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SURFACE ROUGHNESS AND WETTABILITY PERFORMANCE OF THERMALLY MODIFIED ROWAN WOOD AS A FAST-GROWING SPECIES

This study aims to examine the effect of the thermal modification process on the surface roughness properties of the wood of rowan (Sorbus aucuparia L.) as a fast-growing species. Four thermal modification processes were applied, with temperatures of 160 and 180°C and durations of 2 and 4 hours. In total five groups were compared, including the untreated group. Arithmetical mean roughness, maximum height, ten-spot average roughness, and root-mean-square deviation were measured using a stylus-type profilometer, both parallel and perpendicular to the grain, according to the JIS B 0601 standard. Wettability was determined by measuring the contact angle of a droplet of distilled water. After dripping, the camera captured several images to measure the contact angle. The results showed that thermal modification decreases the wettability of the samples. Moreover, increments in temperature and duration may further decrease wettability. On the other hand, there are no significant differences between groups in terms of the surface roughness values, measured both parallel and perpendicular to the grain, except for two groups. It is concluded that these process conditions did not substantially change the surface roughness properties of rowan wood panels. However, the decrease in wettability may provide new possibilities for the use of less-known wood species.

Keywords: fast-growing species, rowan wood, surface roughness, thermal modification, wettability

Introduction

Although the forest is described as a sustainable resource, humanity should conform to the principles of sustainability in order to maintain both the

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phenomenon and the resource. Crowther et al. [2015] indicated that there are 3.04 trillion trees; however, 15 billion of them are cut each year, and the global number of trees has fallen by approximately 46% since the start of human civilization.

Forests have many ecological benefits for the life cycle of nature. On the other hand, the wood industry directly depends on the forest to fulfil the needs of human society. Forest management plays a critical role in balancing these needs. To secure all the benefits that forests provide, many industrial plantation forests have been established worldwide, serving mainly to provide produce for industry. Although fast-growing tree species are preferred to maintain sustainability, the wood quality of these species is low, the wood being of low density. Therefore, many methods of modification have been applied to wood from these species [Yildiz et al. 2005a; Burnard et al. 2017; Ozmen 2007; Marcon et al. 2018.

Wood modification methods can be grouped as follows: (1) chemical treatments; (2) thermo-hydro (TH) and thermo-hydro-mechanical (THM) treatments; (3) treatments based on biological processes; and (4) physical treatment with the use of electromagnetic irradiation or plasma [Sandberg et al. 2017]. In the thermal modification method, the characteristics of wood are altered with temperature in generally oxygen-free atmospheric conditions. This method generally decreases the strength of wood, while improving some physical properties, particularly dimensional stability and durability [Stamn and Hansen 1937; Giebeler 1983; Bekhta and Niemz 2003; Sundqvist 2004; Yildiz et al. 2005b; Inoue et al. 2007; Sivrikaya et al. 2016; Can 2020; Sahin et al. 2020]. The process is generally characterized by heat and duration. The thermal modification is invariably performed between the temperatures of 180 and 260°C, with temperatures lower than 140°C resulting in only slight changes in material properties, and higher temperatures resulting in unacceptable degradation to the substrate [Hill 2007]. Although there are many studies concerning the effect of heat applied by this method, it still needs to be investigated further. One aspect is the determination of the range of temperatures that will favour the maintenance of the wood's original structure [Korkut et al. 2009]. During thermal treatment, physical and chemical processes occur in layers near the surface, resulting in a modified surface with new characteristics [Candan et al. 2012]. Hakkou et al. [2005] indicated that high temperatures above 160°C cause lignin to become thermoplastic, and thus to densify and compact the solid wood surface. After this point (the glass transition temperature of 160°C) the plasticization of lignin starts to affect the surface characteristics of the wood [Candan et al. 2012].

Surface properties of wooden materials are an important factor that can determine their areas of usage, and can be determinative for the quality of many processes, such as coating, machining, etc. For example, wooden materials with rough surfaces require much more sanding, which leads to a decrease in the thickness of the material and, therefore, increases the losses due to the sanding process [Follrich et al. 2006]. Many factors, including macroscopic characteristics, wettability, porosity, surface roughness, colour, and other appearance characteristics, can be measured to determine the surface properties of wood [Sivrikaya et al. 2016; Can 2020; Sahin et al. 2020]. However, these factors can change as a result of various conditions. Olek and Bonarski [2008] indicated that the highly anisotropic microstructure of wood, especially its crystallinity, changed during thermal treatment. Unsal and Ayrilmis [2005] and Kamperidou and Barboutis [2017] indicated that surface roughness decreased in a thermal modification process with increasing temperature and duration for Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) and poplar (*Populus spp.*) wood samples.

Darmawan et al. [2018] indicate that the wettability properties of any wood material can be affected by many factors, such as moisture content, machining conditions, extractives content, etc. Apart from these factors, thermal modification can change the hydrophilic character of wood, and consequently, the wettability of thermally modified wood can produce different behaviour in coating or gluing processes [Petrič et al. 2007].

The wood of rowan, which can be described as a fast-growing and relatively short-lived species, is commonly used to make hoops for barrels, spinning wheels, wagons, etc. due to its strength and flexibility; it is also used to make certain wooden objects such as rough basketwork, household utensils and platters, due to its thin texture [Korkut et al. 2009]. An air-dry wood density of 801 kg/m^3 [Korkut et al. 2010] can explain the areas in which it is used. Although it is a fast-growing species, higher density is desirable for the wood industry. Many fast-growing species, such as paulownia, poplar and eucalyptus, have lower densities which fail to meet the requirements of many areas of usage. It has been indicated that the properties, and accordingly the possible uses of rowan wood are lesser known. Studies will enable the identification of areas in which the wood of this species is suitable for use.

The aim of this study was to investigate the changes in surface roughness and wettability properties due to thermal modification of rowan wood. It is also expected that the study will contribute to expanding knowledge about this tree species.

Materials and methods

Rowan (*Sorbus aucuparia* L.) wood panel was used, and small experimental panel parts were cut to 50 mm width, 50 mm length and 18 mm thickness from commercially supplied lumber.

The thermal modification process was performed in a temperature-controlled oven with ±1°C sensitivity under atmospheric pressure. The experimental design of the thermal modification process is described in Table 1. Twenty samples were used for each group. All samples were conditioned at 20(±2)°C and 65(±5)% relative humidity in a climate chamber until equilibrium moisture content was reached after thermal treatment (Table 1).

Table 1. Experimental design of the thermal modification process

Panel group	Treatment conditions	
	Temperature (°C)	Time (h)
Control	–	–
A	160	2
B	160	4
C	180	2
D	180	4

Twenty samples were used for each of the untreated and treated groups. Measurements were performed both parallel and perpendicular to the grain of each sample. Four roughness parameters were determined in accordance with a Japanese standard [JIS B 0601: 2001]. Arithmetical mean roughness (Ra), maximum height (Ry), ten-spot average roughness (Rz) and root-mean-square deviation (Rq) were used to evaluate the surface roughness properties of the panels. A Mitutoyo SJ-301 surface roughness tester, known as a stylus-type profilometer, was used for the tests (Figure 1). Roughness values were measured with a sensitivity of 0.5 µm. The measuring speed was 10 mm/min, and the λc value was 2.5 mm × 5 = 12.5 mm.

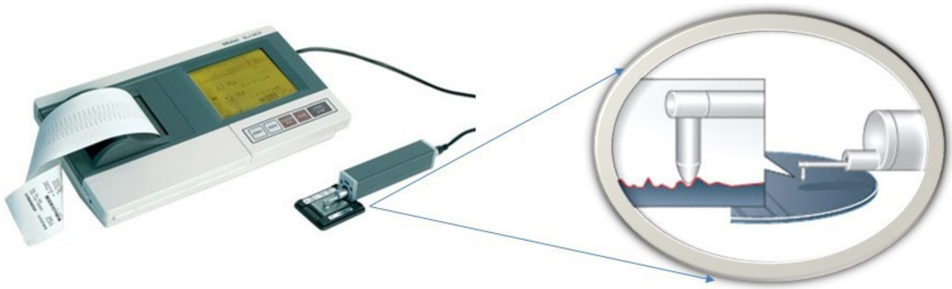

Fig. 1. Surface roughness testing device (Mitutoyo Surftest SJ-301)

Fifteen samples were used from each group in the wettability tests. Contact angle (CA) values were utilized to determine the wettability characteristics of the samples. The values were determined using a KSV Cam-101 Scientific Instrument (Helsinki, Finland). A 5 µL droplet of distilled water was used as the liquid. After the droplet was dripped on the sample surface, the camera captured 30 images at 1-second intervals. CA values were obtained from the images by means of the device's image processing software. As shown in Figure 2, the mean of two contact angle values (left and right) was used in the analysis.

For comparison all groups, multiple comparisons were first subjected to analysis of variance (ANOVA), and significant differences between average values of control and treated samples were determined by Duncan's multiple range test, using SPSS software. A p-value of 0.05 was taken as the significance level.

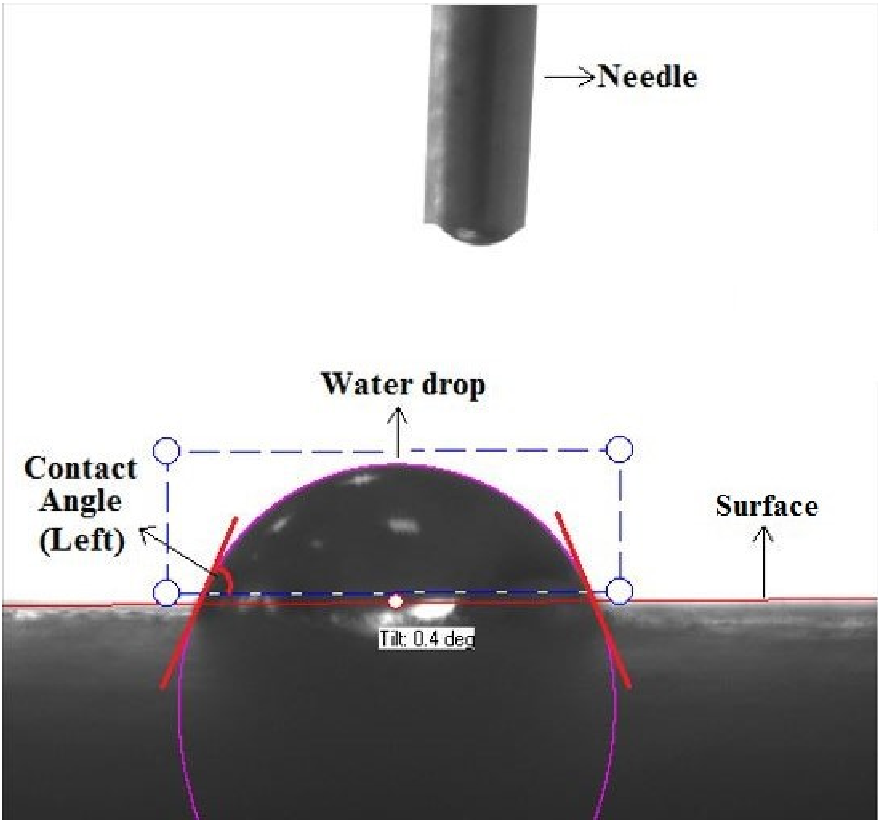

Fig. 2. Digital image processing to determine the contact angle using the KSV Cam-101

Results and discussion

Untreated (control) and treated groups were compared, and homogeneity groups were determined for each test according to Duncan's multiple range test.

The mean surface roughness values (Ra, Ry, Rz, Rq) for all groups of rowan samples were found to be 4.266 µm, 26.698 µm, 16.865 µm and 5.504 µm in the parallel direction, and 6.024 µm, 44.931 µm, 28.693 µm and 8.535 µm in the perpendicular direction.

Table 2. Effect of thermal treatment with different durations on the surface roughness of rowan wood*

Treat-ment (°C)	Dura-tion (h)	Ra (μm)**		Ry (μm)**		Rz (μm)**		Rq (μm)**	
		//	⊥	//	⊥	//	⊥	//	⊥
Control		4.005 (1.86)[a]	6.286 (1.72)[bc]	24.678 (11.08)[d]	43.635 (16.67)[e]	15.728 (7.38)[f]	30.136 (10.45)[gh]	5.112 (2.40)[i]	9.493 (4.89)[j]
160	2	4.245 (2.22)[a]	6.078 (1.85)[bc]	26.956 (14.00)[d]	45.961 (11.41)[e]	16.607 (8.13)[f]	28.461 (7.50)[gh]	5.684 (3.40)[i]	8.525 (2.33)[j]
160	4	4.468 (1.52)[a]	6.662 (1.64)[c]	27.384 (8.89)[d]	50.379 (12.69)[e]	17.268 (5.51)[f]	31.975 (8.84)[h]	5.714 (1.96)[i]	9.255 (2.30)[j]
180	2	4.128 (1.73)[a]	5.441 (1.86)[b]	26.051 (10.13)[d]	43.736 (16.50)[e]	16.344 (6.04)[f]	27.376 (11.06)[gh]	5.246 (2.12)[i]	7.882 (3.18)[j]
180	4	4.486 (1.53)[a]	5.655 (1.28)[bc]	28.422 (10.15)[d]	40.946 (11.18)[e]	18.377 (6.43)[f]	25.520 (6.61)[g]	5.765 (2.00)[i]	7.523 (1.85)[j]

The relation between surface roughness and the conditions of the heat treatment process can be presented by means of a comparison of the present results with those of Korkut and Budakci [2010]. That study used three temperatures (120, 150 and 180°C) and three durations (2, 6 and 10 hours) of heat treatment, while the present study used temperatures of 160 and 180°C and durations of 2 and 4 hours. In general, we found lower roughness values for the control samples. Differences in macroscopic structure and machining properties may be the reason for the difference. Other results showed that there was a significant decrease only at a temperature of 180°C. At other temperatures, there was no decrease in roughness depending on the duration of the process. The shorter durations of thermal treatment may be insufficient to alter the cellulose texture [Olek and Bonarski 2008] on the solid wood surface. For example, Unsal and Ayrilmis [2005] found a decrease in the maximum surface roughness in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) at the same temperature. They observed a 27.9% decrease after treatment at 180°C with a duration of 10 hours.

As shown in Table 2, when the samples are compared only with the control (untreated) group, there are no significant differences between groups in the surface roughness values measured parallel to the grain. When surface roughness values measured perpendicular to the grain are analysed, only two groups gave different values for all measurements ("160°C – 4 hours" gave higher values and "180°C – 2 hours" lower values).

We performed measurements in directions both parallel and perpendicular to the grain, because features of anatomic structure such as wider trachea and ray dimension on the surface may affect the results. We used the same profilometer in each case, with a sensitivity of 0.5 μm. However, Sachsse et al. [1988] found an average value of 5.83 μm for the lumen diameter on untreated rowan wood. Therefore, a larger pin or 3D measurement may provide more accurate results.

The contact angle (CA) values of rowan samples exposed to different process conditions are presented in Table 3.

Table 3. Effect of thermal treatment with different durations on the wettability of rowan wood*

Treatment (°C)	Duration (h)	Contact angle (°)**
Control		55.204 (15.44)[a]
160	2	72.549 (13.68)[b]
160	4	76.053 (14.47)[bc]
180	2	76.884 (12.99)[bc]
180	4	86.912 (17.47)[c]

Statistically significant differences ($p < 0.05$) were found to exist as determined by Duncan's multiple comparison tests. The CA values for all treated samples were higher than for the control (untreated) samples, and the difference increased with increasing modification temperature and duration. The values increased by 35% and 47% following treatment at 160°C and 180°C respectively. The maximum value was attained applying treatment at 180°C for 4 hours (the difference in this case was 56%).

It was found that the CA values increased when the duration of thermal modification increased. In statistical analysis, however, the change cannot be clearly separated. Changes of 5% and 13% were found at 160°C and 180°C respectively.

On the other hand, the wettability of the samples decreased significantly after treatment. The increase in contact angle may indicate a compact surface, as Hakkou et al. [2005] noted. Additionally, it is expected that the results obtained in this study will provide important information for future research and utilization of thermally modified rowan wood. For the efficient use of natural resources, it is essential to assess the wood quality attributes of native species [Korkut and Budakci 2009]. Korkut and Budakci [2010] indicated that the improved characteristics of heat-treated rowan wood would make this species more attractive for the manufacture of value-added products.

Conclusions

A thermal modification process was performed on rowan, a less-known and fast-growing tree species. The wettability and roughness of the solid wood surface were evaluated to determine the effect of the process, by comparing untreated samples. The following conclusions were drawn from the results:

– The surface roughness properties of rowan wood panels did not change significantly at a temperature lower than 180 °C. Treatment duration had an effect only at this temperature.
– The treatment conditions applied in this study had a significant effect on wettability, which decreased with increasing temperature and duration of the process.
– The results indicated a probable significant change in the surface structure following treatment at 180°C. Rowan became more hydrophobic and its surface became less rough.

If the values obtained are appropriate for surface treatments or areas of use, this study may lead to the identification of new areas (for example, in outdoor conditions) in which wood from this species may be used. The process is relatively simple and easily repeatable. We applied the process in a laboratory--type chamber; however, it can also be applied in industrial kilns with corresponding high temperatures.

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List of standards

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