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Investigating Temperature Impact on Physical, Mechanical, and Recovery Properties of Construction Woods in Bangladesh

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Abstract

The impact of temperature on the performance of construction materials is a critical factor in designing durable and efficient structures. Wood is a versatile and widely used construction material, and understanding the thermal effects on its properties is essential to ensure the safety, performance, and longevity of wooden structures. This study investigates the thermal effect on the mechanical properties, physical behaviors, and recovery process of three commercially available wood species in Bangladesh: *Gmelina arborea* (gamhar), *Dictyocarpus turbinatus* (gorjon), and *Albizia saman* (randi-koroi). Mechanical properties such as durometer hardness, density, tensile and compressive strength, elongation, and compression were evaluated at various temperatures. The results showed that the rate of change in mechanical properties due to thermal treatment was highest in *Dictyocarpus turbinatus* and lowest in *Gmelina arborea*. A significant color change was observed in all three species at 175°C. Optical microscopy and Scanning Electron Microscopy (SEM) examined wood cells and surface fractures during tensile and compressive tests. The study concluded that *Dictyocarpus turbinatus* exhibited the best results compared to *Gmelina arborea* and *Albizia saman*. These findings offer insights into temperature's effect on wood behavior, guiding the creation of strategies to improve the use, performance, and sustainability of wood-based structures.

Keywords: *Wood-based construction; Thermal effect; Mechanical properties; Wood species; Scanning Electron Microscopy.*

1 Introduction

Wood, an abundant and cost-effective material, has become an essential component in composite materials and is extensively used in various engineering applications. The demand for wood continues to rise across different fields, making it crucial to understand its properties under different conditions, including thermal, environmental, and chemical factors (Chen et al., 2020; Siraj et al., 2022). However, despite the importance of temperature effects on wood, there has been a lack of research specifically investigating the impact of temperature on construction wood in Bangladesh.

In the global context, diverse studies have explored the mechanical properties of wood, but the research focusing on the thermal effects on commercially available wood in Bangladesh remains a significant gap. As a middle-income country, Bangladesh boasts a wide variety of wood species such as Sundori, Gamari, Gorjon, Koroi, and Mehegoni (Bangladesh National Herbarium, 2020), extensively used in furniture, construction, and other appliances. Understanding the thermal properties of these woods is essential for optimal utilization, particularly in thermally activated environments, where properties can be modified accordingly.

Wood's inherent dimensional instability impacts its performance. Essential properties like hardness, density, compressive strength, and tensile strength determine wood product behavior (Kretschmann, 2010). The present study aims to fill the research gap by comprehensively examining the influence of temperature on the physical, mechanical, and recovery behaviors of commercially available wood in Bangladesh, focusing specifically on Gmelina arborea (gamhar), Dictyocarpus turbinatus (gorjon), and Albizia saman (randi-koroi).

The objectives of this study are to:

a) Assess the impact of thermal treatment on the mechanical properties of wood.
b) Identify the most affected wood species by thermal treatment.

By shedding light on these aspects, our research will contribute to enhancing material selection and fostering efficient utilization of wood in thermally activated environments. The insights obtained from this study will fill the existing research gap, and provide vital information to guide the future development and application of wood-based materials in various domains.

2 Literature Review

The thermal effects on wood properties have been a topic of interest for several researchers globally. This interest is derived from the fact that wood's mechanical and physical properties undergo notable changes under the influence of heat (Esteves, 2009). In response to this need, numerous studies have been conducted across different wood species to evaluate the effects of temperature on various wood properties.

One of the seminal works in this field was carried out by Bekhta and Niemz (2003), who examined the heat-induced color changes and chemical modifications in spruce. Their study was vital in establishing a correlation between temperature and color change in wood, a factor of considerable importance in aesthetics-oriented applications. Another study by Korkut et al. (2008) focused on the effect of heat treatment on the physical properties of wood, such as swelling, shrinkage, and water absorption.

From a mechanical standpoint, studies have identified the effects of heat treatment on various mechanical properties of wood. Boonstra et al. (2007) observed a significant reduction in the bending strength and elasticity of heat-treated pine and spruce. Similarly, Kocaefe et al. (2008) discovered significant alterations in the mechanical properties of heat-treated aspen and black spruce, highlighting the variation in mechanical properties based on species.

However, while these works provide a valuable foundation, they predominantly concentrate on the common softwood species found in temperate regions, and few studies have examined tropical hardwoods. Among the scant research in this area, studies by Esteves (2008) and Brito et al. (2008) offered insights into the effects of heat treatment on tropical hardwoods, but their scope was limited to a small number of species.

Despite the substantial volume of research carried out on the effects of temperature on wood properties, there is a glaring gap in the context of wood species in Bangladesh. The unique and varied types of tropical hardwoods available in Bangladesh, such as *Gmelina arborea*, *Dictyocarpus turbinatus*, and *Albizia saman*, have not been subjected to extensive thermal impact studies (Alamgir and Al-Amin, 2007). Thus, there is a limited understanding of the thermal effects on their physical, mechanical, and recovery properties. This gap is especially crucial considering the extensive use of these species in construction, furniture, and other applications in the region.

Given the above, it becomes clear that a focused study on the thermal effects on commercially available wood species in Bangladesh is required. This study aims to address this need, further expanding our understanding of how wood responds to temperature changes and providing necessary insights to enhance the utilization of wood in the local context.

3 Experimental Methodology

This study used standard-size wood specimens from three species (see Figure 1). The specimens were subjected to various tests to determine their physical and mechanical properties under different temperatures.

Initially, isochronal heating processes were implemented where the heating duration was set to 2 hours and the temperature varied from 0 to 250 degrees Celsius. The tests conducted under these conditions included assessing durometer hardness, density, color change, and moisture loss. The durometer hardness was evaluated using a durometer hardness tester, which provided measurements of relative hardness or shore hardness. In addition, an isothermal heating process was conducted to assess the recovery behavior of the wood specimens post-heating. The specimens were left in an open environment to observe moisture gain and property recovery.

Moreover, a continuous isothermal heating process was executed, studying the effect of prolonged heating on the mechanical properties of the wood specimens. Durometer hardness, density, compressive strength, and tensile strength were among the properties analyzed.

Wood samples were evaluated using both optical microscopy and Scanning Electron Microscopy (SEM) to examine changes in wood cells and surface conditions. Optical microscopy helped in magnifying images of small samples using visible light and a system of lenses, whereas SEM employed a focused beam of electrons to provide images of the sample's surface topography and composition.

Figure 1. Left- Samples used for the experiment; Right- Used equipment for experiment [Durometer hardness tester (top-left), Universal compression tester (top-middle), Automated tensile tester (top-right), Optical microscope (bottom-left), SEM (bottom-right)].

4 Results and Discussion

The results revealed that as temperature increased, durometer hardness and density were significantly impacted for all three wood species (see Figure 2). However, the rate of change differed among the species. *Gmelina arborea* showed the lowest rate of change, whereas *Dictyocarpus turbinatus* exhibited the highest. Furthermore, a noticeable change in the color of all three species was observed at 175°C, attributed to distortions in wood cells caused by heating (see Figure 3).

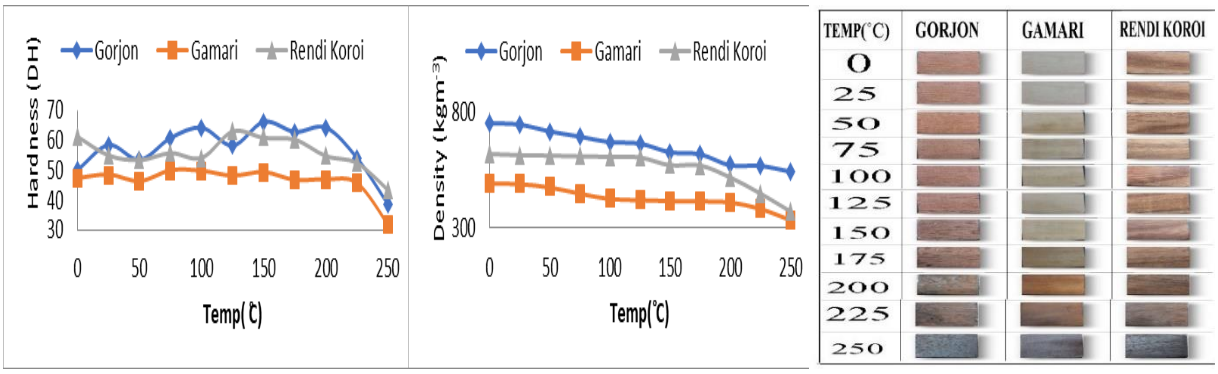

Figure 2. For a 2-hour isochronal heating process, variation in hardness (DH) (left), Variation in density (middle), and effect on the surface color of the wood sample (right)

For continuous heating at 100°C over 8 hours, *Dictyocarpus turbinatus* and *Albizia saman* displayed significant changes in relative hardness, with *Albizia saman* losing a substantial portion of its density. In contrast, *Gmelina arborea* displayed lesser variation.

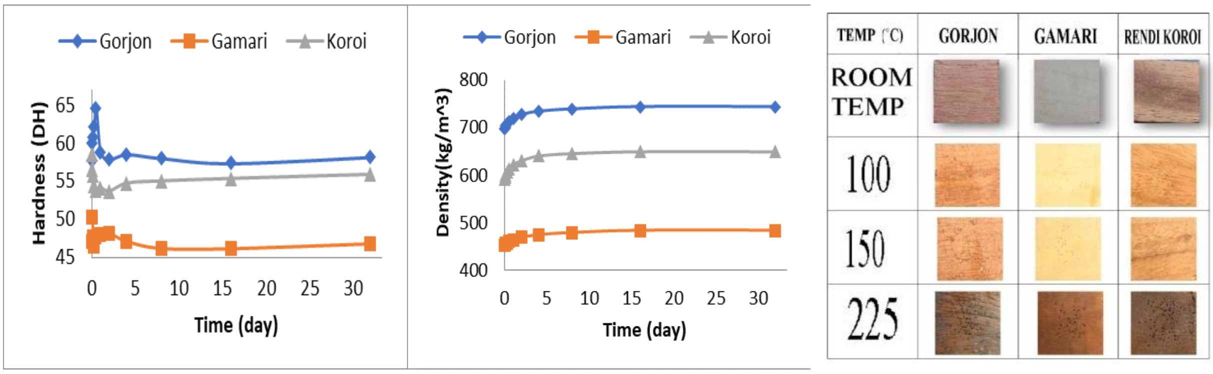

Figure 3. Variation in hardness (DH) for recovery process for 2 hr heating (left), Variation in density for recovery process for 2 hr heating (middle), Surface condition on the recovery process for 2 hr heating

Compression and tensile tests revealed a decline in both ultimate strength and yield strength for all species as temperature increased. *Dictyocarpus turbinatus* presented the highest ultimate strength, whereas *Gmelina arborea* had the lowest. Correspondingly, elongation, which signifies a material's ability to resist breakage, decreased for all wood types with temperature rise.

Heated wood undergoes a recovery phase when exposed to the open environment, absorbing moisture (Figure 4). Absorption rate and extent, and property recovery, depending on environmental conditions and initial heating temperature. Initially, the wood rapidly absorbs moisture due to significant moisture loss during heating, restoring some mechanical strength and elasticity. As the wood approaches equilibrium moisture content, absorption rate, and property changes slow down. Eventually, the wood stabilizes with minimal changes. This highlights the importance of considering environmental factors when working with wood.

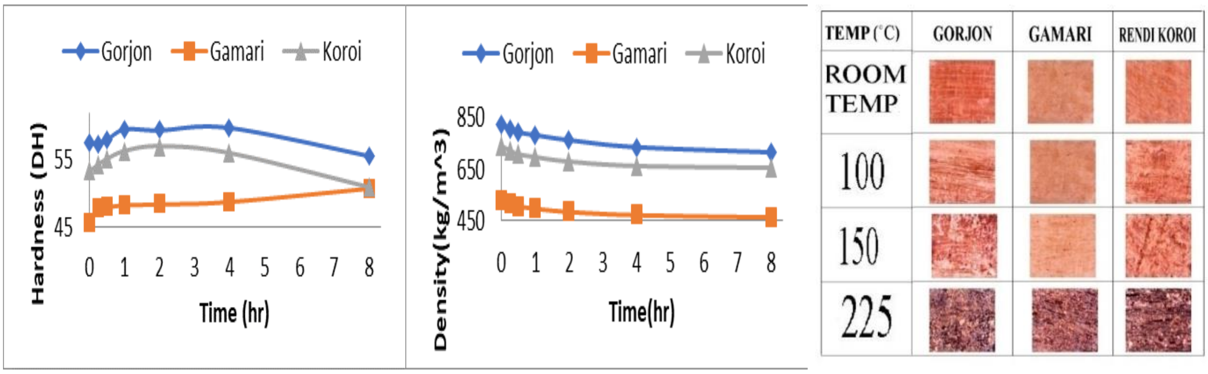

Figure 4. Variation in hardness (DH) for an isothermal heating process (left), Variation in Density for an isothermal heating process (middle), Surface condition for the continuous isothermal heating process

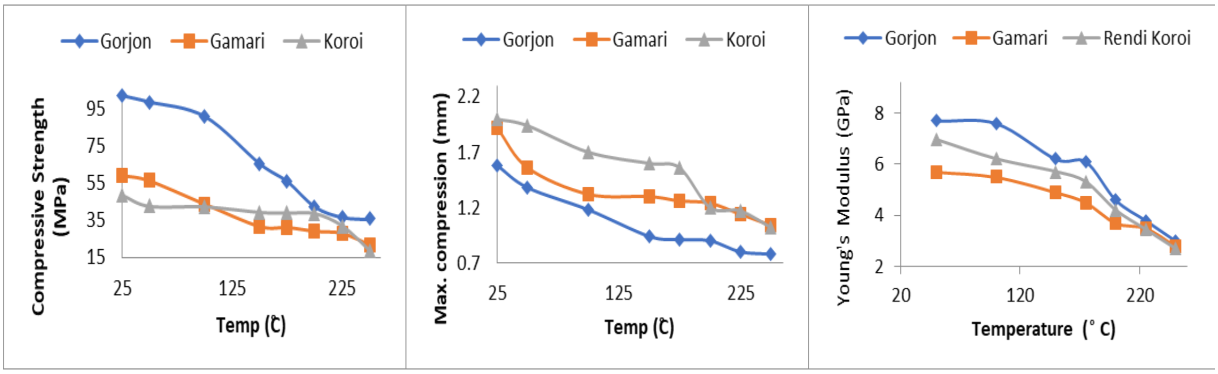

Figure 5. For the 2-hour heating process, variation in compressive strength (left), variation in maximum compression (middle), variation in Young's modulus

Initially, durometer hardness changes due to thermal degradation, altering the cellular structure of wood. This process breaks down key components like cellulose, hemicellulose, and lignin, which contribute to its strength. Simultaneously, density decreases as moisture evaporates, reducing wood mass. Over time, density changes become less significant as free water is completely evaporated. Gradual alterations in density depend on the removal of bound water and ongoing thermal degradation (Figure 5).

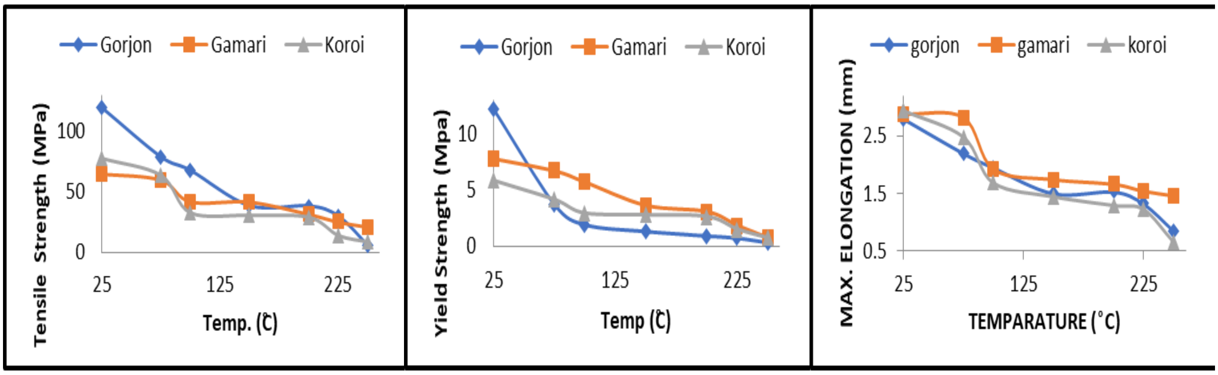

Figure 6. For a 2 hr heating process, variation in tensile strength (left), variation in Yield Strength (middle), variation in maximum elongation (right)

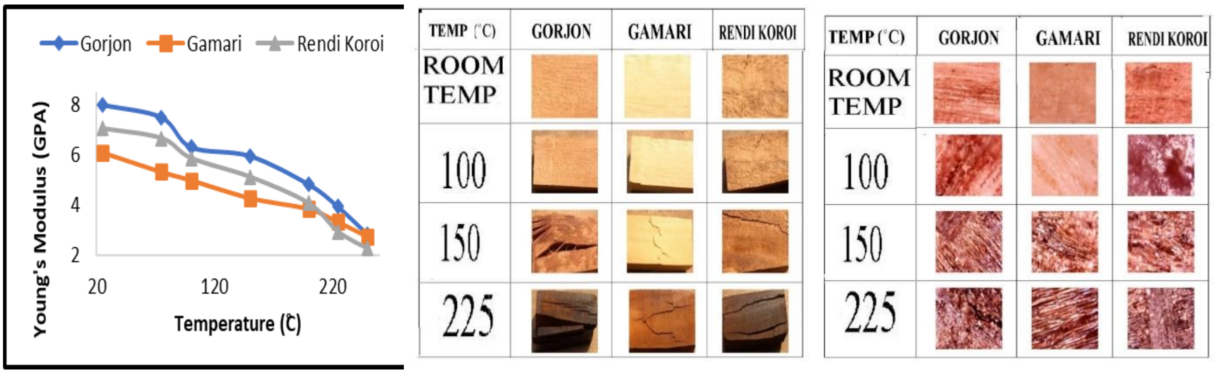

Figure 7. Variation in Young's modulus in different temperatures for a 2hr heating process (left), surface fracture for compressed wood (middle), microscopic view of fracture of wood sample for the tensile test (right)

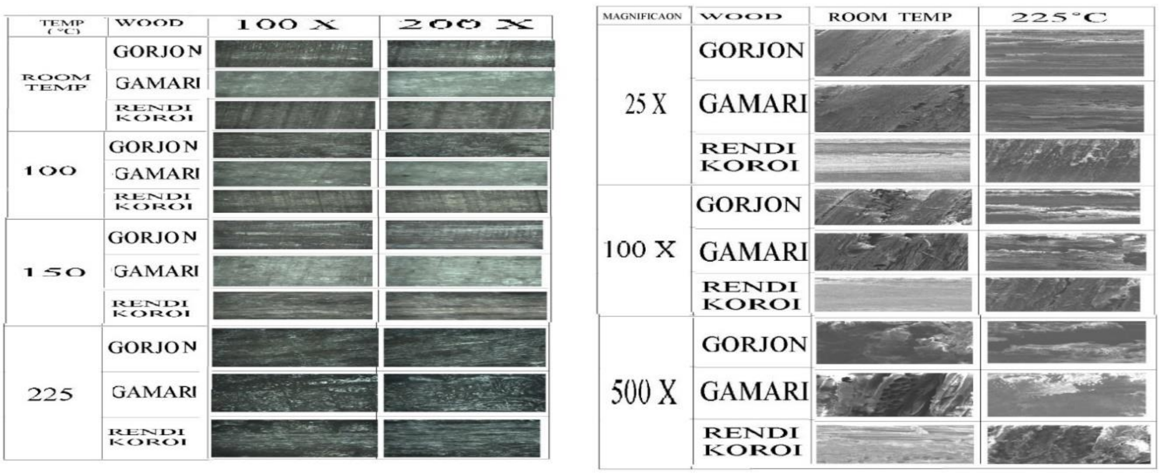

Figure 8. Optical microscopic view of wood samples (left), SEM view of wood samples (right)

Wood's compressive strength varies with temperature, representing its resistance to size reduction. Maximum compression and compressive Young's modulus are influenced by elevated temperature and moisture loss during heating (Figure 6). Tensile strength, measuring resistance to tension, and maximum elongation are affected by temperature changes, vapor absorption/reduction (Figure 6). Yield strength, stress causing plastic deformation, also varies with temperature (Figure 7). SEM scans a sample with an electron beam, generating images revealing surface topography and composition. It achieves sub-nanometer resolution, allowing observation under different conditions (Figure 8). Heating caused notable cell distortion, particularly at 225°C, with *Dictyocarpus turbinatus* showing significant changes.

5 Conclusion

In this study, the thermal effects on wood properties, including Durometer hardness, compression strength, tensile strength, and wood cell distortion, were investigated for three different wood species: *Gmelina arborea* (gamhar), *Dictyocarpus turbinatus* (gorjon), and *Albizia saman* (randi-koroi). Gorjon demonstrated the best results in all experimental tests in this study as a construction wood. The key findings are as follows:

- Gamhar wood consistently had lower Durometer hardness compared to Randi-koroi and Gorjon. Durometer hardness fluctuated between 50°C and 175°C due to temperature and moisture content loss. Color changes occurred after 175°C for Gorjon and Randi-koroi and after 150°C for Gamhar. Heat treatment experiments confirmed variations in relative hardness and surface color, resulting from wood cell distortion due to thermal modification.
- Compression tests showed that the ultimate strength of wood decreased with increasing temperature for all three wood species. Gorjon exhibited the highest ultimate strength at room temperature, while Randi-koroi displayed the lowest. Compression of the woods decreased as moisture content decreased with temperature rise.
- Tensile tests revealed similar trends, with ultimate strength and yield strength decreasing with temperature. Gorjon had the highest ultimate strength at room temperature, while Gamhar exhibited the lowest. Young's modulus decreased with increasing temperature for all three wood species.
- Observation of wood cell distortion through scanning electron microscopy (SEM) confirmed that cells underwent significant distortion at 225°C.

Although this study provided valuable insights into thermal effects on wood properties, there are limitations. Further exploration of sample size, specific wood species, and generalizability to other conditions is necessary. Future research should focus on optimizing heat treatment parameters, studying a wider range of wood species, assessing long-term effects, and evaluating economic and ecological aspects of heat-treated wood versus alternative materials.

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