Original Research Article

An Investigation on the Properties of Alkyd-Based Varnish Coated of Post-Microwave Treated Wood Exposed to Outdoor

Abstract

In this study, it was planned to investigate the effects of microwave irradiation (MW) prior to varnish applications on the pine wood samples, which are subjected to three months of outdoor exposure. The samples of 180W15s, 270W15s, 360W5s, and 360W15s showed lower water sorption properties than the control, while the rest of the samples showed higher sorption properties than the control sample. The lowest water sorption value was 12.50% (-3.85% lower than the control). It was found that post-microwave treated samples provide a 1–3 degree increase in resistance against selected cold liquids of distilled water, fruit juice, milk and coke under similar conditions. After three months of outdoor exposure of the samples, the surface scratch resistance of the samples was found to be 1 to 4 degrees softer than the control sample (HB to 3B pencil hardness properties). However, the cross-cut properties of the samples showed almost similar level of adhesion properties, mostly between 2 and 3 (control sample: 3), which was assumed to be not notable different from control, regardless of treatment conditions. It was found to have various discoloration properties of the samples. But for A-type samples, the larger-sized samples have a higher and wider range for b* (yellowness) and a* (redness) values, while smaller-sized samples (a-type) showed a wider range and higher brightness (L*) properties. Moreover, A-type samples had higher total color difference values than a-types at similar treatment conditions. It is important to note that all measured samples show an ΔE >1.0 (metric) value, which means the discoloration of varnish applied post-microwave treated samples after three months of outdoor exposure could be realizable when carefully examined by the human eye.

The results clearly indicated that the post-microwave radiation before alkyd-varnish application on pine wood samples were some level influence regarding the selected properties. The resistance of selected household cold liquids and surface cross-cut properties were prominent for some samples. In spite of wide properties measured, no any clear trend was found between MW radiation and selected properties.

Keywords: Black pine, microwave irradiation, weathering, color properties,varnish

1. Introduction

Wood can only be used outdoors for very short periods of time without any protective treatment. This is because of the effects of abiotic and biotic factors (Sahin et al., 2011). In this case, the natural aesthetic feature of wood, which is one of the most important purposes of use, may be lost (Bowyer et al., 2003; Feist and Hon 1984; Sahin et al., 2020; Sahin et al., 2011; Sahin and Onay, 2020). However, in outdoor conditions, sunlight (UV), humidity and temperature differences cause complex photochemical reactions, resulting in initially some openings/cracks and then deep crevices are formed, creating a suitable environment for biological detoriations (fungi, insects). Those changes are generally defined as weathering of wood (Feist and Hon 1984; Sahin et al., 2020).

The weathered wood typically has modified in it's as a result of physicochemical reactions. The new functional groups have formed (i.e., hydroxyl, carbonyl, and carboxyl) in the structure (Bowyer et al., 2003, Feist and Hon 1984; Hon, 1991). Some of the most obvious changes are surface erosion with discoloration, fiber distortions, surface roughness changes, and so on. However, the degree of detoriation may vary depending on the wood species and outdoor conditions (Fengel and Wegener 1984; Hon, 1991).

Wood varnishes are suspensions containing at least two elements (solvent and solid material) that generally form a transparent layer after drying on the surface without significantly changing the natural appearance of the wood (FPL, 2010; Papadopoulos and Taghiyari, 2019; Sahin and Erbil, 2021; Sahin and Ozcelik, 2021). In this case, many types and kinds of wood varnishes preferred to protect wood by creating a transparent protective layer on the surface without changing the natural aesthetic appearance of the wood as much as possible (Bowyer et al. 2003; FPL, 2010; Sahin et al., 2020).

However, one of the most important problems encountered in surface coatings is the limited degree of bonding between the agent and the wood. In general, varnish could be applied on the wood surfaces without any pressure/vacuum procedure. In this case, there may a limited interaction with the wood's structure, and they are only formed in the uppermost layers (Bowyer et al. 2003; FPL, 2010; Hon, 1991; Papadopoulos and Taghiyari 2019). Moreover, a well protective property, it is very crucial to make a strong bonding (adhesion force) between wood and the varnish. For this reason, there are intensive studies in the literature for improving the degree of interaction between wood and surface treatment agents to ensure a better adhesion-cohesion balance (Chang and Chang 2003; Feist 1985 and 1990; Sahin and Ozcelik 2021).

Microwave ovens, which we increasingly encounter in our daily lives in recent years, provide high energy transfer to molecules through electromagnetic waves, thanks to their specially designed systems, and enable the emergence of high heat energy in a short time (Chang and Chang, 2003; Hong-Hai et al., 2005; Norimoto and Grill, 1989). However, microwave systems are actually based on the principle that electromagnetic wavelengths operate in the microwave range (300 MHz–300 GHz), generally, operating with a wavelength of 2450 ± 50 MHz are used in domestic ovens (Sahin and Ozcelik, 2021).

Microwave technology has become utilized as an alternative approach for material treatments. If microwaves interact with absorbing materials such as wood, they could be heated up, resulting in an increase in the absorption level of microwaves, which affects the physical and chemical bonds of the wood (Chang and Chang, 2003; Oloyede and Groombridge, 2000; Sahin and Ozcelik, 2021). There has been some research conducted on the effects of microwave systems on lignocellulosic materials. It has been proposed that a microwave system could be used to create a super hydrophobic wood surface based on the formation of $CoFe_2O_4$ nanoparticles (Gan et al., 2016). In another research, an alternative compound was prepared using phenolic resin under microwave-assisted systems (Mehta et al., 2019). It has reported by a number of researchers that microwave parameters must be carefully controlled when wood treated because cell wall polymers could be destroyed/modified at high level and become useful at high levels of reaction. Therefore, too high energy absorption may cause steam expansion checks while it is not having desirable properties (Klinc et al., 2017; Ganguly et al., 2021; Wanf et al., 2013). Some valuable literature reports suggest that microwave treatments of wood is a way to improve surface adhesion with desired agents (Norimoto and Grill, 1989; Chang and Chang, 2003; Oloyede and Groombridge, 2000; Sahin and Ozcelik, 2021).

One of the most important problems encountered in transparent surface treatments applied to wooden materials that are to be used in external atmospheric conditions is that the surface treatment needs to be repeated for a while. This is due to the low adhesion strength of the protective film layer to the wood surface. In order to improve alkyd-based varnish protective properties, a domestic microwave system is applied to pine wood samples and subsequently treated with varnish emulsion in order to create better strength between varnish and wood surfaces. The objective of this study was to investigate MW treatment effects on Calabrian pine wood just before alkyd-based varnish applications to assess the quality of the coating layer on wood after three months of outdoor exposure.

2. Materials and Methods

A domestic, household-type microwave oven [Beko brand, 20 lt capacity] operated under 2.4 GHz conditions, was used for the modification of pine woods. It is operated manually to control the duration of irradiation and power level. The experiments were conducted at power levels of 90-, 180-, 270-, and 360 watts and at three durations of 5.0-, 10.0-, and 15 seconds. The wood samples were placed in the center of the oven and continuously microwave-irradiated for a predetermined time. At the end of microwave procedures, the samples were brought to atmospheric conditions, and then those post-microwave irradiated samples were subjected to varnish treatment by soaking them in varnish for 1.0 min.

Calabrian pine wood (*Pinus brutia Ten.)* was selected for these investigations. The defective free wood boards were supplied from a local manufacturer, and small samples were prepared according to the principles of TS ISO 2470-1. For different experimental procedures, the three different sizes of samples (2.5 x 2.5 x 1.5 cm, 5.0 x 5.0 x 1.5 cm and 30 x 8.0 x 1.5 cm) were prepared from those boards. After the sample preparations, they were left to air dry for 30 days in laboratory conditions with a temperature of 20 °C and 50% relative humidity before being subjected to any tests.A commercially available, ready-to-use, a synthetic alkyd-based varnish was supplied in a 5-liter container. The manufacturer's recommendations were taken into account when using this varnish. It typically dried at 25 °C in 6–10 hours, depending on the type of wood.

After microwave irradiation of wood samples (post-microwave treatment), they were subsequently dipped in varnish solution for a 1.0 min. After the complete drying of samples (72 hours), control (only varnish applied samples) and post-microwave treated and then varnish applied samples were kept in front of a window on the south side of a building for three months. Thus, the wood surface properties of samples subjected to natural weathering were investigated, and the protective effect of alkyd-based wood protection solution on pine wood samples was examined. The water sorption (WA, %) of samples were calculated with using equations 1.

$$WA\ (\%): ((Ay-A0)/(A0))*100 \qquad (1)$$

where; WA= Water uptake rate (%), Ay= wet weight just after the water uptake test, A0= complete dry weight after the water uptake test.

The relative rates of discoloration of varnish applied to control and post-microwave treated samples after three months of atmospheric conditions were determined. To provide meaningful colorimetric properties that can quantify the differences, the discoloration was measured quantitatively. Concerning color determination, three color measurements were made on each sample. The determination of the color coordinates CIE L*a*b* was carried out by using an X-rite SP68 calorimeter, Applying the CIE color system, the color parameters L* (lightness), a* (redness-greeness), and b* (yellowness-blueness) as well as the total color changes (ΔE*) were determined. The total color changes (ΔE*) were calculated using the following equation:

$$\Delta Eab: \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (2)$$

Where: ΔL, Δa* and Δb* are the changes of the color coordinates L*, a* and b* for the respective time intervals.*

The selected surface properties of the samples were assessed by cross-cut (for adhesion properties), surface pencil hardness (scratch resistance properties), and resistance to selected household cold liquids. The pencil hardness tests were conducted on coated wood surfaces by using the EN ISO 15184 method. The results of the test were evaluated according to the pencil that scratched the surface. The cross-cut test is performed to determine the degree of adhesion of coated samples applied to wooden surfaces in single or multi-layers, with a total film thickness not exceeding 250 µm. According to the EN ISO 2409 standard, a pattern consisting of 25 or 100 squares is created with 2 scratches drawn at right angles to each other with a special test apparatus. After the scratched area is processed with an adhesive tape, the particles separated from the surface are compared accordingly.

The surfaces of solid wood materials used in interiors may come into contact with protective materials (paint, varnish, lacquers) and liquids that may interact with the wood surface over time. For this reason, the EN 12720 (2014) standard was developed in order to numerically rate the liquids that are likely to come into contact with the surfaces of aesthetically important woods. The surface resistance to household cold liquids was determined according to the standard EN 12720. We selected four household cold liquids; juice, distilled water, milk and coke to be used in the experiments, and the effects were observed after 24 hours. At the end of the experiments, the surface was cleaned and conditioned, and then the tested areas were carefully examined for any visible damage (marks, changes in gloss and/or color, blistering and other defects), being rated accordingly from 5 (the maximum grade for no visible change) to 1 (the minimum grade for a strong mark/degradation). Figure 1 shows some experimental procedures conducted according to the standards.

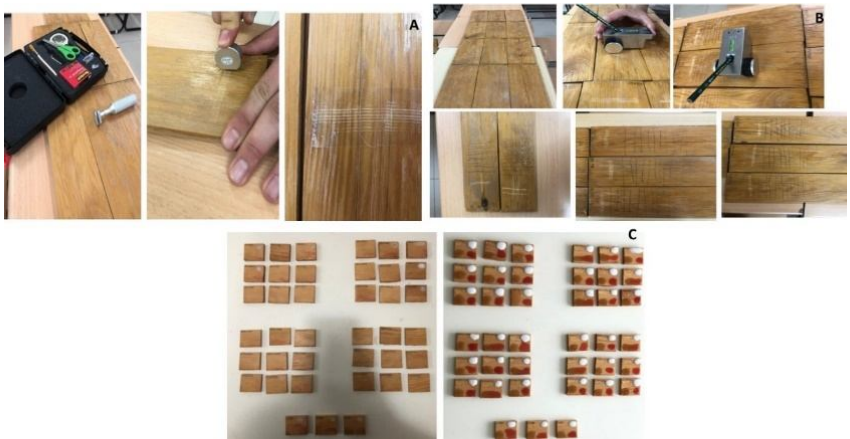

Figure 1. Some standard experimental procedures conducted (A: cross-cut resistrance, B: pencil hardness properties, C: Household cold liquid resistance).

Some code numbers and abbreviations were established throughout the study, as given in Figures and Tables. These are; 90-, 180-, 270-, and 360 are the power levels of MW irradiation (W: watt), 5-, 10-,15- are durations of MW irritations (s: seconds), a: the samples with size of 2.5x2.5x1.5 cm, A: the samples with size of 5.0x5.0x1.5 cm. 0: control (alkyd-based varnish applied samples).

3. Results and Discussions

When a material like wood is irradiated by a high-energy environment (e.g., microwave radiation), some changes occur in microcapillary and macrocapillary. In general, the chemical constituents could be broken down by strong energy interactions as well as some new functional groups (hydroxyl, carbonyl, and carboxyl) could be formed. Those could be further new bonding sites formed, potentially between wood and coating agents.

The water sorption properties of wood samples left in external atmospheric conditions after three months were examined and given in Table 1. It was found to be between 12.50% in the wood sample treated with 270 watts for 15 seconds (270W15s) and 16.33% in the sample treated with 180 watts for 5 seconds (180W5s) microwave irradiated sample. The control sample’s water uptake was calculated at 13.00%. However, only four MW irradiated samples (180W15s, 270W15s, 360W5s, 360W15s) show lower water sorption properties than the control. In all other samples, higher water uptake rates were determined regardless of post-microwave treatments. Many researchers have already reported that wood-water interaction involves quite complex and complicated physicochemical reactions (Berry and Roderick 2005; Sahin, 2008 and 2010; Siau, 1984). In our study, when Table 1 is carefully examined, there is no trend or relationship between microwave irradiation conditions and water sorption properties.

Table 1. Water sorption (%) properties of samples

Samples	WA (%)	Δ from control (%)
0	13.00	-
90W5s	14.62	12.46
90W10s	13.99	7.62
90W15s	14.38	10.62

180W5s	16.33	25.62
180W10s	16.22	24.77
180W15s	12.64	-2.77
270W5s	14.28	9.85
270W10s	14.58	12.15
270W15s	12.50	-3.85
360W5s	12.86	-1.08
360W10s	15.07	15.92
360W15s	12.96	-0.31

Table 2 shows the comparative resistance of samples to four different household cold solutions. It was found that microwave application provides some level resistance increase effect against fruit juice, milk and coke under similar conditions (it is numerically rated lower than the control). In 90-, 180- and 270 watt post-microwave treated samples, 1 to 3 degrees higher surface resistance was determined compared to the control. However, especially 360 watt treated samples provide between 3 (for milk and coke) and 4 (for juice) higher resistance compared to the control. While the varnish solution interacts with wood constituents at the uppermost layer, it appears that MW radiation improves surface resistance against selected household cold liquids, to some level

Table 2. Household cold liquids surface resistance of samples.

Samples	Juice	Milk	Water	Coke
0	5	4	1	4
90W5s	5	5	1	4
90W10s	5	3	1	3
90W15s	3	2	1	2
180W5s	5	1	1	2
180W10s	4	1	1	1
180W15s	4	1	1	1
270W5s	5	2	1	2
270W10s	3	2	1	2
270W15s	2	4	1	2
360W5s	1	1	1	1
360W10s	1	1	1	1
360W15s	1	1	1	1

The pencil hardness values of the control wood sample were found to be H. The varnish applied post microwave treated samples after three months of outdoor exposure show very similar surfaces were obtained, 1 to 4 degrees softer than the control sample (HB to 3B pencil hardness properties). There is no clear relationship found between the microwave parameters (power and time) and the surface pencil hardness properties of the wood samples after three months of outdoor exposure. These is also a clear evidence for complex microwave wood surface varnish interactions.

Table 3 shows the cross-cut properties of the samples. It was realized that the cross-cut properties (varnish-wood surface adhesion) of the post-microwave irradiated and varnish applied samples after 3 months of outdoor expose showed an almost similar level of adhesion properties, mostly between 2 and 3 (control sample: 3) which was assumed to be not notable different from control, regardless of treatment conditions. In a simple explanation, the interaction of microwaves with an absorbing material like wood occurs in three ways: reflection, absorption and permeability with a resulting dipole moment, and ionic interaction to heat up. In this regard, the absorption level of microwaves affects the physical and chemical bonds of the wood (Oloyede and Groombridge 2000; Sahin and Ozcelik 2021). In our study, MW revealed some level of surface modification and resistance against outdoor exposure of wood samples. But it may be suggested that the three-month duration of outdoor exposure of the post microwave treated and varnished wood samples may not good enough to determine surface varnish-wood stability, while the MW radiation effect could not be evaluated properly. There have been many reports suggesting evaluating surface coating-wood properties over a longer period of time (1-5 years).

Table 3. Cross-cut properties of samples.

Samples	Cross-cut (rank)	Δ from control (rank)
0	3	-
90W5s	2	-1
90W10s	3	0
90W15s	2	-1
180W5s	2	-1
180W10s	2	-1
180W15s	3	0
270W5s	3	0
270W10s	2	-1
270W15s	2	-1
360W5s	2	-1
360W10s	2	-1
360W15s	2	-1

The natural appearance of wood is an important criterion for many end use applications such as architectural, structural, household and ornamental purposes. Therefore, it is important to ensure its natural aesthetic appearance as much as possible without scarifying its properties. In that case, many transparent surface protective agents have already been developed for wooden objects. But one of the first important criteria for those agents to be function on wood surface, the well strong bonding formation between the coating agent and wood surface. The transparent protective agent could be preserved wood from external conditions, particularly weathering. Regarding that issue, we have hypothesized to create more binding sites and further functional groups with post-microwave treatments just before varnish applications, which may support varnish-wood interactions to form better/stronger bonds. In this context, we have utilized two different sizes (types) of sampling groups (a-type: 2.5x2.5.1.5 cm and A-type: 5.0x5.0x1.5 cm) to prove this hypothesis. With those approach, we can also evaluate the effects of sample size of the same wood species under similar MW irradiation.

The surface color properties of control (only varnish applied) and varnish applied post-MW treated samples (a-type), using the CIE L*a*b* (1976) standard, after three months of outdoor exposure are given in Table 4.

As for the brightness/darkness (L*), the highest brightness value of 67.39 (metric) was observed in the sample of 360W5s, and the lowest was observed at 60.11 (metric) in the sample of 90W5s. It was understood that there was only a 7.28 (metric) difference between the highest and lowest values. However, these values were calculated to differ from the control sample by -6.2% (90W5s) and 5.2% (360W5s), respectively.

As for the redness-greenness (a*) color properties, the highest a* value was observed as 14.06 (metric) in the sample processed at 180 watts and 10 seconds (180W10s). This value explains that there is approximately 16.3% more redness compared to the control sample. However, the lowest a* value was observed at 11.08 (metric) in the sample of 360W5s. This lowest value explains that the surface turns approximately -8.4% greener compared to the control sample.

As for the yellowness-blueness (b*) color properties, the highest and lowest values were observed in the samples subjected to 270 watt microwave irradiation. The highest b* value was 44.31 (metric) in the sample treated with 270 watts and 10 seconds (270W10s), and the lowest b* value was 41.53 (metric) in the sample treated with 270 watts and 5 seconds (270W5s). It is notable that only a 2.78 (metric) difference was found between the highest and lowest b* values.

Table 4. CIE L*a*b* color properties of samples (a-type).

Samples	L	a	b
0	64.05 (4.51)	12.09 (2.50)	42.87 (3.39)
90W5s	60.11 (5.85)	12.21 (5.45)	41.82 (2.09)
90W10s	62.60 (4.95)	12.62 (2.34)	43.60 (0.72)
90W15s	64.26 (7.08)	12.78 (3.53)	44.65 (2.71)
180W5s	63.91 (4.67)	12.53 (1.26)	43.90 (3.61)
180W10s	64.79 (5.48)	14.06 (2.53)	41.71 (3.52)
180W15s	65.03 (5.78)	12.73 (3.02)	42.24 (2.40)

270W5s	65.99 (4.08)	12.08 (1.93)	41.53 (3.99)
270W10s	64.05 (4.56)	11.29 (1.08)	44.31 (1.33)
270W15s	65.28 (5.13)	13.54 (2.60)	43.30 (2.63)
360W5s	67.39 (4.51)	11.08 (1.74)	43.53 (2.01)
360W10s	61.67 (5.11)	12.60 (2.88)	43.82 (4.67)
360W15s	61.29 (4.38)	11.46 (2.11)	42.22 (1.17)

* the numbers in parenthesis are standard deviations

The surface color properties of control (only varnish applied) and varnish treated post-MW treated samples (A-type), using the CIE L*a*b* (1976) standard, after three months of outdoor exposure are given in Table 5.

The highest L* values were measured as 66.08 (metric) in the sample of 360W10s, and the lowest was measured as 59.34 (metric) in the sample of 360W5s. It was found to be only 6.74 (metric) darkness-lightness difference between these two values.

When the* color values were examined, it was calculated that the sample treated at 180 watts and 15 seconds showed the highest value (21.47 (metric) and approximately 7.58 units (54.6%) higher redness properties than the control sample. However, the lowest a* value of 11.57 (metric) was found in the sample of 360W10s, and this value was found to be approximately -2.32 (metric) lower than the control sample (more green surface).

When the b* color values were examined, it was understood that there was a limited change compared to the control and other color coordinates (L* and a*). The highest b* value of 46.05 (metric) was found with sample of 270W15s (only 1.08 units higher than the control), while the lowest b* value of 42.92 (metric) was found with sample of 270W5s which is only -2.05 units lower than the control sample.

Table 5. CIE L*a*b* color properties of samples (A-type)

Samples	L	a	b
0	62.64 (4.81)	13.89 (2.97)	44.97 (3.19)
90W5s	62.34 (5.82)	13.61 (5.82)	43.64 (1.86)
90W10s	62.48 (3.69)	15.17 (2.11)	44.30 (2.39)
90W15s	61.01 (2.84)	14.10 (2.09)	44.32 (1.35)

180W5s	63.56 (4.24)	12.95 (2.94)	44.51 (3.64)
180W10s	61.69 (3.64)	17.63 (3.47)	45.75 (2.65)
180W15s	59.50 (6.17)	21.47 (2.40)	43.66 (4.14)
270W5s	65.44 (4.42)	13.12 (3.46)	42.92 (4.07)
270W10s	63.32 (4.96)	13.08 (3.39)	45.79 (2.71)
270W15s	62.59 (5.17)	16.88 (1.38)	46.05 (4.12)
360W5s	59.34 (3.59)	14.92 (3.38)	43.32 (2.13)
360W10s	66.08 (5.38)	11.57 (1.93)	45.01 (1.72)
360W15s	59.68 (4.61)	14.01 (4.0)	45.44 (3.51)

* the numbers in parenthesis are standard deviations

When two sets of measured color data in Tables 4 and 5 are examined carefully under similar MW conditions on two different sizes of the same wood species and are examined carefully, it can be seen that there is no any correlation was found between the microwave radiations (power and time) and the color values of the wood samples that were subjected to three months of outdoor exposure. However, it was realized that there were some level differences in the measured color values to a certain extent with the change in wood sample sizes. Moreover, it is very difficult to reveal these changes one by one. Therefore, using the measured values, given in Tables 4 and 5, are plotted in Figure 2, regarding two sampling sets, comparatively. In this case, it was possible to compare those color values under similar conditions conveniently. When the shapes of the graphs in Figure 2 are examined, it can be seen that, the large-sized samples (A-type) have a higher and wider range for b* (yellowness) and a* (redness) values, while the small-sized samples (a-type) show a wider range and higher brightness (L*) properties.

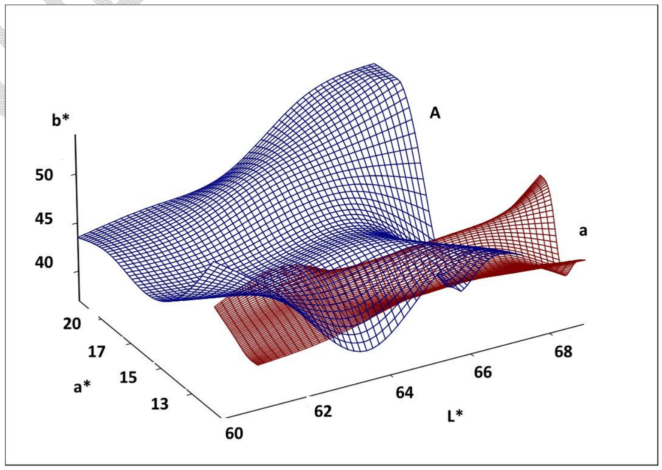

Figure 2. The color coordinate properties of samples treated at similar conditions.

Total color difference (ΔE) is an important color evaluation criterion that expresses the color change between the materials as a single numerical value using CIE color coordination values ($L^*a^*b^*$). In our study, the total color difference properties (compared to the control sample) of wood samples of two different sizes (a- and A-types) treated at similar MW conditions are shown in Table 6.

For a-type samples, the highest color difference value of ΔE: 4.08 (metric) was measured as in the sample of 90W5s, then ΔE: 3.55 (metric) with the sample of 360W5s, ΔE: 2.90 (metric) was measured in the sample of 360W15s, respectively. In A-type samples, the highest color difference value of ΔE: 8.31 (metric) is found in the sample of 180W15s followed by ΔE: 4.15 (metric) in the sample of 360W10s (ΔE: 3.94 metric).

In general, the total color difference of a-type samples was found to be higher than that of A-type samples, except samples at three durations in 90 watt conditions and in the 270 watt 10 second microwave treatment conditions. In all others, it was understood that the A-type samples had higher total color difference values. However, when Table 6 was examined carefully, no trend could be observed between the total color difference properties and MW conditions regarding sample types.

Table 6. Color difference propertiesof samples treated at similar conditions

Samples	a-type	A-type
90w5s	4.08	1.39
90w10s	1.71	1.45
90w15s	1.92	1.77
180w5s	1.13	1.39
180w10s	2.41	3.94
180w15s	1.33	8.31
270w5s	2.36	3.55
270w10s	1.65	1.34
270w15s	1.95	3.18
360w5s	3.55	3.83
360w10s	2.61	4.15
360w15s	2.90	3.0

The effect of the same microwave conditions on the color properties (total color difference) of two different-sized same wood samples is shown comparatively in Figure 3. It is clearly seen that at a 180 watt microwave power level, the color difference of A-type samples is significantly higher than that of a-type samples, while similar color differences occur in other experimental conditions.

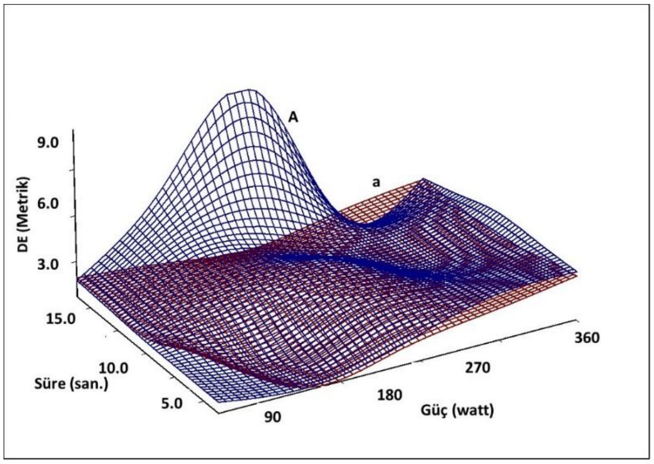

Figure 3. The color difference (ΔE) properties of samples treated at similar conditions (a: small sized samples, A. Larger sized samples).

It has already reported by a number of researchers about the color difference values of samples that the total color difference (ΔE) can be between 0 and 100 while the smaller numbers explain lower color difference, and larger numbers explain a higher color difference (Janin et al., 2001; Mahy et al., 1994; Sahin et al., 2011; Sahin and Onay, 2020). In general,

- if ΔE <1.0 (metric): color change cannot be distinguished by the human eye,
- if ΔE > 1.0 < 3.0 (metric): color change can be distinguished when carefully examined by the human eye,
- if ΔE > 3.0 (metric): color change can be distinguished when examined by the human eye.

With this information, it is reasonable to conclude that all measured samples show ΔE >1.0 (metric) value, which means the discoloration of varnish applied post-microwave treated samples after three months of outdoor exposure could be realizable when carefully examined by the human eye. Moreover, in a-type of samples, the samples of 90w5s (ΔE:4.08), 360w5s(ΔE: 3.55) Show easily distinguished discoloration properties. In A-type samples, the samples of 180w5s (ΔE:3.94), 180w15s (ΔE:8.31), 270w5s (ΔE:3.55), 270w15s (ΔE:3.18), 360w5s (ΔE:3.83), 360w10s (ΔE:4.15), and 360w15s (ΔE:3.0) Show easily recognizable discoloration properties. Those are also another piece of evidence that the type-A samples show more discoloration than the a-type samples, which means smaller sample sizes may be more effective for improving the discoloration of pine samples when exposed to outdoor conditions.

4. Conclusions

There has been numerous literature could be found on wood-surface coating evaluations. However, there is limited information on the use of microwave systems in wood science. The understanding of wood surface interactions is complex and involves changes in many variables. In our study, alkyd-based varnish, which is widely used as a surface protection agent for wood materials and has the feature of protecting both the aesthetic properties of wood and increasing its resistance to external atmospheric conditions (water, moisture, heat, light, etc.), was applied to post microwave treated pine wood samples that are subjected to outdoor exposure.

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