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EVALUATION OF FIRE RESISTANCE OF SELECTED TROPICAL WOODS

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Abstract:

In recent years, tropical wood species such as Iroko, Sapelli, Okoume, Teak have gained increasing importance in Türkiye due to their aesthetic qualities, durability, and resistance to outdoor conditions. These species are widely preferred in furniture manufacturing, interior decoration, decking, and outdoor applications in the form of aesthetical veneer and timber, that require both visual aesthetic and useful performance. Therefore, in relation to their intended applications, it is important to understand the fire resistance of these species as well as their structural properties. The aim of this study is to evaluate the fire resistance performance of these species widely used in various areas. Fire resistance performance of the prepared wood samples (Ayous, Iroko, Sapelli, Okoume, Teak, Sipo, Wengé) was characterized with vertical burning testing (UL-94) and Limiting Oxygen Index (LOI) measurements.

The results show that differences in flammability characteristics among the wood species. It was found that Ayous wood samples exhibited the highest weight loss after combustion while Wengé wood samples showed the lowest weight loss. Wood samples of Teak and Sipo also presented relatively low weight losses. In general, the wood samples exhibited a rapid ignition within the first few seconds of flame exposure; however, they demonstrated a strong self-extinguishing behavior, completely putting out the flame in under 10 seconds after the removal of the ignition source. According to LOI results, the highest LOI level was obtained from Wengé wood samples. The findings of this study suggest that tropical species with high fire resistance will be suitable for use especially in areas at risk of fire. The remains of these species can also be used in the form of pellets and briquettes, as they provide a gradual and not rapid release of heat.

Key words: *Tropical wood; fire resistance; flammability; LOI test.*

INTRODUCTION

Tropical forest plantations are established for three main purposes: First, afforestation is planned to support the demands of local communities for timber, firewood, non-timber forest products, silvopastoral (forest-pasture) and other agroforestry systems. Second, afforestation is part of landscape rehabilitation or environmental protection measures to encounter the effects of wind, erosion, and desertification. The third objective of afforestation activities is to establish industrial plantations, primarily for commercially profitable products such as timber, pulpwood or oilseeds (Goldammer 2016). Tropical forests are vital ecosystems that sustain a substantial amount of biodiversity, provide ecosystem services including food, medicine, and materials, and are vital to protecting the climate, by enrichment of the atmosphere with oxygen through the process of photosynthesis (Fortier 2025). The wide variety of tree species in tropical forests exhibits significant differences in wood properties such as density, color, hardness, biological durability, and mechanical resistance. These wood properties enable the use of tropical woods in chemistry, construction, energy, manufacturing, and many other fields (Ramananantoandro 2024).

Wood is a renewable, sustainable, biodegradable, recyclable, and energy-efficient material with strong aesthetic appeal, but its main drawback is its low resistance to burning (Mensah *et al*. 2023). Therefore, the utilization of wood is restricted by safety standards and regulations related to its flammability and fire propagation characteristics (Lowden and Hull 2013). Fire performance assign to a material's response to combustion, and assessing its fire performance is essential (Ali *et al.* 2019). The combustion characteristics of wood consist of a complicated process that includes pyrolysis, torrefaction, ignition, thermal oxidative degradation, blazing combustion, and extinguishment (Haurie *et al*. 2019, Rabe *et al.* 2020, Mensah *et al*. 2023). In recent years, some studies have been conducted on the fire resistance of wood. Kencanawati *et al*. (2021) conducted fire tests on White teak, Bayur, Rajumas, and Sengon wood species from Indonesia, revealing that the charring rate of tropical wood had a linear inverse correlation with wood density at each exposure duration. Furthermore, based on the examination of post-fire mechanical properties, they determined

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that solid wood exhibited increased strength after fire. Souza *et al.* (2025) reported that the residual mass percentages ranged from 60.7-82.7% and ignition times ranged from 21-55 seconds for twelve different species of wood from the Amazon region, Literature reveals that the fire behavior of tropical woods shows significant differences among species and these differences depend on physical and chemical properties. The chemical composition of tropical woods, especially their extractives, lignin and hemicellulose content, moisture content, and wood density significantly affect their burning behavior (Anjorin and Ogundana 2016, Pinto *et al*. 2016, Haurie *et al.* 2019, Okafor *et al*. 2020, Souza *et al.* 2025).

Despite the existence of research in the literature on the burning behavior of tropical wood species, research focusing on UL-94 and LOI fire tests of tropical wood species not treated with fire retardants appears to be limited. Tropical woods are widely used in the construction industry due to their durability, high density, and aesthetic qualities. Therefore, determining their fire behavior is a critical requirement both for ensuring fire safety standards and for the design of sustainable building materials.

OBJECTIVE

In this study, the fire resistance of selected tropical wood species was experimentally investigated, and the differences between the species were evaluated. The experimental studies included fire parameters such as ignition time, burning time, and mass loss. On the other hand, the aim of this study is also to evaluate fire resistance of selected tropical wood species using the UL-94 and LOI test methods.

METHOD

Wood samples for the experiments were selected from commercially important tropical wood species. For this purpose, the seven tropical wood species have obtained from the Timber and Ply Company in Ankara, Türkiye, are as listed in Table 1. Wood samples measuring wide 13 mm × length 125 mm × thickness 10 mm were cut from each air-dried sample with a moisture content of 12% (Fig. 1.). Each wood sample was weighed to determine its initial weight before the fire tests.

Table 1

Wood species tested and their respective densities (Gérard et al 2017)

Botanical names	**Pilot name/Commercial name***	**Density** (g/cm³)**
Triplochiton scleroxylon	Ayous/Obeche*	0,38
Milicia excelsa	Iroko*	0,64
Entandrophragma cylindricum	Sapelli/Sapele*	0,69
Aucoumea klaineana	Okoumé/Gaboon*	0,44
Tectona grandis	Teak*	0,67
Entandrophragma utile Sprague	Sipo/Utile*	0,62
Millettia laurentii	Wengé*	0,87

** *at 12% moisture content. But, the other ones, what moisture content?*

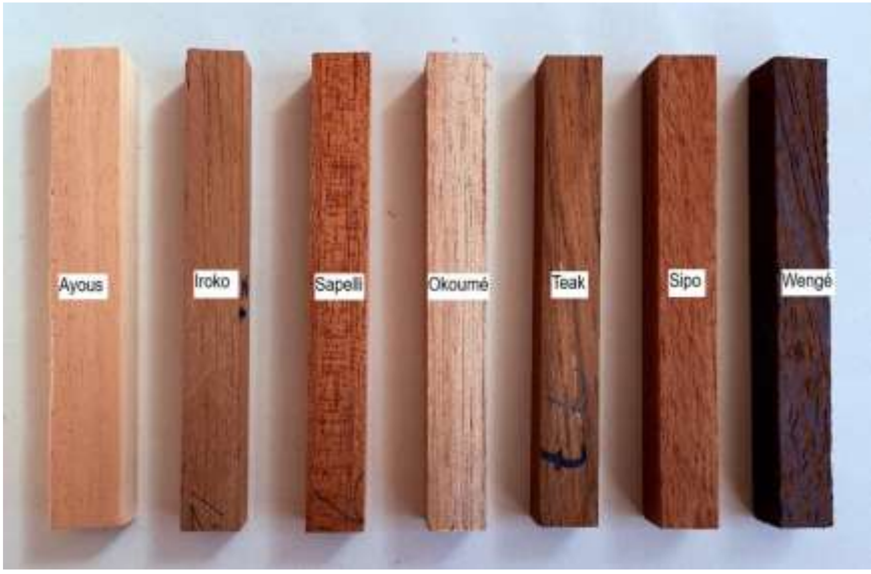

Fig. 1.
Test samples.

Fire Tests

Flammability test

The flammability test of the tropical wood samples was performed by applying vertical burning test according to UL-94 standard specified by Underwriters Laboratories (2013). The UL-94 vertical burning test, which is commonly used to determine the flame resistance of plastic materials, was modified for wood samples. Wood-based materials, unlike plastic materials due to their various structural properties, exhibit slower ignition characteristics upon flame exposure rather than rapid melting. They have also a structure that continues to burn internally even after the flame is extinguished. Therefore, determining the structural integrity of the wood samples under flame exposure, and consequently their mass loss rates, can also be important in terms of flame resistance properties. Based on the original test, modifications were made to the test to determine the ignition and extinction times of the wood samples in the presence of flame, as well as to calculate mass loss data to numerically determine the extent to which their structural integrity is maintained by weight during flame exposure. Accordingly, in the test, some observational and measurement results were obtained, and time-dependent weight loss measurements were performed using a precision balance for repeated 10-second intervals. Fig. 2 shows the vertical burning testing set. During the test, the wood samples were exposed to a flame source for 10 seconds. A stopwatch was used for 10 seconds to determine the ignition and extinguishing times. If no ignition was observed, the flame was applied for another 10 seconds. The ignition and extinguishing times were recorded for each 10-second interval. After the samples were removed from the flame source, their final weights were measured using a 0.1g precision balance (UX-620H Shimadzu) to determine the weight loss caused by burning. The weight loss of each wood sample was calculated using the following Equation.

$$\text{Weight loss (\%)} = \frac{(\boldsymbol{Final\ weight} - \boldsymbol{Initial\ weight})\ (\boldsymbol{g})}{\boldsymbol{Initial\ weight}\ \ (\boldsymbol{g})} \times \mathbf{100}$$

Fig. 2.
Vertical burning testing set.

LOI (Limiting Oxygen Index) Test

The Limiting Oxygen Index (LOI) test of tropical wood samples was measured according to ASTM D2863-10 standard using a Dynisco Limiting Oxygen Index Chamber (Fig. 3). The analysis determined the threshold oxygen level necessary for sustained combustion. Test samples (wide 13mm × length 125mm × thickness 10mm) were exposed to a controlled oxygen-nitrogen gas and ignited via a pilot flame. For each experimental group, five specimens were tested to obtain average and standard deviation values.

Fig. 3.
LOI test of samples.

RESULTS AND DISCUSSION
Flammability Test

The ignition and extinguishing times of wood samples after flammability test are indicated in Table 2. The appearance of test samples after flammability test is shown in Fig. 4. The weight loss percentages of test samples are indicated in Fig. 5.

Table 2

Ignition time/extinguishing time of wood samples for 30 sec

Wood samples	Ignition time/ extinguishing time		
	10 sec.	10 sec.	10 sec.
Ayous	1sec. / 4 sec.	2 sec. / 6 sec.	3 sec. / 7 sec.
Iroko	-	1 sec. / 3 sec.	2 sec. / 4 sec.
Sapelli	-	1 sec. / 2 sec.	2 sec. / 3 sec.
Okoume	1sec. / 3 sec.	2 sec. / 6 sec.	3 sec. / 7 sec.
Teak	-	1 sec. / 2 sec.	2 sec. / 4 sec.
Sipo	-	1 sec. / 2 sec.	2 sec. / 4 sec.
Wengé	-	-	1 sec. / 3 sec.

The ignition time is an important measure for analyzing the characteristics and flammability of materials (Maake *et al*. 2020) and it can vary depending on several parameters, including the ambient temperature, heat transfer mode, and density, thickness, moisture content of wood samples (Bartlett *et al*. 2019). As it can be seen from Table 2, during the initial 10-second flame application in the flammability test, that the tropical wood samples generally did not exhibit ignition. However, Ayous and Okoume wood samples showed a very slight edge ignition for 1 second, which extinguished rapidly within 3-4 seconds. Since these times were less than 10 seconds, a second 10-second flame application was performed. At this stage, all samples except Wengé wood samples showed slight edge ignition, which quickly extinguished spontaneously. Accordingly, to examine the flammability behavior of wood samples in more detail, a third additional 10-second flame exposure was applied in addition to the standard protocol. During these additional exposure times, it was determined that the samples were only briefly exposed to flame, and the flame extinguished spontaneously in less than 10 seconds. To more comprehensively analyze the thermal stability and time-dependent mass loss of the wood samples, the test duration was extended to 40 and 50 seconds. Particularly after 50 seconds of flame exposure, it was observed that the extinguishing times lengthened, the flame height reached several centimeters, and characteristic charring occurred in the samples along with internal combustion (Fig.4). Wengé wood samples exhibited the minimum flame lengths among all tested samples.

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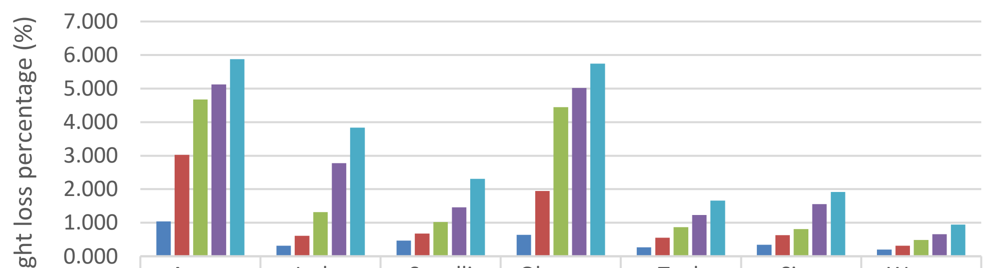
Fig. 4.
Appearance of test samples after flammability test.

Although there was not a significant amount of smoke emission, flame color variations, a sharp aromatic odor, and different smoke levels-likely caused by extractive substances-were observed. Ignition of the Ayous sample occurred within the first 20 seconds, during which the flame length reached approximately 4 cm of the sample height, and more pronounced charring was observed. The sample continued to burn for a longer duration compared to the other species. Okoume exhibited a similar burning behavior to Ayous. Anjorin and Ogundana (2016) stated that the fire performance of tropical woods is affected by density, moisture content and chemical composition. Adetayo and Dahunsi (2019) investigated the density and strength properties of some wood species used as building elements in Nigeria after fire exposure test. As a result, Afara/Limba (*Terminalia superba*), which had the lowest density value of 444 kg/m³ showed the highest percentage loss in density at 29.2% after charring, while Opepe (*Nauclea diderrichii*) which had the highest density of 752 kg/m³ showed a lower percentage loss in density at 26.6%. Haurie *et al*. (2019) investigated the fire characteristics of seven tropical hardwoods from Mexico and determined that the high density wood samples *Cordia elaeagnoides* (CA) and *Tabebuia chrysantha* (TC) showed the longest ignition time in the cone calorimeter test. Giraldo et al. (2016) concluded that fire performance is related to wood density, and specifically, the delay in ignition is directly related to increasing density. Additionally, Osvaldova *et al.* (2023) concluded that the most important factor affecting the fire properties of wood is its density, and that the weight loss of the samples decreased with increasing wood density.



	Ayous	Iroko	Sapelli	Okoume	Teak	Sipo	Wenge
10s	1.039	0.313	0.470	0.638	0.264	0.340	0.198
20s	3.025	0.612	0.676	1.949	0.550	0.626	0.314
30s	4.679	1.315	1.020	4.451	0.869	0.813	0.488
40s	5.126	2.779	1.463	5.022	1.230	1.552	0.662
50s	5.880	3.832	2.305	5.742	1.661	1.920	0.947

10s 20s 30s 40s 50s

Fig. 5.
Weight loss (%).

As the results shown in Fig. 5, the seven tropical wood species differ in terms of their flammability characteristics. The test samples are ranked from most fire-resistant to least fire-resistant as follows. Wengé > Teak > Sipo > Sapelli > Iroko > Okoume > Ayous. The greater weight loss percentage was observed for Ayous and Okoume due to their low density and porous structure, compared to the other species tested. Wengé and Teak with their high density and hard texture showed the greatest resistance to burn. Low-density wood burns faster than high-density wood because its internal voids provide high insulation, reducing heat loss from the combustion zone and leading to higher surface temperatures (Momoh *et al.* 1996).

LOI (Limiting oxygen index) Test

Fig. 6 shows the appearance of wood samples after LOI test and Fig. 7 shows the LOI levels of tropical wood samples. As previously explained, LOI test results showed similarities to flammability test results depending on the density values of the test samples.

Fig. 6.
Appearance of test samples after LOI test.

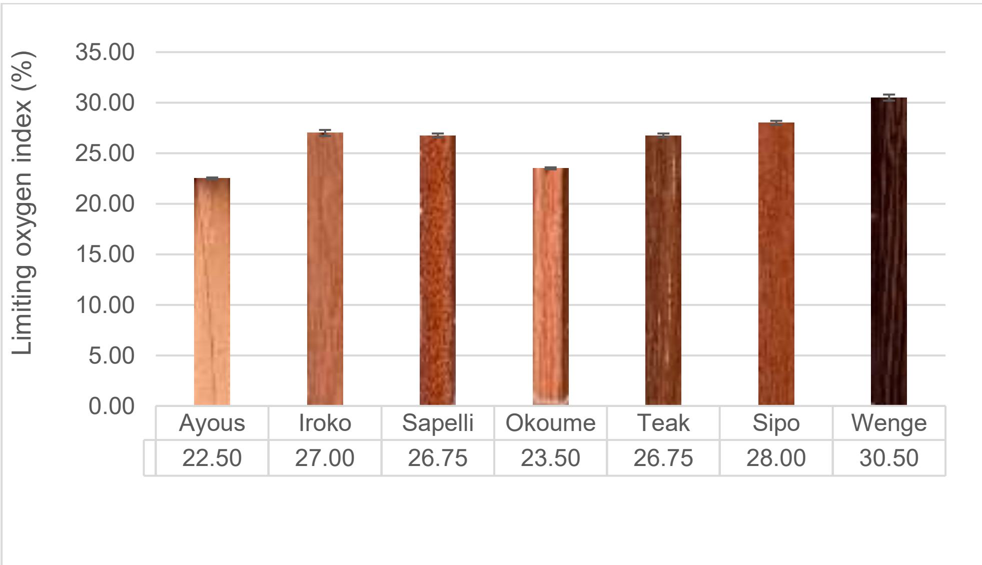


Fig. 7.
Limiting oxygen index (LOI) levels of test samples (%).

As seen in Fig.7, the LOI values ranged from 22,50% to 30,50%. The lowest value was observed in Ayous samples with 22,50%, while the highest value was found in Wengé samples with 30,50%. The LOI ranking among these species is: Ayous < Okoume < Sapelli = Teak < Iroko < Sipo < Wengé. As is known, a lower LOI value indicates that the material is more easily ignited and has less resistance to combustion, while higher LOI values indicate that the material is more difficult to ignite and has higher resistance to combustion. Numerous parameters influence fire behaviour of wood. The wood density, wood morphology, moisture content, extractive substances, and inorganic compounds affect combustion resistance (Haurie *et al.* 2019, Okafor *et al*. 2021, Souza *et al*. 2025). As seen in Table 1, density values of wood species at 12% moisture content examined in this study are as follows: Ayous (0,38 g/cm³) < Okoume (0,44 g/cm³) < Sipo (0,62 g/cm³) < Iroko (0,64 g/cm³) < Teak (0,67 g/cm³) < Sapelli (0,69 g/cm³) < Wengé (0,87 g/cm³) (Gérard et al 2017). It has been observed that the ranking of these species in terms of density values shows similarity to the determined LOI ranking. It was determined that low-density Ayous had the lowest LOI value and high-density Wengé had the highest LOI value. Okafor *et al.* (2021) investigated the relationship between the main flame characteristics and physical properties of some fire-resistant tree species in southeastern Nigeria and found a strong correlation (R_{sq}=0.8678) between wood density and LOI (Limiting Oxygen Index).

CONCLUSIONS

This study investigated and compared the fire resistance of selected tropical African wood species. The important finding of this study can be summarized as follows:

1. It has been observed that low-density species (especially Ayous and Okoume) ignite quickly and experience a high weight loss percentage, whereas species with higher density (Wengé, Teak, Sipo) exhibit greater resistance to heat.

2. To protect against fire risk Wengé, Sipo and Teak, which have a slow ignition time, are recommended for building construction and for applications requiring heat resistance such as exterior cladding or surfaces exposed to high temperatures.

3. These results shows that the two laboratory tests (UL-94 and LOI) used for this study are useful for quickly evaluating the fire performance of wood.

4. The findings show that wood density is important for fire resistance, but not this parameter is the only determinant. Therefore, in order to understand more comprehensive understanding the processs, it is aimed to include other variables in future studies.

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