Studying the high performance and sustainability of vitrimers and their composites intented to advanced engineering applications

MDA2024
5[TH] INTERNATIONAL CONFERENCE ON MATERIALS DESIGN AND APPLICATIONS
4-5 July 2024 - FEUP, Porto - Portugal

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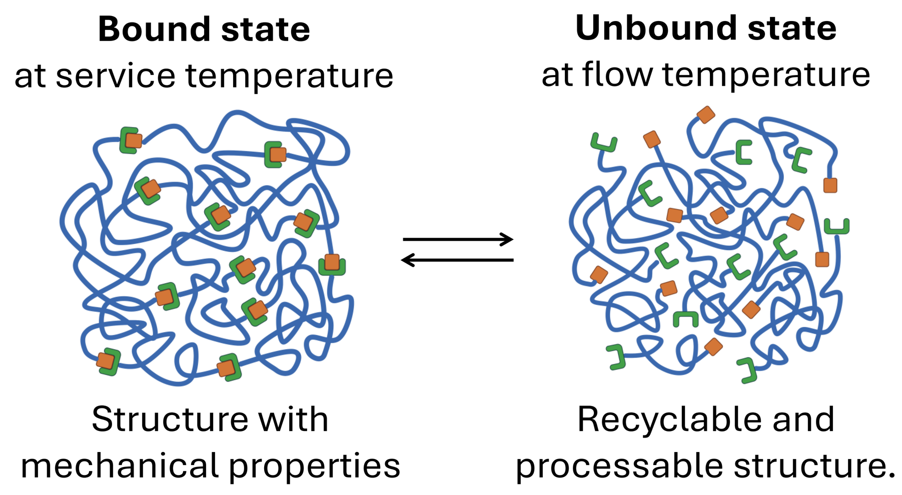
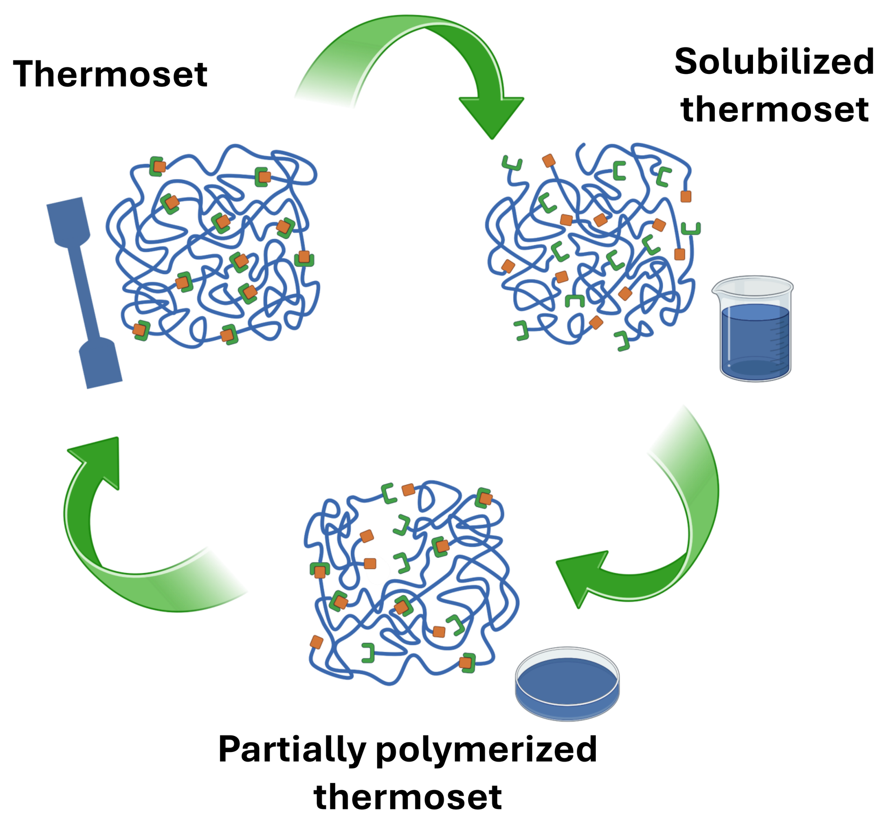
Current composite material production faces several environmental challenges, particularly in industries like aerospace where the use of non-recyclable traditional composites leads to significant waste. This project seeks to analyze the feasibility of recycling vitrimer composites and assess their mechanical properties to ensure suitability for high-performance applications such as aerospace. Vitrimers, with dynamic covalent bonds enable reshaping, repairing and recycling, addressing the limitations of conventional composites. Fiber reinforcement further enhances their mechanical properties and provides additional functionalities like corrosion resistance and fire resistance.

Introduction

Vitrimers are a class of polymers with dynamic covalent networks that allow bond exchange reactions. This unique property enables them to behave like thermosets at room temperature while becoming processable like thermoplastics at elevated temperatures. This dual nature makes them highly versatile for various applications. The integration of fibers such as carbon or glass into vitrimers enhances their mechanical properties making them suitable for a wide range of high-performance applications [1,2].



Recyclability and Reuse of Fibers



Recycling Strategies for vitrimers:

- **Chemical recycling:** It mantains the structural integrity and mechanical properties of the recycled material ansuring high-quality recovery. In addition, it can effectively remove contaminants, resulting in cleaner and more pure recycled material. However, the cost, energy reuiremets ad evironmental impact must be carefully managed to ensure sustainability [3].

- **Unpycling with 3D printing:** enhances the sustainability profile of vitrimers by reducing waste and propmoting cicrcular economi and allows the creation of costumized designs that are difficult to achieve with traditional methods. Nevertheless, ensuring that the mechanical properties of 3D printed parts meet industry can be challenging [3].

Recycling of vitrimer-based carbon fiber-reinforced polymers (CFRP):

Composites were fabricated using vitrimer systems based on polyimine, reinforced with non-woven felt and UD carbon fiber. The manufacturing process involved lamination of prepregs. A 20% diethylenetriamine (DETA) and 80% xylene mixture at 80ºC efficiently dissolved the vitrimer matrix, facilitating fiber recovery. Recovered fibers were analyzed using SEM (Figure 1) and DMA to evaluate the quality and mechanical properties of the reprocessed composites [4].

- **SEM analysis:** post-recycling SEM images showed minimal residue in UD carbon fibers, indicating high-quality fiber recovery. However, the non-woven felt exhibited more vitrimer residue.

- **DMA results:** The recycled non-woven CFRP shows a 42 % decrease in glass transition temperature (Tg) and increased storage modulus (E´), suggesting solvent and residual matrix interaction with the new matrix. In the other hand, recycled UD CFRP had an 8% increase in Tg and doubles storage modulus above Tg, indicating better resistance to deformation. However, interlaminar shear strength decreased by 27%, with more void observed, suggesting some degradation in fiber-matrix adhesion.

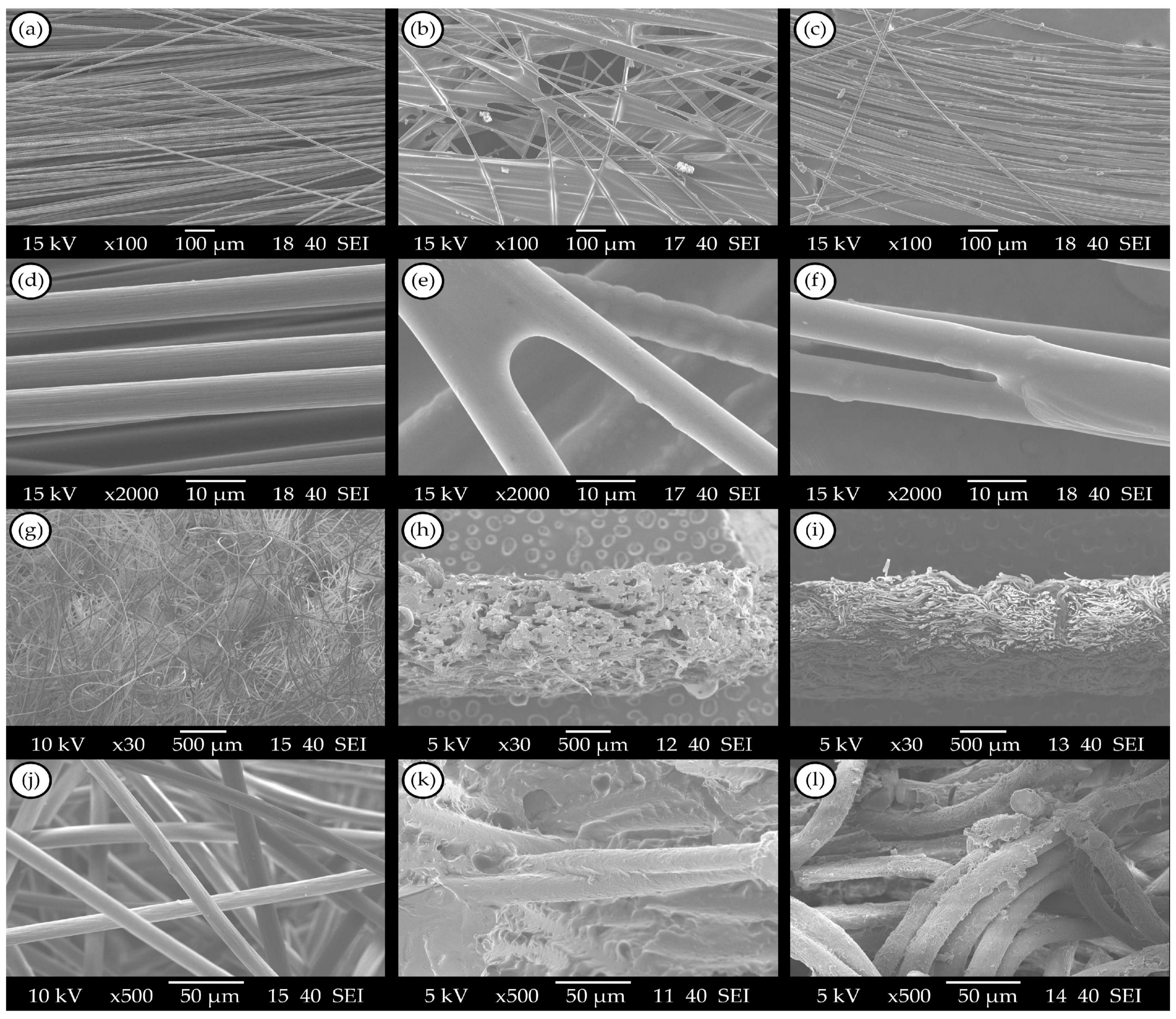


Figure 1. SEM images: (a,d) virgin UD carbon fibers; (b,e) recovered UD carbon fibers after one dissolving cycle; (c,f) recovered UD carbon fibers after two dissolving cycles; (g,j) virgin nonwoven felt; (h,k), recovered nonwoven felt after one dissolving cycle; (i,l) recovered nonwoven felt after two dissolving cycles [4].

Conclusions

- Vitrimers and their composites represent a significant advancement in material science, combining high performance with sustainability. Their ability to be reshaped, repaired and recycled makes them ideal for further engineering applications.
- By addressing the challenges associated with recycling and mechanical property optimization, vitrimers can play a crucial role in material science and promoting sustainability in industries such as aerospace.

ACKNOWLEDGEMENTS:

This work has been developed in the frame of the Projects PLEC2021-007750 (financed by MCIN/AEI/10.13039/501100011033 and by the European Union NextGenerationEU/ PRTR) and PID2022-143329OA-I00 (financed by MCIN/AEI).

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