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Study on Effect of Microwave Treatment on Wood Permeability and Preservative Retention in Imported Timber

Sauradipta Ganguly[1] and SadhnaTripathi[2]

[1]*Research Scholar, Wood Preservation Discipline Forest Products Division Forest Research Institute Dehradun, Uttarakhand*
[2]*Scientist –G, Wood Preservation Discipline Forest Products Division Forest Research Institute Dehradun, Uttarakhand*
E-mail: [1]sauradipta.ganguly@gmail.com, [2]tripathis@icfre.org

Abstract—*In the present time many imported timbers are being used in Indian industries for different end uses, which need to be studied thoroughly for durability improvement for sustainable service life. Thus, in the present study Teak and Southern Yellow Pine (SYP) wood of imported origin were exposed to microwave treatment. Microwave treatment was applied to the specimens of both the species at 112.65 WCm*$^{-2}$ *intensity for three different intervals viz 4 min, 4.5 min, 5 min followed by dipping for 5 mins in water based, environmentally safe preservative ZiBOC. It was observed that substantial max. retention of 7.03 Kg/M*^{3} *could be achieved in soft wood SYP while in hard wood it was only about 2 Kg/M*^{3}*. Thus, the Tectonagrandis wood specimens were again subjected to pressure treatment which resulted in substantially higher retention. Samples were left for 21 days for mobilization/ impregnation and fixation of preservative. Results revealed that an average retention in teak was increased to max. about 8 Kg/M*^{3}*.This shows that hard wood has lower permeability than soft wood. It was confirmed further by splitting samples into equal halves and through colour spot test which substantiated the results and revealed 95% impregnation in soft wood and 80-90% in hard wood with pressure treatment. The research results aim to demonstrate that this treatment method could be applied to increase the permeability and retention of preservative in wood. However high intensity and exposure for longer duration had resulted in charring and checks in the inner core or surface.*
Keywords: Microwave, Permeability, Impregnation, Treatability, SYP (Southern Yellow Pine), Tectonagrandis.

1. INTRODUCTION

Wood is arguably the most important forest product harvested from forests, so far as human civilisation is concerned. However, rapid industrialisation resulted in depletion of forest cover worldwide, making this resource dearer. Acute crisis of raw material is one of the biggest concerns that the wood industries of India are facing, lately. Very low permeability and the subsequent shallow penetration of preservatives, in many wood species in use, has been another major cause of apprehension in the woodworking sector for quite a while now. The fissure between supply and demand of raw material is ever increasing. Whereas the policies developed, to maintain green cover across the country, in many ways worked in favour of the Government as several reports highlighted in the past, at the same time several innovative ideas are coming up too, to make the wood in use more durable and to ensure its sustainability for a longer run. Most of these innovations are sustainable and are capable of phasing out older techniques used in this sector for ages.

Microwave wood modification is one such eco-friendly technique, that not only aims at minimizing the requirement of energy for several wood working operations by merging extensive and rigorous processing parameters such as seasoning and treatment of timber, but also significantly improves its permeability and preservative uptake, resulting in its viable use for a longer period which in return helps in carbon trapping for eons.

In general, wood contains a certain amount of moisture in it and in most of the wood treating methods, this significant amount of moisture in the wood cell cavities may decelerate or prevent the penetration of the preservative chemical.

In the cases where the moisture content in wood is very high, the microwave treatment is found to be very useful especially in freshly felled logs where moisture content ranges from 40% to 250%. Wood exposed to intense MW power generates steam pressure within the cells. Under high internal pressure the weak ray cells are ruptured to form pathways for easy transportation of liquids and vapours. Greenwood readily absorbs Microwave energy because of its high moisture content. The incidence of MW energy through wood results in an abundant release of high energy from within the material. Wood has dielectric properties. The dipolar components of its molecules couple electro statically to the microwave electric field and tend to align themselves with it mechanically **[6].** The two positively charged hydrogen ions and double negatively charged single oxygen ion of water molecule rotate and align with the electrical field direction. Due to the variation in the microwave field, a reversal of the field causes the molecules to realign at 180^o causing a vibration. The dipoles, therefore, attempt to realign as the field reverses, and so are in a constant state of mechanical oscillation at the microwave frequency. This process manifests itself as heat **[7],[3]**, and causes the temperatures inside the wood to rise. The energy is directly transferred into the wood, absorbed by water molecules and changed into heat. The microwave has the ability to maintain an adequate moisture flow to the evaporating surface and therefore helps in extending the constant drying rate beyond the critical moisture content for wood **[12].**

An increase in the intensity of microwave energy applied to wood increases the internal pressure, forming narrow voids in the radial and longitudinal planes. Manifold increase in permeability in the radial and longitudinal directions can hence be achieved in any wood species that have been previously reported as impermeable by using this technique. Microwave modification of wood enables opportunities for developing a number of new industrial applications such as; rapid preservative treatment of heartwood of softwoods, the treatment of refractory wood species with preservatives, rapid drying of hardwoods and new wood-based material production. Additionally, it is also found helpful for impregnation with preservatives and resins, providing a uniform distribution and uptake throughout.

On the other hand, to achieve the required degree of wood modification, the applied MW power must be high enough to boil water within the wood to create high steam pressure in the cells to rupture the required elements of the wood structure. However, the MW power level must be lower than that, which initiates wood burning which may otherwise, result in wastage of resources.

2. MATERIALS AND METHODS

To study the effects of MW treatment on preservative uptake, MW heating was carried out on wood specimens of soft wood spp. Southern Yellow Pine (SYP) and hardwood spp. *Tectonagrandis*. Samples were made from imported seasoned sleepers and while preparing the samples, care was taken to select defect free planks. Sothern Yellow Pine and *Tectonagrandis* wood of imported origin were procured in the form of sleepers from local vendor and were converted into specimens of desired dimensions. Experimentation was carried out at Forest Research Institute, Dehradun. Relatively straight grained and defect free specimens liberated from insects, borers, termite attack or any other notable microbial contamination were chosen so as to obtain best result.

2.1 Specimen Dimension

Specimens of Size (35mm*35mm*35mm) were prepared for the proposed study, at Wood Preservation Discipline, Forest Research Institute, Dehradun.

2.2. Determination of Initial Moisture Content (IMC)

The initial moisture content of the specimens was determined by Oven Dry method **[4]**. Five samples of each species were selected and the mean value was recorded to determine the MC of the lot. MC found, was in the optimum range of 12.22% for Southern Yellow Pine and 14.57% for *Tectonagrandis* prior commencement of experimental work.

2.3. Distribution of Samples

Each set of experiment consisted of 10 replications and 1 control. Preservative ZiBOC, used for the experiment was of 2% concentration**[11]**.Sample distribution per species and exposure time is briefed in the table below. While performing the experiment, effects of MW exposure for three different time periods were observed at a fixed intensity level of 112.65W/Cm^2. Samples of both the species were exposed to MW radiation respectively for 4, 4.5 and 5 mins.

Table 2.3.1: Distribution of Samples

Teak		Treatment Time	SYP	
T1= ZiBOC	Replicates		T1= ZiBOC	Replicates
$T1X_{(1-10)}$	10	4min	$T1A_{(1-10)}$	10
$T1Y_{(1-10)}$	10	4.5min	$T1B_{(1-10)}$	10
$T1Z_{(1-10)}$	10	5min	$T1C_{(1-10)}$	10
Control	3	No Treatment	Control	3

Where X, Y, Z are replicates of 4, 4.5 and 5min exposure respectively for Teak and A, B, C denotes the same for SY Pine specimens.

2.4. Microwave Treatment

Specimens of both the species, received treatment at three time intervals:

a) 4 Mins b) 4.5 Mins and c) 5 Mins

All specimens (except the controls) of both the spp. were subjected to MW treatment at different time periods viz. 4min, 4.5 min and 5 min and same intensity level of 112.65 W/Cm^2, which was kept constant throughout the experiment. During the microwave treatment, free and bound water are liable to be removed thus it creates internal steam pressure that in return could “open-up” the internal structure by creating micro-voids, possibly break aspirated pits/tyloses and/or increase permeability **[1]**. Several reports indicate that, it improves wood properties such as permeability and treatability.

2.4.1. MW Treatment Equipment

MW Oven (model: 30SC3) with maximum output power 900W at frequency 2450 MHz was used for the experiment as shown in plate 1.

Plate 1: Microwave Oven (Model 30SC3)

2.4.2. MW Treatment Procedure:

In the present study, samples of both the species were weighed individually prior being exposed to MW radiation for different intervals as mentioned above (Table 2.3.1). MW treatment was carried out in a microwave heating device (model: 30SC3) at frequency 2450 MHz with maximum output power 900W with power density (intensity) of 2300 W/cm^2. MW treatments were carried out for three different exposure times at a fixed intensity level. Intensity level was kept at 60 throughout the experimental procedure. Specimens were exposed to MW, one at a time. During this heating, the samples were placed at the centre of the heating plate in vertical position. Intensity was calculated using the formula given below:

$$\text{Intensity} = \frac{\text{Total Power intensity (Density)} * \text{Intensity Level}}{\text{CrossSection (area)}}$$

2.4.3 Dipping or Soaking in Water Borne Preservative:

Specimens belonging to both the species received this treatment. In this process the microwave treated wood specimens were soaked in preservative solutions of ZiBOC (2%) for 5mins immediately after being removed from the oven and checked for absorbed quantity of the preservatives on wet weight basis.

The absorption depends upon the type of wood, its moisture content, thickness and nature of the penetrating chemicals. Given sufficient time, thorough penetrations can be obtained. This method is most suited to woods which are refractory to treatment under pressure after drying.

In the present study SYP and *Tectonagrandis* species were taken. The MW treated specimens of both the species were pre-weighed (W1) and soaked in water soluble preservative solutions mentioned above in preservative tank/ storing unit **[9].** Ten samples and one control were taken for each set of exposure duration per species as mentioned above. After the microwave treatment, specimens were dipped immediately into preservative solution to get better absorption and optimum retention of chemical. Afterwards, weight of the samples was noted down. After each treatment, the samples were taken out and the excess preservative was blotted out with filter paper to ensure there was no excess preservative on samples and specimens were weighed (W2) immediately to determine the preservative uptake and retention **[5].** Controls were maintained without MW treatment which was only dipped and subsequent weights were noted down.

2.5. Pressure Treatment of Teak Specimens

Teak being a hardwood species of refractory nature, is relatively difficult to treat and impregnate. Similar end result was on offer in this case as well as the desired penetration and retention could not be achieved by means of the regular soaking and dipping procedure followed otherwise. Hence, Teak samples were subjected to 2 hours of pressure treatment in a pressure chamber by full cell method. In this case no vacuum was applied/ required as the samples were MW treated already. Samples were put under a pressure of 150 psi for 2 hours and dipped overnight so as to obtain optimum retention level. Result obtained was satisfactory and in accordance to the range mentioned in Indian Standards.

Plate 2: Pressure Chamber Loaded with Charge

2.6. Retention

Retention is defined as the amount of preservative solution absorbed by block after treatment. (retention value in kg/m^3) The value for the same was calculated for each specimen as follows **[2]**

$$\text{Retention(R)} = \left(\frac{GC}{V} * 10\right) \ \text{Kg/M}^3$$

Where,

G = Mass of the treating solution absorbed by block in gm;

C = Mass of the preservative present in 100g of the treating solution, in gm;

And, V = Volume of the test block, in cm^3.

2.7. Spot Test for Determination of depth of Impregnation:

The treated specimens were kept for conditioning for 3 weeks for mobilization, fixation and absorption of the preservatives. After that these specimens were cut into two halves to examine the presence and distribution of copper in interior of wood surface by spot test using Chrome Azurol, as an indicator of copper.

The indicator was prepared by dissolving 0.5g Chrome Azurol-s and 5.0g of Sodium acetate in 80ml distilled water and diluted to 100ml **[2].**

The prepared solution was then sprayed over cut surface of treated wood and allowed to dry. The change of wood surface to deep blue colour showed the presence of Copper.

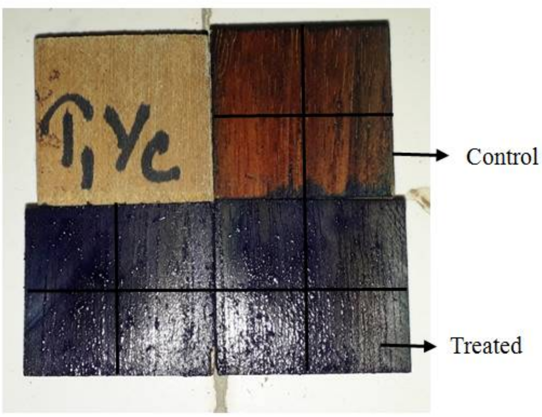

Plate 3: Spot test showing penetration of preservative (Control Vs. Treated).

2.8. Spot Test to Determine Penetration Percentage

The penetration of the preservative in each sample was determined by cross cutting the sample in the middle to expose a fresh cross section. The exposed surfaces were then sprayed with Chrome Azurol S solution to indicate the presence of copper. The wood turned blue where the preservative (copper) had penetrated, whereas, the untreated zones remained same (Plate 5). The area of the treated zone and its percentage on total cross section was calculated visually by measuring penetration of preservative in each specimen. The retention and penetration data was analysed as per **[5],** to evaluate the treatability class **[10].** Where different treatability classes are defined on total area covered by colour developed for copper.

Class a: Very permeable; impregnated cross-cut area (ICCA):65-100%; (3.8×3.8cm cross-section)
Class b: Permeable; ICCA: 47-65%
Class c: Moderately permeable; ICCA: 21-42%
Class d: Very resistant; ICCA: 10-15%
Class e: Impermeable; ICCA: nil.

The above stated classification is based on the criteria of preservative impregnated cross-cut area of specimens. Whenever the treatment data did not suffice and comprehend with the above classification criteria, classification was made to the nearest class. On the basis of penetration and retention of preservative in specimens resulted from different treatments.

2.9. **Statistical Analysis**

The data obtained during the experiment were processed to find the deductions briefed in the result and discussions and conclusion parts of the study. Statistical analysis was performed and suppositions were made using the IBM SPSS 25 Software package.

3. Results and Discussions

3.1. Mean Retention of SYP Specimens

The mean retention obtained for 10 replicates of SYP specimens and the controls for different exposure levels followed by treatment with ZiBOC is depicted in Plate 4 below for 3 different exposures viz 4, 4.5 and 5 mins respectively.

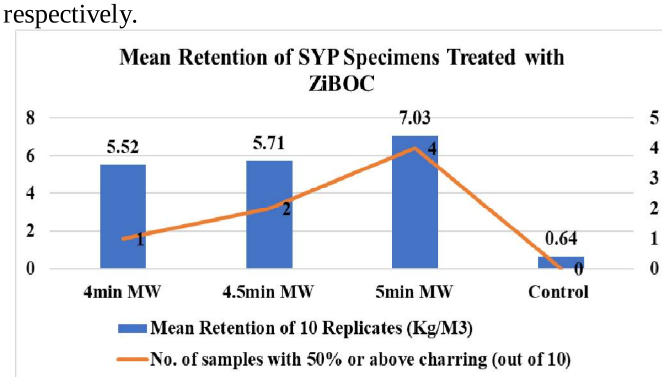

Plate 4: Mean Retention of SYP Specimens Treated with ZiBOC

Mean retentions of 5.52, 5.71 and 7.03 Kg/M^3 were recorded for the SYP samples respectively as depicted above. However, the control samples exhibited only 0.64 Kg/$M^3$of mean retention. So from the above data set it can be inferred that the retention obtained is substantially higher in the treated samples and retention values significantly increase with increasing exposure time that is the difference in retention values obtained for control and treated specimens are statistically significant (Table 3.1.1.)($p \leq 0.05$). Mean retention values for 4, 4.5 and 5mins were respectively 9 to 11 times higher than that of the control samples. The result found is in conformity with the result obtained by previous researchers during similar set of experiments **[8],** Which may be attributed to the fact of generation of higher amount of steam pressure with increased duration which further aids in opening flow paths or channels within the wood micro structure.

Table 3.1.1: ANOVA Table

ANOVA Table					
Dependent Variable: Retention					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Time	94.48	3	31.49	10.82	.000
Error	84.34	29	2.90		
Total	1211.36	33			
Corrected Total	178.83	32			
a. R Squared = .528 (Adjusted R Squared = .480)					

Table 3.1.2: Duncan Table

Retention					
	Species	**MW Exposure Time**	**Number of Samples**	**Subset**	
				1	**2**
Duncan	SYP	Control	3	.64	
	SYP	4 min	10		5.52
	SYP	4.5 min	10		5.71
	SYP	5 min	10		7.03
		Sig.		1.0	.148

The Duncan's test for homogeneity further substantiates the claim and the Duncan table (Table 3.1.2) exhibits further that at the given confidence interval ($p \leq 0.05$), retention value shown by the control specimens are statistically different than those of the treated specimens as both are part of different subsets. However, there is no significant statistical difference between the treatments irrespective of the exposure time. That is the retention attained by the preservative at all times of treatment was statistically similar.

The optimum condition returning the best yield that is lower material loss and maximum retention can be hence selected and recommended for further processing.

Here, though the retention value increases with increasing exposure time, the no. of samples showing excessive charring increases proportionally too. So for dry samples 5mins exposure time is not recommended as 40% material lost is incurred as depicted in plate 4.

3.2. Mean Retention for Teak Specimens

The mean retention obtained for 10 replicates of Teak specimens and the control for different exposure levels followed by treatment with ZiBOC is represented in plate 5 below for 3 different exposures viz 4, 4.5 and 5mins respectively.

The set of data obtained as shown in plate 5 indicate that for hardwood teak the increase in retention with increasing exposure time is marginal and almost negligible, in this case, teak samples were subjected to pressure treatment without applying any vacuum as simple dipping and soaking were not enough to obtain optimum retention.

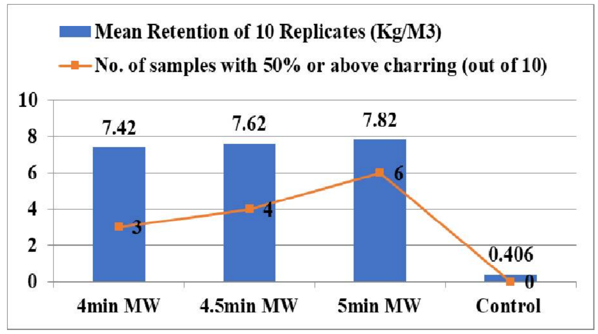

Plate 5: Mean Retention for Teak Specimens Treated with ZiBOC

In case of teak, however the no. of samples with charring and surface deterioration was significantly higher and a similar trend of the occurrence of charring increasing with high exposure was followed as was seen in case of SYP. This could be attributed to the fact of teak being a refractory species and the degree of occlusion in it being more than the other hardwoods in use. Furthermore, in pine the manifestation of charring might be less due to the presence of resin in it which was leached out during the process, creating broader pathways within the microstructure and preventing burning within the interior. In this experimental setup, for time periods 4, 4.5 and 5mins, 14 to 24 times higher retention was attained than that of the control. However, 3,4 and 6 samples showed more than 50% of charring respectively (Plate 5) for the above mentioned time periods in the same order, which incurs a substantial amount of material loss. So standardizing the parameters is a must prior conducting the experimental trial at the industry level.

Table 3.2.1: ANOVA Table

ANOVA Table					
Dependent Variable: Retention					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Time	142.78	3	47.59	20.85	0.000
Error	66.19	29	2.283		
Total	1810.34	33			
Corrected Total	208.98	32			
a. R Squared = .683 (Adjusted R Squared = .650)					

The analysis for Teak also indicated that the treatments (Control and Treated Specimens) were different (Table 3.2.1) ($p \leq 0.05$). Which ascertains that the control samples showed significantly different (less) retention than the treated ones which substantiates the success of the process overall. Hence, in this case, too, the minimum exposure time resulting in optimum retention and relatively fewer charred samples must be recommended.

Table 3.2.2: Duncan Table

Retention					
	Species	**MW Exposure Time**	**No. of Samples**	**Subset**	
				1	**2**
Duncan	Teak	Control	3	.40	
	Teak	4 min	10		7.42
	Teak	4.5 min	10		7.62
	Teak	5 min	10		7.82
		Sig.		1	.661

The Duncan table (3.2.2.)too substantiates the claim thatin the given confidence interval ($p \leq 0.05$), retention value shown by the control specimens are statistically different from those of the treated specimens as both are part of different subsets. However, there is no significant statistical difference between the treatments (Time intervals). The retention attained at all times of treatment was statistically similar. The optimum condition returning the best yield that is lower material loss and maximum retention can be hence selected and recommended for further consideration.

3.3. Spot Test for Measurement of Penetration Percentage

Visual observations indicated that the control samples of both the species were very resistant (Class d) to preservative treatment due to presence of resin in SYP and tyloses and vessel deposits in teak, which however was converted into very permeable Class a timber by means of the MW treatment (Plate 6) showing ICCA of more than 85% for both SYP and Teak. So using this method, permeability and penetration of refractory timber species can be increased manifold which will be beneficial for the wood working industries in the longer run if implemented successfully.

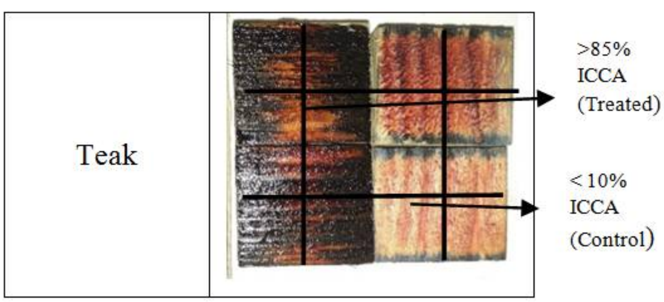

Plate 6: Demarcation of samples for evaluating penetration and depth of impregnation

3. CONCLUSION

From the result obtained, it can be inferred that MW treatment has a positive impact on wood permeability and significantly improves its retention and penetration percentages which are in accordance with similar findings by previous researchers in this particular field. For softwood SYP, the increase in retention was noteworthy whereas, for teak, the initial results with dipping and soaking method were not up to the mark as teak is a refractory hardwood species. Hence, the teak specimens were subjected to pressure treatment additionally, which resulted in optimum retention**.**

This study and findings, in particular, might well be advantageous for all handicrafts and other such medium and small-scale wood-based industries where a considerable amount of energy can be saved by merging the process of seasoning and preservative treatment by MW process. The MW treatment of wood thus gives rise to a greener and cleaner woodworking experience, making the process parameters eco-friendlier and more energy efficient.

Several previous discoveries, however, indicated that the process becomes more useful when wood in use was in a green state with mean moisture content ranging from 50-150%. In these cases, the occurrence of charring and development of cracks on the wood surface were very less and rapid loss of moisture was attained. When the moisture content of specimens was below FSP as it was in this experiment, the occurrence of charring and surface deterioration amplified manifold with higher exposure time which resulted in the material loss and hence such parameters need to be standardized by conducting extensive researches before going for a pilot trial at the industry level.

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