Chapter 2
Fracture Toughness of Tropical and Temperate Species for Mobility Applications

Riccardo Houngbegnon, Rostand Moutou Pitti, Bruno Castanié, Valery Doko, and José Xavier

Abstract Environmental protection is one of the most pressing issues of our time, and addressing this challenge increasingly requires the use of environmentally friendly materials. This explains the growing body of work being done on wood, an ancient material that is biodegradable, renewable, readily available, recyclable, and has low embodied energy. Among the recent innovative developments in the use of wood, the first space exposure experiment was conducted in 2022. Over a period of 10 months, samples of cherry (*Prunus avium*), birch (*Betula pendula*), and magnolia (*Magnolia obovata*) were exposed to space conditions—vacuum testing, solar radiation, ultraviolet rays. Following this experiment, magnolia wood was selected for the design of the first wooden satellite, launched in 2024. However, the results obtained for cherry and birch revealed significant potential that deserved further investigation. In this context, we decided to resume the study of these two temperate species, adding *Khaya ivorensis* as a secondary tropical species. The main objective of this work is to analyze their cracking behavior, firstly at room temperature, using an approach combining experimental tests and fracture mechanics tools. The specific feature of the study lies in the use of Mixed Mode Crack Growth (MMCG) test specimens, which allow different crack modes to be tested, combined with Localized Spectrum Analysis (LSA), facilitating the interpretation of crack trajectories and the determination of deformations in anisotropic materials. The results obtained provide a better characterization of the differences between temperate and tropical species, particularly in terms of propagation stability and sensitivity to fiber orientation. Such analysis contributes to a deeper fundamental understanding of cracking in wood and helps to clarify the conditions for using these species in demanding environments related to mobility.

Keywords Wood · Mobility · Fracture · MMCG · LSA

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Introduction

Structures used for mobility are constantly subjected to mechanical and climatic stresses, whether they are land vehicles, aircraft, or satellites. Given their sensitive nature and operating conditions, these structures must be able to withstand all these stresses to ensure their durability and the safety of users. Recently, the potential for using wood has been boosted by the *Lignosat* project [1, 2] which led to the design and launch of the first satellite made of magnolia wood. The renewable nature and availability of wood, coupled with the success of this ambitious project, have revived interest in the use of wood in mobility applications. This study focuses on two temperate and one tropical species tested under the same conditions, with potential for use in mobility applications. They were selected based on previous work conducted inside the ISS with cherry and birch exposure and for the promotion of khaya as a secondary African tropical species [3]. In this context, the cracking characteristics of the two temperate species were compared with those of the tropical species using LSA, a localized spectrum analysis method based on the Fourier transformation.

Materials and methods

Three hardwood species with distinct anatomical characteristics were selected: cherry (*Prunus avium*), birch (*Betula pendula*), and khaya (*Khaya ivorensis*). Cherry is characterized by a light pink to reddish-brown heartwood, a fine and uniform texture, and a diffuse-porous structure with relatively small vessels evenly distributed across the growth ring. The cherry wood used for this study has a density of 0.58 g/cm^3 at 12% moisture content. Birch, with an average density of 0.75 g/cm^3 at 12% moisture content, presents a pale cream to light yellow coloration and a diffuse-porous anatomy with fine, homogeneously distributed vessels and generally straight grain. In contrast, khaya, denser at about 0.82 g/cm^3, exhibits a reddish to golden-brown heartwood, a slightly coarser texture, and a diffuse-porous structure with larger vessels and more visible parenchyma patterns. These differences in color, grain regularity, vessel size, cellular architecture and density are expected to influence crack initiation and propagation mechanisms.

To carry out cracking tests, we opted for modified Mixed Mode Crack Growth (MMCG) specimens, which promote stable crack propagation and a gradual decrease in energy release rate over a controlled propagation range [4, 5]. The MMCG specimens tested were obtained by laser cutting khaya, cherry and birch planks, which had previously been saw-cut. Laser cutting did not affect the structural integrity of the specimens but enabled us, on the contrary, to respect all their shapes and dimensions as shown in Fig. 1 with the example of a cherry wood specimen.

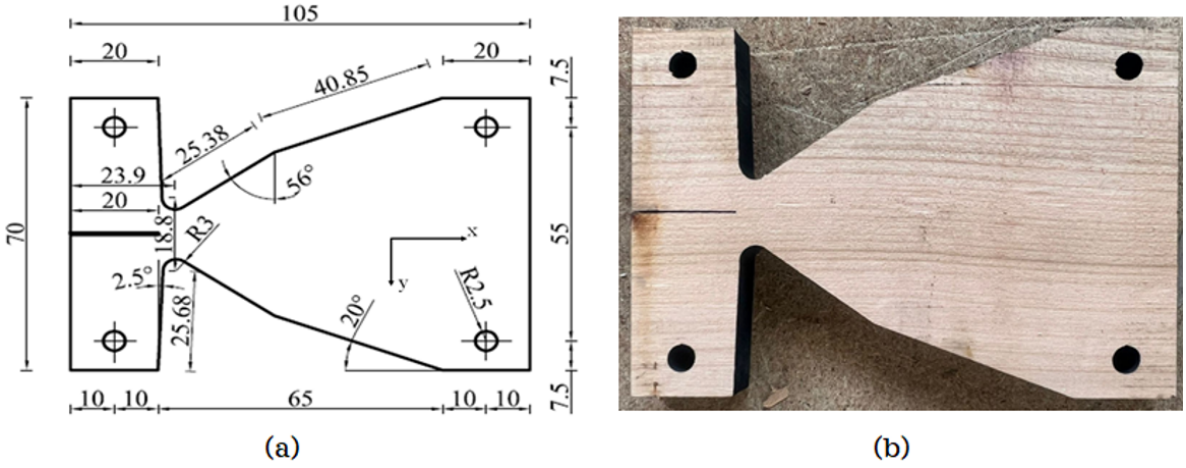

Fig. 1 (a) Shape and dimensions of MMCG specimen; (b) Cherry specimen.

Localized Spectrum Analysis (LSA) was used to measure the displacement fields during the tests. LSA is a full-field measurement technique that extracts displacement and strain fields from periodic patterns such as checkerboards or 2D grids. It is based on the minimization of the optical residual in the Fourier domain [6]. Referring to the results obtained by [7], displacements along the x and y directions, designated by u_x and u_y, respectively, are proportional to the phase change

between the current (or distorted) image and the reference image. Thus, we have:

$$\underline{u}\,(\underline{m}) = -\frac{p}{2\pi}\left(\underline{\Phi}^{cur}\,(\underline{m}+\underline{u}\,(\underline{m})) - \underline{\Phi}^{ref}\,(\underline{m})\right) \# (1)$$

Where $\underline{m}$ is the pixel of interest and $\underline{u}$ is the displacement vector of the components u_x and u_y in the base (x, y). $\underline{\Phi}^{cur}$ and $\underline{\Phi}^{ref}$ denote the current and reference phases, respectively. To engrave the pattern on the test specimens, two coats of white paint were first applied to their surface (Fig. 2). The checkerboard was then obtained using a laser engraver.

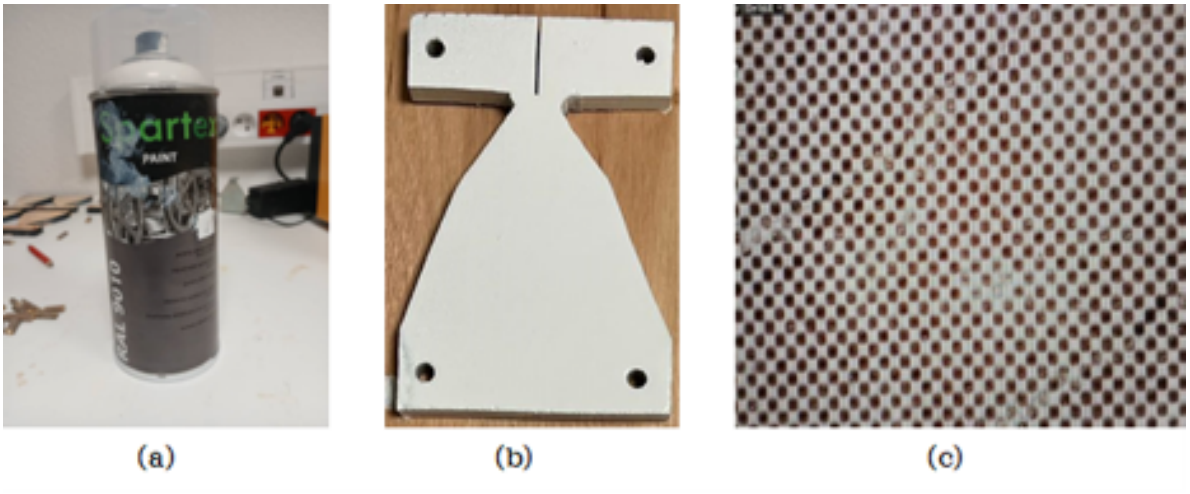

Fig. 2 Paint; (b) Specimen surface after painting; (c) Checkerboard.

Cracking tests were carried out in crack opening mode and in mixed mode using a Zwick/Roel machine, with a capacity of 200 kN. The specimens were placed in an Arcan system [8], a device enabling the specimens to be tested in both loading modes. A light was used to improve the lighting of the specimen surface, and a camera was used to take photos of the checkerboard during the tests. The experimental setup is shown in Fig 3. Specimen humidity was 12%.

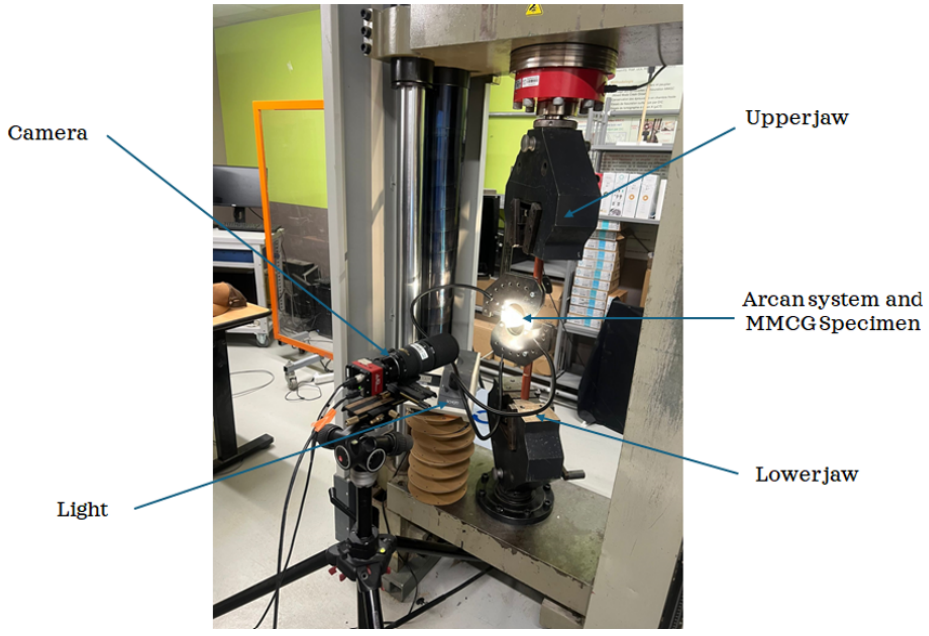

Fig. 3 Experimental set-up for cracking tests in opening mode.

Results and analysis

The crack tests carried out enabled us to plot the force-displacement curves for the samples we tested. Some of these curves, which we got in crack opening mode for khaya and cherry, are shown in Fig 4. The analysis of these curves reveals distinct crack propagation behaviors between the two species. Khaya exhibits a higher average peak load at fracture initiation (485 N) and therefore greater resistance to crack onset. This corresponds to its higher density, but it exhibits steeper load drops, indicating less stable crack growth. In contrast, cherry exhibits lower maximum loads (245 N on average), but a more regular force-displacement curve, suggesting improved damage tolerance and more stable crack propagation. In the context of use for mobility applications, these initial results clearly demonstrate the high crack resistance of *Khaya ivorensis*, facilitated by its highly interlocked anatomical structure.

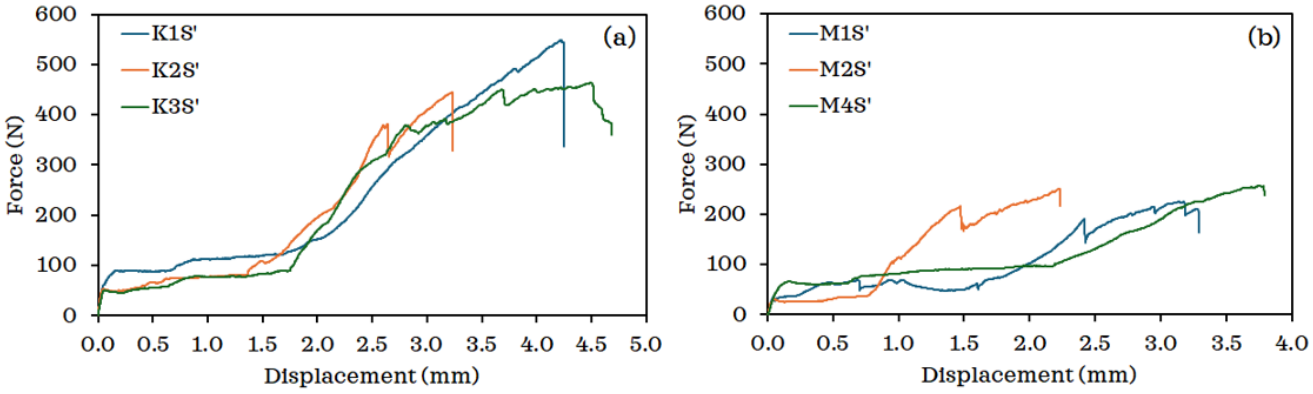

Fig. 4 Force-displacement curves of some specimens of (a) khaya; (b) cherry.

Conclusion and Future Work

This paper proposes a comparative study between the cracking characteristics of *Khaya ivorensis*, *Prunus avium* and *Betula pendula*. These species were selected with the aim of not only observing the behavior of temperate and tropical woods tested under the same conditions but also analyzing the influence of intrinsic properties (density, anatomical structure) on their fracture mechanisms with a view to their use in mobility applications. Initial results show greater resistance to crack initiation and propagation for *Khaya ivorensis*, attributed to its interlocked grain and higher density, though with less stable propagation compared to *Prunus avium*. The next step will be to carry out a detailed analysis of energy release rates, followed by the evaluation of cracking characteristics of three species under variations in temperature and humidity, to simulate real-world conditions for the use of mobility structures as accurately as possible.

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