**WOOD RESEARCH**
**55 (1): 2010**
**67-78**

# THE EFFECTS OF HIGH-TEMPERATURE HEAT-TREATMENT ON PHYSICAL PROPERTIES AND SURFACE ROUGHNESS OF ROWAN (*SORBUS AUCUPARIA* L.) WOOD

Suleyman Korkut
Duzce University, Faculty of Forestry, Duzce, Turkey

Mehmet Budakci
Duzce University, Faculty of Technical Education,
Department of Furniture and Design, Duzce, Turkey

## ABSTRACT

Heat treatment of wood has attracted a lot of attention both in Europe and recently in North America as an environmentally-friendly wood-protection method. The untreated wood is hydrophilic (high affinity for water). During the heat treatment, wood becomes more and more hydrophobic (low affinity for water) with increasing heat treatment temperature. As a result, it becomes dimensionally more stable compared to untreated wood. The high temperature thermal treatment of wood is an environment-friendly method for wood preservation. This technique has attracted considerable attention in recent years.

This study investigated the influence of heat treatment on the physical and surface roughness of Rowan (*Sorbus aucuparia* L.) wood to understand its role in wood processing. Samples obtained from Kastamonu Forest Enterprises, Turkey, were subjected to heat treatment at varying temperatures and durations. The physical properties of heat-treated and control samples were tested, and oven-dry density, air-dry density, and swelling properties were determined. A stylus method was employed to evaluate the surface characteristics of the samples. Roughness measurements, using the stylus method, were made in the direction perpendicular to the fiber. Four main roughness parameters, mean arithmetic deviation of profile (Ra), mean peak-to-valley height (Rz), root mean square roughness (Rq), and maximum roughness (Ry) obtained from the surface of wood were used to evaluate the effect of heat treatment on the surface characteristics of the specimens. Significant difference was determined ($p = 0.05$) between physical properties and surface roughness parameters (Ra, Rz, Ry, Rq) for three temperatures and three durations of heat treatment.

The results showed that the values of density, swelling and surface roughness decreased with increasing temperature treatment and treatment times. The results obtained in this study provide important information for future research and utilization of thermally modified wood.

KEYWORDS: rowan, heat treatment, physical properties, surface roughness

## INTRODUCTION

Solid wood is a versatile and renewable material that is widely used in different applications. However, due to the hygroscopic nature of wood it has some undesirable properties such as poor resistance against biological attack of fungi and insects, and swelling and shrinkage caused by water adsorption and desorption. These limit the outdoor applications of wood (Kocaefe et al. 2008a). The most commonly used method of wood preservation is chemical treatment which involves the impregnation of chemical substances such as traditional oil (creosote, pentachloro-phenol) and chromated copper arsenate into the wood. Different preservation methods are sought in order to avoid the toxic effects of these chemicals. Wood treatment at high temperature is a very promising alternative to the chemical treatment (Poncsák et al. 2006).

Thermal treatment of wood is nothing new and has been around since 1930's. This technology was of no commercial interest then due to huge availability of cheap hardwoods. Today, as tropical hardwood prices rise, this technology becomes extremely valuable. In the heat-treatment process, wood is heated to temperatures of 160–250 °C, usually above 200 °C depending on the species used and the desired material properties (Kocaefe et al. 2008b).

Increased environmental pressures over the last decade in many European countries resulted in an important development of thermally modified wood, as a non-biocidal alternative to classical preservation techniques. There are various wood thermal treatments available in Europe. This technology is registered in various European countries: France (Perdure, New Option wood, retifraction), Finland (Thermowood), Netherlands (Plato, Lignius, Lambowood), Danmark (Wood Treatment Technology - WTT)), Austria (Huber Holz), Germany (Menz Holz), Russia (Barkett), and Netherlands (Plato, Lignius, Lambowood) (Tjeerdsma 2006). The main differences between the processes are to be seen in the process conditions, process steps, oxygen or nitrogen, steaming, wet or dry process, use of oils, steering schedules etc. (Militz 2002).

Heat treatment reduces the hydrophilic behaviour of the wood by modifying the chemical structure of some of its components. It also results in a significant reduction of the hemicellulose content, thus improving the dimensional stability of the wood (Popper et al. 2005, Wang and Cooper 2005). The dimensional stabilization is caused by the control of volume swelling by water because the hydroxyl groups of cellulose and hemicellulose decrease by thermal treatment (Tjeerdsma and Militz 2005, Mitsui et al. 2008).

When wood absorbs humidity from its surroundings, water molecules are inserted between and within the wood polymers (lignin, cellulose, and hemicelluloses), and hydrogen bonds are formed. This phenomenon makes the wood swell. During the heat treatment, the number of hydrophilic OH groups is decreased and replaced by hydrophobic oxygen-acetyl groups. The latter creates cross-links between wood fibers and thus it significantly reduces the ability of the water to penetrate into the wood (Kocaefe et al. 2008b). The reduction in water absorption causes a decrease in swelling and shrinking of wood leading to improved dimensional stability. This was observed by Stamm as early as 1940's and 1950's (Stamm et al. 1946, Stamm 1956). Fengel and Wegener (1989) have shown the probable thermal degradation pathway for cellulose and hemicelluloses of wood. Significant decrease of hemicellulose content is also reported in the literature (Bekhta and Niemz 2003). Weiland and Guyonnet (2003) investigated the chemical modifications, the dimensional stability and the resistance against fungal degradation, and observed a formation of new ether linkage in addition to the acidic hydrolysis reactions.

Since the main goal of modification is to improve dimensional stability and durability, the reduced hygroscopicity of the wood after treatment is an important parameter. Previous research on important properties of heat-treated wood show that hygroscopicity can be reduced to 60 %

compared to non-treated wood and an improved dimensional stability demonstrated by an anti-shrinking efficiency (ASE) of 50 % (Tjeerdsma et al. 1998) . Rezayati Charani et al. (2007) found that anti-swelling efficiency value of beech wood was increased by increment the exposure durations and temperatures and some soaking cycles.

Burmester (1973) observed that swelling could be reduced in wood based on heating wood in a sealed system under pressure. He compressed oak, beech, spruce and pine with moisture contents ranging from 20 to 30 % and found 52-75 % reductions in deformation due to moisture regain.

Inari et al. (2007) studied heat treatment of beech and pine and observed that holocellulose content determined before heat treatment was approximately 75 % for both species, while the values determined after heat treatment were between 50 % and 60 %.

Thermal modification reduces the equilibrium moisture content. This reduction of the equilibrium moisture content is permanent in thermal modified wood, even at relative humidities near 100 %, which makes it an excellent material for siding/cladding, hardwood flooring and window/door components (Boonstra et al. 2006).

Above 200 °C, significant thermal degradation takes place, with major mass loss occurring beyond 250 °C (Borrega and Kärenlampi 2008). Mass loss has been used as a criterion in identifying the stages of wood degradation when submitted to heat. This criterion is based on the existence of a strong correlation between internal chemical reactions and temperature increase (Brito et al. 2008).

## MATERIAL AND METHODS

Five trees with a diameter at breast height diameter (DBH. 1.3 m above ground) of 255 cm were obtained from Kastamonu Forest Enterprises (TS 4176, 1984). The area from which the trees were taken was at an elevation of 1250m and had a slope of 65. Lumber from the logs was prepared by Oney Kaplama San. A.Ş. Rowan umber was finished by a fixed-knife planer with a feed speed of 1 $m.s^{-1}$. The bias angle of the knife was 45° for the lumber. If the wood pieces are sawn so that the annual rings are at least in 45° angle to the surface the deformations will be smaller, the hardness of the surface will be stronger and the "general looks" after heat treatment is better. Sampling and tests were performed according to several Turkish and ISO standards. Small clear samples were obtained for density and swelling (20x20x30 mm), and surface roughness measurements (50x50x50 mm).

The samples were subjected to heat treatment at 120°, 150°, or 180 °C for 2, 6, or 10 h in a small heating unit controlled to within ±1 °C under atmospheric pressure. After heat treatment, treated and untreated samples were conditioned at 20 ± 2 °C and 65 % (±5 %) relative humidity (RH) in a conditioning room to reach equilibrium moisture content (EMC) of 12 %. The air-dry density of the samples was determined. The dimensions and weights of the samples were measured. The oven-dry and air-dry density of the samples was determined at 0.01 mm and 0.001 g sensitivity.

After the oven-dry dimensions were determined, the samples were soaked in water (20 ± 2 °C). When no changes in sample dimensions were observed, the dimensions were measured.

Tests for density (30 samples) and swelling (30 samples) were carried out based on ISO 3131 and TS 4084, respectively.

Surface roughness of the samples was measured using a profilometer (Mitutoyo Surftest SJ-301). Measurements were made with the profile method using a stylus device standard. The measuring speed, pin diameter, and pin top angle of the tool were 10 $mm.min^{-1}$, 4 μm, and 90°, respectively. The points of roughness measurement were randomly marked on the surface of the samples. Measurements were carried out in the direction perpendicular to the fiber of the samples.

Three roughness parameters, mean arithmetic deviationof profile (Ra), mean peak-to-valley

height (Rz), and maximum roughness (Ry) were commonly used in previous studies to evaluate surface characteristics of wood and wood composites including veneer (Stombo 1963). Ra is the average distance from the profile to the mean line over the length of assessment. Rq is the square root of the arithmetic mean of the squares of profile deviations from the mean line. Rz can be calculated from the peak-to-valley values of five equal lengths within the profile while maximum roughness (Ry) is the distance between peak and valley points of the profile which can be used as an indicator of the maximum defect height within the assessed profile (Mummery 1993). Therefore, such parameters which are characterized by ISO 4287 and DIN 4768 were recorded.

Specification of this parameter is described by Hiziroglu (1996) and Hiziroglu and Graham (1998). Roughness values were measured with a sensitivity of 0.5 μm. The length of scanning line (Lt) was 15 mm and the cut off was λ = 2.5 mm. The measuring force of the scanning arm on the surfaces was 4 mN (0.4 g), which did not put any significant damage on the surface according to Mitutoyo Surftest SJ-301 user manual (Anonymous 2002). Measurements were performed at room temperature and the pin was calibrated before the tests. Fig. 1 shows the Mitutoyo Surftest SJ-301.

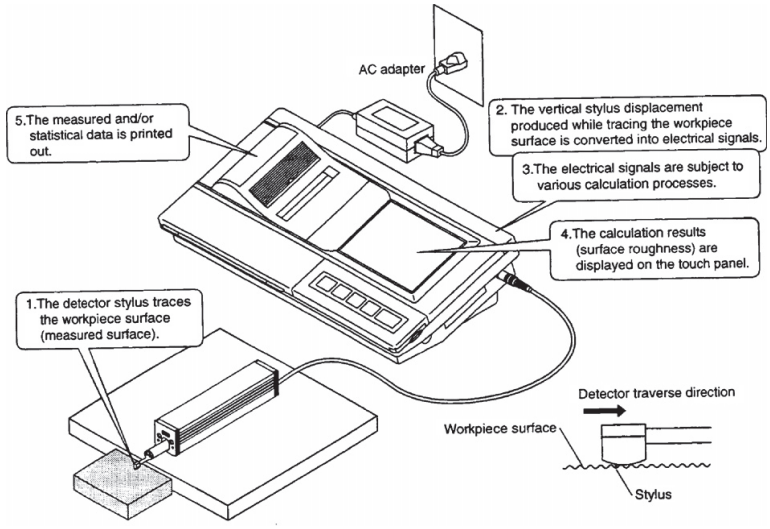


*Fig. 1: Schematic description of the Mitutoyo Surftest SJ-301*

For the oven-dry density, air-dry density, swelling and average roughness, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test.

## RESULTS AND DISCUSSION

Tab. 1 shows the oven-dry and air-dry densities and swelling ratios under the different treatment regimes. It is evident from Tab. 1 that the oven-dry density and air-dry density values decrease with increasing temperature and heat treatment time under the conditions used. Heat-

treated wood samples at a temperature of 180 °C for 10 h gave the lowest air-dry and oven-dry density values when compared with other conditions studied. The effect of the heat treatments was significant for all the variables analyzed.

Time and duration of heat treatment are crucial parameters to obtain a material with good properties. As it can be seen, the weight loss increased if the wood was kept at the maximum heat treatment temperature for a longer time.

*Tab. 1: The effect of heat treatment for different durations on physical properties and surface roughness in Rowan (Sorbus aucuparia L.) wood*[a]

| Heat Treatment | Times | Unit[b] | Oven-dry Density[c] | Air-dry Density[c] | Surface Roughness[c] | | | | Swelling[c] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Do ($g.cm^{-3}$) | $D_{12}$ ($g.cm^{-3}$) | Ra (µm) | Ry (µm) | Rz (µm) | Rq (µm) | Radial (%) | Tangential (%) | Longitudinal (%) |
| Control | | Avg. | 0.764 A | 0.830 A | 7.487 A | 99.687 A | 62.726 A | 10.179 A | 7.068 A | 12.064 A | 0.743 A |
| | | ± s | 0.038 | 0.063 | 1.27 | 14.317 | 13.354 | 1.204 | 1.116 | 1.619 | 0.218 |
| | | $s^2$ | 0.001 | 0.004 | 1.614 | 204.991 | 178.335 | 1.450 | 1.246 | 2.623 | 0.047 |
| | | V | 4.956 | 7.539 | 16.97 | 14.362 | 21.289 | 11.832 | 15.79 | 13.425 | 29.32 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| **120** °C | 2 hr. | Avg. | 0.756 AFGH | 0.822 ACDE | 7.400 ABC | 95.966 ADEF | 60.913 AD | 10.073 ABC | 7.013 ABCDEFG | 11.873 ACDEF | 0.709 ADEFG |
| | | ± s | 0.046 | 0.079 | 1.151 | 13.899 | 12.503 | 1.704 | 1.002 | 1.639 | 0.199 |
| | | $s^2$ | 0.002 | 0.006 | 1.325 | 193.18 | 156.33 | 2.906 | 1.004 | 2.686 | 0.04 |
| | | V | 6.026 | 9.649 | 15.555 | 14.483 | 20.526 | 16.925 | 14.29 | 13.804 | 28.05 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 6 hr. | Avg. | 0.742 A | 0.819 ADE | 7.328 AC | 92.474 A | 60.685 AD | 9.921 ABC | 6.972 ABCDEFG | 11.672 ADEF | 0.704 ADEFG |
| | | ± s | 0.048 | 0.055 | 0.684 | 14.392 | 8.162 | 1.067 | 0.152 | 1.866 | 0.191 |
| | | $s^2$ | 0.002 | 0.003 | 0.468 | 207.134 | 66.629 | 1.138 | 0.023 | 3.485 | 0.037 |
| | | V | 6.404 | 6.772 | 9.34 | 15.563 | 13.450 | 10.756 | 2.181 | 15.994 | 27.16 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 10 hr. | Avg. | 0.732 B | 0.812 AE | 7.246 AC | 91.781 A | 60.08 A | 9.874 ABC | 6.730 AEFG | 11.246 ADEF | 0.661 AFG |
| | | ± s | 0.067 | 0.067 | 0.818 | 20.528 | 12.085 | 1.660 | 1.72 | 1.970 | 0.212 |
| | | $s^2$ | 0.004 | 0.005 | 0.669 | 421.38 | 146.05 | 2.758 | 2.97 | 3.884 | 0.045 |
| | | V | 9.13 | 8.286 | 11.29 | 22.366 | 20.115 | 16.819 | 25.6 | 17.525 | 32.09 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| **150** °C | 2 hr. | Avg. | 0.730 C | 0.799 AE | 7.177 AC | 90.447 A | 58.927 A | 9.773 AC | 6.316 BFG | 11.013 ADEF | 0.624 B |
| | | ± s | 0.052 | 0.077 | 1.246 | 19.358 | 14.089 | 2.493 | 0.968 | 2.389 | 0.175 |
| | | $s^2$ | 0.003 | 0.006 | 1.553 | 374.72 | 198.5 | 6.214 | 0.937 | 5.708 | 0.031 |
| | | V | 7.156 | 9.693 | 17.36 | 21.402 | 23.909 | 25.51 | 15.33 | 21.694 | 28.05 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 6 hr. | Avg. | 0.728 D | 0.795 AE | 7.140 AC | 87.385 B | 57.306 A | 9.656 AC | 6.273 CFG | 10.91 BDEF | 0.622 C |
| | | ± s | 0.06 | 0.068 | 0.78 | 22.478 | 17.670 | 0.931 | 1.404 | 1.922 | 0.095 |
| | | $s^2$ | 0.004 | 0.005 | 0.608 | 505.303 | 312.243 | 0.867 | 1.971 | 3.695 | 0.009 |
| | | V | 8.257 | 8.59 | 10.92 | 25.724 | 30.835 | 9.642 | 22.38 | 17.62 | 15.24 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 10 hr. | Avg. | 0.727 E | 0.783 B | 7.103 AC | 85.052 C | 56.646 A | 9.48 A | 6.189 DFG | 10.677 CEF | 0.597 D |
| | | ± s | 0.059 | 0.041 | 0.79 | 24.112 | 10.070 | 1.614 | 0.921 | 0.953 | 0.183 |
| | | $s^2$ | 0.004 | 0.002 | 0.625 | 581.41 | 101.414 | 2.606 | 0.849 | 0.909 | 0.034 |
| | | V | 8.168 | 5.192 | 11.13 | 28.35 | 17.777 | 17.03 | 14.89 | 8.932 | 30.69 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| **180** °C | 2 hr. | Avg. | 0.720 F | 0.775 C | 6.922 A | 84.385 D | 54.26 B | 9.365 A | 5.922 EFG | 9.793 D | 0.562 E |
| | | ± s | 0.072 | 0.155 | 1.213 | 18.856 | 11.834 | 1.083 | 1.174 | 1.574 | 0.126 |
| | | $s^2$ | 0.005 | 0.024 | 1.472 | 355.556 | 140.059 | 1.172 | 1.379 | 2.478 | 0.016 |
| | | V | 10.04 | 19.992 | 17.53 | 22.345 | 21.811 | 11.56 | 19.83 | 16.07 | 22.4 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 6 hr. | Avg. | 0.718 G | 0.769 D | 6.728 B | 82.718 E | 53.328 C | 8.89 B | 5.355 F | 9.516 E | 0.553 F |
| | | ± s | 0.05 | 0.074 | 1.003 | 21.301 | 17.328 | 1.23 | 1.135 | 2.352 | 0.151 |
| | | $s^2$ | 0.003 | 0.006 | 1.005 | 453.75 | 300.291 | 1.51 | 1.288 | 5.534 | 0.023 |
| | | V | 6.986 | 9.673 | 14.9 | 25.752 | 32.494 | 13.8 | 21.19 | 24.72 | 27.33 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 10 hr. | Avg. | 0.714 H | 0.750 E | 6.525 C | 81.718 F | 52.306 D | 8.605 C | 5.253 G | 9.037 F | 0.549 G |
| | | ± s | 0.009 | 0.016 | 1.084 | 16.648 | 15.535 | 2.163 | 0.428 | 2.068 | 0.173 |
| | | $s^2$ | 0.0002 | 0.0002 | 1.175 | 277.15 | 241.353 | 4.681 | 0.184 | 4.277 | 0.03 |
| | | V | 1.294 | 2.078 | 16.62 | 20.372 | 29.701 | 25.143 | 8.155 | 22.89 | 31.58 |
| | | N | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |

[a] Number of samples used in each test is 30.

[b] Avg = average; ± s =standard deviation; $s^2$=variance. V= coefficient of variation. N= number of samples used in each test.

[c] Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test at $P < 0.05$.
Comparisons were between each control and its test.

Decreases in swelling to radial, tangential and longitudinal directions were found tobe 25.68 %, 25.10 %, and 26.08 %, respectively, when treated at 180 °C for 10 h. A decrease in swelling results in an increase in dimensional stability, which is required for several uses of wood.

Surface roughness decreased by up to 12.85 % in the sample heat-treated at 180 °C for 10 h when compared with the control samples. This increase in smoothness is very important for many applications of solid wood. In addition, losses occurring in the planing machine are reduced and high quality surfaces are attained.

It may be concluded that the heat treatment resulted a plastification on the solid wood surfaces. High temperatures above 160 °C cause lignin to a thermoplastic condition and thus to densify and compact solid wood surface. Also, the wooden materials with rough surface requires much more sanding process compared to one with smooth surface, which leads to decrease in thickness of material and, therefore, increase the losses due to the sanding process (Follrich et al. 2006).

The maximum decreases for all parameters were recorded at the treatment of 180 °C for 10 h. The lowest oven-dry density values obtained was 0.714 g.cm$^{-3}$, total loss compared to the control was calculated to be 6.60 %. Similarly, the lowest air-dry density was also obtained for samples treated at 180 °C for 10 h (0.750 g.cm$^{-3}$). The air-dry density loss was 9.67 % when compared to the control.

Tab. 2 shows the percentage decrease of values in relation to the control for each treatment and each measured parameter.

*Tab. 2: Percentage decrease of physical properties and surface roughness in Rowan (Sorbus aucuparia L.) wood following heat treatment for different durations*

| Heat treatment | Time (hr.) | Oven-dry density | Air-dry density | Swelling | | | Surface Roughness | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Radial | Tangential | Longitudinal | Ra | Ry | Rz | Rq |
| | | % | % | % | % | % | % | % | % | % |
| 120 °C | 2 | 1.08 | 0.99 | 0.78 | 1.58 | 4.54 | 1.16 | 3.73 | 2.89 | 1.03 |
| | 6 | 2.93 | 1.43 | 1.35 | 3.25 | 5.28 | 2.12 | 7.24 | 3.25 | 2.53 |
| | 10 | 4.16 | 2.19 | 4.78 | 6.78 | 10.96 | 3.21 | 7.93 | 4.22 | 2.99 |
| 150 °C | 2 | 4.49 | 3.82 | 10.65 | 8.71 | 15.95 | 4.14 | 9.27 | 6.06 | 3.98 |
| | 6 | 4.77 | 4.27 | 11.25 | 9.57 | 16.26 | 4.63 | 12.34 | 8.64 | 5.13 |
| | 10 | 4.91 | 5.66 | 12.44 | 11.50 | 19.68 | 5.12 | 14.68 | 9.69 | 6.86 |
| 180 °C | 2 | 5.78 | 6.69 | 16.22 | 18.83 | 24.39 | 7.55 | 15.35 | 13.5 | 7.99 |
| | 6 | 6.01 | 7.39 | 24.24 | 21.12 | 25.51 | 10.13 | 17.02 | 14.98 | 12.70 |
| | 10 | 6.60 | 9.67 | 25.68 | 25.10 | 26.08 | 12.85 | 18.03 | 16.61 | 15.50 |

The parameters measured varied in their rates of decrease with some experiencing a gradual loss and others exhibiting more dramatic changes (Fig. 2). Heat treatment resulted in varying amounts of weight loss, depending on the treatment temperature and time.

In general the results of this study on the effect of heat treatment on Rowan are compatible with the findings in literature on the effect of heat treatment on different tree species.

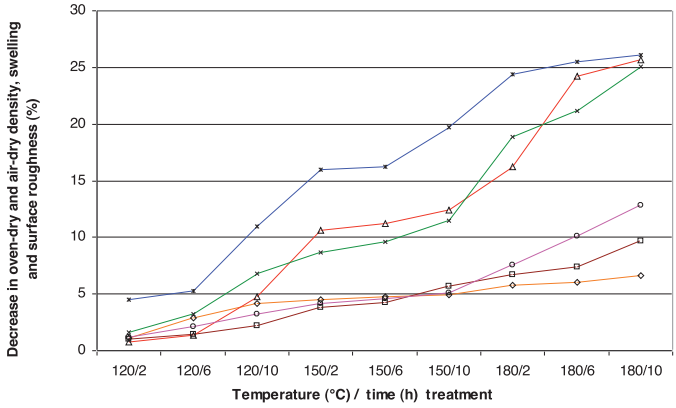


*Fig. 2: Percentage decrease of physical properties in Rowan (Sorbus aucuparia L.) wood following heat treatment for different durations. (◊) oven-dry density; (□) air-dry density; (Δ) radial swelling; (x) tangential swelling; (*) longitudinal swelling; (o) surface roughness (Ra)*

Unsal et al. (2003) reported that in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood samples the largest swelling loss was at 180 °C after 10 h treatment. The loss was 14.11 % radially, and 21.51 % tangentially. Oven-dry density decreased by up to 11.76 % in the sample heat-treated at 180 °C for 10 h when compared with the control samples.

A similar study was made by Yildiz (2002) with oriental beech and spruce. For oriental beech at 200 °C and 10 hours, density, anti-swelling efficiency decreased up to 18.4 % and 52.9 %, respectively. At 180 °C and 10 hr, maximum hardness loss (cross section 25.9 %, radial 45.1 % and tangential 41.8 %) were measured. Also for oriental spruce, density decreasing was 10.5 %. In another study anti swelling efficiency was found 24 % in the study on Eucalyptus *(Eucalyptus globulus)* wood at 180 °C by (Santos 2000).

Esteves et al. (2007) reported that in *Pinus pinaster* and *Eucalyptus globulus* wood samples in the absence of air by steaming, treatment inside an autoclave heated at 190–210 °C for 2–12 h resulted in an equilibrium moisture content decrease by 46 % for pine and 61 % for eucalyptus, while the dimensional stability increased (maximum anti-shrinking efficiency in the radial direction of 57 and 90 % for pine and eucalyptus, respectively) and the surface wettability was lowered. Mass losses increased with treatment time and temperature, reaching 7.3 % for pine and 14.5 % for eucalyptus wood. The wood behaviour towards moisture was improved.

Metsä-Kortelainen et al. (2006) investigated water absorption differences between sapwood and heartwood of Scots pine and Norway spruce heat-treated at temperatures 170 °C, 190 °C, 210 °C and 230 °C and observed that the heartwood of both wood species absorbed less water than sapwood.

Heat treatment of wood resulted in a significant reduction of water adsorption. The availability and/or accessibility of the free hydroxyl groups of the wood carbohydrates play an important role in the process of water adsorption and desorption. It is by no doubt that heat treatment results in a reduction of the accessible, free hydroxyl groups and several causes are reported, e.g. depolymerisation of the carbohydrates and especially hemicelluloses causing a reduction of the total amount of hydroxyl groups, including the free hydroxyl groups; an increase of the relative proportion of the crystalline cellulose, in which the hydroxyl groups are not easily accessible to water molecules; and crosslinking of the lignin network, which might

hinder the accessibility of free hydroxyl groups to water (Boonstra 2008, Kocaefe et al. 2007).

The relative weight loss includes the evaporation of water as well as evaporation of extractives, degradation of wood components espacially hemicelluloses and evaporation of degradation products (Kocaefe et al. 2008a). Kollmann and Fengel (1965) concluded that there was only mass loss for temperatures higher than 100 °C for pine wood, and 130-150 °C for oak wood. Zaman et al. (2000) treated *Pinus sylvestris* and *Betula pendula* at temperatures between 200 °C and 230 °C during 4-8 h and determined that the mass losses for pine varied between 5.7 % (4h) to 7.0 % (8h) at 205 °C, and between 11.1 % (4h) and 15.2 % (8h) at 220 °C. Alén et al. (2002) studied the mass loss of heat treated spruce at temperatures between 180 °C and 225 °C during 4 to 8 hours and concluded that they were between 1.5 % at 180 °C (4h) and 12.5 % at 225 °C (6h).

Unsal and Ayrilmis (2005) also found that the maximum surface roughness decrease in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood samples was 27.9 % at 180 °C for 10 h. Korkut (2008) obtained similar oven-dry and air-dry density, swelling and surface roughness values for Uludag fir (*Abies bornmuelleriana* Mattf.) wood for the same treatment time and temperature.

## CONLUSIONS

In conclusion, it was found that the density, swelling and surface roughness of the Rowan decreased for all treatment conditions (temperatures and times). The smallest decrease was observed in the treatment at 120 °C for 2 h. The largest decrease found was for swelling, followed by surface roughness and air-dry density, when samples were heat-treated under the specific conditions of this research.

Thermal modified wood has lower moisture permeability reducing the need to acclimatize or condition the wood on site before installation. The amount of shrinkage and swelling is stabilized, even for unstable species, reducing after sales problems. Stabilization lowers the wood variation for fitting pieces together and remaining tightly connected. No warping, twisting or cupping is observed because thermal modified wood has no internal drying stress found in normal kiln-dried wood.

The improved characteristics of heat treated timber offer the timber product industry many potential and attractive new opportunities. The most important property, when compared to untreated wood, is that the equilibrium moisture content of the heat-treated wood is reduced and as a consequence of this shrinkage and swelling of the wood is also reduced. The best way of utilizing heat-treated timber is to make use of these improved properties. New design opportunities are created by thermal modified species such as ash, beech, larch and some softwood as colour darkens with treatment and make the wood similar to tropical species. Indeed, it is possible to use low cost species for a higher end market. Higher stability allows plank width to be increased without cupping or moving problems. Costs of staining during the manufacturing process are also reduced by less absorptive wood (Welzbacher et al. 2008, Gündüz et al. 2008, Kaygin et al. 2009).

Thermal treatment of wood is the next best thing to have happened to the wood industry. Now wood species that have no commercial value before can be heat-treated to achieve these improved properties. Heat treatment of rowan wood shows an interesting potential to improve the wood quality for solid timber products.

## REFERENCES


1. Alén, R., Kotilainen, R., Zaman, A., 2002: Themochemical behaviour of Norway spruce (*Picea abies*) at 180–225 °C, Wood Science and Technology 36(2): 163–171
2. Anonymous, 2002: Mitutoyo surface roughness tester, Mitutoyo Surftest SJ-301, Product no. 99MBB035A 1. Series No. 178, Mitutoyo Corporation, 20-1, Sakado 1-chome, Takatsu-ku, Kawasaki, Kanagawa 213-0012, Japan
3. Bekhta, P., Niemz, P., 2003: Effect of High Temperature on the Change in Color, Dimensional Stability and Mechanical Properties of Spruce Wood, Holzforschung, 57(5): 539–546
4. Boonstra, M.J., Rijsdijk, J.F., Sander, C., Kegel, E., Tjeerdsma, B., Militz, H., van Acker, J., Stevens, M., 2006: Microstructural and Physical Aspects of Heat Treated Wood. Part 2. Hardwoods, Maderas. Ciencia y tecnología, 8(3): 209-217
5. Boonstra, M.J., 2008: A two-stage thermal modification of wood, Ghent University, Faculty of Bioscience Engineering, Laboratory of Wood Technology, Ph.D. Dissertation, Belgium
6. Borrega, M., Kärenlampi, P.P., 2008: Effect of relative humidity on thermal degradation of Norway spruce (*Picea abies*) wood, Journal of Wood Science, 54(4): 323-328
7. Brito, J.O., Silva, F.G., Leão, M.M., Almeida, G., 2008: Chemical composition changes in eucalyptus and pinus woods submitted to heat treatment, Bioresource Technology, 99(18): 8545–8548
8. Burmester, V.A., 1973: Effects of heat-pressure-treatments of semi-dry wood on its dimensional stability, Holz als Roh- und Werkstoff, 31: 237-243
9. DIN 4768, 1990: Determination of values of surface roughness parameters Ra, Rz, Rmax using electrical contact (stylus) instruments, concepts and measuring conditions
10. Esteves, B.M., Marques, A.V., Domingos, I.J., Pereira, H.M., 2007: Influence of steam heating on the properties of pine (*Pinus pinaster*) and eucalypt (*Eucalyptus globulus*) wood, Wood Science and Technology, 41(3): 193–207
11. Fengel, D., Wegener, G., 1989: Wood Chemistry, Ultrastructure, Reactions; Walter de Gruyter: Berlin-Germany
12. Follrich, J., Muller, U., Gindl, W., 2006: Effects of thermal modification on the adhesion between spruce wood (*Picea abies* Karst.) and a thermoplastic polymer. Holz als Roh- und Werkstoff, 64: 373–376
13. Gündüz, G., Niemz, P., Aydemir, D., 2008: Changes in Specific Gravity and Equilibrium Moisture Contenet in Heat Treated Fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf.) Wood, Drying Technology, 26(9): 1135-1139
14. Hiziroglu, S., 1996: Surface roughness analysis of wood composites: a stylus method. Forest Products Journal, 46: 67–72
15. Hiziroglu, S., Graham, S., 1998: Effect of press closing time and target thickness on surface roughness of particleboard. Forest Products Journal, 48: 50–54
16. Inari, G.N., Petrissans, M., Gerardin, P., 2007: Chemical reactivity of heat-treated wood, Wood Science and Technology, 41(2): 157–168
17. ISO 3131, 1975: Wood–determination of density for physical and mechanical tests
18. ISO 4287, 1997: Geometrical product specifications (GPS) surface texture: profile method–terms, definitions, and surface texture parameters
19. Kaygin, B., Gündüz, G., Aydemir, D., 2009: Some Physical Properties of Heat-Treated Paulownia (*Paulownia elongata*) Wood**,** Drying Technology, 27(1): 89-93

20. Kocaefe, D., Chaudhry, B., Poncsák, S., Bouazara, M., Pichette, A., 2007: Thermogravimetric study of high temperature treatment of aspen: effect of treatment parameters on weight loss and mechanical properties, Journal of Materials Science 42(3): 854-866
21. Kocaefe, D., Poncsak, S., Boluk, Y., 2008a: Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen, BioResources 3(2): 517-537
22. Kocaefe, D., Poncsák, S., Doré, G., Younsi, R., 2008b: Effect of heat treatment on the wettability of white ash and softmaple by water, Holz als Roh- und Werkstoff 66(5): 355–361
23. Kollmann, F., Fengel, D., 1965: Changes in the chemical composition of wood by thermal treatment, Holz als Roh- und Werkstoff 12: 461- 468
24. Korkut, S., 2008: The effects of heat treatment on some technological properties in Uludag fir (*Abies bornmuelleriana* Mattf.) wood. Building and Environment 43: 422- 428
25. Metsä-Kortelainen, S., Antikainen, T., Viitaniemi, P., 2006: The water absorption of sapwood and heartwood of Scots pine and Norway spruce heat-treated at 170 °C, 190 °C, 210 °C and 230 °C, Holz als Roh- und Werkstoff 64(3): 192–197
26. Militz, H., 2002: Thermal treatment of wood: European processes and their background. Doc. no. IRG/WP 02-40241. The International Research Group on Wood Preservation, Stockholm-Sweden
27. Mitsui, K., Inagaki, T., Tsuchikawa, S., 2008: Monitoring of Hydroxyl Groups in Wood during Heat Treatment Using NIR Spectroscopy, Biomacromolecules, 9: 286–288
28. Mummery, L., 1993: Surface texture analysis. The handbook. Muhlhausen, Germany: Hommelwerke, 106 pp.
29. Poncsák, S., Kocaefe, D., Bouazara, M., Pichette, A., 2006: Effect of high temperature treatment on the mechanical properties of birch (*Betula papyrifera*), Wood Science and Technology 40(8): 647-663
30. Popper, R., Niemz, P., Eberle, G., 2005: Investigations on sorption and swelling properties of thermally treated wood, Holz als Roh-und Werkstoff 63(2): 135-148
31. Rezayati Charani, P., Mohammadi Rovshandeh, J., Mohebby, B., Ramezani, O., 2007: Influence of hydrothermal treatment on the dimensional stability of beech wood, Caspian Journal of Environmental Sciences 5(2): 125-131
32. Santos, J.A., 2000: Mechanical behaviour of Eucalyptus wood modified by heat, Wood Science and Technology 34(1): 39-43
33. Stamm, A.J., Burr, H.K., Kline, A.A., 1946: Heat-stabilized wood, Industrial & Engineering Chemistry, 38(6): 630–634
34. Stamm, A.J., 1956: Thermal degradation of cellulose, Industrial & Engineering Chemistry, 48(3): 413–417
35. Stombo, D.A., 1963: Surface texture measurement. Forest Products Journal 13(6): 99–304
36. Tjeerdsma, B.F., Militz, H., 2005: Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood, Holz als Roh- und Werkstoff, 63(2*)*: 102–111.
37. Tjeerdsma, B.F., 2006: Heat treatment of wood -thermal modification, SHR Timber Research, Wageningen, The Netherlands
38. Tjeerdsma, B.F., Boonstra, M., Militz, H., 1998: Thermal modification of non-durable wood species. 2. Improved wood properties of thermally treated wood. International Research Group on Wood Preservation, Document no. IRG/WP 98-40124

39. TS 4176, 1984: Wood-sampling sample trees and logs for determination of physical and mechanical properties of wood in homogeneous stands
40. TS 4084, 1983: Wood-determination of Radial and Tangential Swelling
41. Unsal, O., Korkut, S., Atik, C., 2003: The effect of heat treatment on some properties and colour in eucalyptus (*Eucalyptus camaldulensis* Dehn.) wood. Maderas. Ciencia y tecnología, 2: 145–152
42. Unsal, O., Ayrilmis, N., 2005: Variations in compression strength and surface roughness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood. Journal of Wood Science, 51: 405–409
43. Wang, J.Y., Cooper, P.A., 2005: Effect of oil type, temperature and time on moisture properties of hot oil-treated wood, Holz als Roh- und Werkstoff, 63(6): 417–422
44. Weiland, J.J., Guyonnet, R., 2003: Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. Holz als Roh- und Werkstoff, 61(3): 216–220
45. Welzbacher, C.R., Wehsener, J., Rapp, A.O., Haller, P., 2008: Thermo-mechanical densification combined with thermal modification ofNorway spruce (*Picea abies* Karst) in industrial scale –Dimensional stability and durability aspects, Holz als Roh- und Werkstoff, 66(1): 39–49
46. Yildiz, S., 2002: Physical, mechanical, technological, and chemical properties of *Fagus orientalis* and *Picea orientalis* wood treated by heating. PhD Thesis, Blacksea Technical University, Trabzon-Turkey
47. Zaman, A., Alén, R., Kotilainen, R., 2000: Thermal behavior of *Pinus sylvestris* and *Betula pendula* at 200-230 °C, Wood and Fiber Science, 32(2): 138-143

Suleyman Korkut
Duzce University
Faculty of Forestry,
81620 Duzce
Turkey
E-mail: suleymankorkut@hotmail.com

Mehmet Budakci
Duzce University
Faculty of Technical Education
Department of Furniture and Design
81620 Duzce
Turkey