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INFLUENCE OF THERMAL TREATMENTS ON WETTABILITY AND WATER SPREADING ON THE SURFACE OF POPLAR VENEER

Vladislav Zdravković, D.Sc., Aleksandar Lovrić, M.Sc.

vladislav.zdravkovic@sfb.bg.ac.rs

Faculty of Forestry, Kneza Višeslava 1 , Belgrade/Serbia

Abstract: The influence of thermal modification on water spreading on the surface of poplar veneer was researched. Veneer samples were thermally treated at 180ºC, 190ºC, 200ºC, 210ºC and 220ºC, and the treatment time varied from half an hour to three hours. Five drops of water, using a pipette, were dropped on the prepared material every 10s. The influence of thermal treatment was determined through the wetting angle changes and the changes in spreading surface during the observed time. The results show that the wetting of the treated material decreased with the increase in the treatment temperature and duration.

Key words: thermal modification, wettability, spreading surface, poplar veneer

1. INTRODUCTION

Heat treatment of wood was scientifically studied by Stamm and Hansen in the 1930s in Germany and by White in the 1940s in the United States. In the 1950s, Germans Bavendam, Runkel, and Buro continued the research into the subject. Kollman and Schneider published their findings in the 1960s, and Rusche and Burmester in the 1970s. More recently, the research was carried out in Finland, France, and the Netherlands in the 1990s. The most intensive and comprehensive research was conducted by VTT in Finland. Significant practical research is also being done by YTI (the Institute of Environmental Technology).

Today, thermally modified wood is produced by many companies in the World. Wood material is heated to a temperature of at least 180 degrees Celsius while it is protected with steam. Besides providing protection, the steam also affects the chemical changes taking place in the wood. As a result of the treatment, a non-toxic, environmentally friendly thermally modified wood product is created. Its colour darkens, it is more stable than normal wood in the conditions of changing humidity, and its thermal insulation properties are improved. The treatment of thermal modification makes the wood resistant to decay and insect attack but, on the other hand, its mechanical properties decrease, especially the bending strength. The choice of optimal treatment temperature and duration is a matter of optimization and finding the balance between the benefits of the treatment and the decrease in the mechanical properties.

During the thermal modification process, the surface inactivation occurs. Surface inactivation is defined as a heat-induced change in the wood structure resulting in a loss of bonding ability (Troughton, Chow 1971). An inactivated wood surface does not bond well with adhesives, because the inactivation process reduces the ability of an adhesive to properly wet, flow, penetrate and cure (USDA 1999).

In the production of plywood, as composite wood, the efficiency of stress transfer from wood component to non-wood component (in this case adhesive) is strongly influenced by the surface properties of both components. Surface properties can be divided into two major groups: physical and chemical properties. Physical properties include morphology, roughness, smoothness and permeability. Chemical properties include elemental and molecular, or functional, group composition. Together, these two major groups of properties determine the thermodynamic characteristics of wood surface such as surface free energy.

The interaction between wood surface and adhesives should be optimized and well understood. The characterization of surface properties of wood is very complex and difficult to undertake. Methods of wood surface characterizing can be divided into three broad categories: microscopic, spectroscopic, and thermodynamic. Microscopic methods provide information on surface morphology, spectroscopic methods provide information on surface chemistry, and thermodynamic methods provide information on the surface energy.

Wood bonding includes the general aspects of wetting, flow, and penetration. Wood has a relatively polar surface that allows the general use of waterborne adhesives although some woods are harder to wet, such as teak, thanks to the oil content.

Wettability is defined as a condition of a wood surface that determines how fast a liquid will wet and how fast a liquid will spread on the surface (USDA 1999). Since the tendency for the liquid to spread increases as contact angle decreases, the determination of contact angle is a useful inverse measure of spreadability or wettability. The contact angle is the angle formed between the surface of a solid (in this case the veneer surface) and the line tangent to the droplet radius in the point of contact with the solid (Figure 1). When in mechanical equilibrium, the relationship among the surface tension and the contact angle (θ) for a liquid drop on a solid surface is expressed by Young's equation (Šernek 2002).

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV} \cdot \cos\theta$$

where: γ interfractional surface tension, S is solid, L is liquid, and V is vapour.

Some investigations in this field are reported by Zdravković, Stanković (1997). Wetting characteristics of poplar veneer of three different moisture contents, three different roughness and three different percents of glue extender 3%, 5% and 7% were investigated. It was concluded that, from the point of view of veneer wetting, it was better to work with somewhat higher veneer moisture contents.

According to Vukas and Horman (2009), contact angle during the spreading of polyurethane varnish over beech wood surface depends on the dry substance content and the nature of varnish. Some experiments in wood wetting were made with water drop at room temperature. The contact angle θ was taken as a measure of wood wettability.

By comparing the wetting angle of treated and untreated white ash (*Fraxinus americana*) and maple (*Acer rubrum*), Kocaefe et al. (2008) proved that thermal treatments diminished wood hydrophobicity. Their experimental results showed that contact angle rose with applying thermal treatments (wood surface becomes more hydrophobic). They also concluded that the contact angle increase was the highest in axial direction, while contact angles in radial and tangential directions were almost the same.

The flow over the wood surface is complicated to understand due to the fact that wood surface has macroscopic roughness and penetration is taking place at the same time. We have already dealt with the influence of high temperature treatments on physical properties of beech and poplar peeled veneer such as: density, swelling, and mass loss (Lovrić, Zdravković 2009).

During the experiment, it was noticed that water drops spread faster along the veneer fibres than across the fibres. Consequently, we measured simultaneously with contact angle (θ), the x and y axes of the ellipse formed during the drop spreading, and calculated the area of the formed ellipse by formula:

$$P = a \cdot b \cdot \pi \ \ (\text{mm}^2)$$

where: $a = \frac{x}{2}, \quad b = \frac{y}{2}.$

The main idea in this paper was to research the effects of high temperature treatments on wood veneer surface measured by contact angle (θ), for a set of five water drops per one sample. Simultaneous with measuring of contact angle, the area of such formed ellipse was calculated by measuring its axes (x and y).

2. EXPERIMENTAL METHOD

For this experiment we used the poplar peeled veneer nominal thickness of 3mm. The samples dimensions of 100x100mm were cut from veneer sheets. Five samples used for the determination of initial moisture content of material were selected by random choice method. The average moisture content of the samples measured by gravimetric method was 6.5%.

The rest of the samples were divided into 30 groups of five samples each, for different thermal treatments. The veneer samples were packed into aluminium foil to prevent the contact of the samples with oxygen and burning. The following temperatures were applied in the experiment: 180ºC, 190ºC, 200ºC, 210ºC and 220ºC. The exposure time to each temperature was: 30min, 60min, 90min, 120min, 150min and 180min.

After each thermal treatment, the samples were conditioned at room temperature for 24 hours. On such prepared veneer samples, five water drops were applied by pipette every 10 seconds. After the fifth water drop had been applied, each sample was filmed by two digital cameras one in front of the sample and the other above the sample.

The photographs were processed by computer program *Image tool* to measure the change of the contact angle and the drop area (Figure 1) during the time period of 40 seconds. The area of spread drop was calculated by ellipse axes measured in the x and y directions. The data was processed using the computer package *Excel*.

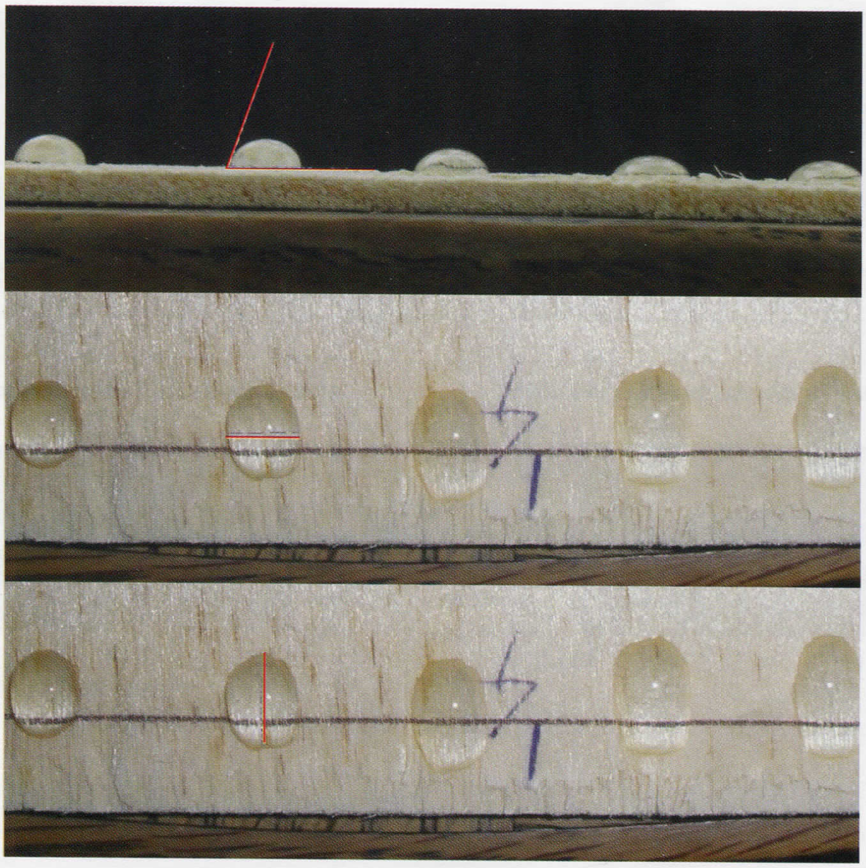


Figure 1: Method of measuring the contact angle (θ) and spreading area in (x) and (y) direction

3. RESULTS AND DISCUSSION

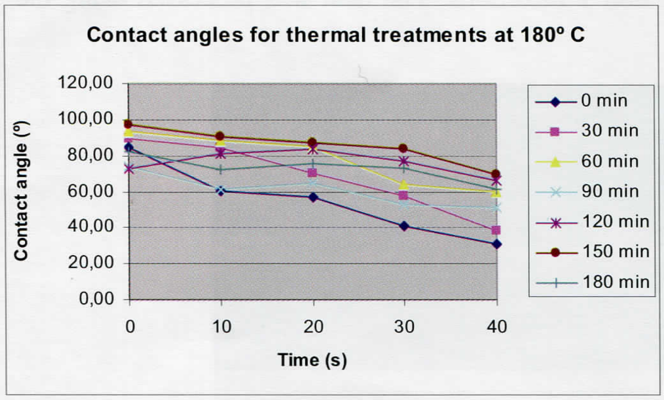
The changes of contact angle depending on the applied temperature and treatment duration are presented on Figures 2-6. The line marked with "0 min" presents the changes in contact angle of untreated material during 40 seconds. The other lines present the changes in contact angle depending on the treatment duration at each temperature.

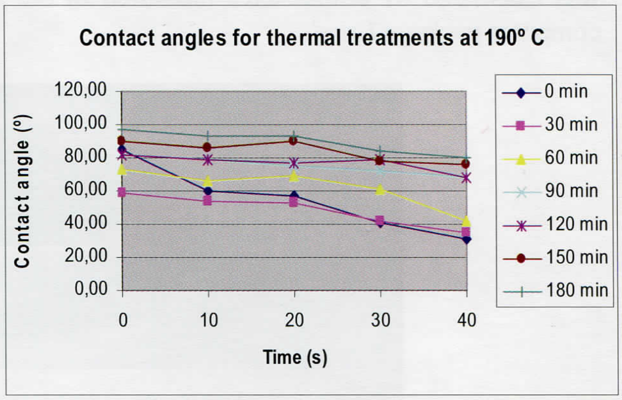
At the temperature of 180ºC, contact angle decreased in all treatments except in the treatment of 120 min (contact angle first increased and then decreased). Based on this data, the regularity in the decease in contact angle between treatments at this temperature cannot be seen. It can be concluded that after 40 seconds all treatments produced greater contact angle than those of untreated wood. The contact angle in the treatment of 30 min was most similar to contact angle of untreated veneer (39º and 31º respectively).

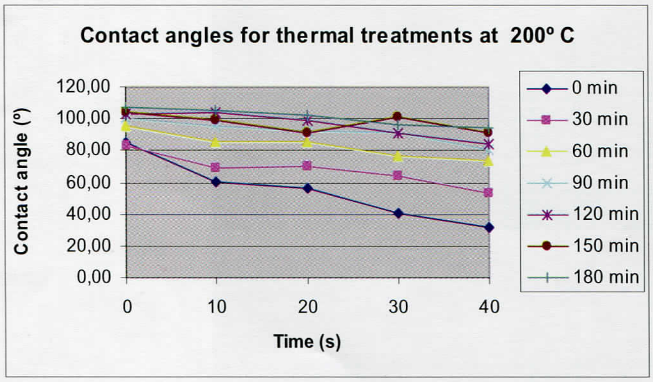
With the temperature increase, the differences among treatments became more obvious. So at the temperature of 190ºC, treatments of 90, 120, 150 and 180min had similar results, while shorter treatments (30 and 60min) were more similar to untreated veneers.

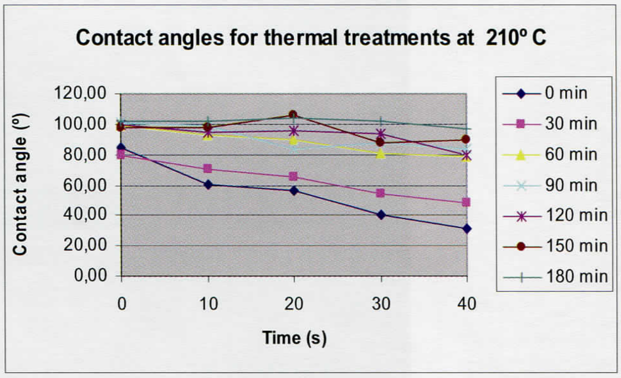
By further increase in temperature, the results of shorter treatments became closer to the results of longer treatments. At the temperature of 210ºC, only the shortest treatment of 30 min showed significantly different values, and at the temperature of 220ºC, the contact angle of this treatment became closer to the contact angle of longer treatments.

The presented diagrams show that the decrease in the contact angle is smaller as the temperature rises. So at the temperature of 180ºC, the drop of contact angle from 0s to 40s, for treatments of 30min and 180min amounts to 50º and 20º respectively, while at the temperature of 220º for the same treatments, the drop of contact angle is 15º and 3º.









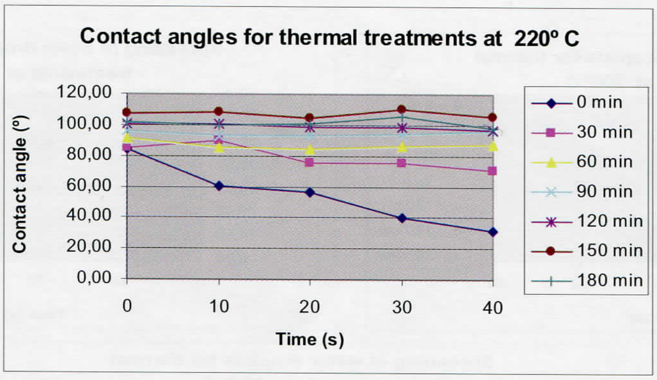


Figure 2-6: Changes in contact angle depending on the treatment temperature and duration

It can be concluded that thermal treatments increase the veneer surface hydrophobicity and diminish the water drop spreading on the wood surface. The calculated values show that lower temperatures and shorter times of exposition lead to optimal properties of veneer surface characteristics. So, at higher temperatures (200, 210 and 220°C), the difference in contact angle after 40 seconds between the treatments of 90 and 180 min is only about 10°. At the same time, the difference between untreated veneers and veneers treated at the same temperatures during a period of 180 min is about 65°.

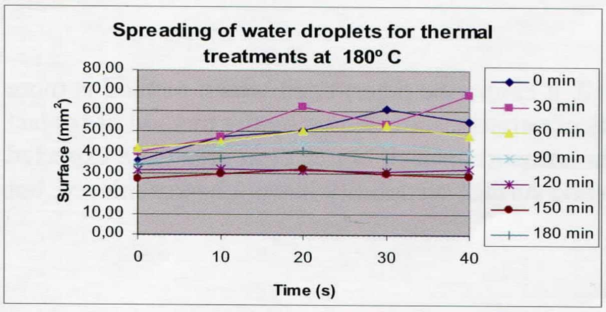
If we compare the same treatments at different temperatures, it can be seen that temperatures of 200 and 210°C give similar contact angles: the difference between contact angle for the treatment of 180 min. at 210 and 220°C is only 2°. Some shorter treatments at higher temperatures gave almost the same values of contact angle as the longer treatments at lower temperatures. For instance, the treatment of 60 min at 220°C and the treatment of 150 min at the temperature of 210°C after 40 seconds had the value of contact angle about 96°.

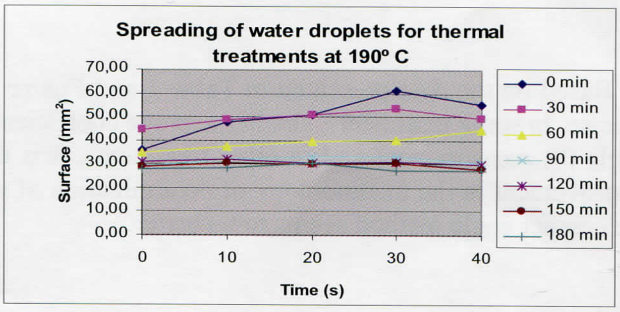
This is very important, because the increase in temperature and time of exposition induce the decease in some mechanical properties of the treated veneer. For this reason, it is necessary to select the thermal treatment regime as mild as possible, which ensures the target value of veneer surface hydrophobicity, measured by the contact angle.

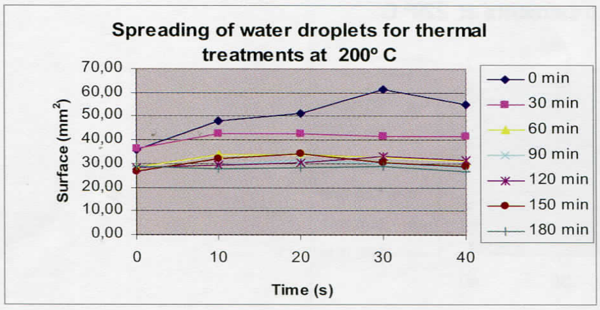
If the increase in hydrophobicity of the treated veneer is observed through the spreading surface (Figures 7-11), it can be seen that the curves of individual treatments have similar characteristics as the wetting angle curves.

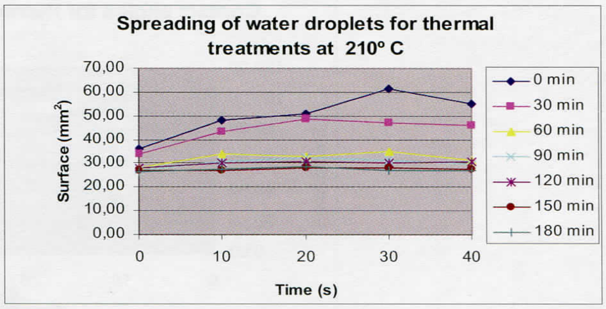
If the change in veneer surface hygrophobicity due to same treatments is observed by the area of drop spreading (ellipse) instead of by contact angle (θ) (Figures 7-11), it is obvious that the curves of drop spread area are almost of the same shape as the curves of contact angle, for the same treatments. Also with increasing temperature, the curves of treatment duration become closer to each other.

The important fact is that (at all applied temperatures) the changes in water drop area in the interval from 0 to 40 seconds, are less obvious in comparison to the changes in contact angle (θ). Also, the changes in water drop area between the treatments are smaller than the changes in contact angle. With the increase in the temperature of all treatments, water drop area approaches the value of 30mm^2. Also the values of contact angle have the tendency to group about 100°, but with greater variations compared to the curves of water drop area.









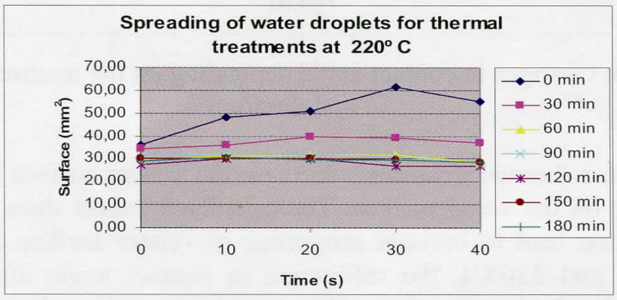


Figure 7-11: Changes in water drop area depending on the treatment temperature and duration

To determine which method has greater accuracy, average coefficients of variation of contact angle and water drop area were compared (Table 1 and Figure 1). Each data in the Table presents the average value of five measurements during the period of 40 seconds.

Coefficients of variation of contact angle (θ) and water drop area								
Temperature	Method	0 min	30 min	60 min	90 min	120 min	150 min	180 min
180° C	Angle (θ)	**26.73**	**37.91**	**21.24**	**27.09**	**16.54**	**12.52**	**31.08**
	Area	**22.82**	**31.81**	**27.01**	**26.78**	**15.68**	**13.62**	**26.99**
190° C	Angle (θ)	**26.73**	**28.91**	**28.06**	**12.94**	**11.52**	**14.91**	**7.65**
	Area	**22.82**	**24.45**	**19.91**	**10.53**	**12.42**	**7.46**	**8.22**
200° C	Angle (θ)	**26.73**	**21.83**	**13.29**	**11.93**	**6.56**	**6.84**	**9.41**
	Area	**22.82**	**14.96**	**15.44**	**10.84**	**11.06**	**19.13**	**12.72**
210° C	Angle (θ)	**26.73**	**27.04**	**10.73**	**10.15**	**8.88**	**13.74**	**5.82**
	Area	**22.82**	**27.49**	**13.59**	**13.35**	**9.95**	**11.97**	**6.88**
220° C	Angle (θ)	**26.73**	**21.00**	**15.49**	**5.79**	**4.29**	**6.76**	**6.44**
	Area	**22.82**	**25.17**	**11.09**	**6.58**	**7.22**	**9.99**	**9.58**

Table 1: Average coefficients of variation of contact angle (θ) and water drop spread area in observed time period of 0-40 seconds

Based on the data presented in Table 1 and Figure 12, it cannot be determined which method is more precise. In some treatments, smaller average coefficients of variations are shown by the method of contact angle (θ) measurement and in other treatments, it is the measurement of water drop area. The expected improvement in the methodology of determination of wood surface wettability has not been achieved, but the contact angle method seems to be better.

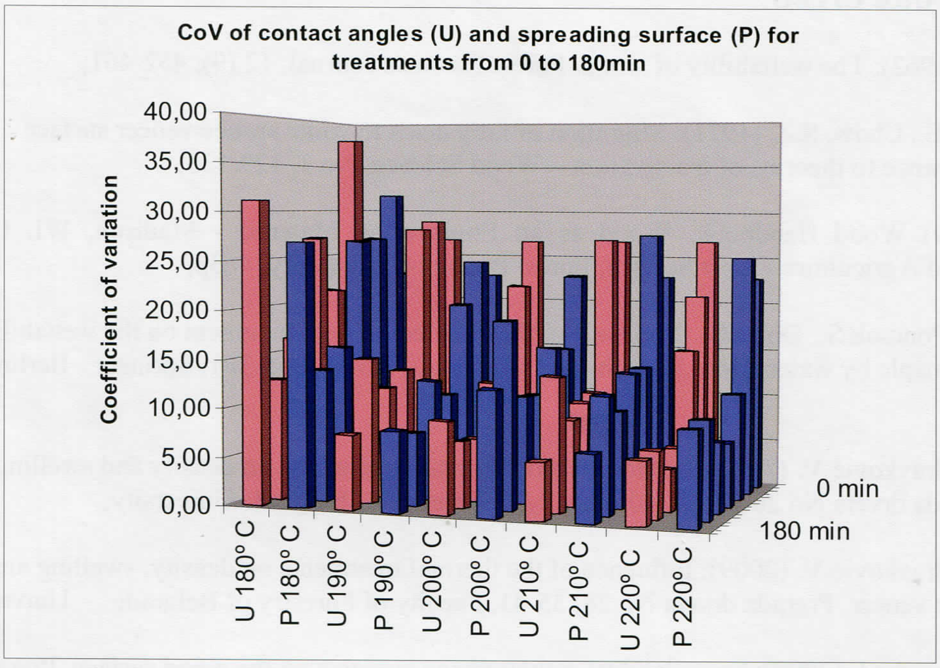


Figure 12. Comparison of coefficients of variation of contact angle (θ) and water drop spreading area in the observed time period of 0-40 seconds

4. CONCLUSION

Thermal modification of wood decreases the wood ability of water absorption and produces a more stabile material. Thermal treatment influences the physical properties of wood surface. This characteristic is usually measured by the change in contact angle (θ). The objective of this experiment was to determine the optimal treatment temperature and duration through the changes in contact angle (θ) and through the changes in water drop spreading area (form of ellipse – by measuring x and y axes) and to determine which of the two measuring methods is more suitable and reliable.

The treatment of thermal modification makes the wood resistant to decay and insect attack. On the other hand, there is a decrease in mechanical properties, especially the bending strength. The choice of optimal treatment temperature and duration is a matter of optimization and finding the balance between the benefits of the treatment and the decrease in the mechanical properties.

Although the stronger treatment makes poplar veneer more hygrophobic, these changes are not linear. For this reason, it is possible to apply some milder treatments with almost the same effect as the stronger ones. For instance, almost all treatments at 200 and 210ºC give very similar contact angles after 40 seconds.

By the comparison of these two methods of measuring of wood surface wettability, it was not determined which method is more precise. In some cases, smaller coefficients of variations are shown by the contact angle method, and in other cases by the method of measuring of formed water drop ellipse area. The expected improvement in the methodology of determination of wood surface wettability has not been strictly achieved, but the contact angle method seems to be better for the measurement of water spreading on the surface of the treated material.

5. LITERATURE CITED

Gray V. R. (1962): The wettability of wood. Forest Products Journal, 12 (9), 452-461;

Trougton, G.E., Chow, S.Z. (1971): Migration of fatty acids to white spruce veneer surface during drying: Relevance to theories of inactivation – Wood Science, No 3, 129-133;

USDA (1999) Wood Handbook. Wood as an Engineering Material - Madison, WI, United States Department of Agriculture Forest Service, Forest Products Laboratory, 463p;

Kocaefe D., Poncsak S., Dor´e G., Younsi R. (2008): Effect of heat treatment on the wettability of white ash and soft maple by water, Holz als Roh- und Werkstoff, No 66, 355-361, Springer Berlin / Heidelberg;

Lovrić A., Zdravković V. (2009): Influence of the thermal treatments on density and swelling of Beech veneer. Prerada drveta No 26-27, 34-40, Faculty of Forestry of Belgrade University;

Lovrić A., Zdravković V. (2009): Influence of the thermal treatments on density, swelling and mass loss of Poplar veneer. Prerada drveta No 28, 35-41, Faculty of Forestry of Belgrade University;

Vukas N., Horman I. (2009): Spreadability polyurethane lacquers on the wood surface. Prerada drveta No 26-27, 13-18, Faculty of Forestry of Belgrade University;

Zdravković V., Stanković B. (1997): Inter-dependence of wetting characteristics of phenolic glue on extender proportion, moisture content and roughness of poplar veneer. ICFWST 3rd International Conference on the development of Forestry and Wood Science and Technology, 29 September-03 October, Faculty of Forestry of Belgrade University, Serbia, Proceedings, Vol II 674p, 436-441;

Šernek M. (2002): Influence of drying temperature on properties of wood surfaces. Zbornik gozdarstva in lesarstva. No 67, 173-191, Ljubljana.