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Investigation of impact fatigue resistance and residual strength of adhesive joints using hybrid wood configurations

Sh Jalali (INEGI, Portugal) | RJC Carbas | EAS Marques | LFM da Silva

Introduction

Adhesively bonded wood joints are widely used in structural applications, but their long-term durability under impact fatigue—repeated low-energy impacts—is not well understood. Unlike static or traditional fatigue loads, these impacts can cause hidden damage and gradual strength loss without visible failure. This study addresses this gap by exploring how hybrid joint configurations and adhesive toughening techniques influence the performance of wood joints under impact fatigue. A bio-based polyurethane adhesive was used with pine and oak substrates to evaluate how material combination and surface reinforcement affect strength retention, energy absorption, and damage tolerance under repeated impact loading.

Experimental details

1. Substrates Types

Two wood types—pine and oak—were used to evaluate a bio-based polyurethane adhesive. Defect-free, moisture-controlled specimens were assembled into single-lap joints (25 mm overlap) and cured at 100°C under 30 bar. A zero-thickness bondline was used, and toughness was enhanced through a two-step adhesive penetration method. Four configurations were tested: untreated pine and oak, and two hybrid joints with reinforced outer layers.

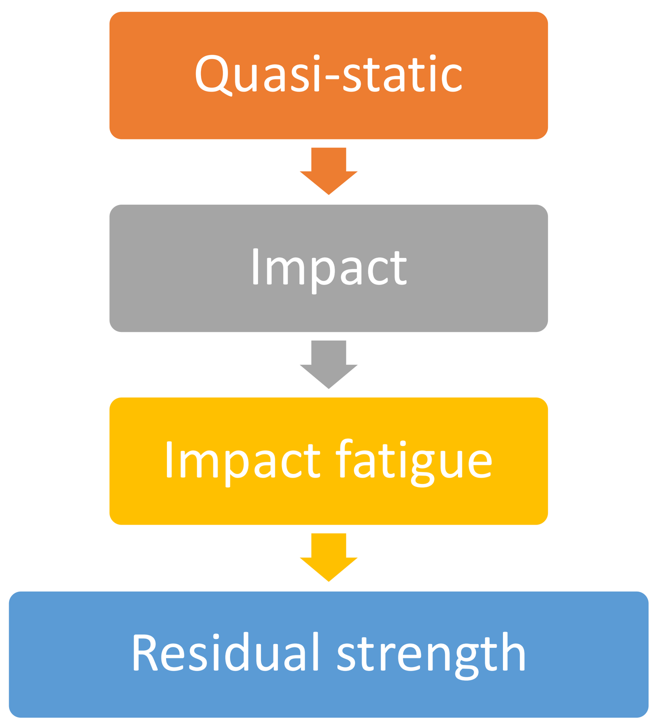

Figure 1 – Test Plan.

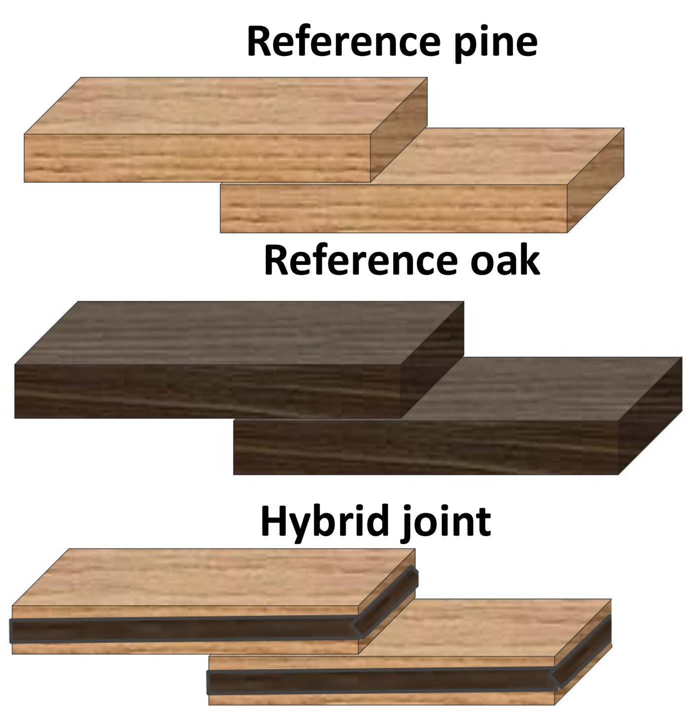

Figure 2 – SLJ configurations.

2. Substrates Toughening

Substrate toughening involves pre-treating wood surfaces to allow adhesive to deeply penetrate the fibers, creating a reinforced interphase. This improves the joint's resistance to cracking and delamination by enhancing stress transfer and energy dissipation at the bondline.

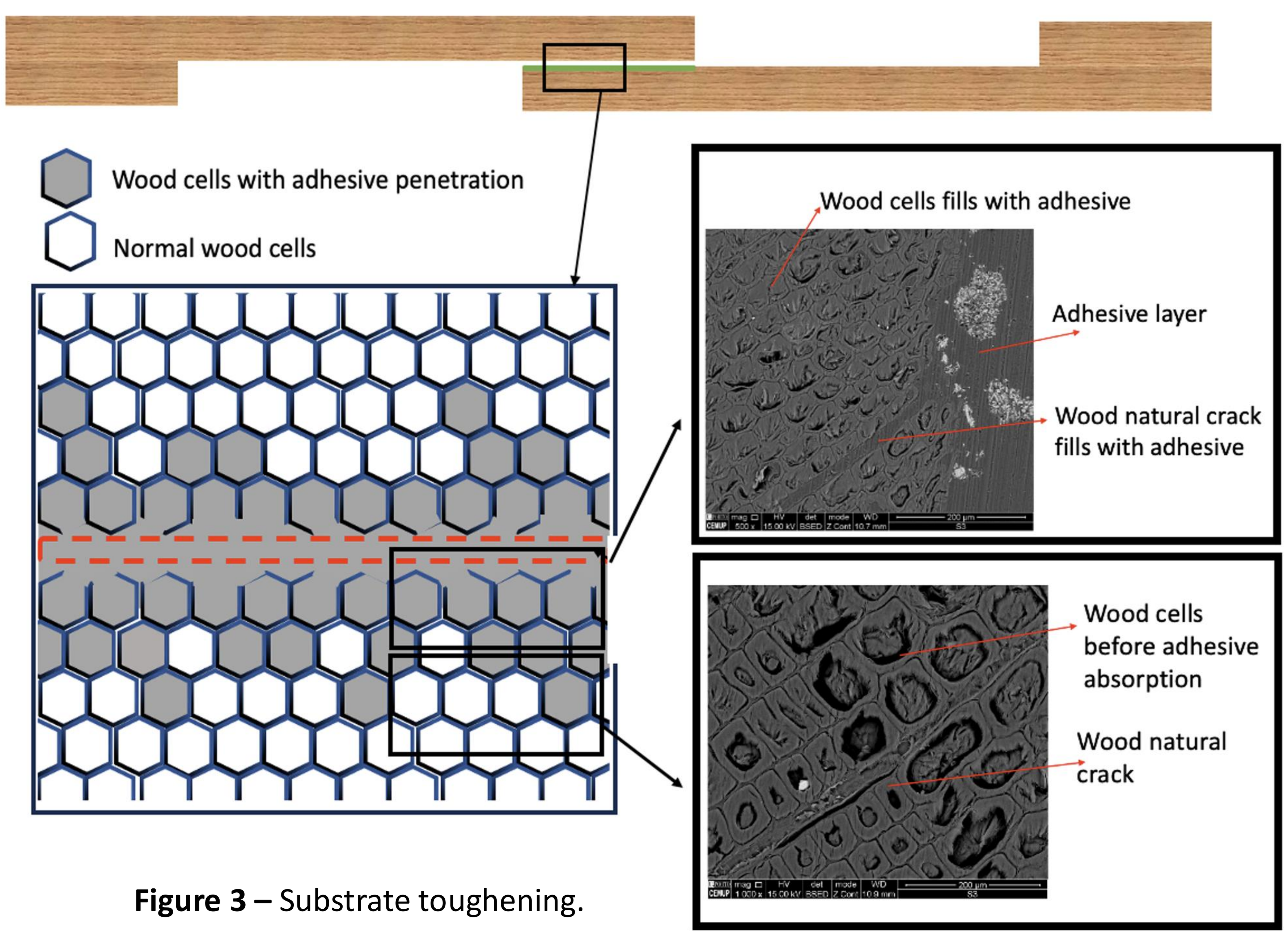

Figure 3 – Substrate toughening.

Results and discussion

Mechanical tests showed hybrid joints—especially those with oak layers—had the highest strength (6.3 kN) and best energy absorption under impact. They outperformed reference joints, with pine being the weakest. Improved performance is linked to stiff oak layers and stronger adhesive bonding, which enhance stress distribution and reduce cracking.

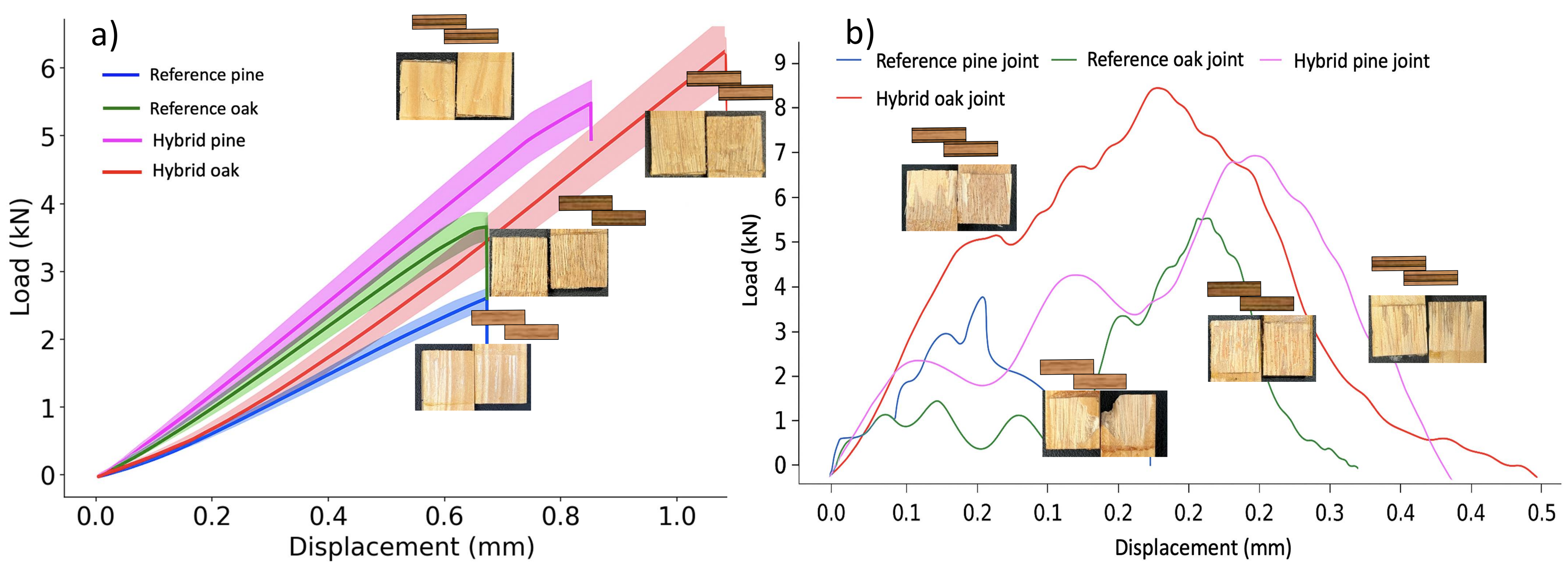

Figure 4 – Load–displacement behavior under (a) quasi-static and (b) impact loading.

Hybrid joints showed much longer fatigue life under cyclic impact, especially those with oak outer layers—lasting up to 3× longer than monolithic joints. This is due to improved stress distribution, deeper adhesive penetration, and the combination of stiff and flexible wood layers.

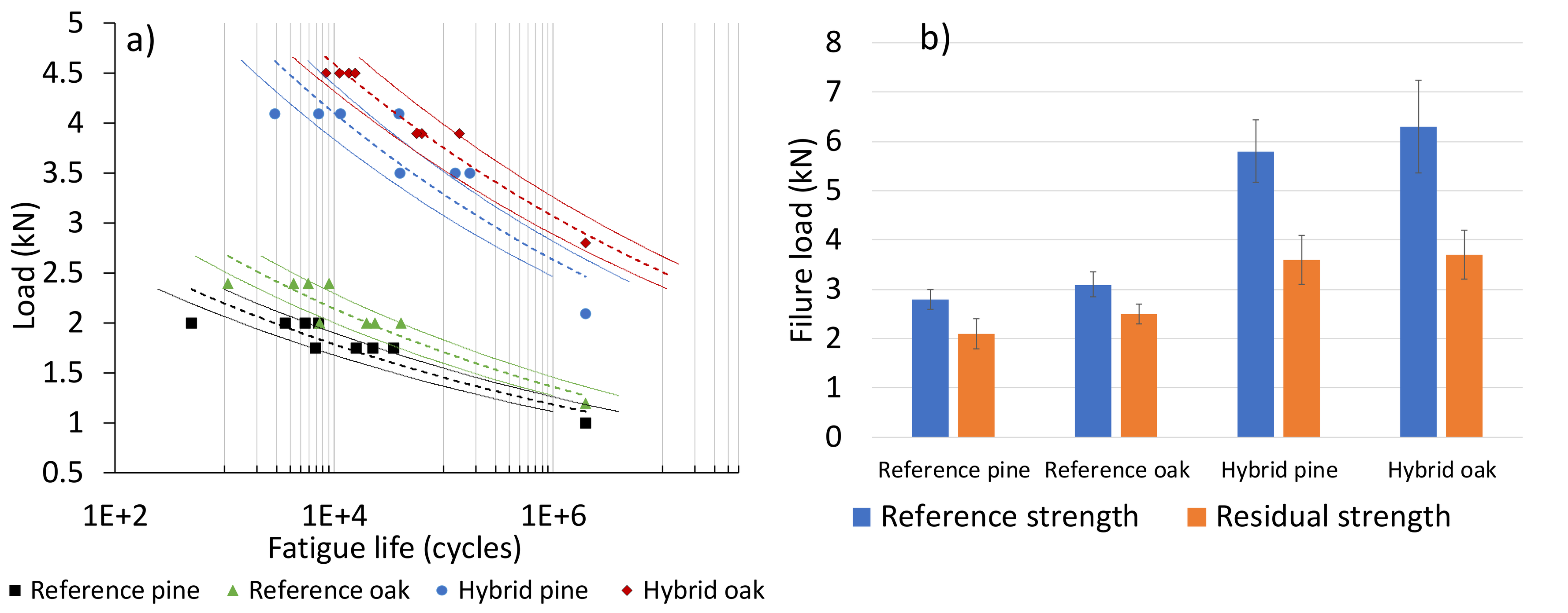

Figure 5 – (a) S-N curve of the SLJs subjected to impact fatigue; (b) Strength and residual strength of the joins.

CONCLUSION

Hybrid joints, particularly those with oak outer layers, showed the best overall performance under both impact and fatigue loading. They demonstrated higher strength, better energy absorption, and longer fatigue life compared to monolithic pine or oak joints. The results highlight the effectiveness of combining adhesive penetration with strategic material layering to improve durability in dynamic structural applications.

REFERENCES

[1] Jalali, Shahin, et al. "Improving Eco-Friendly Polymer Adhesive Joints: Innovative Toughening Strategies for Consistent Performance Under Various Loading Conditions." Polymers 17.5 (2025): 648.

[2] Jalali, Shahin, et al. "A novel technique for substrate toughening in wood single lap joints using a zero-thickness bio-adhesive." Materials 17.2 (2024): 448.

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