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Advancing Timber for the Future Built Environment

CHARACTERIZATION OF THE FIRE PERFORMANCE OF TROPICAL TIMBERS FOR STRUCTURAL USE IN COLOMBIA

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ABSTRACT: Wood is an extremely versatile material, widely used in the construction industry and, in some cases, for structural applications. However, it exhibits varying degrees of combustibility and flammability depending on its physical and chemical properties. The fire response of wood is not uniform across species and is influenced by factors such as anatomical structure, density, hardness, and moisture content. This study evaluates the fire behavior of five tropical wood species commonly used in construction in Colombia. Laboratory tests were conducted to assess ignition time, weight loss, and mechanical inertia for rectangular wood sections exposed to fire. The results show that low-density woods tended to ignite more quickly, and experienced greater mass loss compared to higher-density species. Similarly, high-density woods demonstrated superior mechanical inertia performance due to lower weight loss during combustion. This analysis seeks to correlate wood structure and composition with fire behavior in order to identify species that provide enhanced safety and performance for construction applications.

KEYWORDS: *Tropical wood, fire behavior, ignition time, mechanical inertia, wood density*

1 – INTRODUCTION

Wood has been widely used by humans throughout history as a structural material in construction due to its strength, durability, and light weight. Many wooden structures from past centuries now form part of the cultural heritage of various countries and are recognized as world heritage sites [1]. Today, the growing demand for construction materials such as wood is contributing to increased environmental pressure. However, advances in technology now allow for the design and construction of complex structures using wood. In addition to its versatility, wood possesses valuable mechanical and thermal properties [2].

In Colombia, the use of wood in construction remains limited, despite the country's significant forest resources. It is estimated that only 0.03013 m³ of wood is used per square meter in construction activities [3].Given that wood is a combustible material, it is essential to obtain technical information about its fire resistance. Such data is critical for engineering calculations, construction safety, and product design. Although wood is flammable, it is possible to develop effective construction solutions that enhance fire safety.

In this context, the technological potential of tropical wood species and their derived products is increasingly recognized within the wood industry. However, in Colombia, construction with wood is still underdeveloped, and research on the fire behavior and safety of tropical wood species remains insufficient. More experimental studies are needed to support the safe and efficient use of these materials in construction.

This study aims to provide an approach to understanding the fire behavior of tropical woods and their potential structural implications.

2 – BACKGROUND

The fire behavior of wood has been studied for decades due to its combustible nature. This behavior is influenced by factors such as density, moisture content, grain orientation, anatomical structure, and the presence of extractives [4]. Under extreme heat, wood undergoes pyrolysis, releasing gases that fuel the flame. Understanding these processes is crucial for ensuring safety in wood-based buildings.

Various studies have developed methods to evaluate fire resistance using international standards like ISO 834 and ASTM E84 [5]. While temperate regions have advanced in fire-retardant treatments, tropical areas—especially countries like Colombia—lack sufficient research on the fire behavior of native woods.

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In Colombia, despite abundant tropical timber species, wood use in construction is limited, often confined to temporary structures or isolated projects.

A study by the Ministry of Environment and ONF Andina (2016) found that wood consumption in housing is 0.03013 m³ per square meter, with over 60% used for interior finishes and minimal use in structural elements. The study also highlights the low participation of wood in construction costs, particularly in social housing, and notes the national market's limited supply of quality wood products, discouraging their use in permanent buildings.

In rural or low-income areas, untreated local species pose significant fire risks. For example, in Tumaco (Nariño), wooden houses are highly vulnerable due to a lack of technical knowledge about combustibility, leading to human and material losses [6]. This underscores the need for scientific data on the thermal behavior of tropical species to enhance construction safety.

Therefore, further research linking the physical and anatomical properties of tropical species with their fire performance is essential. This will support the responsible and safe use of wood in construction, particularly in regions like Colombia, where forestry potential is high but technical data is still lacking.

3 – PROJECT DESCRIPTION

This project aims to evaluate the fire behavior of five tropical wood species. By analyzing their mass loss and ignition characteristics under fire exposure, the study seeks to understand how factors such as wood density and anatomical structure influence combustibility.

Drawing on experimental testing and existing scientific literature, the objective is to identify species with favorable fire resistance profiles that may be safely used in construction. The results are intended to contribute to the technical knowledge needed for safer and more sustainable use of tropical woods in Colombia.

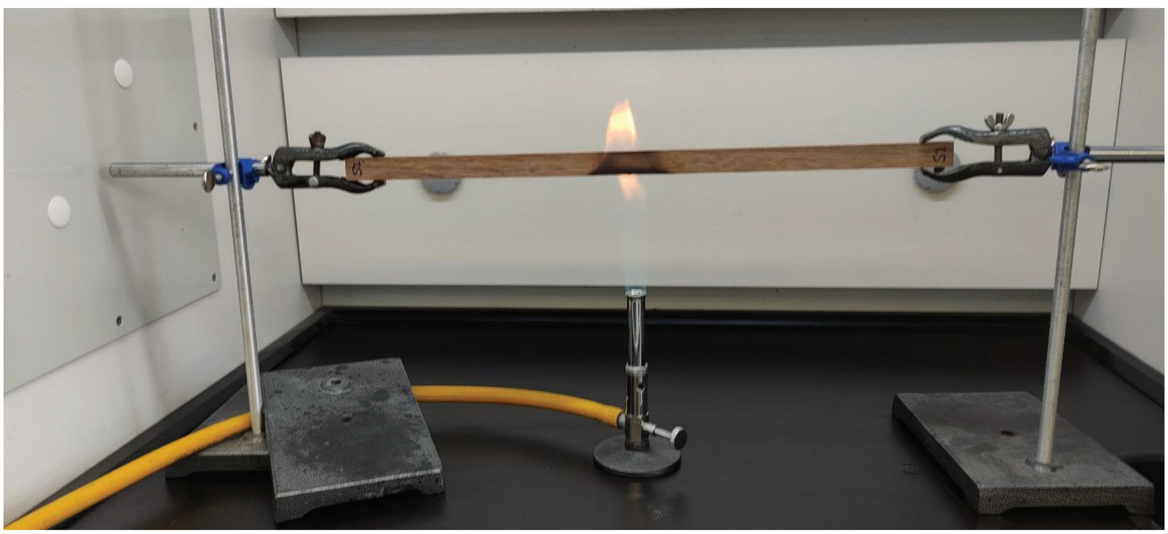

Figure 1. *Flammability Test Setup According to Sotomayor Castellanos and Carrillo Gómez (2017).*

4 – MATERIALS

Five species of tropical hardwood were used in this study. Each wooden specimen was cut into standardized rectangular strips to ensure consistent testing conditions.

The experimental setup is shown in Figure 1. It consisted of two metal support stands with clamps to hold the wood sample in a horizontal position. A Bunsen burner was placed directly beneath the midpoint of the specimen to apply a direct flame during the test. Metal clamps were used to firmly secure the wood specimens at both ends, ensuring stability and preventing displacement during combustion.

A digital balance was used to measure the initial and final weight of each specimen, allowing the evaluation of mass loss due to combustion.

Tests were conducted in the Chemistry Laboratory at the District University Francisco José de Caldas, Bosa Porvenir campus, under appropriate safety conditions with adequate ventilation and protective equipment.

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In addition, a static bending test was performed to assess the mechanical strength of the wood specimens under load.

Table 1. Surface Area and Density of Five Wood Species

Scientific name	Surface	Density g/ cm³
Clathrotropis brunnea Amshoff		0,96
Tabebuia rosea (Bertol.) DC.		0,57
Simarouba amara Aubl.		0,44
Cedrela sp. P. Browne		0,61
Jacaranda copaia (Aubl.) D. Don		0,47

5 – METHODS

5.1. Flammability test

A total of 35 wood specimens were prepared, with seven samples for each of the following species: *Cedrela* sp., *Clathrotropis brunnea*, *Tabebuia rosea*, *Simarouba amara*, and *Jacaranda copaia*. The specimens had a cross-sectional area of 20 mm × 20 mm and a length of 500 mm.

For the fire tests, the methodology described by Sotomayor Castellanos and Carrillo Gómez (2017) was followed [7]. The test involved the use of a central gas burner that directed the flame toward the transverse face of the wood specimen. Two supports were used to hold the specimen in place.

The procedure consisted of the following steps:

1. Measurement of the weight and dimensions of each specimen prior to fire exposure.

2. Placement of the specimen on the supports, with the flame directed vertically at the center of the piece.

3. Each specimen was exposed to the flame for 2 minutes.

4. Using a stopwatch, the time required for ignition on at least three faces of the specimen was recorded.

5. After exposure, the flame was extinguished using sand.

6. The charred area was removed, and the post-treatment weight of the specimen was recorded.

5.2 Inertia Calculation

In this section, we take measurements of the cross-sectional area of the wood samples after the flammability test, focusing on the most critically affected part. These measurements include the height (h) and width (b) of the section. Based on this data, we calculate the moment of inertia of the fire-damaged cross section using the following formula for a rectangular section:

$$I = \frac{b \times h^3}{12} \tag{1}$$

Where:

I = Moment of inertia (cm⁴ or mm⁴, depending on units)

b = Width of the section (base)

h = Height of the section (measured vertically)

5.3 Static bending test

The same number of control specimens and fire-exposed specimens were tested in a static bending test, using the setup shown below (Figure 2).

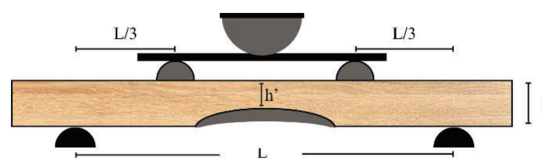

Figure 2. Static bending test setup.

Where:

L = 25 times h'

h = Height of the section

h'= Critical height of the burned section

5.3.1. Calculation of the elastic Modulus E

To determine each beam's modulus of elasticity, we first solve the deflection formula for E.

For a simply supported beam carrying two identical, symmetrically positioned point loads, the deflection at mid-span is expressed by:

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$$E = \frac{Pa}{24\Delta I}(3L^2 - 4a^2) \qquad (2)$$

Where:

E = Modulus of Elasticity (MOE)

Δ = Deflection

P = Load (force)

A = Distance from a support to the nearest load (L/3)

I = Second moment of area (moment of inertia of the beam's cross-section)

L = Span (distance between supports) (25 h')

The aim is to determine the modulus of elasticity while treating I as a constant, then solve for its value in the fire-treated specimens and compare the initial moment of inertia with the inertia obtained after the bending test.

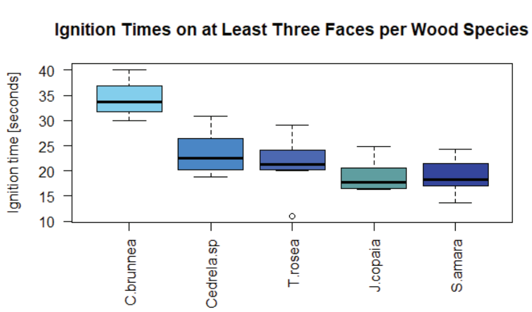
6 – RESULTS

6.1. Flammability test

Initially, the ignition times were analyzed, identifying the moment when at least three faces of each specimen were fully exposed to this phenomenon. Based on this, a maximum standard deviation ranging between 4.54 and 3.16 seconds was reported across all evaluated species.

However, as shown in Figure 3. it is evident that the species C. brunnea exhibited a slower ignition compared to the others. In this regard, Martínez et al. (2018) identified that one of the physical properties directly related to impact resistance is density, which also plays an important and positive role in thermal conductivity [8]. Therefore, lower density is associated with lower-intensity ignitions occurring in a shorter amount of time.

Figure 3. Ignition time on the least three faces per wood



As shown, *Clathrotropis brunnea* exhibited the lowest average mass loss (1.97%), suggesting greater thermal resistance compared to the other species tested. In contrast, *Simarouba amara* and *Jacaranda copaia* experienced the highest mass losses (6.38% and 5.27%, respectively), indicating greater susceptibility to thermal degradation.

This behavior appears to be associated with the physical and structural properties of the wood, particularly density. Previous studies have demonstrated that higher-density wood tends to have lower mass loss rates during combustion due to the formation of a more stable and continuous char layer. This char acts as a thermal barrier, reducing heat transfer and protecting the interior of the material [9]. Hevyer wood demonstrates notable inherent fire resistance, primarily due to the formation of a char layer that acts as an insulating barrier, slowing down heat penetration[10].

Additionally, the low mass loss observed in *Clathrotropis brunnea* may be related to a higher lignin content. Lignin is the most thermally stable of the three main wood polymers and contributes significantly to char formation rather than releasing volatile gases during pyrolysis. This behavior enhances fire resistance by retaining structural material [11].

Table 2. Summary of results of flammability

Species	Average Initial Mass (g)	Average Final Mass (g)	Standard Deviation of Final Mass (g)	Average Mass Loss (%)
Clathrotropis brunnea	191.89	188.11	4.84	1.97
Tabebuia rosea	113.99	110.03	6.75	3.48
Simarouba amara	87.27	81.70	1.81	6.38
Cedrela sp.	122.21	118.44	6.51	3.10
Jacaranda copaia	94.81	89.84	6.80	5.27

6.2 Inertia Calculation

Table 3. Inertia results per test test in each species, expressed in cm4.

SAMPLE	***Clathrotropis brunnea***	***Cedrela sp.***	***Tabebuia rosea***	***Jacaranda copaia***	***Simarouba amara***
1	1.029	0.893	0.924	0.651	0.556
2	1.029	0.832	0.795	0.648	0.550
3	1.013	0.827	0.791	0.640	0.546
4	0.960	0.826	0.737	0.546	0.526
5	0.964	0.826	0.733	0.542	0.503
6	0.944	0.817	0.733	0.542	0.503

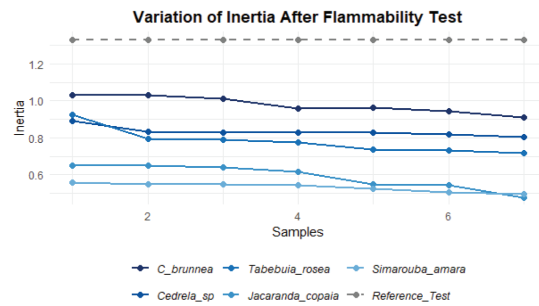
7	0.908	0.804	0.719	0.478	0.492
AVERAGE	**0.978**	**0.832**	**0.782**	**0.589**	**0.531**
STANDARD DEVIATION	**0.047**	**0.028**	**0.069**	**0.067**	**0.024**

After evaluating the mass loss due to ignition in each specimen, an inertia analysis was conducted by assessing the critical section where fire had the greatest impact on material reduction.

In processing the data, it was considered that all specimens initially had a standard moment of inertia of 1.33 cm^4. However, after the flammability test, the critical sections showed values ranging between 0.024 and 0.069 cm^4. This variation showed low data dispersion, as presented in Table 3.

It is also noted that the loss of cross-sectional area is directly associated with the reduction in the moment of inertia. Therefore, a decrease in the effective cross section due to fire exposure significantly impacts the structural behavior of the material.

Figure 4. Variation of inertia after flammability test.



The graph shows the behavior of five wood species exposed to fire, representing the final moment of inertia. The trends highlight significant differences between species, with *C. brunnea* consistently exhibiting the highest final inertia values at longer ignition times, compared to lower-density species that suffered greater structural degradation, such as *J. copai*a and *S. amara.*It is concluded that the moment of inertia is not significantly affected in higher-density species, such as C. brunnea, compared to the other species. In this behavior, the anatomical structure of the species plays an important role in its fire resistance and the observed final inertia.

Figure 5. *Samples post-flammability test.*

6.3 Static bending test

The bending test reveals that the greatest deflection occurs, on average, in the *Tabebuia rosea* specimens—both the untreated controls and those subjected to the flammability test. The next-largest deflections are observed in *Cedrela odorata*, which behaves in a similar manner. Considerably smaller deflections are recorded for *Jacaranda copaia* and *Simarouba amara*, which were tested under a lower load. Finally, the results confirm the high strength of *Clathrotropis brunnea*, whose

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specimens undergo only slight deformation even under the highest applied weight.

Table 4. Average deflection per specimen.

	P (kg)	Mid-span deflection, reference specimen (mm)	Mid-span deflection, fire-treated specimen (mm)
Clathrotropis brunnea	36,3	4	5
Tabebuia rosea	36,3	12	10
Cedrela sp.	36,3	12	9
Simarouba amara	31,75	8	8
Jacaranda copaia	36,3	8	8

6.3.1 Comparison between theoretical and experimental moment of inertia

Table 5. Ratio (Experimental intertia/theoretical inertia) per specimen.

Species	Ratio (Experimental intertia/theoretical inertia)
Clathrotropis brunnea	0,98
Tabebuia rosea	0,81
Simarouba amara	0,54
Cedrela sp.	0,84
Jacaranda copaia	0,60

This table shows the relationship between experimental and theoretical inertia for five tropical wood species, considering exposure to fire. The ratio indicates how much of the theoretical inertia is retained under experimental conditions. Higher values suggest better performance under thermal stress. *Clathrotropis brunnea* shows the highest ratio (0.98), indicating strong stability when exposed to fire, while *S.amara* has the lowest (0.54), reflecting a greater loss of structural integrity.

7 – CONCLUSION

Based on the results obtained, it can be concluded that *Clathrotropis brunnea* exhibited the most favorable fire performance among the five tropical wood species tested. Its high density contributed to a slower ignition time, the lowest average mass loss (1.97%), and the greatest retention of structural inertia, indicating strong thermal resistance. It is important to highlight that mass loss plays a crucial role in assessing fire behavior, as it reflects the extent of material degradation during combustion.

Additionally, wood density significantly influences char formation, which acts as a barrier that inhibits or limits combustion by reducing heat transfer and volatile release. In contrast, lower-density species such as *Simarouba amara* and *Jacaranda copaia* showed higher mass losses and more significant reductions in cross-sectional area, which adversely affected their final moment of inertia.

These findings confirm that both the species type and wood density critically influence fire performance, affecting combustion dynamics and structural integrity differently depending on the wood's anatomical and physical characteristics. This study provides valuable information for understanding the fire behavior of Colombian tropical woods and highlights the need for continued research into the characteristics that affect their structural capacity under fire exposure.

The final moment-of-inertia values confirmed a poor performance for *S.amara* after fire treatment; its inertia fell well below the level required for structural work. *J. copaia* was also heavily affected. By contrast, *T.rosea* retained a moderately acceptable share of its initial stiffness, and both *C. brunnea* and *Cedrela sp.* showed the smallest losses. These two species therefore remain viable candidates for structural applications and can justifiably claim a place in the market as load-bearing timbers.

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