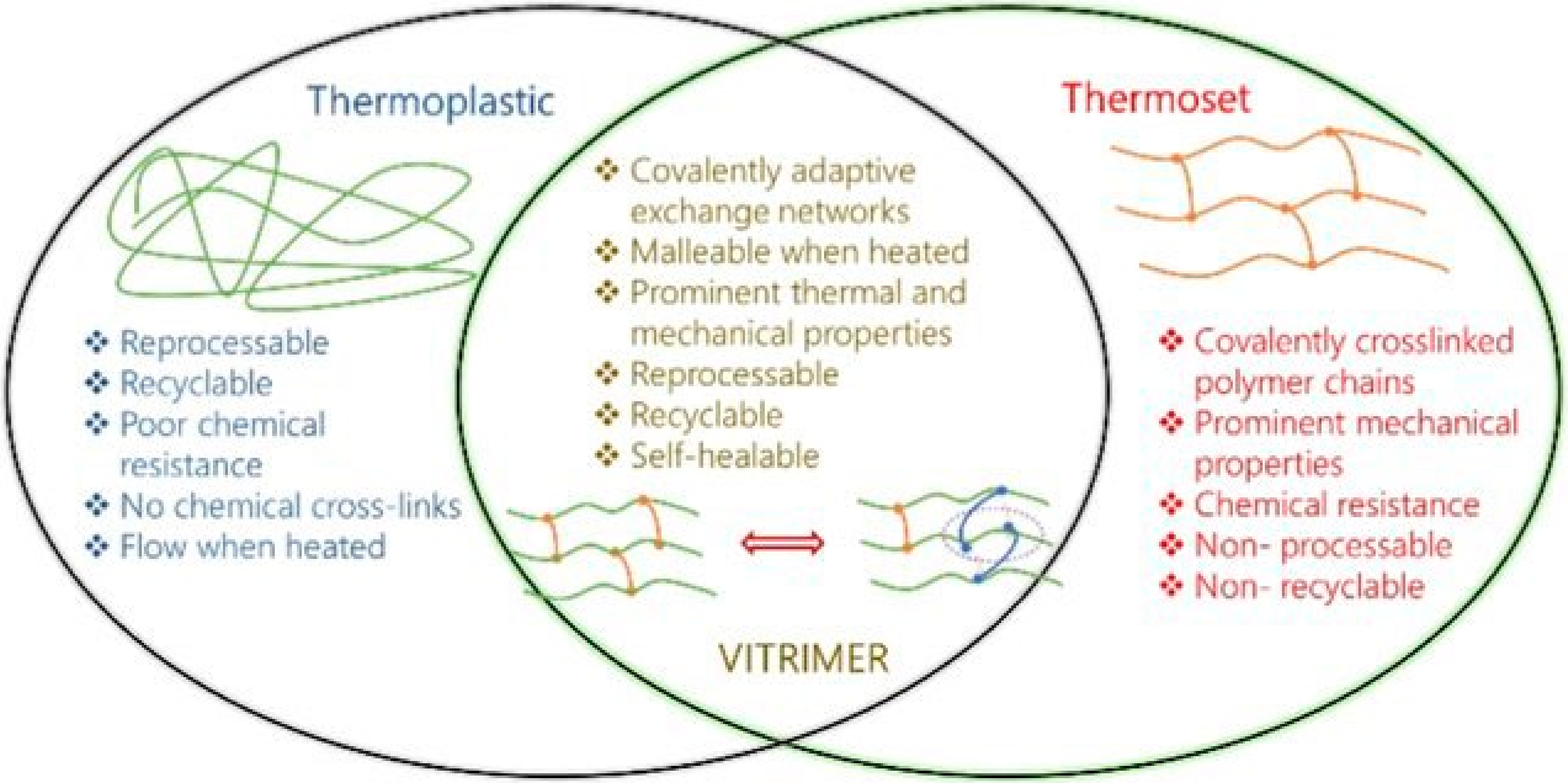


requires a method to apply tensile force to the reinforcement during matrix curing, which hinges on the feasibility of incorporating the appropriate mechanism or apparatus.

Zhendong, L. I. U., Zheng, X., Wenjing, F. A. N., Fei, W. A. N. G., Ahmed, S., & Leilei, Y. A. N. (2022). An alternative method to reduce process-induced deformation of CFRP by introducing prestresses. *Chinese Journal of Aeronautics*, *35*(8), 314-323.
Jevons MP. The effects of fibre pre-stressing on the impact performance of composite laminates. PhD Thesis, Engineering Systems Department, College of Defence Technology, Cranfield University, UK, 2004.

UdG

CAN’s: Covalent Adaptable Network



Sharma, H., Rana, S., Singh, P., Hayashi, M., Binder, W. H., Rossegger, E., ... & Schlögl, S. (2022). Self-healable fiber-reinforced vitrimer composites: overview and future prospects. *RSC advances*, *12*(50), 32569-32582.

Exploring vitrimers as novel matrix materials for structural composites

Spanish project (2022-25): ***In search of sustainable, bio-based, hybrid, long-fibre reinforced composites for structural applications*** - SUBHYCO

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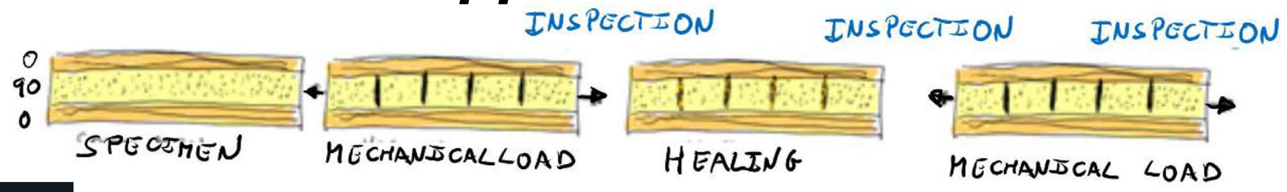


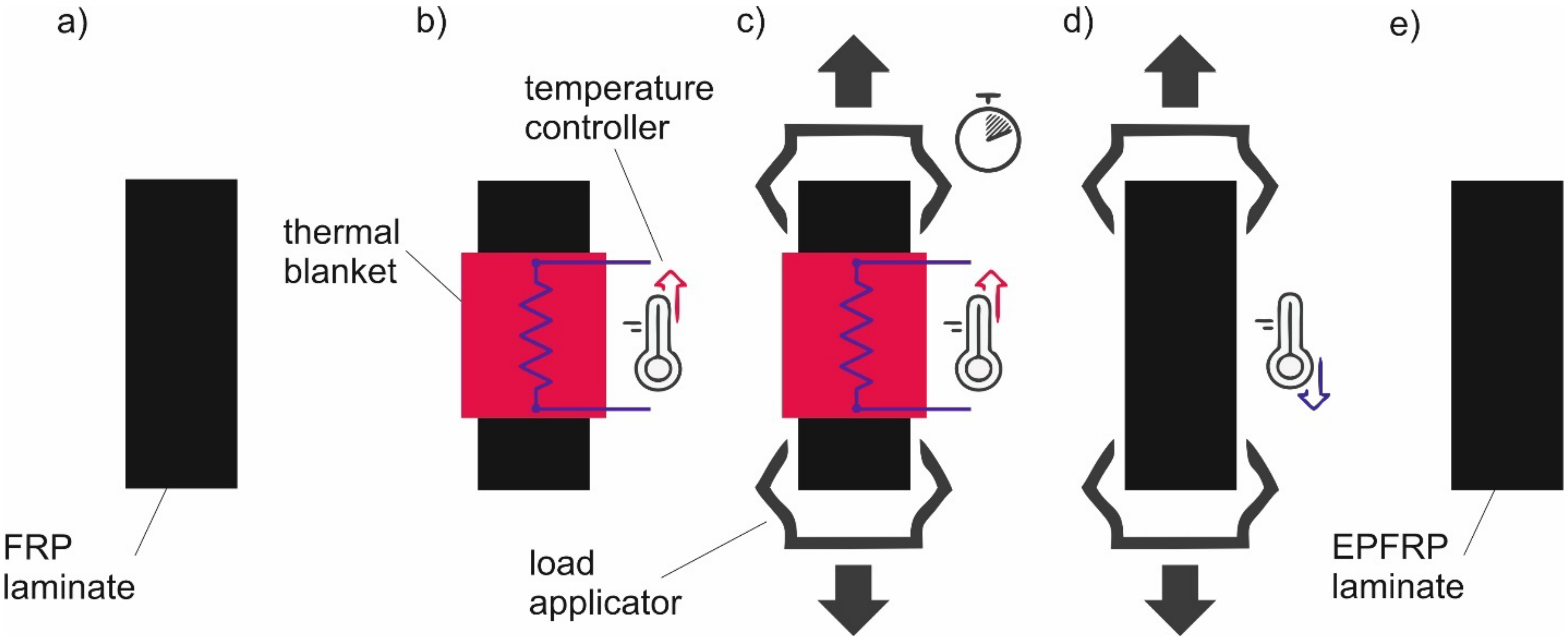
cidetec
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

3R
Reprocessing, Repairing, Recycling of cured laminates

vitrimers

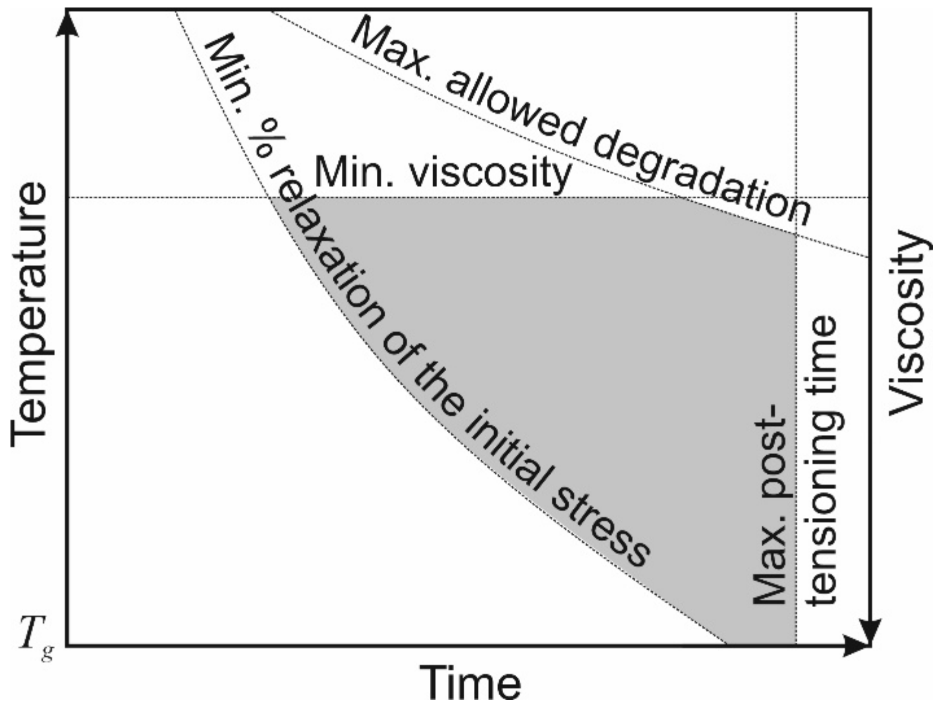
Spanish project (2024-27): ***VItrimeric matrices for mitigating PROcess-induced Stresses in Sustainable composite components*** - VIPROSS

Post-tensioning method to achieve prestressed FRPC



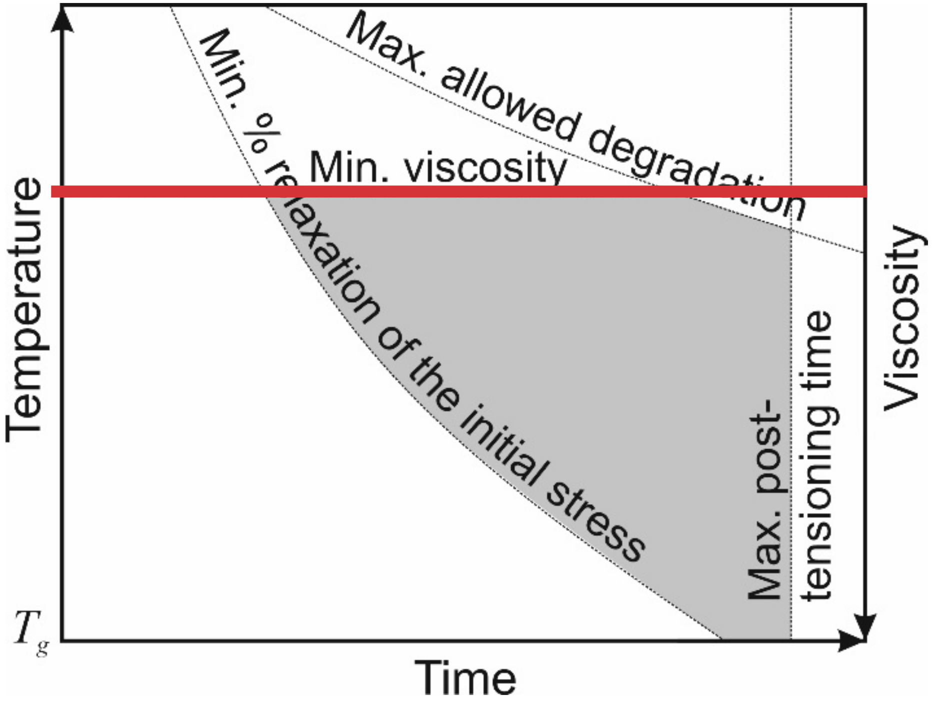
Five post-tensioning steps to produce an elastically prestressed FRP (EPFRP) laminate:
a) curing a FRP laminate under standard condition,
b) pre-heating to the post-tensioning treatment temperature,
c) applying tensile loading and facilitating stress relaxation in the matrix,
d) cooling down to room temperature,
e) releasing the load.

Selection of thermal conditions to ensure matrix stress relaxation



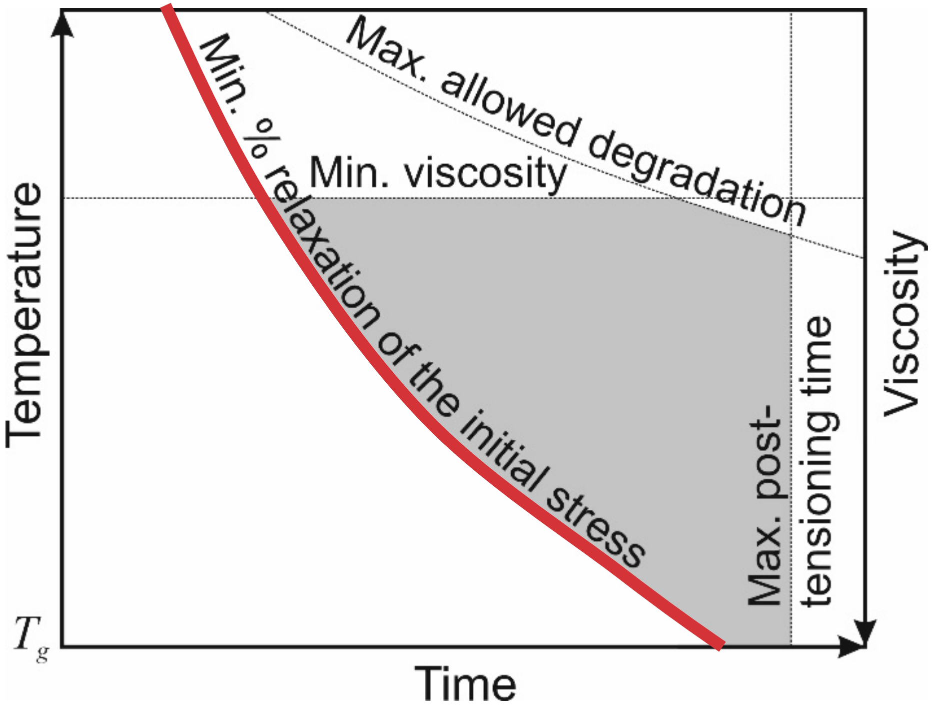
The shaded region denotes the working area delimited by the four process design constraints.

Selection of thermal conditions to ensure matrix stress relaxation



Ensure stress relaxation of the matrix

Selection of thermal conditions to ensure matrix stress relaxation



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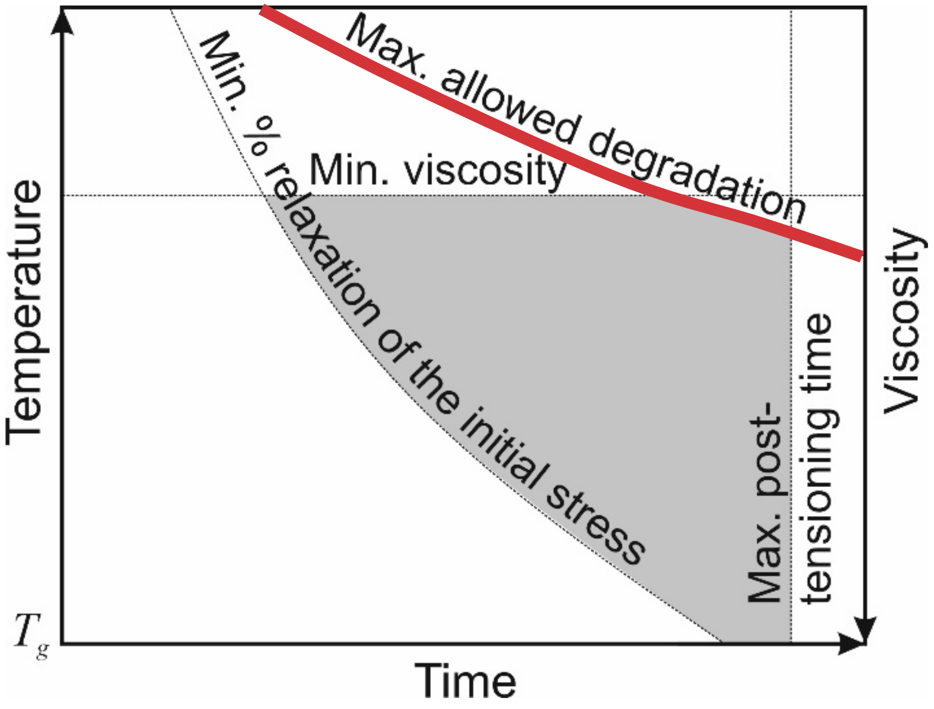
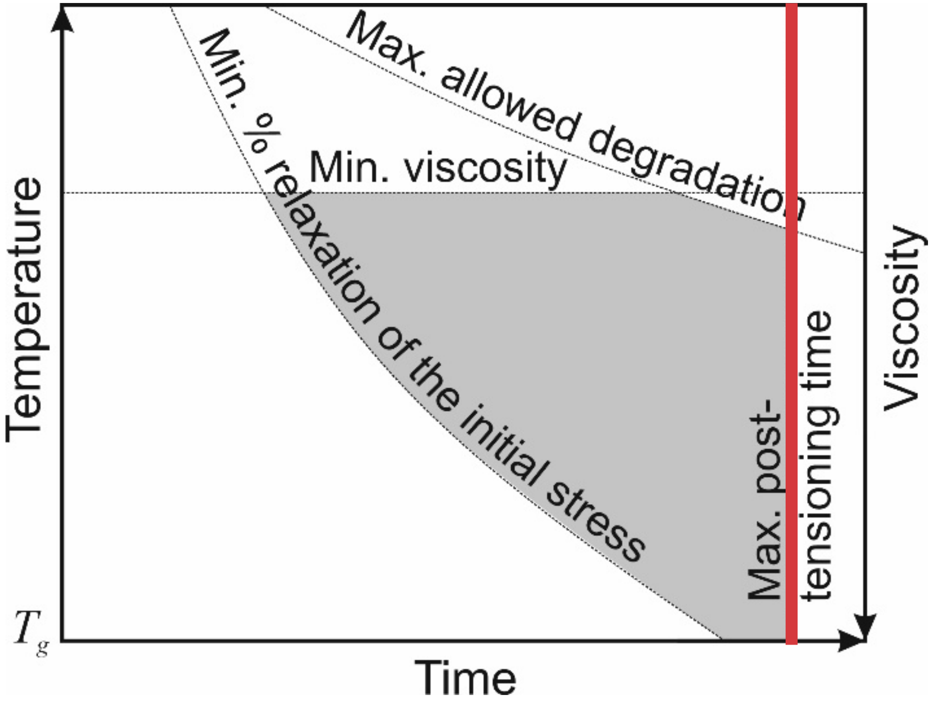
Selection of thermal conditions to ensure matrix stress relaxation



Thermal degradation can lead to detrimental changes in the properties of post-tensioned polymers. Therefore, the safe post-tensioning treatment requires avoiding degradation

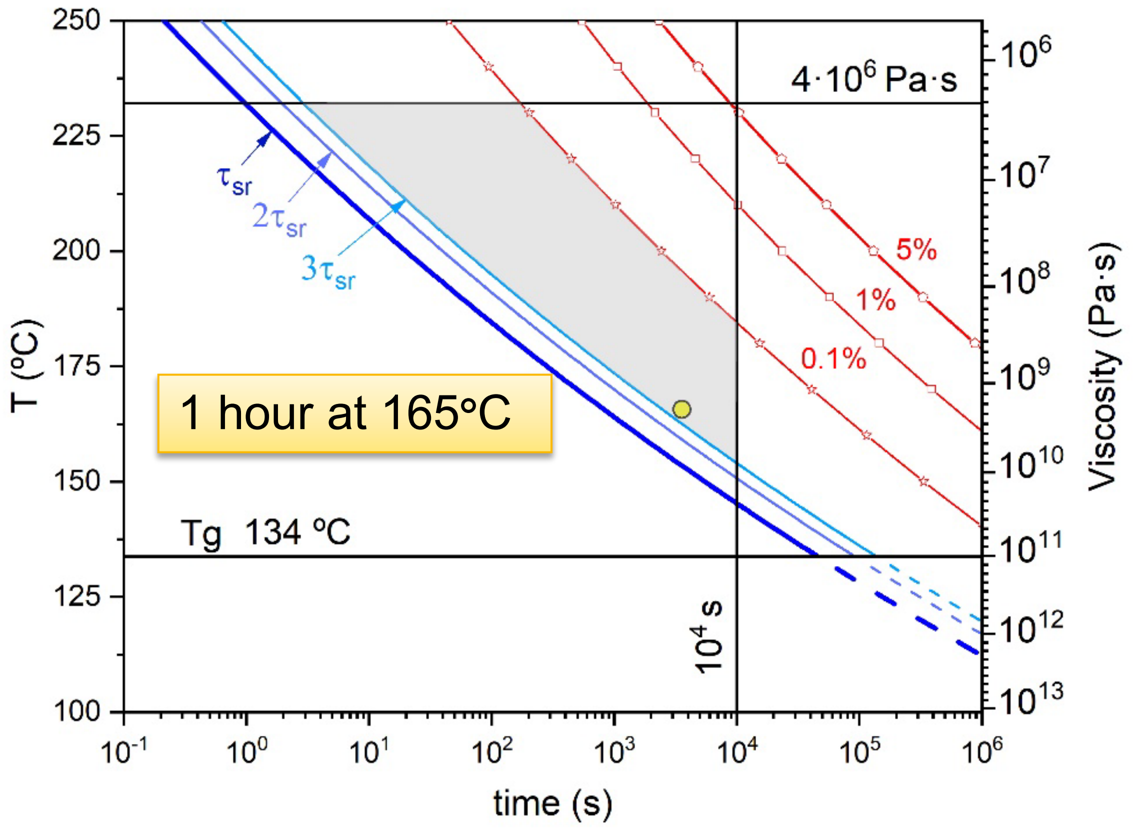
Selection of thermal conditions to ensure matrix stress relaxation



From an industrial perspective, the duration of the treatment should be restrained to a practical limit to assure that the benefits gained from the improved mechanical properties of the material overcome the cost of the conditioning process

Selection of thermal conditions to ensure matrix stress relaxation: validation tests

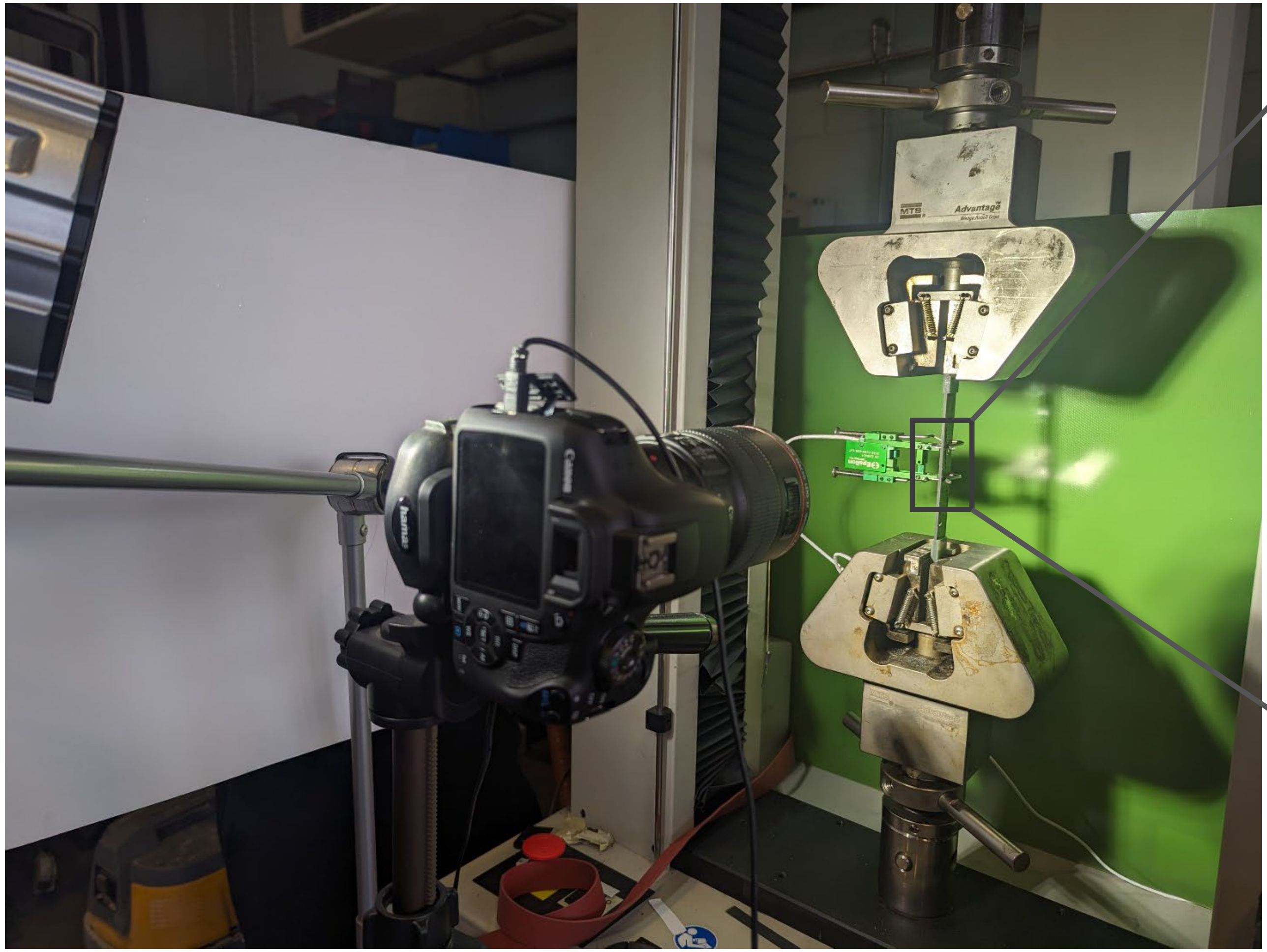
Specimen ID	Constant force applied during post-tensioning conditioning (kN)	Post-tensioning strain (%)
A-Notreat	Non- post-tensioning conditioned	-
B-Notreat	Non- post-tensioning conditioned	-
C-7.5	7.5	0.228
D-7.5	7.5	0.214
E-10	10	0.306
F-10	10	0.296

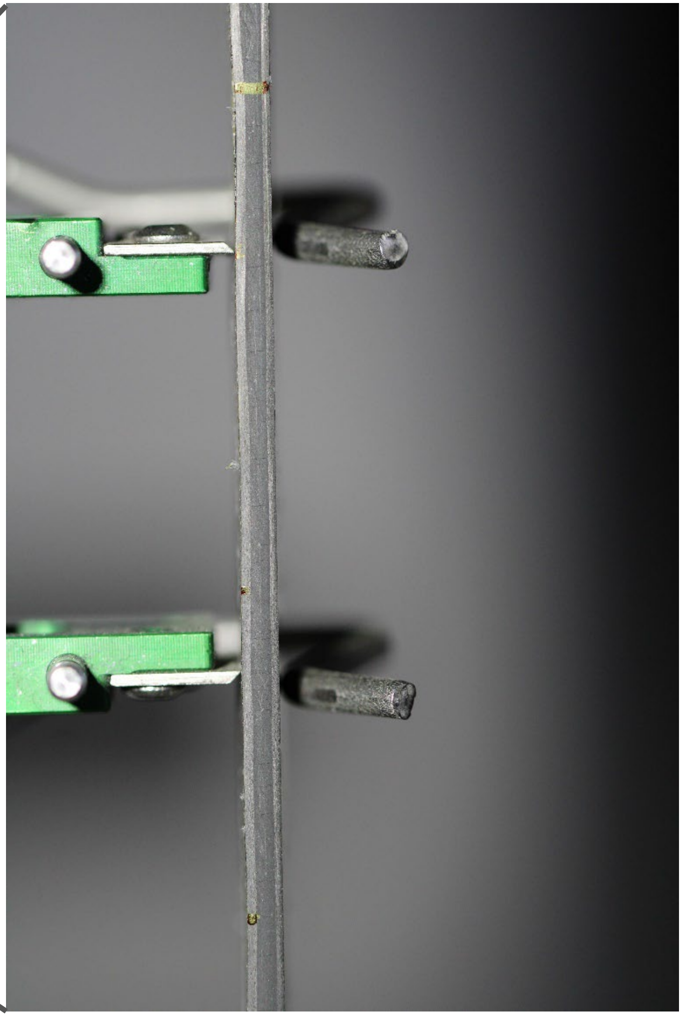


The shaded region denotes the working area of the validation tests material.

Tuned residual stress to avoid matrix cracking – Validation experiments

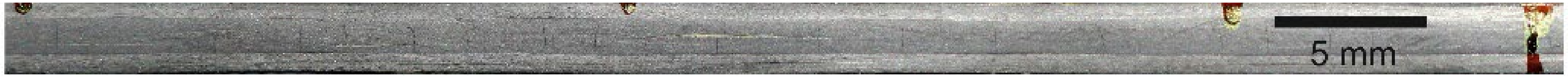
- Real time edge images during post-treatment testing





Tuned residual stress to avoid matrix cracking – Validation experiments

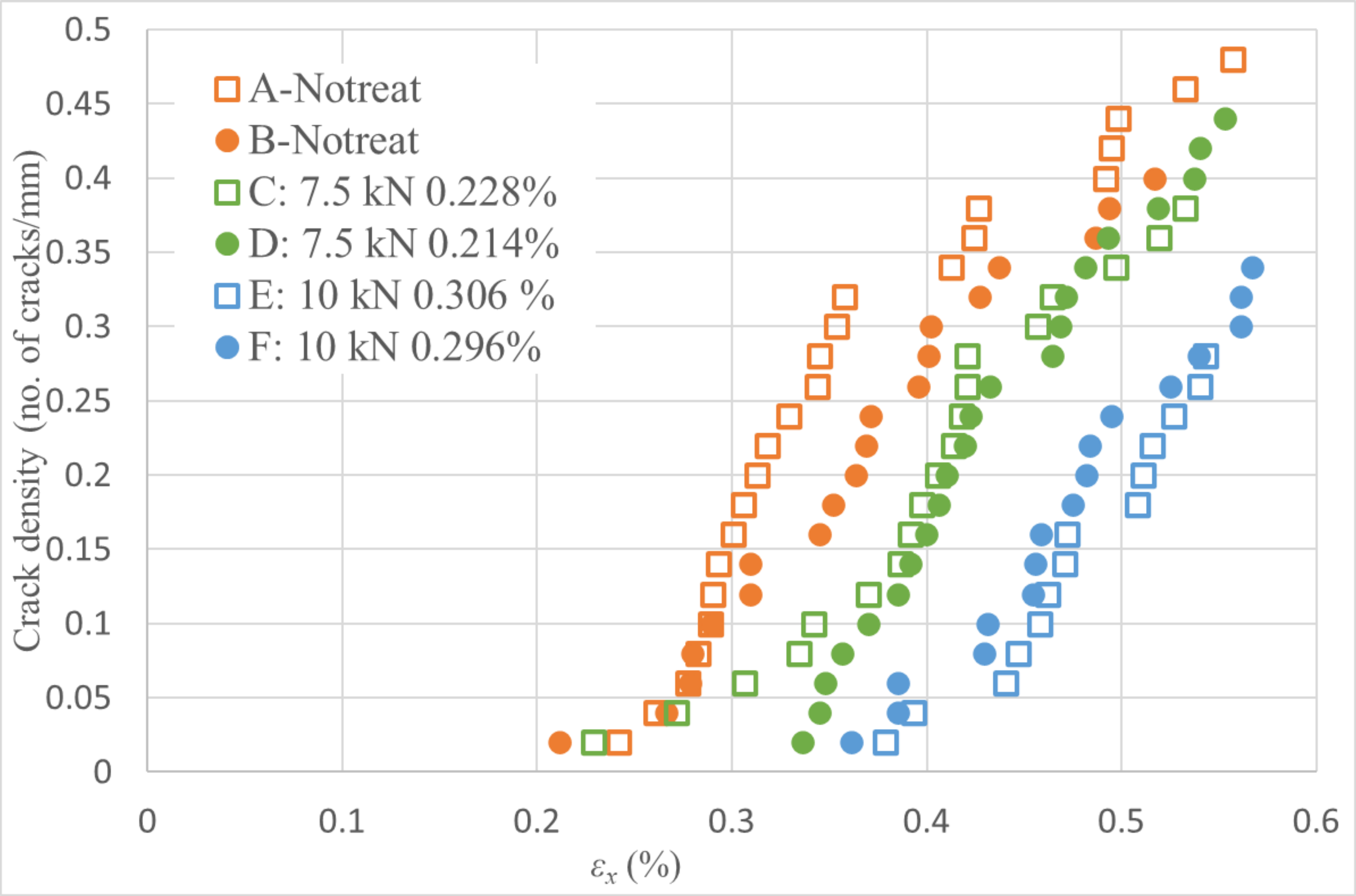
- Real time edge images during post-treatment testing



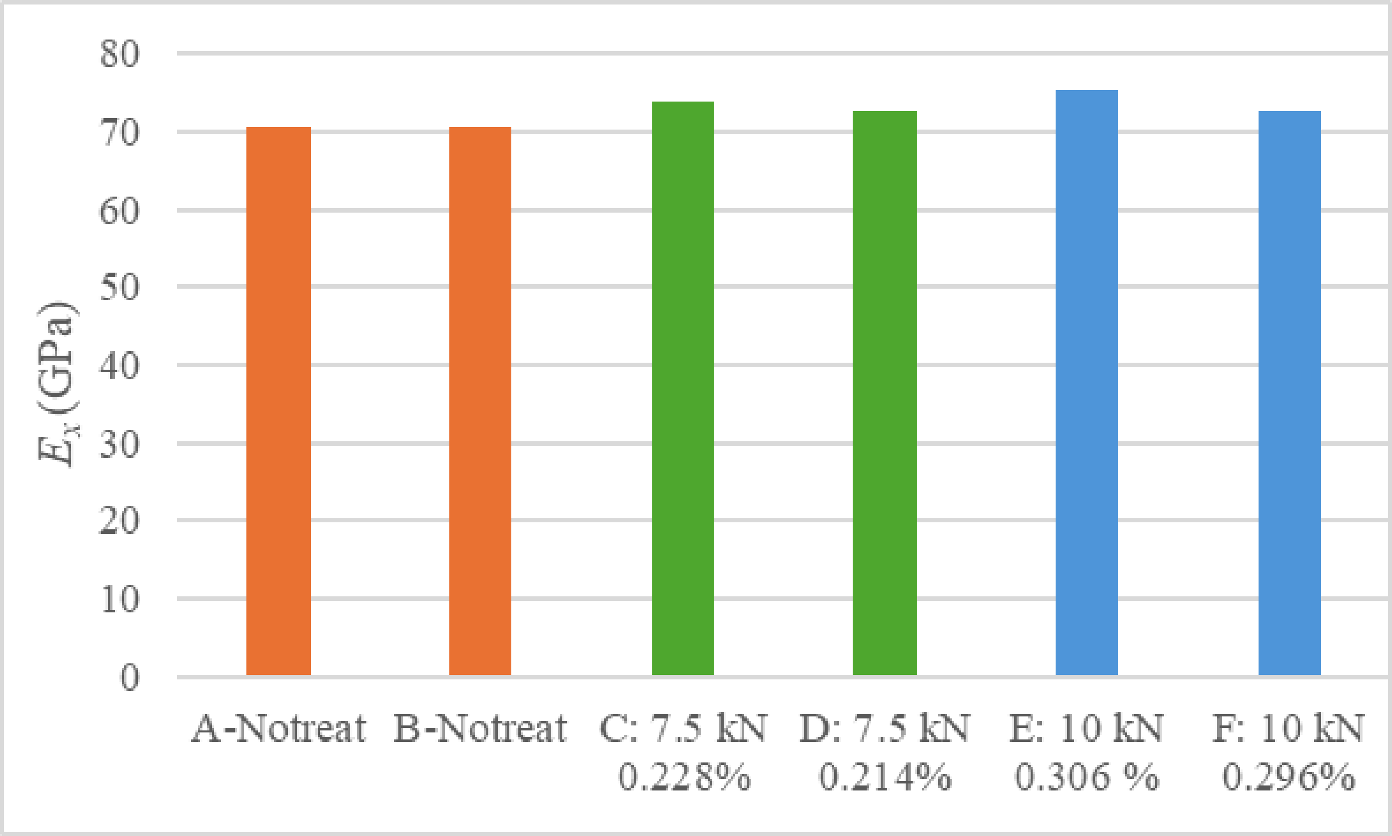
a) Image of the zone of the specimen edge acquired with each picture.

b) Image in full resolution.

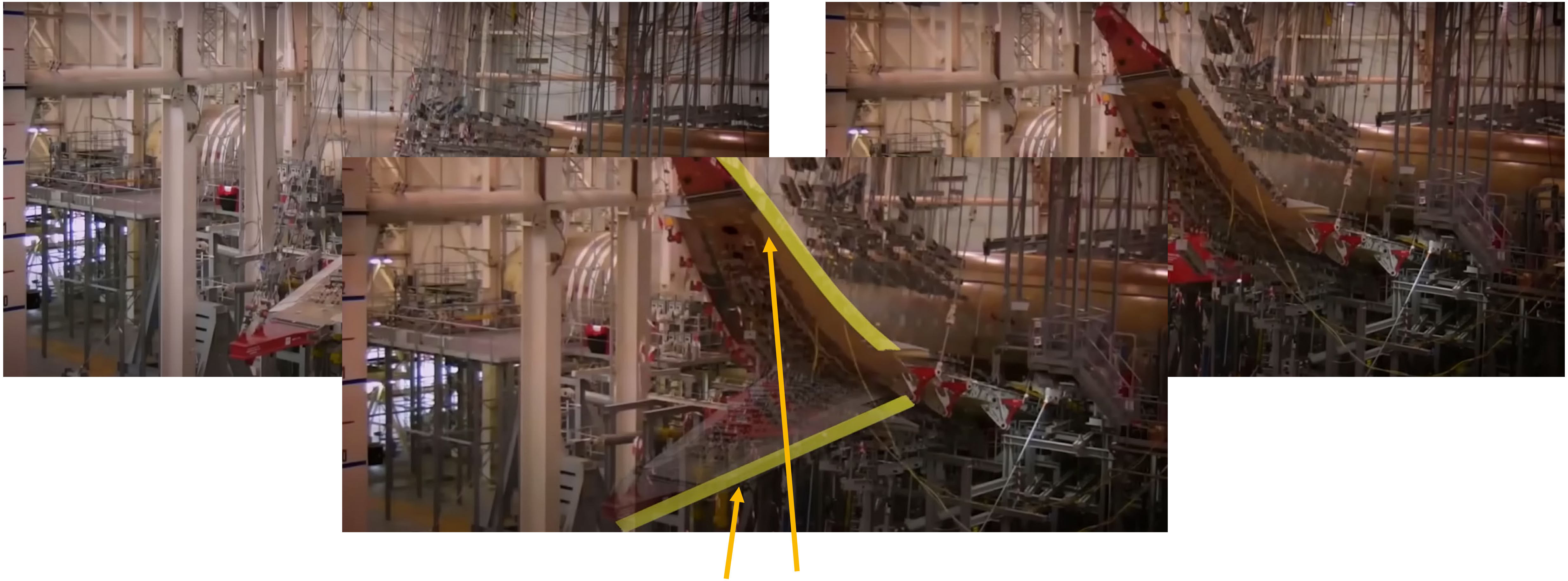
Tuned residual stress to avoid matrix cracking – Validation experiments



Tuned residual stress to avoid matrix cracking – Validation experiments



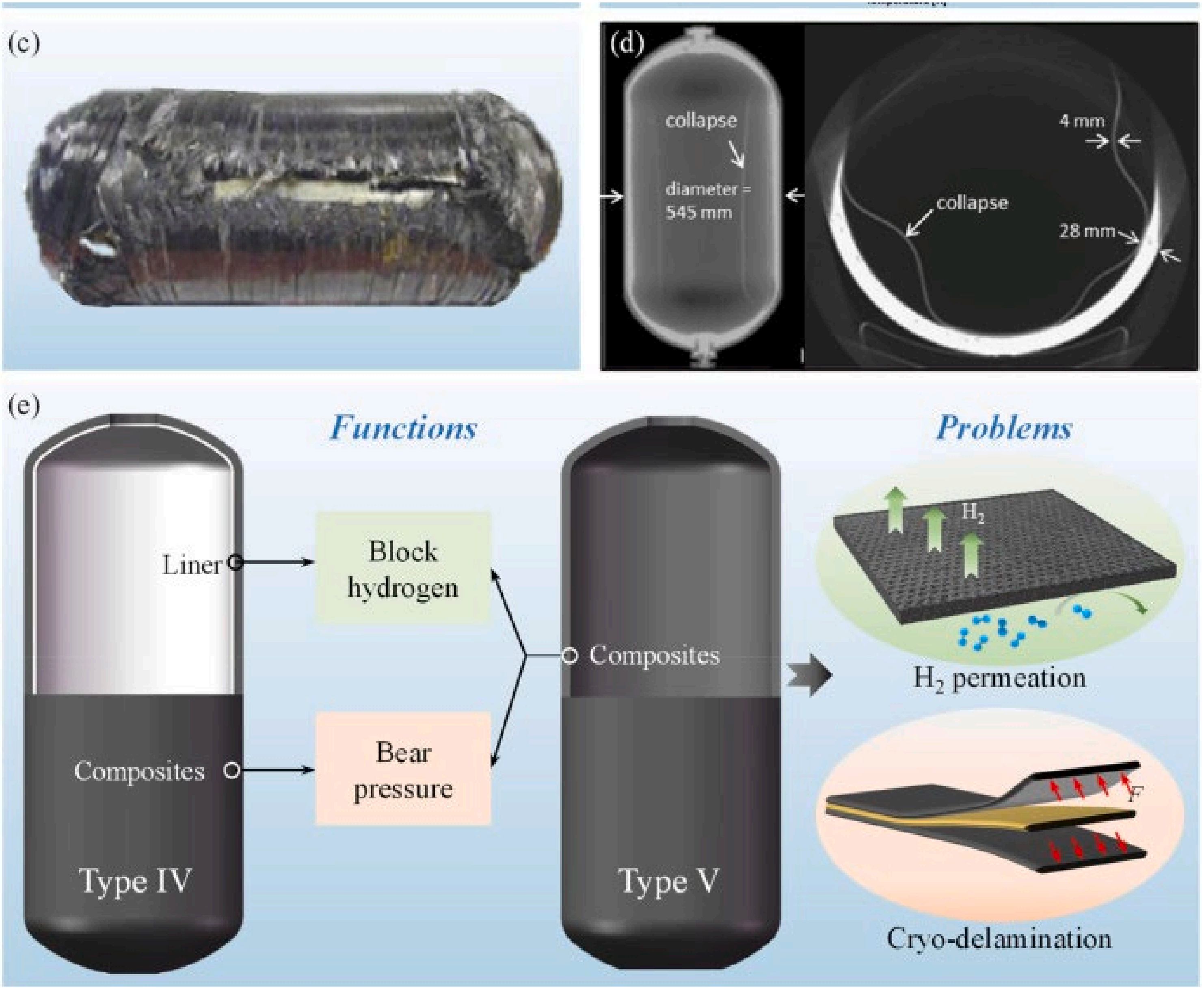
Discussion: Post-tensioning load application



Multiple stages local heating

Pushing the A350 XWB to the brink https://www.youtube.com/watch?v=B74_w3Ar9nI

Type V LH2 vessels



Conclusions

- Prestressing technique that relies on matrices that can relax stress, like vitrimers, which also improve **sustainability by allowing for recycling and repair**.
- **Post-tensioning method → separates the curing and post-tensioning processes**, facilitating laminate production under conventional processing conditions.
- The method has been applied to vitrimeric cross-ply laminate **demonstrating a delay in matrix cracking** with post-tensioning conditioning.
- Potential of prestressing technique to improve the durability composites, especially for applications where matrix cracking and environmental exposure are the main challenges.

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