



A Study on Microwave Exposure Effects on Surface Coating Properties of Linden (*Tilia cordata*) and Spruce (*Picea abies*) Woods

Halil Turgut Sahin^{1*#} and Gamze Ozcelik²

¹*Isparta University of Applied Sciences, Faculty of Forestry, Dept. of Forest Products Engineering, 32260, Isparta, Turkiye.*

²*Isparta University of Applied Sciences, Graduate Education Institute, Isparta 32260, Turkiye.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JALSI/2021/v24i530235

Editor(s):

(1) . Dr. Palanisamy Arulselvan, Universiti Putra Malaysia, Malaysia.

Reviewers:

(1) Marko Petrič, University of Ljubljana, Slovenia.

(2) Natalia V. Kamanina, Russia.

(3) Arnaud M. Cheumani Yona, University of Ljubljana, Slovenia.

Complete Peer review History: <https://www.sdiarticle4.com/review-history/71313>

Original Research Article

Received 30 May 2021
Accepted 05 August 2021
Published 10 August 2021

ABSTRACT

The quality performance of surface coatings are evaluated with emphasis on Microwave (Mw) irradiation, on both wood and oil modified alkyd-based varnish, separately. The surface pencil film hardness value of 2B (5 in metric) found for neat varnish coated linden and spruce control samples. It appears Mw exposure on both woods and varnish were effective for further increasing pencil hardness which are about 4 and 5 unit higher than controls. It is also noticeable that a clear improvement for cross-cut (adhesion) properties were realized with Mw treated varnish coated linden woods. Although cold liquid resistance evaluations have conducted with 11 liquids, but coated surfaces were showed the lowest resistance, assessed grade 1 (considerably changes) for five of these liquids (juice, milk, ketchup, lemon juice, cola) regardless of conditions or wood species. Therefore, results revealed some level correlation between Mw conditions and wood samples for six of the cold liquids involved in the examination. Mw treated spruce samples usually show 1 to 2 unit higher olive oil, vinegar, mayonnaise, ethyl alcohol resistance while no any improvement found for coffee and mineral water. Linden samples usually show 1 to 3 unit improving (higher) resistance against all these six cold liquids, regardless of Mw conditions. It is important to

*Corresponding author: E-mail: turkomans@yahoo.com;

0000-0001-5633-6505.

note that all Mw treated and varnish applied wood species subjected to olive oil, mayonnaise and ethyl alcohol show very high resistant properties (graded 4 and 5). Similar results are also realized with applying Mw irradiated varnish to both wood species. These variations and changes could be results of chemical structural changes, including cross-linking by esterification and etherification, promoted by Mw irradiation.

Keywords: Microwave exposure; surface adhesion; pencil hardness; cross-cut properties; cold liquid resistance; alkyd varnish.

1. INTRODUCTION

The surface coating of wood substrates are generally used to protect the aesthetic appearance and deteriorations from creatures [1-3]. These may increase attractive value with improving lifespan of wood substrates [4,5]. However, some surface coatings based on natural and synthetic formulations can fill the wood lumens and cavities, not being chemically well bonded to the cell walls. In this case, the effectiveness of coatings have limiting quality characteristics which are, less resistance to abiotic and biotic factors. Therefore, long-term durability of coatings are paramount importance [1-7].

The influences of coatings on the woods could be found in many literature reports [1-7]. But understanding of interaction mechanisms between coating agent and wood are essential for extending the service life of woods. However, surface reactivity, hardness and resistance against liquids are some important parameters on surface quality assessments. Beside these properties, the surface adhesion is also fundamental, since it provides bonds between the coating film and the wood surface. In this challenging topic, some methods have been developed to improve interaction (adhesion) between surface agents and wood surfaces. For instance, microwave treatment has been suggested to be an effective method for modification of some common wood properties of glueability, permeability, dryability and hydrophilicity which could improved the performances of surface finishing products [8-13].

Microwave (Mw) radiation has become an important alternative approach for modification of materials. The chemical properties of wood and other lignocellulosic sources make them suitable substrates for Mw treatments. The Mw systems have already been used to modify lignocellulosic materials from simple surface properties to

complex structural changes. A microwave system was used to create a super hydrophobic wood surface based on the formation of CoFe_2O_4 nanoparticles and subsequent hydrophobization using fluoridated alkylsilane [14]. However, a novel approach with using phenolic resin via microwave-assisted solvent-free synthesis were prepared [15]. A detailed study conducted on visual, mechanical, and chemical modifications of coatings when exposed to microwave, operated under 2.4 GHz and 750 Watts conditions [16]. It was found mechanical and chemical properties of coatings exposed to microwaves were not changed, while colour and gloss exhibited minor changes [16]. It is very important to control Mw parameters when subjected to wood treatment. Because cell wall polymers could be restrained and become hardened at high temperature levels. Hence, too high energy absorption may cause steam expansion checks. But checking in the wood structure is not to be always desirable for improving its reactivity, depending on the wood species and anatomical properties. It is consistently noticed that for preventing detritus effects, the lower power levels and small-time intervals of Mw should be used [16,17].

Although numerous literature could be found on surface coating evaluations, understanding wood surface interactions are complex and involve changes in many variables [13-20]. Some literature reports has suggested modification of wood substrates for making better adhesion with surface agents [9-12]. But the majority of these studies are usually focused on single parameter (wood and/or coating agent) rather than both while limited studies could be found on surface property evaluations. In this regard, the objective of this study was to investigate Mw treatment effects on woods (spruce and linden) and oil modified alkyd-based varnish, separately to assess the quality of the coating layer on woods.

2. MATERIALS AND METHODS

2.1 Materials

The wood materials of linden (*Tilia cordata*) and spruce (*Picea abies*) samples were selected for this study. An oil-modified, solvent-type alkyd varnish, were supplied from a retail store (A Turkish brand, carried label of K-Q, TS-EN-ISO 9001, KG 708/98). 25 experimental wood samples prepared for each wood species in three different size groups: 11.0×11.0×1.5 cm; 5.0×5.0×1.5 cm and 30×8.0×1.5 cm (length parallel to tree axis x width in radial direction x thickness in radial direction). After preparation in the mentioned dimensions, the samples were kept for 10 days to become air-dry at 23 ± 2 °C and 50 ± 5% relative humidity.

2.2 Methods

2.2.1 Microwave Treatment

A household type microwave oven, operated under 2.4 GHz conditions, was used for the modification of both wood and varnish [(Beko brand, 20 lt capacity with dimensions of 42.5 cm (wide) x 26.2 cm (height) x 32.5 (length)]. It is operated manually for controlling duration of irradiation and power level. Two different set Mw treatments were conducted, that is, Mw treated wood + untreated varnish, and untreated wood + Mw treated varnish, separately. The Mw trials were conducted at power levels of 90-, 180-, 270-, and 360 Watts and at four durations (3.0-, 6.0-, 9.0- and 12 seconds) for woods (Mw treated wood + untreated coating) experiments and 15-, 30-, 45-, 60 seconds for varnish (untreated wood + Mw treated varnish) at atmospheric pressures. For Mw treatments of wood, the small wood samples were placed in the center of the oven and continuously Mw irradiated for a predetermined time. At the end of Mw procedure, the samples was brought to atmospheric conditions, then these Mw treated woods were subjected to varnish treatment by soaking them in varnish for 1.0 min. Similar Mw procedure was also conducted for alkyd varnish. 25 ml varnish in glass tube was Mw irradiated for a predetermined time. At the end of Mw exposure, the varnish was brought to atmospheric conditions and wood samples were soaked in it for 1.0 min. After end of experimental procedures, the varnished and completely dried

samples were air-conditioned for 24 hours at 23 ± 2 °C and 50 ± 5 % relative humidity.

While many combinations were utilized during Mw treatments on wood species and varnish separately, for simplicity, some code number and abbreviations were established throughout the study given in Text, Figures and Tables. These are; s: spruce wood, b: linden wood; 0: control samples; 90, 180, 270 and 360: Mw power level; X: Mw exposed wood, Y: Mw exposed varnish, Xs/b_{3,6,9,12}: Mw irradiation time on woods, Ys/b_{15,30,45,60}: Mw irradiation time on varnish.

2.2.2 Surface coating characterization

The properties the of cured coatings on wood were assessed by cross-cut (adhesion), surface pencil hardness (scratch resistance) and resistance to selected household cold liquids. The pencil hardness tests were conducted on coated wood surfaces by using standard of EN ISO 15184 [20]. The results of the test were evaluated according to the pencil that scratched the surface. There are 13 standard pencils utilized in this experiment. They can be ordered from soft to hard as follows; 6B, 5B, 4B, 3B, 2B, B, HB, H, 2H, 3H, 4H, 5H, 6H. However, in order to compare results more conveniently, the pencil letter values are converted to numeric values as given in Table 1. The test started with the softest pencil (pencil number 6B or numeric 1). The surface coating adhesion properties were determined using cross-cut test procedure. This method could be applied to wood surfaces finished with one or multiple coating layers with a total film thickness not exceeding 250 µm. The adhesion of the coating film was classified according to the standard EN ISO 2409 [21]. The surface resistance to cold liquids was determined according to the standard EN 12720 [22]. All the variants of finished wood surfaces investigated in this research were tested with respect to their resistance to 11 selected cold liquids. Juice, mineral water, milk, cola, ethyl alcohol, lemon juice, olive oil, vinegar, coffee, ketchup, and mayonnaise were used in the experiments, and the effects were observed after 24 h. At the end of the experiments, the surface was cleaned, conditioned and then the tested areas were carefully examined for any visible damage (marks, change in gloss and/or colour, blistering and other defects), being rated accordingly from 5 (maximum grade for no visible change) to 1 (minimum grade for strong mark/degradation).

Table 1. Converted numeric values of pencils

| Pencil | 6B | 5B | 4B | 3B | 2B | B | HB | H | 2H | 3H | 4H | 5H | 6H |
|---------------|----|----|----|----|----|---|----|---|----|----|----|----|----|
| Numeric value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

3. RESULTS AND DISCUSSIONS

Table 2 clearly confirm, Mw irradiation was very effective for increasing surface film hardness for both wood species. However, the pencil hardness values were 2H and 3H (9 and 10 in metric) in all conditions, regardless of Mw time and power level. These are about 4 and 5 unit higher than the control samples which exhibited lower values. A clear correlation was not found between Mw conditions and spruce's pencil hardness values while a better responds were observed with linden samples. Except linden samples that treated in 90 Watt Mw conditions which responds pencil hardness values of 2H (9 in metric), all others show surface pencil hardness value of 10 (in metric) regardless of Mw conditions. It could be speculated that the surface scratch resistance of a wood is a property of a coating film; but it was demonstrated it could be influenced by the Mw irradiated woods. It could be explained that Mw treatment increased adhesion between varnish and woods, probably by removing the low-molecular weight compounds from the surfaces with creating further reactive groups

(radicals) in the porous structure of wood surfaces by forming bonds across the interface. There are numerous literature have already demonstrated very high energy on irradiated substrates could be created by microwave radiations which are enough for cleavage and/or etching of surfaces.

The pencil hardness properties of Mw treated varnish applied on spruce and linden samples, are comparatively shown in Table 3. Mw heated varnish effective for increasing the surface film hardness properties for both species. The treatment seems to be more efficient, 1 to 2 unit pencil hardness further improved, for linden at similar conditions compared to spruce. Depending on conditions, spruce woods show 4 to 5 units (metric) and linden samples show 5 to 6 units (metric) higher surface film hardness values than the controls. As mentioned above, modification of mw treated varnish could be explained by the presence of further reactive groups in the varnish. It might be hypothesized this was due to presence of new groups in varnish, that effects bonding between wood and varnish.

Table 2. Surface pencil hardness properties of Mw irradiated woods

| Time (Seconds) | Spruce | | | Linden | | |
|--------------------------------|-----------------|----------------|-------------------|-----------------|----------------|-------------------|
| | Pencil hardness | Value (metric) | Δ (metric) | Pencil hardness | Value (metric) | Δ (metric) |
| 0 | 2B | 5 | - | 2B | 5 | - |
| 90 Watts Mw treatments | | | | | | |
| 3.0 | 3H | 10 | 5 | 2H | 9 | 4 |
| 6.0 | 3H | 10 | 5 | 2H | 9 | 4 |
| 9.0 | 2H | 9 | 4 | 2H | 9 | 4 |
| 12.0 | 2H | 9 | 4 | 2H | 9 | 4 |
| 180 Watts Mw treatments | | | | | | |
| 3.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 6.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 9.0 | 2H | 9 | 4 | 3H | 10 | 5 |
| 12.0 | 2H | 9 | 4 | 3H | 10 | 5 |
| 270 Watts Mw treatments | | | | | | |
| 3.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 6.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 9.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 12.0 | 3H | 10 | 5 | 3H | 10 | 5 |
| 360 Watts Mw treatments | | | | | | |
| 3.0 | 2H | 9 | 4 | 3H | 10 | 5 |
| 6.0 | 2H | 9 | 4 | 3H | 10 | 5 |
| 9.0 | 2H | 9 | 4 | 3H | 10 | 5 |
| 12.0 | 2H | 9 | 4 | 3H | 10 | 5 |

Table 3. Surface hardness properties of Mw irradiated varnish applied woods

| Time (Seconds) | SPRUCE | | | LINDEN | | |
|--------------------------------|--------------------|-------------------|-------------------|--------------------|-------------------|-------------------|
| | Pencil hardness | Value (metric) | Δ (metric) | Pencil hardness | Value (metric) | Δ (metric) |
| 0 | 2B | 5 | - | 2B | 5 | - |
| 90 Watts Mw treatments | | | | | | |
| 15 | 2H | 9 | 4 | 3H | 10 | 5 |
| 30 | 2H | 9 | 4 | 3H | 10 | 5 |
| 45 | 2H | 9 | 4 | 3H | 10 | 5 |
| 60 | 2H | 9 | 4 | 3H | 10 | 5 |
| 180 Watts Mw treatments | | | | | | |
| 15 | 3H | 10 | 5 | 3H | 10 | 5 |
| 30 | 3H | 10 | 5 | 4H | 11 | 6 |
| 45 | 2H | 9 | 4 | 4H | 11 | 6 |
| 60 | 2H | 9 | 4 | 4H | 11 | 6 |
| 270 Watts Mw treatments | | | | | | |
| 15 | 2H | 9 | 4 | 4H | 11 | 6 |
| 30 | 2H | 9 | 4 | 4H | 11 | 6 |
| 45 | 2H | 9 | 4 | 4H | 11 | 6 |
| 60 | 2H | 9 | 4 | 4H | 11 | 6 |
| 360 Watts Mw treatments | | | | | | |
| 15 | 3H | 10 | 5 | 4H | 11 | 6 |
| 30 | 2H | 9 | 4 | 4H | 11 | 6 |
| 45 | 2H | 9 | 4 | 4H | 11 | 6 |
| 60 | 3H | 10 | 5 | 4H | 11 | 6 |

For evaluating the surface scratch resistance properties of both wood species at similar experimental conditions, the measured values were plotted (Figure 1). However, a similar plot shapes were observed for both Mw treated woods (Fig. 1a) and Mw irradiated varnish applications (Fig. 1b). As mentioned above, it is clearly seen in both Mw situations (Fig. 1a and b), linden samples showed a few units higher scratch resistance properties than spruce samples.

The cross-cut test is a visual method for assessment of the resistance of coatings to separation from wood by utilizing a standardized tool to cut a right angle lattice pattern into the coating, penetrating all the way to the coated surface. The coating adhesion assessed using EN ISO 2409 standard (cross-cut test) and evaluation chart shown in Table 4.

The cross-cut results of Mw treated and then varnish coated wood samples are comparatively shown in Table 5. The 90- and 180 Watt at 3.0 second Mw coated spruce samples show 1 unit lower (negative value difference from control indicates higher surface resistance) surface cross-cut properties than control. It is noticeable that 360 Watt in 3.0 second treated sample show

the lowest cross-cut properties (assessed grade 4) while others usually show equal and/or 1 unit higher cross-cut properties, compare to control (control's assessed grade 2). However, linden samples usually show lower cross-cut resistance than spruce at similar Mw treated conditions. The Mw treated linden samples at 90 Watt in 9.0 seconds (X90b₉) and 360 Watt in 3.0 and 6.0 seconds (X360b₃ and X360b₆) show the lowest cross-cut resistance (assessed grade 5). It could be summarized, neat varnish make a better adhesion with Mw treated spruce woods than Mw treated linden at similar conditions.

The adhesion between coatings and wood surface could be measured numerically with the help of special devices (Cross-cut) and materials can be classified accordingly. The measured numerical value is determined as adhesion properties. The cross-cut properties of Mw treated varnish coated wood samples are comparatively shown in Table 6. For spruce, it is noticeable that samples of Y90s₆₀ and Y180s₁₅ show higher cross-cut resistance than control while rest of show equal and/or 1 to 3 level lower cross-cut values. However, the lowest cross-cut value of 5 (metric) was found at 360 Watt in 15 seconds Mw irradiated varnish applied spruce sample (Y360s₁₅). In contrast to Table 5 findings

for linden, a clear improvement for cross-cut properties was realized with Mw exposed varnish applied linden woods. The samples of Y80b₄₅, Y270b₆₀, Y360b₁₅ and Y360b₆₀ show only 1 unit lower cross-cut values while the rest of show equal and/or 1 to 2 unit higher cross-cut resistance, compare to control sample. It is noticeable that Mw exposed varnish application

on linden show improved cross-cut resistance properties compare to results found with Mw irradiated spruce samples in Table 5. Microwave treatment technique suggested being an effective way for improving wettability and bonding properties for some selected wood species [10,13,16, 19]. The similar results were found in this study.

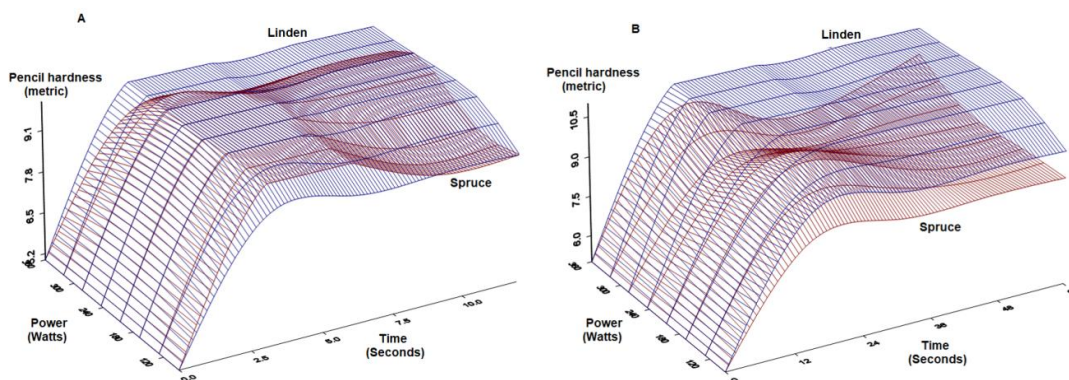


Fig. 1. Surface sctrach resistance properties of woods (A: Neat varnish applied on Mw treated woods; B: Mw treated varnish applied on woods)

Table 4. Evaluation of the cross-cut area

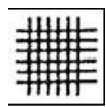
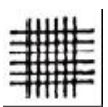
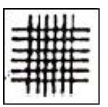
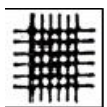
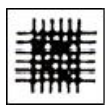

| Classification | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|--|--|
| Surface of cross- cut area from which flaking has occurred. |  none |  < 5% |  5% - 15% |  15% - 35% |  35% - 65% |  > 65% |

Table 5. The cross-cut properties of Mw irradiated woods

| Time (Seconds) | Spruce | | Linden | |
|-------------------------------|--------------------|------------|--------------------|------------|
| | Cross cut (metric) | Δ (metric) | Cross cut (metric) | Δ (metric) |
| 0 | 2 | - | 3 | - |
| 90 Watt Mw treatments | | | | |
| 3.0 | 1 | -1 | 3 | 0 |
| 6.0 | 2 | 0 | 4 | 1 |
| 9.0 | 2 | 0 | 5 | 2 |
| 12.0 | 2 | 0 | 4 | 1 |
| 180 Watt Mw treatments | | | | |
| 3.0 | 1 | -1 | 3 | 0 |
| 6.0 | 2 | 0 | 3 | 0 |
| 9.0 | 2 | 0 | 4 | 1 |
| 12.0 | 3 | 1 | 4 | 1 |
| 270 Watt Mw treatments | | | | |
| 3.0 | 3 | 1 | 4 | 1 |
| 6.0 | 3 | 1 | 4 | 1 |
| 9.0 | 2 | 0 | 4 | 1 |
| 12.0 | 2 | 0 | 4 | 1 |

| Time (Seconds) | Spruce | | Linden | |
|-------------------------------|--------------------|------------|--------------------|------------|
| | Cross cut (metric) | Δ (metric) | Cross cut (metric) | Δ (metric) |
| 360 Watt Mw treatments | | | | |
| 3.0 | 4 | 2 | 5 | 2 |
| 6.0 | 3 | 1 | 5 | 2 |
| 9.0 | 3 | 1 | 4 | 1 |
| 12.0 | 3 | 1 | 4 | 1 |

Table 6. The cross-cut properties of Mw irradiated varnish applied woods

| Time (Seconds) | Spruce | | Linden | |
|-------------------------------|--------------------|------------|--------------------|------------|
| | Cross cut (metric) | Δ (metric) | Cross cut (metric) | Δ (metric) |
| 0 | 2 | - | 3 | - |
| 90 Watt Mw treatments | | | | |
| 15 | 3 | 1 | 1 | -2 |
| 30 | 2 | 0 | 2 | -1 |
| 45 | 3 | 1 | 1 | -2 |
| 60 | 1 | -1 | 1 | -2 |
| 180 Watt Mw treatments | | | | |
| 15 | 1 | -1 | 3 | 0 |
| 30 | 3 | 1 | 3 | 0 |
| 45 | 3 | 1 | 4 | 1 |
| 60 | 2 | 0 | 2 | -1 |
| 270 Watt Mw treatments | | | | |
| 15 | 2 | 0 | 3 | 0 |
| 30 | 3 | 1 | 3 | 0 |
| 45 | 3 | 1 | 3 | 0 |
| 60 | 4 | 2 | 4 | 1 |
| 360 Watt Mw treatments | | | | |
| 15 | 5 | 3 | 4 | 1 |
| 30 | 3 | 1 | 2 | -1 |
| 45 | 4 | 2 | 3 | 0 |
| 60 | 4 | 2 | 4 | 1 |

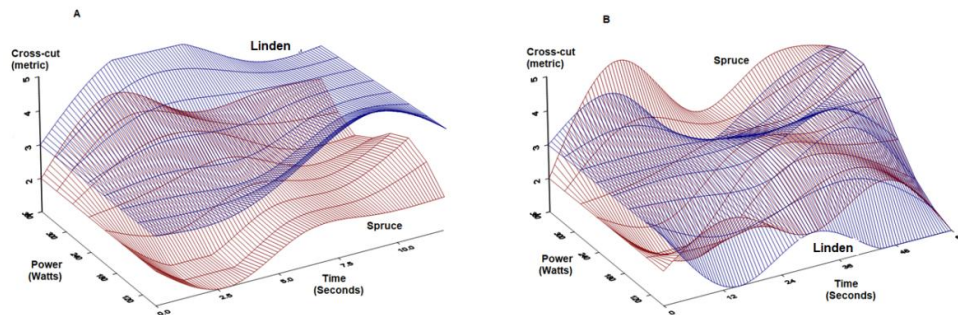


Fig. 2. Surface adhesion properties of woods (A: Varnish applied on Mw treated woods; B: Mw exposed varnish applied on woods)

For evaluating Mw and coating variables affecting on surface adhesion properties, finding cross-cut values were plotted; as a correlation between two wood substrates comparatively at similar conditions (Figure 2). It seems to Mw treated linden surfaces make a better bond with

varnish than spruce samples (Fig. 2a). In contrast, Mw exposed varnish appear to make better bond formation with spruce surfaces than linden (Fig.2b). Due to very high temperature distribution, heat and mass transfer rates in the microwave radiation, it is reasonable to

hypothesized that the surface coating-wood interactions are very complex phenomenon and numerous variables effects on that context. It has already well proposed that wood contains a high amount of -OH groups, which is very suitable for microwave irradiations [10]. In this regards, Mw treatments readily modify surface properties particularly permeability in some extent. But for preventing deteriorious effects, the controlled power levels and small-time intervals of Mw should be used. Therefore, very complex mechanisms should control the surface adhesions.

The coated surface resistance against cold liquid tests have conducted with 11 liquids, but 5 of them (juice, milk, ketchup, lemon juice, cola) show the lowest resistance, assessed grade 1 (strong mark, the structure of the surface being changed totally) and even not modified with Mw treatments. Therefore, test results of six of these liquids are given in Table 7, where average values are presented for the 24-hour testing time. However, the experimental results given in Table 7 clearly demonstrate spruce samples usually show 1 to 2 unit higher olive oil, vinegar, mayonnaise, ethyl alcohol resistance while not any improvement found for coffee and mineral water. Moreover, all linden samples show 1 to 3 unit improving (higher) resistance against all these six cold liquids than control, regardless of Mw conditions. It is important to note that all Mw treated and then varnish applied wood samples subjected to olive oil, mayonnaise and ethyl alcohol show very high resistant properties (graded 4 and 5).

The Mw-exposed varnish applied woods to the resistance of selected six cold liquids are shown in Table 8, where average values are presented for the 24 hours testing time. Similar results are also realized in here that all spruce and linden samples subjected to juice, milk, lemon juice, ketchup and cola show the lowest resistance which assessed grade 1 (strong mark, the structure of the surface being changed totally). The effects of other six selected cold liquids on control samples were graded as 2 to 4 for spruce and linden samples. However, these were improved for all Mw treated varnish applied spruce and linden, regardless of Mw conditions. The wood surfaces coated with Mw exposed varnish showed a medium resistance (grade 3-4) to mineral water, vinegar and coffee for spruce and vinegar and coffee for linden, which was 1 to 2 unit positively influenced by Mw. These changes probably by promoting cross-linking, possible due to the remained double carbon bonds on varnish film in surface. It is important to note that all Mw treated varnish applied samples subjected to olive oil, mayonnaise and ethyl alcohol show totally resistant to water (graded 4 and 5). It should be noticeable that the visible marks following testing should not be necessarily linked to the degradation of the coatings, but could be determined by the penetration of liquids through the coatings. It has already suggested by number of researchers that the microwave radiation could be modified wood while particularly at the surfaces than its inside layers [10,17,19].

Table 7. The cold liquid resistance properties of Mw irradiated woods

| Time (Sec.) | Spruce | | | | | | Linden | | | | | |
|-------------------------------|---------------|-----------|---------|------------|---------------|--------|---------------|-----------|---------|------------|---------------|--------|
| | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee |
| 0 | 4 | 4 | 2 | 3 | 3 | 4 | 4 | 4 | 2 | 3 | 2 | 2 |
| 90 Watt Mw treatments | | | | | | | | | | | | |
| 3.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |
| 6.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 3 |
| 9.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 4 | 4 | 4 | 3 |
| 12.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 180 Watt Mw treatments | | | | | | | | | | | | |
| 3.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 6.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 9.0 | 3 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 12.0 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |

| Time (Sec.) | Spruce | | | | | Linden | | | | | | |
|-------------------------------|---------------|-----------|---------|------------|---------------|--------|---------------|-----------|---------|------------|---------------|--------|
| | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee |
| 270 Watt Mw treatments | | | | | | | | | | | | |
| 3.0 | 3 | 5 | 3 | 5 | 4 | 3 | 5 | 5 | 3 | 5 | 4 | 3 |
| 6.0 | 4 | 5 | 3 | 5 | 4 | 3 | 5 | 5 | 3 | 5 | 4 | 3 |
| 9.0 | 4 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 12.0 | 3 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 360 Watt Mw treatments | | | | | | | | | | | | |
| 3.0 | 3 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |
| 6.0 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |
| 9.0 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |
| 12.0 | 3 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |

Table 8. The cold liquid resistance properties of Mw irradiated varnish applied woods

| Time (Sec.) | SPRUCE | | | | | LINDEN | | | | | | |
|-------------------------------|---------------|-----------|---------|------------|---------------|--------|---------------|-----------|---------|------------|---------------|--------|
| | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee | Mineral water | Olive oil | Vinegar | Mayonnaise | Ethyl alcohol | Coffee |
| 0 | 2 | 4 | 2 | 3 | 3 | 2 | 4 | 4 | 2 | 3 | 2 | 2 |
| 90 Watt Mw treatments | | | | | | | | | | | | |
| 15 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 4 | 5 | 3 |
| 30 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 2 | 5 | 5 | 3 |
| 45 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 2 | 4 | 4 | 3 |
| 60 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 180 Watt Mw treatments | | | | | | | | | | | | |
| 15 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 2 | 5 | 5 | 3 |
| 30 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 45 | 3 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 60 | 3 | 5 | 3 | 5 | 5 | 3 | 4 | 5 | 3 | 5 | 5 | 3 |
| 270 Watt Mw treatments | | | | | | | | | | | | |
| 15 | 3 | 5 | 3 | 5 | 4 | 3 | 5 | 5 | 3 | 5 | 4 | 3 |
| 30 | 4 | 5 | 3 | 5 | 4 | 3 | 5 | 5 | 3 | 5 | 4 | 3 |
| 45 | 4 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 60 | 3 | 5 | 3 | 5 | 4 | 3 | 4 | 5 | 3 | 5 | 4 | 3 |
| 360 Watt Mw treatments | | | | | | | | | | | | |
| 15 | 3 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 3 | 4 | 5 | 3 |
| 30 | 4 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 3 | 4 | 5 | 3 |
| 45 | 4 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 3 | 4 | 5 | 3 |
| 60 | 3 | 5 | 3 | 4 | 5 | 4 | 5 | 5 | 3 | 4 | 5 | 3 |

4. CONCLUSIONS

An alternative approach has been used to improve and assess wood surfaces in direct relation with Mw treatments. However, effects of Mw were revealed not only by wood changes, which are actually part of material properties, but

also by modifications of varnish and resistance of surfaces to selected physical properties. These alterations depended on the type of Mw treatments and the substrate factors. An interesting behavior was revealed for Mw irradiated varnish. Its adherence to the

spruce and linden slightly modified by Mw, whilst their resistance to scratch resistance increased. These results might be explained with some chemical structural changes, including cross-linking by esterification and etherification, promoted by Mw irradiation. However, changes in the chemistry of the Mw treated substrates as a function of their chemical composition and of the wood substrate at the interface level may result in more serious damaging effects such as: formation of micro-fissures affecting transparency, decrease or loss of adherence, flaking, and ultimately exfoliation. In these regards, it reveals the fact that Mw might bring both positive and negative effects which should be carefully controlled.

ACKNOWLEDGEMENTS

The authors wish to thank Isparta University of Applied Sciences, Scientific Research Coordination Division (ISUBU-BAP) for financial support and contribution to this research. This study was carried out within the ISUBU-BAP project no: 2020-YL1-0097.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Feist WC. Outdoor wood weathering and protection. Archaeological wood, properties, chemistry, and preservation. *Advanced in Chemistry Series*. 1990; (225):263-298.
2. Sahin CK, Topay M, Var AAA. Study on suitability of some wood species for landscape applications: surface color, hardness and roughness changes at outdoor conditions. *Wood Research*. 2020; 65(3):395-404.
3. Feist, W. The outdoor finish, how and when to paint or stain, *Fine hausebuilding*. 1985;54-55.
4. Cassens D, Feist, W. Exterior wood in south, selections applications and finishes, USDA Forest Service, FPL-GTR-69. Madison, WI. USA; 1991.
5. Sahin HT, Erbil IA. study on surface physicochemical properties of woods treated in emulsion of waterborne varnish with sesame and grape seed oil. *Asian Journal of Biotechnology and Bioresource Technology*. 2021;7(1):1-9.
6. Papadopoulos AN, Taghiyari HR. Innovative wood surface treatments based on nanotechnology. *Coatings*. 2019;9(12): 866.
7. Bowyer JL, Shmulsky R, Haygreen JG. *Forest Products and Wood Science-An Introduction*. Fourth edition, Iowa State University, Ames, IA. 2003;553.
8. Johansson, J. Property predictions of wood using microwaves. Doctoral thesis. Luleå University of Technology, Lulea, Sweden. 2007;12.
9. Torgovnikov G, Vinden P. New equipment for microwave wood modification, 10th Int. Conf. on Microwave and High Frequency Heating, *Proceed. Modena, Italy*. 2005;293-297:12-15.
10. Hansson L. Microwave treatment of wood, Doctoral thesis, Luleå University of Technology, Lulea, Sweden. 2007;137.
11. Norimoto, M., Gril, J. Wood bending using microwave heating. *Journal of Microwave Power and Electromagnetic Energy*. 1989;24(4):203-212.
12. Oloyede A, Groombridge P. The influence of microwave heating on the mechanical properties of wood. *Journal of Materials Processing Technology*. 2000;100(1-3):67-73.
13. Sun Z, Du G, Huang L. Effect of microwave plasma treatment on surface wettability of common teak wood. *Frontiers of Forestry in China*. 2009;4(2):249-254.
14. Gan W, Gao L, Zhang W, Li J, Zhan X. Fabrication of microwave absorbing CoFe₂O₄ coatings with robust superhydrophobicity on natural wood surfaces. *Ceramics International*. 2016; 42 (11):13199-13206.
15. Mehta L, Wadgaonkar K, Suryawanshi M, Jagtap R. Solvent-free microwave-assisted synthesis and characterization of polybenzoxazine as a thermochromic material for smart coatings. *Colloid and Polymer Science*. 2019;297(5): 795-798.
16. Klinc M, Pavlič M, Petrič M, Pohleven F. Influence of microwave heating in wood preservation on traditional surface coatings. *Acta Silvae et Ligni*. 2017;(112): 21-33.
17. Ganguly S, Balzano A, Petrič M, Kržišnik D, Tripathi S, Žigon J, Merela M. Effects of different energy intensities of microwave treatment on heartwood and sapwood microstructures in Norway Spruce. *Forests*, 2021;12(5):598.

18. Wang, H., Maxim, M. L., Gurau, G., Rogers, R. D. Microwave-assisted dissolution and delignification of wood in 1-ethyl-3-methylimidazolium acetate. *Bioresource Technology*. 2013;136:739-742.
19. Hong-Hai L, Qing-Wen W, Lin Y, Tao J, Ying-Chun CAI. Modification of larch wood by intensive microwave irradiation. *Journal of Forestry Research*. 2005;16(3):237-240.
20. European Committee for Standardization. BS EN ISO 15184. Paints and varnishes. Determination of film hardness by pencil test. Brussels, Belgium; 2020.
21. European Committee for Standardization. BS EN ISO 2409. Paints and varnishes. Cross-cut test, Brussels, Belgium, 2020.
22. European Committee for Standardization. EN 12720:2009+ A1:2014 Furniture - Assessment of Surface Resistance to Cold Liquids; Brussels, Belgium; 2014.

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