Effects of Microwave and Infrared + Microwave Drying of Wood Materials on Energy Consumption, Water Absorption, and Mechanical Properties

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The objective of this study was to shorten the drying time of wood material using microwave and infrared + microwave drying methods, compare the energy assumption, analyze their improvement in water absorption, and compare the compression strength perpendicular and parallel to fibers. Red pine (*Pinus brutia*) and Eastern spruce (*Picea orientalis*) woods were prepared in three groups. The first group was oven dried, the second group was dried by microwave, and the third group was dried by infrared + microwave methods. The analysis results for energy consumption, moisture content, and compression strength perpendicular and parallel to the fibers were performed. Compression strengths were determined with a universal testing device. According to the results obtained, with 15 min microwave drying, 4% moisture content was reached in the wood samples and both time and energy were saved. It was observed that oven drying consumed 93% more energy than 15 min microwave drying. Samples dried with infrared 30 s + microwave 5 min had higher compression strength in the direction perpendicular to the fibers and samples dried with microwave for 5 min had higher compression strength in the direction parallel to the fibers.

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INTRODUCTION

Wood material is a natural, renewable, easy-to-process, aesthetic material that has been used to meet many needs of human beings since ancient times (Efe and Kasal 2007). However, because of its vulnerability to change such as moisture, decay, deformation, fire resistance, and color change, it requires protection in various ways. After being cut from the forest, wood material may contain more water than its own weight. It is necessary to remove the water in the material before processing it (Erdin and Bozkurt 2013). Wooden material can provide shelter and be a food source for harmful organisms. To eliminate the living conditions of harmful organisms, wood material must be dried at rates appropriate to the area of use. Wooden material that is not suitably dried for the environment under which it will be used can be expected to change its dimensions by absorbing or losing moisture (Burdurlu 1995). Thus, undesirable deformations and defects occur in wooden products. It is known that many properties of dried wood material improve. For instance, if the degree of dryness is maintained in well-dried wood, it does not rot, warps less, and gives smoother surfaces when processed. Properties, such as adhesion ability, resistance, and hardness increase (Kantay 1993) in dry wood materials.

Two different drying techniques are used to dry wood materials: natural and technical. While natural drying is done outdoors, technical drying is done with various systems under which the conditions can be adjusted (Schiffmann 1987). Natural drying takes a long time, and it may not be possible to dry it to the required moisture content at the place of use. Technical drying is a method that is more practical, gives faster results, and can be used to reach targeted values of moisture content (Altinok *et al.* 2009). Drying with conventional ovens used in the wood industry is carried out with the principle of transferring heat from the outside to the inside of the material. In this case, because it is difficult to reach the center of the dried material, serious losses in time and energy are experienced. There are four important drying periods in conventional drying. These include heating, drying, balancing, and air conditioning. Because it takes a long time to perform all these operations, time loss and energy costs increase (Efe and Kasal 2007). Wood drying businesses that use existing drying systems in the sector cannot reach the desired capacities due to long drying periods and experience financial losses and face high energy costs (Torgovnikov and Vinden 2010).

Microwave energy, which first became widely used in kitchen ovens, is today used successfully in many industrial areas such as cooking, bleaching of food, chemical reactions, hardening, heating, and drying. The reason for this is that the microwave technique has some advantages compared to other drying techniques (Caglar et al. 2009) These advantages include convenience, efficiency of energy, ability to defrost, and easy cleaning. Convective drying has been used in numerous investigations in conjunction with microwave pre-treatment to expedite the drying process. Turner (1994) emphasized the advantages of using microwave drying in addition to convective drying. Before drying in a solar kiln, Brodie (2003) microwave-treated wooden planks. Samples of *Populus alba* treated with microwave radiation showed a 17% reduction in drying time when compared to untreated samples dried in a kiln for the same amount of time. In a follow-up study, samples of *Eucalyptus regnant* that had been microwave-pretreated dried 33% quicker than samples that had been left untreated in a sun kiln for the same amount of time. The microwave radiation vibrates the water molecules in the wood material, causing it to heat up quickly and evaporate out.

In microwave technology, heating occurs from the center outward, rather than from the surface to the center, as in oven drying, resulting in faster drying (Hansson 2007). Microwave is not a new method in wood drying (Tiuri et al. 1980). In fact, according to ISPM 15 (2002) standards, it has been reported that heat treatment of wood material can be done by treating it with microwave energy for just one minute. In addition, according to ISPM 15 (2002) standards, it has been reported that sterilization can be achieved by treating the wooden material with a microwave for 1 min, providing the core temperature sufficient for the heat treatment (Saltik 2023). The situation in infrared technology is as follows, electromagnetic radiation with a wavelength longer than visible light and shorter than microwave is used. The difference of infrared rays from other rays is that they can carry more heat than others (Metaxas and Meredith 1982). The most important feature of infrared radiation is that it directly heats the product without heating the air, that is, without using the air as an intermediary medium. Because heat transfer is made to the surfaces directly, the drying with infrared rays gives an economic advantage compared to other heating systems (Mujumdar 1995).

Other advantages can be listed as shortening the drying time, having high energy efficiency, uniform distribution of product temperature during drying, easy control of process parameters, and saving space (Ozkoc 2009).

In this study, red pine and eastern spruce wood samples were dried using oven, microwave, and infrared + microwave technology. Their moisture content was calculated. Then energy consumption and compression strength perpendicular and parallel to fibers were compared between the wood samples dried using the three different methods.

EXPERIMENTAL

Material

Wood samples from eastern spruce (*Picea orientalis*) and red pine (*Pinus brutia*) with an average moisture content of 60% were employed in this study. The wood came from a company in Izmir, Turkey, that makes wooden products. They began their production process by processing recently cut forest logs. Several characteristics were considered, including their strength, natural color, and flawlessness, as well as their parallel fibers, lack of fiber curl, and resistance to fungus and insects. The preparation of test samples was done in compliance with TS ISO 3129 (2021) guidelines. Following cutting, the samples were sealed tightly with stretch film to keep moisture from evaporating, air contact was closed off, and they were stored in a humid environment until they were dried. Ten samples, each measuring 20 × 20 × 30 mm, were used for all tests and analysis processes.

Method

Wood drying procedure

Drying processes were carried out at Mugla Sitki Kocman University, Woodworking Industrial Engineering Laboratories. Three different methods were used as drying methods. The samples in the first group (oven drying) were dried in a Thermal brand oven at 103 ± 2 °C. The drying time applied was 24 h. The samples in the second group (microwave drying) were dried in three subgroups in a Bosch brand industrial microwave oven at 900 W power. The subgroups were saved as drying in 5, 10, and 15 min. Three subgroups of the third group used microwave + infrared drying method. A Bosch brand industrial microwave was utilized to finish the test setup, and an 80 cm length × 50 cm width Tek-Iz brand industrial infrared (IR) device was employed. The IR module uses medium wave infrared bulbs, which have a 420-mm filament length and 2.5 KW of power per bulb. The module contains seven infrared bulbs in total. Wooden samples were placed under the device, with its wide surface facing the machine and leaving a certain space.

The drying processes were as follows for the 2nd Group, which is dried with microwave; 1st Subgroup dried with MW 5 min, 2nd Subgroup dried with MW 10 min, and 3rd Subgroup dried with MW 15 min. The drying process in the 3rd Group, which was dried with infrared + microwave was broken down as follows: 1st Subgroup IR 30 s + MW 1 min, 2nd Subgroup IR 1 min + MW 5 min, and 3rd Subgroup IR 30 s + MW 10 min.

Table 1. Groups - Drying Method - Drying Times, Microwave, Microwave + Infrared

Drying Methods	Groups	Subgroup	Drying Time
Oven	1st Group	-	24 h
Microwave	2nd Group	1st Subgroup	5 min
		2nd Subgroup	10 min
		3rd Subgroup	15 min
IR + MW	3rd Group	1st Subgroup	IR 30 min + MW 5 min
		2nd Subgroup	IR 1 min + MW 5 min
		3rd Subgroup	IR 30 s + MW 10 min

Test and Analysis

Moisture content

The moisture content of wood samples was determined according to TS ISO 323 (1993). The moisture content, *W*, of each test piece was calculated as follows,

$$W\% = \frac{(m_1 - m_2)}{m_2}\ x\ 100 \tag{1}$$

where m_1 and m_2 are the wet weights (g) before and after drying, respectively.

Measuring energy consumption

An optimum price and performance ratio was calculated with input from the Wellhise brand energy consumption measuring device. The measuring device has a sensitivity of 0.1 kW and energy consumption was determined by connecting it between the socket and the device in both drying cycles.

Fig. 1. Energy consumption measuring device (Wellhise)

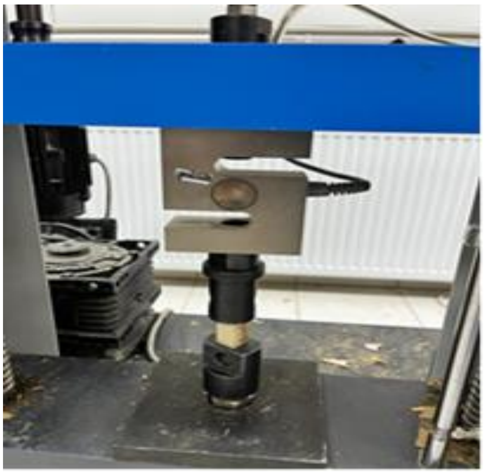

Fig. 2. Universal test mechanism (Marestek)

Compression strength testing perpendicular and parallel to fibers

According to see the effect of drying methods on mechanical properties, the test was determined using samples with dimensions of 20 × 20 × 30 mm, according to the principles specified in TS ISO 13061-17 (2019). The Marestek brand universal test machine was operated to ensure that crushing occurred within 1 to 2 min from the moment of loading.

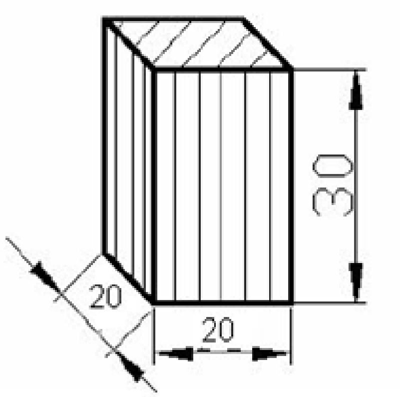

Fig. 3. Compression test samples (dimensions in mm)

In the tests, the force at break (F_{maxb}) and the compression strength (σ_b) for the sample cross-sectional area (A_b) were calculated from the formula below:

$$\sigma_b = \frac{F}{A} \tag{2}$$

In Eq. 2, F denotes maximum force at break (N), and A refers to the cross-sectional area (mm^2) values of the sample.

Calculated compression strength results must be adjusted according to the 12% moisture content level specified in TS ISO 13061-17 (2019). For this purpose, the calculation was made with Eq. 3,

$$\sigma_{b12} = \sigma_e[1 + \alpha(W - 12)] \tag{3}$$

where σ_e denotes compression strength (N/mm^2), α is correction factor for moisture content (%), and W represents the calculated moisture content (%).

Statistical Analysis

All data collected within the parameters of the study were statistically analyzed with a 95% confidence level using SPSS (IBM Corp., Armonk, NY, USA), and analysis of variance was used to show the statistical difference between the factors. Duncan Test was performed to identify the contributing variables to the variations.

RESULTS AND DISCUSSION

Moisture Content Result

The moisture contents of before and after drying and output temperatures of red pine and eastern spruce wood samples measured are given in Table 2. Before drying, wood samples typically have a moisture level of about 60%. Table 2 shows that after drying in an oven at 103 °C for 24 h, the moisture content for red pine wood samples was 4.36%.

Table 2. Wood Samples Output Temperature and Moisture Content of Red Pine and Eastern Spruce Measured After Drying

Drying Method	Drying Time	Output Temperature (°C)	Red Pine (%) MC Before Drying	Red Pine (%) MC After Drying	Eastern Spruce (%) MC Before Drying	Eastern Spruce (%) MC After Drying
Oven	24 h	103	60.50 (1.22)	4.35 (0.17)	60.52 (1.65)	4.36 (0.66)
MW	5 min	49	60.10 (1.72)	23.72 (0.78)	60.25 (1.11)	23.76 (0.25)
	10 min	94	60.35 (1.18)	12.41 (0.90)	60.40 (0.87)	12.42 (0.96)
	15 min	107	60.55 (1.13)	4.41 (0.50)	60.30 (1.22)	4.45 (0.29)
IR + MW	IR 1 min + MW 5 min	IR 166 / MW 110	60.40 (1.22)	14.14 (0.11)	60.44 (0.66)	14.15 (0.77)
	IR 30 s + MW 5 min	IR 144 / MW 95	60.50 (0.66)	20.44 (0.23)	60.45 (1.44)	20.21 (0.73)
	IR 30 s + MW 10 min	IR 146 / MW 119	60.22 (1.81)	6.16 (0.19)	60.30 (1.75)	6.30 (0.61)

Note: MW: Microwave. IR: Infrared. MC: Moisture content. The values in parentheses indicate standard deviation (SD).

Following 5 min, 10 min, and 15 min of microwave (MW) drying, the samples' moisture contents were determined to be 23.72%, 12.41%, and 4.45%, respectively. Red pine samples that had been dried and subjected to the infrared + microwave (IR + MW) method were found to have a moisture content of 14% after 1 min, 20.44% after 5 min, and 6.16% after 30 s of infrared and 10 min of microwave drying. The moisture content of the eastern spruce wood samples dried in the oven was found to be 4.36%, 23.76%, 10.22%, and 4.45% after 5 min, respectively. In contrast, the moisture content of samples of eastern spruce dried by IR + MW method was determined to be 14.15% after 30 s of IR and 5 min of MW, 20.21% after 1 min of IR and 5 min of MW, and 6.30% after 30 s of IR and 10 min of MW.

The results of multiple variance analysis for the main factors of wood type, drying method, and drying time, and the double and triple interactions of these factors are given in Table 3. The parameters were as follows: Factor A: Wood type (red pine, eastern spruce), Factor B: Drying method (oven, microwave, infrared + microwave), Factor C: Drying time (24 h, 5 min, 10 min, 15 min, 30 s + 5 min, 1min + 5 min, 30 s + 10 min).

Table 3. Analysis of Variance Results Regarding the Moisture Values of Two Different Wood Species According to Different Drying Method and Drying Time

Variance Source	Sum of Squares	Degrees of Freedom	Mean of Squares	F Value	Statistical significance (P)
Factor A	211.482	1	213.643	11.475	0.001
Factor B	152.215	2	76.107	10.698	0.001
Factor C	885.286	6	147.547	8.838	0.001
A*B	33.988	2	16.994	0.859	0.428
A*C	77.570	6	12.928	0.676	0.659
B*C	189.260	3	63.086	3.387	0.032
A*B*C	1.441	1	1.441	0.076	0.653
Error	1532.610	77	18.618		
Total	26546.349	100			

The primary wood type, drying method, and drying time effects, as well as their interactions, were shown to have statistically significant effects on moisture levels, with a margin of error of $P < 0.05$, based on the results of variance analysis. It may be concluded from a study of the F values shown in Table 3 that the primary factor of tree type had a higher impact on moisture levels. Duncan dual comparison tests were performed for the main factors and simultaneous effects to determine the significant effects of the main factors and bilateral interactions. Comparison Duncan test results regarding moisture values according to the drying method are given in Table 4.

Table 4. Pairwise Comparison Test Results According to Drying Method

Drying Method	Average (%)	Homogeneity Group
Oven	9.47	A*
Microwave	13.27	B
Infrared + Microwave	13.53	C

Duncan: 0.050 *Lowest moisture values

The moisture content of the samples dried in the oven was found to be lower than that of the samples dried using other methods, as per the findings of the dual comparison Duncan test. The IR + MW drying was group C with a value of 13.53%, microwave drying was group B with a value of 13.27%, and oven drying was group A with a value of 9.47% based on homogeneity groups. Table 5 displays the Duncan test findings for moisture content based on drying time.

Table 5. Pairwise Comparison Test Results Regarding Moisture Values According to Drying Time

Drying Time	Average (%)	Homogeneity Group
Oven 24 h	5.68	A*
MW 15 min	5.98	A
IR 30 s + MW 10 min	7.87	A
MW 10 min	13.01	B
IR 1 min + MW 5 min	14.14	B
IR 30 s + MW 5 min	20.49	C
MW 5 min	21.33	C

Duncan: 0.050 *Lowest moisture values

The samples dried in the oven for 24 h had a lower moisture content than samples dried for longer periods of time, according to the findings of the Duncan test of Dual comparison about drying times and moisture contents.

Homogeneity groups yielded values of 21.3% and 20.5% for 5 min of MW drying and 30 s of IR plus 5 min of MW drying, respectively. Group C: infrared radiation for one min plus five min; results were 14.1% and 13.0%, respectively, with values of 7.9%, 6.0%, and 5.7%, respectively, drying and 10 min MW drying, group B, 30 seconds IR + 5 min MW drying, 15 min MW drying, and oven drying. After being dried in an oven, Group A was also discovered to have the lowest moisture level. Another result was that the drying effect was observed during microwave drying. It has been observed that drying with infrared remains superficial. After the 1 min infrared drying time, burning occurred on the samples which were exposed to infrared. The decreases in weight values occurred after microwave drying in parallel with the decreases in moisture contents.

Similar findings of alternative drying techniques and traditional drying were investigated in studies by Saltik (2023) and Terziev *et al.* (2020). It was reported that as a result of drying, weight and moisture decreased for all wood types.

Energy Consumption Result

The total energy consumption amounts resulting from oven and microwave drying measurements are given in Table 6.

Table 6. Comparison of Energy Consumptions in Oven and Microwave Dryings

Drying Method	Drying Time	Total Energy Consumption (KW)	Output Moisture Content (%)
Oven	24 h	5.131	4
Microwave	5 min	0.093	24
	10 min	0.237	12
	15 min	0.348	4

In both methods, an equal number of pieces were used in the drying methods. According to the consumption values given in Table 6, it was observed that the highest energy consumption value was obtained in oven drying with 5.13 kW, and the lowest value was obtained in microwave drying with 0.093 kW for 5 min.

It has been observed that in oven drying, it took 24 hours until the desired 4% moisture content was reached and long drying time increased energy consumption. In microwave drying, it was observed that the desired moisture content of both red pine and eastern spruce wood samples was reduced to 4% within 15 minutes at 900 W power and this reduced energy consumption by 93% in direct proportion to the time used.

In the master's thesis published by Korkmaz (2018) it was stated that drying with the classical drying method is 50% more energy consumption than drying with the solar energy system.

Compression Strength Tests Perpendicular and Parallel to Fibers

The compression test results of perpendicular and parallel to fibers for red pine and eastern spruce wood samples are given in Table 7.

Table 7. Results of Compression Strength Tests Perpendicular and Parallel to Fibers for Red Pine and Eastern Spruce Wood Samples

Wood Type	Drying Method	Drying Time	Compression Strength Perpendicular to Fibers (N/mm²)	Compression Strength Parallel to Fibers (N/mm²)
Red pine	Oven	24 h	22.97 (1.72)	21.25 (0.50)
	MW	5 min	22.68 (0.39)	21.99 (2.40)
		10 min	18.15 (1.50)	16.59 (0.36)
		15 min	12.18 (0.76)	12.53 (0.41)
	IR + MW	1 min + 5 min	27.23 (1.69)	17.30 (2.11)
		30 s + 5 min	28.44 (1.54)	19.26 (0.10)
		30 s + 10 min	17.62 (1.26)	15.42 (0.42)
Eastern spruce	Oven	24 h	19.82 (1.59)	19.18 (0.34)
	MW	5 min	19.49 (0.78)	20.64 (0.49)
		10 min	18.39 (1.23)	15.33 (0.47)
		15 min	12.01 (1.18)	11.94 (0.76)
	IR + MW	1 min + 5 min	25.89 (1.55)	16.12 (0.35)
		30 s + 5 min	26.99 (0.79)	17.20 (0.25)
		30 s + 10 min	15.99 (0.77)	14.97 (0.12)

MW: Microwave. IR: Infrared. The values in parentheses indicate standard deviation (SD).

When the compression strength test values perpendicular to the fibers of the wood samples were examined after the drying tests, it was observed that red pine (28.4 N/mm²) wood samples had higher compression strength values than eastern spruce (27.0 N/mm²) wood samples.

It was determined that the samples dried with infrared 30 s + microwave 5 min had higher compression strength in the direction perpendicular to the fibers compared to the samples dried with other drying methods.

When the compression strength test values of the wood samples parallel to the fibers were examined after the drying tests, it was observed that red pine (22.0 N/mm²) wood samples had higher compression strength values than eastern spruce (20.6 N/mm²) wood samples.

It was observed that the samples dried with microwave for 5 min had higher compression strength in the direction parallel to the fibers compared to the samples dried with other drying methods.

It was determined that the bending strength values perpendicular to the fibers decreased due to drying in all drying methods. It was observed that microwave drying had a decreasing effect on the bending strength of wood samples.

Despite the decrease in moisture values due to drying, there was a decrease in bending strength values.

On this subject, it was concluded by Cayir (2021) within the scope of his doctoral thesis that "The increase in the duration of exposure to microwave treatment due to the increase in the moisture content of wood has a parallel effect on the decrease in mechanical properties." This can be explained as the reason for the decreased in the specified drying method and time.

The results of multiple variance analysis for the main factors of drying method and drying time and the double and triple interactions of these factors are given in Table 8.

Table 8. Analysis of Variance Results of the Effect of Two Different Wood Species on the Compression Strength Perpendicular to Fibers Based on Different Drying Method and Drying Time

Variance Source	Sum of Squares	Degrees of Freedom	Mean of Squares	F-Value	Statistical significance (P)
Factor A	57.828	1	57.828	31.046	0.001
Factor B	497.764	2	248.882	133.616	0.001
Factor C	964.852	6	160.807	86.332	0.001
A*B	23.006	2	11.503	6.176	0.008
A*C	21.809	6	3.635	1.951	0.083
B*C	650.208	3	216.736	116.358	0.010
A*B*C	2.815	1	2.815	1.511	0.223
Error	143.425	77	1.863		
Total	44728.220	100			

Factor A: Wood type (red pine, eastern spruce), Factor B: Drying method (oven, microwave, infrared + microwave), Factor C: Drying time (24 h, 5 min, 10 min, 15 min, 30 s + 5 min, 1 min + 5 min, 30 s + 10 min)

According to the results of variance analysis, the effects of the main factors based on wood type, drying method, and drying time, and their interactions on the compression strength values perpendicular to the fibers were found to be statistically significant with a margin of error of $P < 0.05$. When the F values calculated in Table 8 are examined, it can be said that the main factor of the drying method has a greater effect on the compression strength perpendicular to the fibers. To see the significant effects of the main factors and bilateral interactions, Duncan comparison tests were conducted for the main factors and simultaneous effects.

Table 9. Analysis of Variance Results on the Effect of Two Different Wood Species on the Compression Strength Parallel to Fibers According to Different Drying Method and Drying Time

Variance Source	Sum of Squares	Degrees of Freedom	Mean of Squares	F Value	Statistical significance (P)
Factor A	132.846	1	132.846	75.208	0.001
Factor B	70.931	2	35.466	20.245	0.001
Factor C	75.485	6	12.581	7.122	0.001
A*B	6.171	2	3.085	1.747	0.181
A*C	75.485	6	12.581	7.122	0.255
B*C	130.402	3	43.467	24.608	0.015
A*B*C	0.570	1	0.570	0.322	0.572
Error	136.013	77	1.766		
Total	8370.762	100			

Factor A: Wood type (red pine, eastern spruce), Factor B: Drying method (oven, microwave, infrared + microwave), Factor C: Drying time (24 h, 5 min, 10 min, 15 min, 30 s + 5 min, 1 min + 5 min, 30 s + 10 min)

According to the results of variance analysis, the effects of the main factors of wood type, drying method, and drying time and their interactions on the compression strength values parallel to the fibers were found to be statistically significant with a margin of error of $P < 0.05$. When the F values calculated in Table 9 were examined, the main factor of wood type had a greater effect on the compression strength parallel to the fibers. To see the significant effects of the main factors and bilateral interactions, Duncan comparison tests were conducted for the main factors and simultaneous effects. Dual comparison Duncan Test results regarding compression strength perpendicular and parallel to fibers according to the drying method are given in Table 10.

Table 10. Compression Strength Perpendicular and Parallel Values According to Drying Method

Drying Method	Perpendicular to Fibers		Parallel to Fibers		
	Average (N/Mm^2)	Homogeneity Group	Drying Method	Average (N/Mm^2)	Homogeneity Group
Infrared + Microwave	25.62	A*	Microwave	17.46	A*
Oven	19.86	B	Oven	16.54	B
Microwave	14.59	C	Infrared + Microwave	14.91	C

Duncan: 0.050 *Lowest moisture values

As seen in Table 10, the highest compression strength perpendicular to the fibers was obtained in the samples dried with IR + MW, with 25.6 N/mm^2, and the lowest compression strength perpendicular to the fibers was obtained in the samples dried with microwaves, with 14.6 N/mm^2.

According to the comparison results of the main factor drying method of compression strength perpendicular to the fibers, the data obtained from the IR + MW drying method gave 76% higher results than the data obtained from the microwave drying method.

As seen in Table 10, the highest compression strength parallel to the fibers was obtained in samples dried with microwaves, with 17.5 N/mm^2, and the lowest compression strength parallel to the fibers with 14.9 N/mm^2, was obtained in samples dried with IR + MW.

According to the main factor comparison results of the compression strength drying method parallel to the fibers, the data obtained from the microwave drying method gave 17% higher results than the data obtained from the IR + Microwave drying method.

Comparison Duncan test results regarding compression strength perpendicular and parallel to fibers according to drying time are given in Table 11.

Table 11. Pairwise Comparison Test Results Regarding Compression Strength Perpendicular and Parallel to Fibers Based on Drying Time

Drying Time	Perpendicular to Fibers		Parallel to Fibers		
	Average (N/mm^2)	Homogeneity Group	Drying Time	Average (N/mm^2)	Homogeneity Group
IR 30 s + MW 5 min	28.71	A*	MW 5 min	25.05	A*
IR 1 min+ MW 5 min	26.56	B	IR 30 s + MW 5 min	19.52	B
MW 5 min	20.72	C	MW 10 min	18.23	C
Oven 24 h	20.53	C	Oven 24 h	17.71	DC
IR 30 s + MW 10 min	16.77	D	IR 1 min + MW 5 min	17.19	DC
MW 10 min	12.59	E	MW 15 min	15.31	E
MW 15 min	10.62	F	IR 30 s + MW 10 min	15.18	E

Duncan: 0.050 *Lowest moisture values

As shown in Table 11, the highest compression strength perpendicular to the fibers, 28.7 N/mm^2 was obtained in the samples dried with IR 30 s + MW 5 min, and the lowest compression strength perpendicular to the fibers, 10.6 N/mm^2 was obtained in the samples dried with MW 15 min.

According to the comparison results of the main factor of drying time of compression strength perpendicular to the fibers, the data obtained from the drying time with IR 30 s + MW 5 min gave 170% higher results than the data obtained from the drying time of MW 15 min.

Based on homogeneity groups, MW15 min drying, group F, with a value of 10.62 N/mm^2, MW 10 min drying, group E with a value of 12.6 N/mm^2, drying with IR 30 s +

MW 10 min, group D with a value of 16.8 N/mm², drying with an oven for 24 h, a value of 20.5 N/mm² and microwave for 5 min, respectively with 20.7 N/mm² values in group C, drying with IR 1 min + MW 5 min, group B with 26.6 N/mm² values and drying with IR 30 s + MW 5 min with 28.71 N/mm². It was determined that group A had the highest fiber perpendicular compression strength value.

The highest compression strength parallel to the fibers, 25.0 N/mm^2, was obtained in the samples dried with MW 5 min, and the lowest compression strength parallel to the fibers, 15.2 N/mm^2, was obtained in the samples dried with IR 30 s + MW 10 min.

According to the comparison results of the main factor of compression strength drying time parallel to the fibers, the data obtained from the drying time with MW 15 min gave 65% higher results than the data obtained from the drying time with IR 30 s + MW 10 min.

According to homogeneity groups, group E; drying with IR 30 s + MW 10 min, MW 15 min, group DC; drying with IR 1 min + MW 5 min and 24 h oven, Group C; drying with MW10 min, Group B; IR 30 s + MW 5 min, and finally group A; drying with MW 5 min, had the highest compression strength value parallel to the fibers.

CONCLUSIONS

1. It is observed that for both kinds of wood products, the necessary target moisture values rapidly decreased as the microwave drying time increased. The desired moisture content values were obtained in 24 h using the oven drying method and only 15 min using the microwave drying method.
2. After the 1 min infrared drying time, burning occurred on the samples in the infrared + microwave drying group.
3. According to the energy consumption result, it was observed that drying with a microwave for 5-10-15 min consumed less energy than drying with an oven. It has been observed that in oven drying, it takes 24 h until the desired moisture content is reduced, and a long drying time increases energy consumption.
4. In microwave drying, it was observed that the desired moisture content level of both red pine and eastern spruce wood samples was reduced to desired moisture within 15 min at 900 W power, and this reduced energy consumption in direct proportion to the time used.
5. According to the results of compression strength tests perpendicular and parallel to the fibers, it was determined that the compression strength values perpendicular and parallel to the fibers decreased in both red pine and eastern spruce wood samples due to drying.
6. In the compression strength test perpendicular to the fibers, it was determined that the highest compression strength value was in the samples dried with infrared 30 s + microwave 5 min, and in the parallel to the fibers, the highest compression strength value was found in the samples dried with microwave 5 min.

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