Experimental study on the coupling effect of knots and thermal radiation in timber

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Abstract. This study explores the coupling effect of knots and thermal radiation on the degradation of timber mechanical properties. Timber specimens were thermally radiated at temperatures up to 240 ºC. The specimens were then loaded to failure in four-point bending whilst monitored using digital image correlation. Timber with knots experienced a significant reduction in maximum flexural strength compared to the pristine ones heated to the same temperatures. Different failure modes were also observed on the lateral surfaces of all specimens. This highlighted the importance of considering both factors in structural applications where they may be subject to high temperatures, such as vehicle structures or structures at risk of fire.

Introduction

Timber is widely used in the construction industry as a structural material due to its excellent strength-to-weight ratio. There is also increased interest in using timber for vehicle structures due to aesthetic and sustainability concerns. However, timber is highly susceptible to heat, which can significantly impact its mechanical performance. Knots are one of the most common natural defects found in timber that reduce timber structural integrity. Many studies have identified the effect of knots in timber, aiming to understand their mechanical behaviour [1]. Previous studies have explored the effect of thermal radiation or timber knots on mechanical properties, but none have explored them together. This gap is significant as the presence of knots in thermally radiated timber could further reduce structural strength. This study explores the coupling of knots and thermal radiation on timber mechanical properties using four-point bending tests. Five different temperatures, ranging from 20 ºC to 240 ºC were explored to provide a comprehensive temperature profiles up to the timber ignition temperature.

Experimental Methodology

Fifty specimens with dimensions of 25 mm x 25 mm x 350 mm were involved in this study, including twenty-nine knotted specimens and the remaining being pristine timber. Each knotted specimen contained a single knot located at the centre of the specimen to ensure comparability. However, knot areas varied as they were dependent on the branch diameter before they were sawn. The wood grain on the other hand were kept nominally horizontal for all specimens to ensure consistency. Specimens were then weighed and heated in an oven at a rate of 2 ºC per minute to the desired temperature and maintained at temperature for 3 hours. Heated specimens were allowed to cool naturally in the oven to room temperature and weighed again to identify their weight loss after temperature exposure. Finally, the specimens were loaded to failure whilst being monitored using a stereoscopic digital image correlation system to track damage propagation on the bottom tensile surface of the specimens, example data is shown in Fig 1.

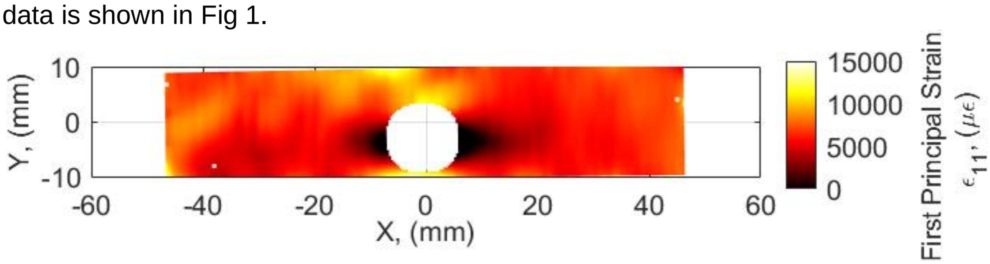

Fig 1: *An example of a first principal strain field for a knotted timber specimen just prior to failure.*

Results and Discussion

Post test imaging of the lateral surfaces of the specimens revealed three different failure modes. Delamination was the only failure mode found in all pristine specimens, regardless of the temperature they were exposed to. For knotted specimens, failure modes on the timber specimens were dependent on the knot areas. Specimens with knots smaller than 40 mm^2 had the same failure mode as the pristine specimens, indicating similar behaviour. The second type of failure mode found was the combination of cracks along the knot direction and delaminations. This scenario occurred in specimens with knot areas between 40 mm^2 and 150 mm^2. For the third type of failure mode, cracks propagated along the full thickness of the specimens in the knot direction. This was found in timber with knot areas larger than 150 mm^2 where the knot had significantly influenced the material.

Fig 2 left shows a negative correlation between knot area and maximum flexural stress for specimens that were not exposed to any heat. The occurrence of knots caused discontinuities in the timber, resulting in stress concentrations as they were loaded, leading to a significant degradation in material strength. This trend was similar to that reported in previous studies. However, when both knots and elevated temperatures occurred, timber exhibited a non-linear behaviour in its mechanical properties, see Fig 2 right. The degradation of flexural strength in 240 ºC knotted specimens were particularly significant, likely due to cellulose decomposition [2]. This resulted in the timber being around 87% weaker than at 20ºC, suggesting cellulose is the main component to provide timber flexural strength.

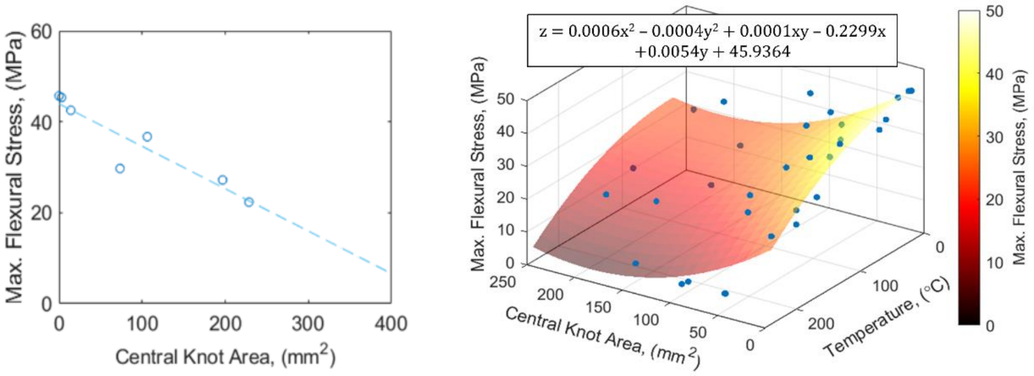

Fig 2: *Maximum flexural stress of knotted specimens not exposed to heat with line-of-best-fit (dashed-line) (left) and a scatter plot of maximum flexural stress as a function of knot area and temperature with a fitted quadratic surface (right).*

Conclusion

This study has explored the coupled effect of knots and thermal degradation on timber by quantifying flexural properties and failure behaviour through four-point bending tests. As maximum flexural stress decreased non-linearly for knotted timber after being exposed to elevated temperatures. These findings are vital for fire safety design, providing insights into material performance under realistic conditions.

References

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2. *Schaffer, E.L., Effect of Pyrolytic Temperatures on the Longitudinal Strength of Dry Douglas-Fir. Journal of Testing and Evaluation, 1973.* ***1****(4): p. 319-329.*