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Effect of Microwave Treatment on Hydrophilicity and Bonding Strength Properties of Woods

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Abstract

It was found that Microwave (MW) assisted wood preservative (WP) treatments affects further lowering swelling and water absortion values for selected hardwoods and softwood species in this study. It is clear that the post MW treated woods effects further reaction or bonding to hydroxyl group (–C-OH) of cell wall constituents to create further water repellent (hyrophobic) surfaces with WP applications. However, the water absorptiveness was found to be lowered extensively on all WP treated samples. The further lowering water absortiveness values calculated for all post MW treated samples. The calculated values have indicated approximately further reducing of 14.9% for Eucalyptus, 6.9% for Poplar, 6.8% Chestnut samples, 7.9% for Cedrus and 18.1% for Pine samples respectively. It has also found that MW treated samples are a clear evidence on increasing bonding strength for all post MW treated wood species. The MW treatments increased bonding strengths of wood in the range of 6.5-20.2% for hardwoods and 5.5-10.4% for softwood species.

Keywords: Microwave, softwood, hardwood, physical properties, bonding strength

Ahşabın Hidrofilikliği ve Yapışma Direnci Üzerine Mikrodalga Muamelesinin Etkisi

Öz

Bu çalışmanın amacı ahşap materyalin hidrofilikliği ve yapışma direnci üzerinde mikrodalga muamelesinin etkilerini araştırmaktır. Elde edilen sonuçlar mikrodalga (MW) yardımıyla odun koruyucu (WP) muamelelerin seçilen iğne yapraklı ve yapraklı türler için daha düşük su alma ve şişme değerleri göstermiştir. MW muameleli ahşaplar, WP uygulamalarında su itici (hidrofobik) yüzeylerin oluşumunda hüçre duvarı bileşenlerinin hidroksil gruplarına (–C-OH) bağlanması ya da reaksiyon oluşumunu etkilediği açıktır. Fakat su emiciliği tüm MP muameleli örnekler üzerinde önemli ölçüde düşürdüğü bulundu buna karşın çok daha fazla su su emiciliğindeki azalma MW muameleli örnekler için elde edilmiştir. Hesaplanan değerler Ekaliptus için 14.9%, Kavak için 6.9%, Kestane için 6.8%, Sedir için 7.9% ve Çam için 18.1% oranında azalma göstermiştir. MW muameleli örnekler yüksek yapışma direnci üzerinde açık bir kanıt gösterdiği bulundu. MW muameleleri yapraklı ağaç odunları için %6,5-20 ve yapraklı ağaç türleri için %5,5-10,4 arasında yapışma direncini artırdı.

Anahtar kelimeler: Mikrodalga, iğne yapraklı agaç, yapraklı ağaç, fiziksel özellikler, yapışma direnci.

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1. Introduction

The development of the cavity magnetron made possible to production of electromagnetic waves of a small enough wavelength like microwaves. However, micowave oven is work at non-ionizing electromagnetic radiation with a frequency in one of the Industrial Scientific Medical (ISM) bands in order to prevent with other frequencies (radio services) (Hansson, 2007).

However, the primary heating effect at microwave frequencies occurs via the dielectric heating, as polarized molecules are affected by a rapidly alternating electric field (Appleton, et al.2005). It has proposed that depending on water content of substrates, the depth of initial heat deposition may be several centimetres or more with microwaves, in contrast to convection heating methods which deposit heat outer most level at the surfaces (Appleton, et al.2005; Hansson, 2007; Ohlsson & Bengtsson 2001). Moreover, it should be noted that 2.45 GHz microwaves could be penetrate approximately 1.0 cm into most substrates (i.e. foods) (Anon 1).

Kržan and Žagar (2009) utilized microwave to wood liquefaction in glycols. They proposed that microwaves offers very rapid heating throughout the volume of the reaction mixture, and has been shown to cause reaction acceleration in many cases. Mekhtiev and Torgovnikov (2004) has developwed a method to analysis of microwave (MW)-modified Radiata pine and Eucalyptus timbers. Their approaches are based on filling the checks in timber with stain solution and analysing the wood surface. It has reported that microwave (MW) wood modification effects on wood's some elements and forms cavities of various sizes. Oloyede and Groombridge, (2000) suggested that due to wood contains high amount of water, which makes it suitable for microwave heating in very short drying times, very effective penetration into the depth of the wood is possible after microwave oven treatments. But the penetration depth is dependent on substrate and the frequency, with lower microwave frequencies (longer wavelengths) penetrating further.

Moreover, it is important to note that for preventing deterious effects of microwave treatment of substrates like wood, the heating cycles should be used by small time intervals. A detailed study on microwave modification of wood material was conducted by Torgovnikov and Vinden (2005). They claimed that microwave (MW) wood modification provides an increase in wood permeability for liquids and gases while reduces internal stresses in timber. They have hypothesized that the MW conditions could generates steam pressure (internal pressure) within the wood cells resulting in the formation of narrow voids in the radial-longitudinal planes. But, under high internal pressure, the weak ray cells are ruptured to form pathways for easy transportation of liquids and vapours in the radial direction. In addition, MW could also effects some physical properties of woods that could be improved; permeability, acoustic properties, impregnation/liquid uptake, drying while could be reduced; heat conductivity, shrinkage and swelling (Torgovnikov and Vinden 2005).

It has proposed that the 60 kW, 2.45 GHz MW generator could be supply an intensity of 5.3 kW/cm2 to the wood. Such MW intensity effects for wood modification. It has also suggested that the high levels of MW intensity provide a high level of energy release in the wood. However, the energy release required for MW wood modification must be in the range of 300-2000 J/cm3 (or MJ/m3) (Torgovnikov and Vinden 2005).

Sun and his groups (2009) found that microwave plasma (MWP) technique could be used to improve of wood surface wettability and bonding properties on teak wood. It was reported that the modification effect improved when the sample was located 120 mm from the resonance cavity, rather than at 80 mm. However, over a short span of time is useful to lower the contact angles and improve the surface wettability considerably.

A detailed study on the impact of microwave treatment on wood properties was conducted by Hansson (2007). He speculated that increasing densities and moisture contents result in decreased power penetration depth while the MW penetration depth is correlated by the dielectric properties of wood. However, it was proposed that the uneven internal wood temperature is caused by the electromagnetic field distribution and the power penetration depth in which the higher the moisture content, the less is the power penetration. In addition, the temperature has not much impact on the power penetration depth in to wood structure. For an example for that is the microwave energy penetrates deeper into frozen wood than into wood at room temperature Hansson (2007).

The primary objective of this study was to determine the swelling, water absorption and glue bonding of Microwave asisted and wood preservative treated of five different wood species that three hardwood (Eucalyptus, Poplar and Chestnut) and two softwood (Cedrus and Pine) species. Knowledge of these properties and relation with MW conditions may be essential for establishing new wood modification tecqnique.

2. Material and Methods

Eucalyptus (Eucalyptus camaldulensis Dehn), Poplar (Populus canadensis), Chestnut (Castanea sativa Mill), Black pine (Pinus nigra, Arnold) and Cedar (Cedrus libani, A. Rich) woods were selected for surface treatment agent (Wood Preservative; WP) and Microwave (MW) treatments. The samples were cut in the dimesnions of 50×50×10 mm for shear bonding experiments, 20×20×15 mm mm for swelling and water intake determinations. Only distilled water was used in all conditions. The wood samples were oven-dried for 48 hours at 50 °C prior to experiments. The oven-dry density of woods was calculated as 0.39, 0.48, 0.56, 0.58, and 0.60 gr/cm3 for poplar, eucalyptus, chestnut, pine and cedar, respectively.

A commercially available oil-modified solvent-type alkyd resins of wood preservative (WP), were supplied from retail stores. The wood samples were subjected to treatment by soaking in WP solution for 1.0 min.

All swelling measurements were made at room temperature with digital Mitutoyo-500 caliper (± 0.02 mm). Water absorption data were obtained by placing the wood samples in 1500 ml flasks containing distilled water. Experiments were conducted at 25 oC and for immersion period at about 24 hours. After soaking, the moisture content of samples was calculated based on the increase in the sample weight. The samples were rapidly removed and superficially dried on a large filter paper to eliminate the surface water. The samples were then weighed to determine the moisture uptake. At least three experiments were conducted for each wood sample and the mean results were used for further analysis.

PVA having a polymerization degree of 1200 and solid content of 50% was supplied from retail store. The microwave treatments (MW) of wood substrates were conducted using a commerically available general purpose microwave oven with 0-600 Watts operationable power level. Only selected wood species treated in MW and then the adhesive was applied with a brush at an application rate of 200 g/m2. The samples were pressed for overnight at room temperature (23 ± 2°C). The shear tests were conducted for determining bonding strength properties of samples using a Zwick–Rowell universal testing machine with 10 kN load cell at a rate of 5 mm/min according to EN 392 under room temperatures (23 ± 2°C). The loading were applied on the surfaces of the bonded samples in the vertical direction under displacement control. Specimens were loaded until the onset of cracking. At least ten specimens were tested for each composition, and the average values of the obtained results are presented. The shear strength was calculated by dividing the tension load by the area of overlap.

$$\tau = \frac{F_{max}}{\text{Surface } (a \times b)}$$

Where τ is lap shear strength (LSS), Fmax is the tension load, a is the length of the specimens, and b is the width of the specimens.

3. Results and Discussion

The comparative tangential swelling (%) properties of three hardwood (Eucalyptus, Poplar, Chestnut) and two softwood (Cedrus and Pine) species are shown in Figures 1 and 2, respectively.

The untreated Eucalyptus, Poplar and Chestnut samples show tangential swelling values of 6.54%; 5.65%; and 7.61%, respectively. However, after WP treatments (surface agent), the swelling values reduced significantly. The lowering rate of swelling of treated samples was found to be 28.7% for Eucalyptus, 3.4% for Poplar and 51.5% for Chestnut samples, respectively.

However, it was realized that the MW treatments before WP application have clear effects on hardwoods hydrophilicity (Figure 1). It could be seen that MW assisted WP treatements effects further lowering swelling values for Eucalyptus and Chestnut samples while Poplar samples show some variations. Interestingly, Eucalyptus has high swelling initially in contrast to Chestnut that lower swelling initially but when MW treatment conditions (power and time) increases, both species show more less similar trend as lowering swelling properties. The lowest swelling of 4.24% for Eucalyptus and 4.99% for Poplar woods found at 90 Watts and 150 second MW contions while a swelling value of 2.83% for Chestnut calculated at 180 Watts and 60 second MW treatment level.

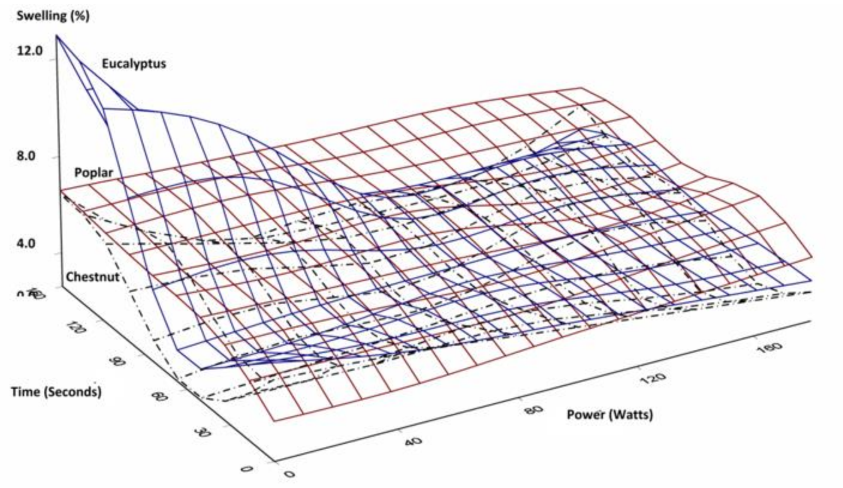

Figure 1. The swelling (%) properties of MW treated hardwoods.

The untreated Cedrus and Pine samples show trangential swelling values of 5.20% and 8.65%, respectively. As a result of only WP treatments; the swelling properties lowered 49.1% and 28.3% for Cedrus and Pine samples, respectively (Figure 2). However, MW assisted WP treatments have further lowering effects on hydrophilic properties of samples that the lowest swelling rate of 1.94% calculated for Cedrus at 180 Watts and 30 second while 5.51% for Pine at same power level but 60 second, MW treatment conditions.

When Figure 2 carefully reviewed, it could be seen that Cedrus shows a decreasing swelling property when higher MW power level used at short treatment conditions. In contrast, although MW treatments somehow lowering effects on swelling at certain conditions that Pine samples shows a smooth trend that not clear effects realized with MW treatmens. These observations are important considering selected wood species and MW conditions have improving effects at certain conditions on MW assisted WP applications on Pine and Cedrus woods.

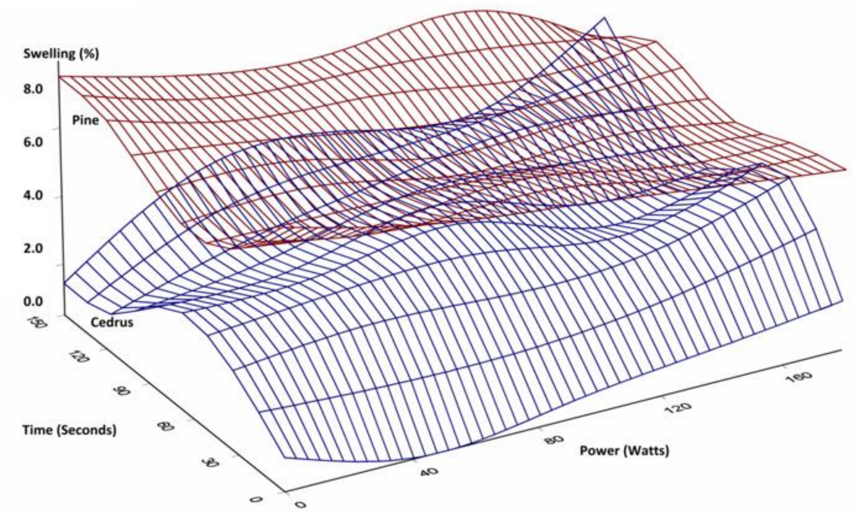

Figure 2. The swelling (%) properties of MW treated softwoods.

Some wood properties such as; species, structure, moisture content, density and morhology could be affect during MW treatments. However, the swelling of wood species usually correlated with wood density and water diffusion property. At the beginning of wood-water interactions, capillaries and cavities near the surface are filled up very fast with water. However, when WP treatment is occur on wood substrates, the moisture movement is restricted to inside the material. Although water moves freely in the large cavities, but in the WP treatments effects trapped these cavities that negatively influences the water movement inside the material that resulting lowering swelling properties. Moreover, from MW treatment results, it may be suggested that the water movement inside wood substrate could be lowered that reflecting a lower water diffusion coefficient that MW asisted WP treatment may effects further reaction or bonding to hydroxyl group (–C-OH) of cell Wall constituents to create further water repellent (hyrophobic) surfaces. The results found above suggest this hypothesis.

Figures 3 and 4 shows water intake (absorption%) of selected hardwood (Fig.3) and softwoods species (Fig. 4) with correlation to MW treatment conditions.

As expected, WP treatment could be improved water absortiveness properties some level. It can clearly seen that wood types affect the subsequent water intake characteristics. In all cases, the level of water absorptiveness was found to be lowered extensively on all WP treated samples (Figure 3). Initially, the water absorptiveness was about 62.4% lowered for Eucalyptus, 52.3% for Poplar, and 73.4% for Chestnut, respectively. However, the water absorptiveness further decreased with MW treatments. The lowest water absortiveness value of 37.13% and 47.19% were found at 180 Watts and 150 second MW treatment conditions for Eucalyptus and Chestnut species, respectively. Moreover, for Poplar wood, the lowest water absorption value of 70.3% was found at 90 Watts and 120 second MW treated sample. These calculated absortiveness have indicated approximately further reducing of 14.9% for Eucalyptus, 6.9% for Poplar and 6.8% Chestnut samples, respectively.

Plot with MW treatment conditions (power level and time) effects on water absoprtiveness properties of Cedrus and Pine wood species are shown in Figure 4. The MW treatments and their effects show interesting variations in the initial and subsequent conditions. It can be confirmed that MW was an effective way, a markedly improving dimensional stability was achieved for both woods. Initially, the water absorptiveness was about 101.4% for Cedrus and 90.0% for Pine woods. However, WP lowered 71.6% for Poplar, and 166.6% for Pine, respectively. However, it further decreased with MW treatments that the lowest water absortiveness value of 26.7% found at 180 Watts and 90 sec treatment conditions for Cedrus while 27.6% was found at 180 Watts and 30 sec treatment conditions for Pine. These calculated absortiveness have indicated approximately further reducing of 7.9% for Cedrus and 18.1% for Pine samples, respectively.

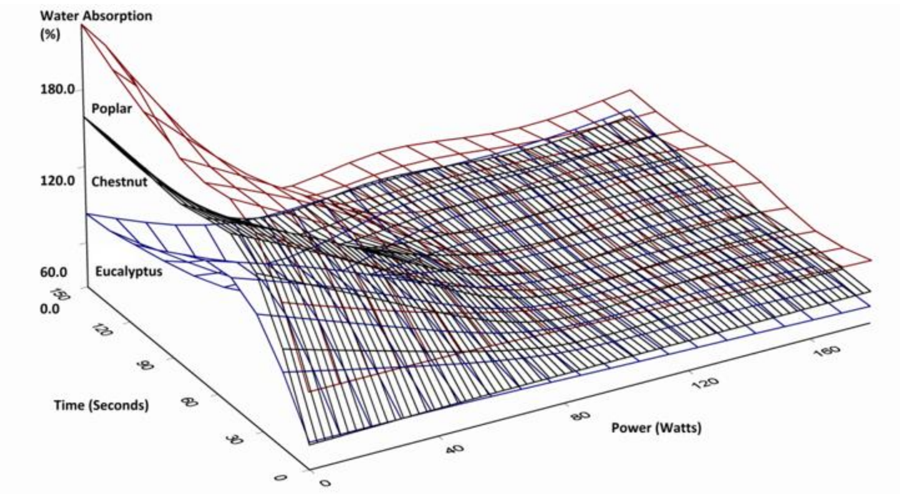

Figure 3. The water absorption (%) properties of MW treated hardwoods.

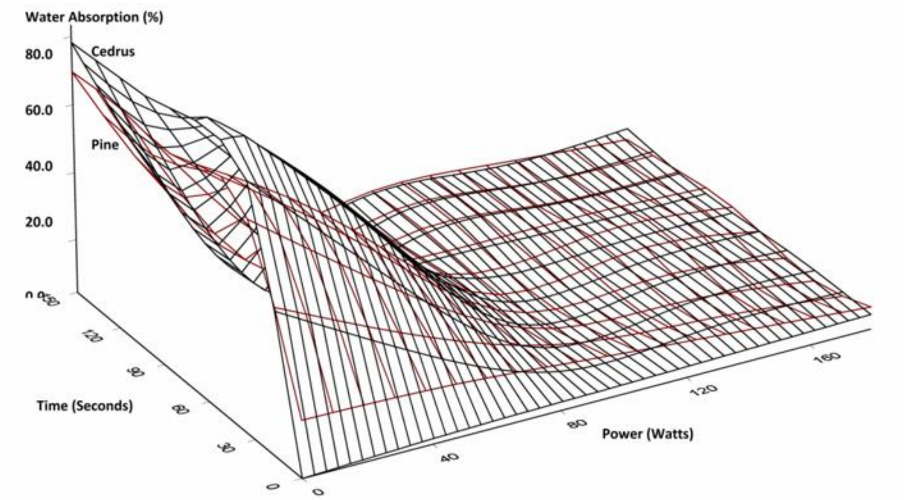

Figure 4. The water absorption (%) properties of MW treated softwoods.

These comparison between the wood species and the measured results reveals that the water absorptiveness response of selected woods can be quite well predicted. However, the selected samples in this study presented characteristic water absorption behaviour that untreated samples exhibited an initial high rate of moisture sorption followed by lowering with WP treatments. However, the pattern of water uptake suggests a further lowering with MW asisted WP application. This could be explained that the chemical composition and the cell wall organisation in the hardwoods differ so much from the softwoods, that they can affect the water intake. However, the density of the samples may also affect the diffusion coefficient of the wood samples. But lowering water absorption rate of MW treated and WP applied samples can be explained by the diffusion phenomenon. It is clear that MW effects modification of cell Wall molecules and creates further reachable surfaces for WP to reacting linkages.

It has alreday pointed number of researchers that microwave technology can be applied to the modification of wood, making it possible to improve some properties such as; glueabiliy, permeabailitry, dryability, swelling/shrinkage so on. (Johansson, 2001; Lundgren, 2007; Torgovnikov and Vinden 2000 and 2005). Because wood has appropriate amount of water, which makes it suitable for microwave heating in very short times into effective penetration. It has alreday reported that the plauasable explanation of these modification might be possible to create further creating surface and or reaction areaa inside wood that could be bonded with other substrates (glues, surface agents or water molecules). The experimental results found in this study with post MW treated and WP applied wood samples consisted with these literature reports.

The MW assisted adhesive bonding properties of four wood species are presented in Table 1. It can be clear evidence that MW treated samples exhibited an initial high bonding strength (at 60 second) followed by lowering at 120 second conditions for Poplar, Cedrus and Pine species, respectively. In contrast, Eucalyptus show lower bonding strength at 60 second while increased at 120 second treatment conditions. The highest bonding stregth of 1.47 N/mm2 was found for Eucalyptus, 1.07 N/mm2 for Poplar, 1.48 N/mm2 for Cedrus and 1.15 N/mm2 for Pine species that these values shows aproximately 6.5% higher for Eucalyptus, 20.2% higher for Poplar, 10.4% higher for Cedrus and 5.5% higher for Pine wood samples, respectively.

Table 1. The bonding strength (N/mm^2) properties MW treated woods (at 90 watts).

	Eucalyptus	Diff. (%)	Poplar	Diff. (%)	Cedrus	Diff. (%)	Pine	Diff. (%)
Control	1.38 (0.09)	-	0.89 (0.06)	-	1.34 (0.1)	-	1.09 (0.02)	-
60 sec.	1.11 (0.21)	-19.6	1.07 (0.18)	20.2	1.48 (0.02)	10.4	1.15 (0.14)	5.5
120 sec.	1.47 (0.14)	6.5	1.0 (0.17)	12.4	1.19 (0.12)	-11.2	1.04 (0.03)	-4.8

Figure 5 show a macroscopic analysis of wood-wood bonding surface chracteristics after shear bonding tests. These pictures clearly shows that the MW treatments at various level could be effects in either decrease or increase bonding between woods. However, these observations also indicate that certain level bonding strength improvements (Fig.5 C, F-I).

Figure 5. The effects of MW treatment conditions on bonding surface after shear bonding tests (A and B: typical

shear test placements; C, D and E: Typical bonded wood surface after sheap bonding test, F-I: strongly bonded wood surfaces after shear test).

The bonding of wood is very complicated process. However, wood is basically a series of tubular fibers or cells cemented (lignified) together. The mechanical properties change with specific conditions (i.e. thermal) can have significant effects on the bonding strength of wood. Moreover, adhesive can flow into cavities (pores) to develop a mechanical interlocking.

It has suggested that for achieveing suitable degree of wood modification with MW, power level must be high enough to boil water within the wood to create high steam pressure in the cells to rupture the elements of the wood structure. In this level, it is possible to create further reacting surfaces and potantial areas for fluids (i.e adhesive). The result found in this study support this opinions. Moreover, bond strength is dependent on the distribution of internal forces, such as expansion and contraction of the wood in addition to applied forces. Therefore bond strength is not limited to bond formation.

4. Conclusion

Particularly wood species that (i.e. hardwoods), have a very low permeability causing problems during gluing or surface treatments. These include, very long drying times, expensive adhesive uses and difficulty in impregnating the wood with resins. But further work is needed to understand the surface modification level (chemically and physically) of wood substrates. Although fundamental principles involved in the interaction of MWs with matter are still not fully understood. However, MW modification of wood could be established opportunities for developing a new industrial applications including effective surface treatment of wood species for rapid and strong bonding.

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