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# Microwave Drying of *Melia dubia* and Its Effect on Mechanical Properties †

**Rohit Sharma *, Rakesh Kumar and Anil Kumar Sethy**

Wood Properties and Processing Division, ICFRE-Institute of Wood Science and Technology, Bangalore 560003, India
* Correspondence: rohitsharma.fri@gmail.com

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**Abstract:** This study explores the microwave (MW) drying of *Melia dubia* wood, with a comprehensive approach that addresses various facets. The primary objectives were to examine drying behavior and the evaluation of drying defects. The drying rates for various treatments were calculated both above and below the Fiber Saturation Point (FSP). The most optimal treatment, characterized by minimal defects, exhibited a drying rate of 0.4 g/min above FSP, 0.29 g/min below FSP, and an overall drying rate of 0.35 g/min. There were no observable drying-induced defects in the dried wood, suggesting a promising aspect of MW drying. Static bending and compression tests parallel to the grain were carried out to analyze the impact of MW drying on the mechanical properties. MW-dried wood exhibited reductions of 7 ± 3%, 10 ± 2%, and 9 ± 2% in the modulus of elasticity (MOE), modulus of rupture (MOR), and maximum compressive strength (MCS), respectively. The decline in mechanical properties may be attributed to the micro-cracks or damage in its microstructures. These findings emphasize the need for a balanced approach in optimizing MW drying methods to mitigate the reduction in mechanical properties while capitalizing on the advantages of reduced drying time and uniform drying.

**Keywords:** *Melia dubia*; MW drying; drying time; mechanical properties; microstructures

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## 1. Introduction

The significance of wood as a natural resource is universally acknowledged and valued. The drying process is a vital component in enhancing the value of solid wood products [1,2]. There is an increasing interest in advancing technologies to expedite the drying process of wood. Thus, the prevailing trend leans towards developing technologies that are rapid, energy-efficient, and result in fewer drying defects. In this context, MW drying proves itself to be advantageous. Unlike conventional methods, MW heating offers numerous benefits such as accelerated drying and reduced defects [3,4]. MW treatment is a time-saving approach [5].

MW heating provides several advantages over traditional methods, which include faster drying rates and fewer defects compared to conventional kilns [6,7]. Although not widely used, MW radiation for wood drying shows promise, as it can significantly accelerate the drying process while maintaining the wood's quality [8]. MW treatment is an effective method to reduce the drying time and increase the permeability of wood [9]. MWs produce heat within materials through oscillatory electric fields. When MWs interact with moist materials, water's dielectric properties absorb the MW energy, converting it into heat within the material. This rapid heating accelerates the evaporation rate during the drying process [10]. MW drying significantly reduces drying time compared to conventional kiln drying, cutting down the duration from several days to just a few hours [11,12]. Despite all these advantages, the use of MW is still negligible in the wood science field, the reason being due to the lack of research for industry consideration.

In 2022, Vongpradubchai et al. [13] dried rubberwood using MW, conventional heating, and also a combined treatment, and the findings showed that the final quality of the rubberwood samples dried using MW-assisted drying was comparable to conventional drying methods. However, it surpassed the quality of the samples dried using a combination of MW and air drying. In another study, He et al. [14] dried *Eucalyptus urophylla* with MW pre-treatment and found that the drying rate was significantly accelerated, thus reducing the total drying time. The influence of MW power on mechanical properties was not statistically notable. However, there was a tendency for mechanical properties to reduce as the MW exposure increased [15,16].

The present study focuses on plantation-grown *M. dubia* timber, which is in high demand and has the potential to be used in wood-based industries. The drying rate was studied at constant MW intensity and different exposure times. Changes in the properties due to exposure were also evaluated. It is important to dry the wood in such a way that it does not deteriorate the properties drastically. In our study, we sought to understand the behavior and changes in mechanical properties under MW drying, as well as identify the underlying factors responsible for these changes in wood characteristics.

## 2. Materials and Method

Small clear specimens of *M. dubia* 25 mm × 45 mm × 300 mm (thickness × width × length) were obtained from the local market.

The MW treatment was conducted using a domestic MW device equipped with a 310 mm diameter turntable, ensuring even MW distribution. The device runs at a frequency of 2.45 GHz and has a maximum power output of 900 W. The wood samples were exposed to continuous MW power of 540 W for 30 s and 1 min, with a 2 and 5 min cooling interval (Table 1), and then the samples were removed to record their weight before being returned to the MW oven.

**Table 1.** Different MW treatments for *M. dubia*.

| Treatment | MW Power | Exposure Time | Idle Time | Total Drying Cycle Time |
|---|---|---|---|---|
| T1 | 540 W | 30 s | 2 min | 2 min 30 s |
| T2 | 540 W | 30 s | 5 min | 5 min 30 s |
| T3 | 540 W | 1 min | 2 min | 3 min |
| T4 | 540 W | 1 min | 5 min | 6 min |

The drying rate for each treatment indicates the volume of water extracted per specific time duration, as determined by Equation (1):

$$\text{Drying Rate (g/min)} = \frac{Amount\ of\ moisture\ removed}{Total\ drying\ time} \quad (1)$$

where *Total drying time* = MW exposure + idle time.

The mechanical properties of *M. dubia* were evaluated as per the Indian standard [17] on a universal testing machine. For compression parallel to grains, wood samples with dimensions 20 mm × 20 mm × 80 mm (b × h× l), and for static bending wood samples of dimensions 10 mm × 10 mm × 150 mm (b × h× l), were used. The samples for static bending were modified; however, the depth-to-span ratio was maintained at 1:14 as per the standard.

## 3. Results and Discussion

Wood was dried under MW and samples were exposed to 540 W under various MW exposure durations and various idle times, making the full cycles as shown in Table 1. During the idle periods, the samples were left undisturbed to cool, allowing for any generated steam to evaporate. These cooling breaks not only facilitated weight measurements but also protected the wood from potential harm caused by overheating [18]. During the drying process, the MC of *M. dubia* was reduced from about 70 to 80% to a range of 8 to 12%. The extent of moisture loss and the moisture content after each cycle were recorded throughout the procedure. The rate of moisture loss in wood varies across different stages. When the MC was high during the early stages of drying, water evaporated more quickly as compared to when the MC dropped, and the same occurred with the water evaporation rate; similar results were obtained by Du et al. [19] when they dried wood strands. The drying rates for various treatments are presented in Table 2. The drying rate is influenced by both exposure time and idle time. For treatments T1 and T2, the exposure time remained constant at 30 s, but the idle times differed at 2 min and 5 min, respectively.

**Table 2.** Moisture loss (g/min) above FSP and below FSP for all treatments.

| | **T1** | **T2** | **T3** | **T4** |
|---|---|---|---|---|
| Above FSP | 0.79 | 0.4 | 1.39 | 0.77 |
| Below FSP | 0.68 | 0.29 | 0.67 | 0.39 |
| Overall | 0.74 | 0.35 | 1.11 | 0.59 |

Notably, the drying rate for T2 was lower than that for T1, possibly because longer idle times led to energy loss, requiring some energy in the subsequent cycle to reheat the samples. A similar pattern was observed for treatments T3 and T4, with exposure times of 1 min and idle times of 2 min and 5 min. Compared to T1 and T2, T3 and T4 exhibited higher drying rates, suggesting that with a consistent exposure time, even with the same power levels, increased drying rates are shown (Table 2). The increased MW power and reduced thickness of the samples resulted in an increased drying rate [16,20]. When drying occurs below the FSP, it requires more energy to reduce bound water. The MC of wood reduced gradually as the average wood MC came near the FSP [21].

Despite achieving a superior drying rate in T1, T3, and T4, the samples exhibited defects such as checks, splits, and warping. In contrast, T2, which had a lower drying rate, produced samples without defects. Thus, the samples from T2 were selected for further experiments. Table 3 shows the mechanical properties of *M. dubia* for both control and MW dried samples. The ANOVA analysis showed a significant reduction when the treatment groups were compared to the control group. In a study by, Balboni et al. [3] the MW treatment of *Eucalyptus macrorhyncha* showed that shear and compression strength decreased in MW-treated samples, but MOE and MOR in static bending remained unaffected.

**Table 3.** Mechanical Properties of *M. dubia*.

| **Properties** | **MOE (MPa)** | | **MOR (MPa)** | | **MCS (MPa)** | |
|---|---|---|---|---|---|---|
| **Treatments** | **Control** | **MW** | **Control** | **MW** | **Control** | **MW** |
| Mean | 7985.15 $^{a}$ | 7549.3 $^{b}$ | 87.2 $^{a}$ | 80.46 $^{b}$ | 39.4 $^{a}$ | 35.71 $^{b}$ |
| Standard Deviation | 1013.80 | 501.01 | 0.86 | 3.44 | 2.44 | 4.02 |

Values with different letters are significantly different from each other at $\alpha = 0.05$.

The Caribbean Pine timber was MW-dried at two distinct power levels and found that MW drying led to a substantial 60% reduction in the strength of the dried timber [15]. In Table 3, it is shown that the MOE and MOR of MW-dried *M. dubia* samples were reduced. The reduction in MW-dried samples was around 5% in MOE and a 7% reduction in MOR. High-intensity MW treatments or prolonged exposure leads to more substantial reductions in strength [5,22]. When oak (*Quercus pyrenaica*) wood was exposed to microwave for 10 min, it showed a drastic reduction in compressive strength as compared to 5 min of exposure [22]. Table 3 also shows a reduction of 9% in the compressive strength for the MW-dried *M. dubia* samples. A reduction of 10% in compression strength parallel to grain was observed when *Eucalyptus macrorhyncha* was treated with different MW intensities [3]. *Fagus sylvatica* L. showed a reduction of 35–41% of the MCS values when compared to the untreated samples [23]. In another study, *Eucalyptus globulus* showed a 12% reduction in MCS when treated with MW [24]. The reason for such a reduction can be the damage of the microstructure and the generation of macro cracks [14].

The sub-alpine fir (*Abies lasiocarpa*) and larch (*Larix gmelinii*) wood subjected to steam explosion showed significant damage to microstructures [25,26]. During the MW treatment, intensive MW irradiation generates high steam pressure, causing the rupture of wood ray cells, lamella cells, and other microstructures [6,7,27]. Lu JianXiong et al. [28] found that the steam pressure produced during high-frequency vacuum drying can lead to the development of cracks adjacent to cross-field pits in Chinese fir. In another study, it was reported that the damage induced to vessels increased as the MW exposure time increased [29]. The breakages in microstructures or little damage in the ray cells and other cells lead to a reduction in mechanical properties and the increased permeability of wood [14]. Some cracks extend along both the radial and longitudinal (RL) planes; they not only weaken the tracheid structure but also lead to stress concentrations. These concentrated stresses further exacerbate the risk of cell wall fractures and reduced mechanical properties [28]. Consequently, such microstructural damage may directly lead to a significant reduction in the mechanical properties of the wood.

## 4. Conclusions

In wood-drying technologies, MW treatment emerges as a potential method, offering an accelerated drying rate. Through our study on *M. dubia*, we observed the significant effects of MW treatment on the mechanical properties. These findings explained a clear correlation between the intensity and duration of MW exposure and the resulting changes in wood properties. While MW drying accelerated moisture removal, leading to reduced drying times, it also induced structural changes in the wood, notably in the microstructure of wood. These changes in microstructures result in reduced mechanical properties. Future research should focus on refining MW treatment parameters, optimizing drying protocols, and comprehensively assessing the long-term implications on wood quality and performance for different timber species. The MW treatment demonstrated promising results, suggesting a need for further studies to optimize permeability without compromising strength. While MW drying presents a promising avenue for the timber industry, its application requires a cautious balance. Future studies should focus on refining MW treatment and industrial application with pilot plant-level studies.

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