Physical and Mechanical Properties of Thermo-mechanically Densified Poplar

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Abstract – The main aim of the presented research work was to enhance the technical performance of the poplar wood (*Populus x euramericana* cv. 'Pannonia'). Poplar plantations with high growing rates deliver valuable raw material for different sectors in the wood industry (plywood, WPC, construction wood, and even solid wood for different applications). However there are some disadvantageous properties like low mechanical strength, low surface hardness, and nevertheless the unexciting texture and appearance. The last mentioned properties restrict the use of poplar in many fields of applications, e.g. in the furniture and the flooring industry. By upgrading the unfavourable properties of poplar wood new and very promising applications could be defined.

The idea of our research was to enhance the surface hardness and the colour of poplar wood in order to make it suitable for furniture industry (fronts) and flooring (parquet).

Thermo-mechanical densification schedules using different temperatures (160°C, 180°C, 200°C), densification grades (20%, 30%, 40%), and durations (15 min, 30 min, 45 min) were applied to poplar wood.

After the treatments the colour, the average density, the density profile, moisture related properties, modulus of rupture and the surface hardness were analysed.

Keywords: Thermo-mechanical densification / *Populus x euramericana* cv. 'Pannonia'

1. INTRODUCTION

Poplars play an important role in the plantation forestry in Hungary. Nowadays the share of poplars in the afforestations amounts to ca. 30%, the fellings come to 1 Million m^3/year. However the utilisation of poplar timber shows many difficulties. Top quality logs are processed in the plywood industry, while sawlogs deliver the raw material for pallets and boxes. The short logs are utilised in the particle board and fibreboard mills. Recently poplar species are grown on energy plantations as well. The major problem is that even quality sawlogs are processed to low price pallets, thus the technology is uneconomical. In spite of some positive examples (e.g. in the building sector), the utilisation of poplar timber in Hungary is still an unsolved challenge.

Possible outbreak from this situation could be the production of furniture and other interior products. Unfavourable properties of poplar, such as low strength and stiffness, low durability, inexpressive colour and texture are a clear hindrance for widespread utilisation of the material in the furniture industry.

In order to surmount the obstacles we focussed our research work to enhance the relevant physical, mechanical and aesthetical properties of poplar wood. The specific aim of our work

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was to establish the scientific background for a thermo-mechanical modification method. The process should enhance the surface hardness, the strength and the appearance of this low density wood with thin fibre walls.

Studying the literature there is a lack of scientific results concerning thermo-mechanical densification of poplar wood. Basically conifers were studied as reported by Welzbacher et al 2008, Unsala et al 2009, Navi and Girardet 2000, Unsala et al 2009. Recently results were published concerning hardwoods by Rautkari et al 2009, and Gong et al 2010. A good summary about the densification of wood was given by Kuatnar and Sernek 2007.

2. MATERIAL AND METHODS

2.1. Test materials and apparatus

Poplar boards for the investigations were delivered by the KAEG Zrt. The freshly cut boards were dried in a conventional dryer down to 12% MC. The boards were then cut into laths. The laths were densified in hot press across the grain at 3 different temperatures. 160°C, 180°C and 200°C. Three different starting thicknesses (25.0mm, 28.5mm and 33.3mm) were used. The final thickness of the laths was set to 20mm for all laths. Thus the grade of the densification was 20%, 30% and 40%. After the densification under heat, the wood material was kept for 10, 20 and 30 minutes in the hot press at the corresponding temperature.

After the treatment the change in different material properties were studied. The investigated properties were: the colour change, moisture related shrinking and swelling, surface hardness, MOR and the grade of densification across the thickness.

The colour properties were measured by a CM-2600d spectrophotometer working in the CIELab system. The colour coordinates were measured prior and after the treatments (thermal densification).

The ovendry density was determined according to MSZ 6786-3:1988 using specimen with the dimension of 20mmx20mmx30mm (RxTxL).

The shrinking properties were measured following the standard MSZ 6786-18:1989, with the deviation that the directions across the grain were defined as directions parallel and perpendicular to the pressing force rather than radial and tangential anatomical directions.

The modulus of rupture was measured following the standard MSZ 6786-5:1976. The dimension of specimen was 20mmx20mmx300mm (RxTxL). The distance between the supports was 240mm. The tests were carried out by using one force, where the direction of the testing force corresponded to the treating force (pressure).

The surface hardness (Brinell-Mörath) was determined according to MSZ 6786-11:1982. The hardness was determined prior and after the densification, so the change in percentage caused by the treatment could be calculated.

After the treatment the degree of the densification was determined across the thickness. In order to be able to detect the deformations in different depths, lines in 45°to the pressing direction were drawn onto the side surface of the laths. The curving of the straight lines (not shown in the article) delivers data on the deformations of the material. The lines were photographed after the treatment and analysed by sectioning them into 20 parts.

3. RESULTS AND DISCUSSION

3.1. Results - Colour

The change of red hue (Δa^*) was for all treatments positive, which means that the colour of the surface turned to red. Higher temperatures and longer treatments resulted in more pronounced changes, while the densification grade did not influence the red hue changes significantly.

The yellow hue values changed in positive direction (Δb*), thus the surfaces became more yellowish. Compared to red hue values similar tendencies could be found concerning the effect of temperature and duration, but the changes showed higher values.

The treatments caused reduction of lightness, thus the ΔL* values are negative, the colour became darker. Minor changes could be proved by the lowest temperature (160°C), but the darkening became more significant as temperature and duration increased.

Studying the total colour change, values over 3 can be found by all treatments. Thus the colour change is visible even at the lowest duration, temperature and densification grade to the naked eye (Fig 1.). As for all the three investigated colour coordinates (a*, b*, L*) showed similar changes, the ΔE* is influenced particularly by the temperature (highest changes at 200°C, 30% and 30 min.). The longer duration of the pressing treatment did not resulted in significantly higher total colour changes at 160°C and 180°C. The densification grade did not influence the colour change.

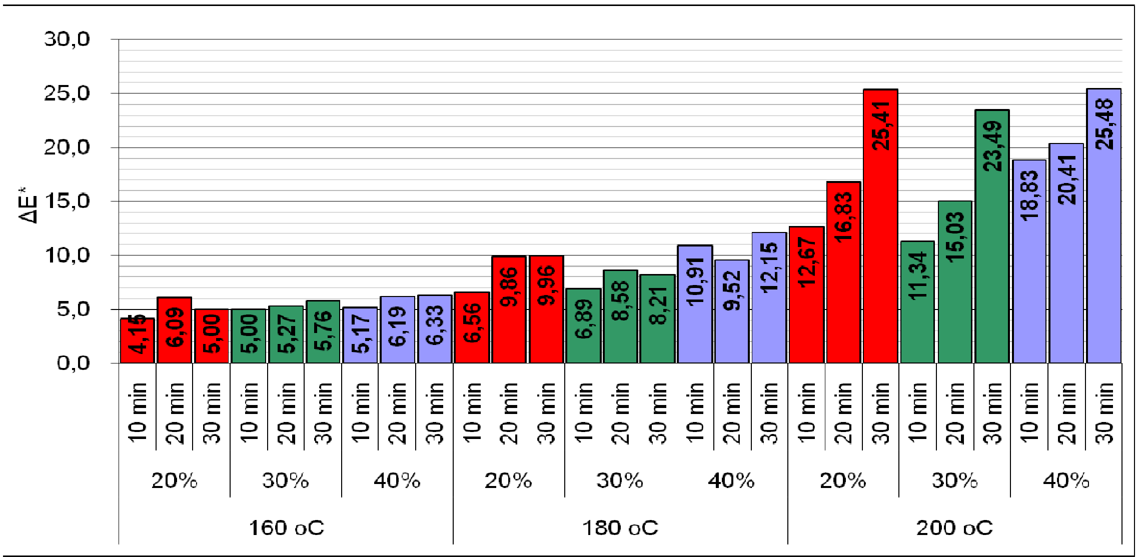

*Figure 1: The effect of treatment parameters on ΔE**

Similar tendencies for colour changes were reported by Bak et al (2008) for different plantation grown timbers, and by Nemeth et al (2009) for Poplar and Robinia using hot vegetable oils. In their studies the duration of the treatments was longer, therefore the achieved total colour changes were superior to the values reported here.

3.2. Results - MOR

The average MOR of control material amounted to 79,85 MPa. These values could be increased to the range of 87-116 MPa. The treatments enhanced the MOR of the material. No clear influence could be proved for single treatment parameters (temperature, duration and densification grade). It has to be mentioned that the coefficient of variation (20-25% cv) for treated MOR values increased compared to the cv of the controls.

3.3. Results - MOE

The control poplar material showed an average MOE of 8,2 GPa, while the treated material's values ranged between 9,3-13,3 GPa. Thus the treatment resulted in higher MOEs compared to the control. Similar to MOR, no clear effect of the single treatment parameters could be proved.

3.4. Results - Hardness

One of the main targets of this research work was to enhance the surface hardness of poplar wood. The corresponding values for untreated timber were in the range of 8-11 MPa. The relative low values could be increased by the applied thermal densification method up to the range of 15-22 MPa. Figure 2 shows a clear positive effect of the treatment in terms of hardness change. From the results we can conclude that the densification grade is the most prevailing among the treatment parameters.

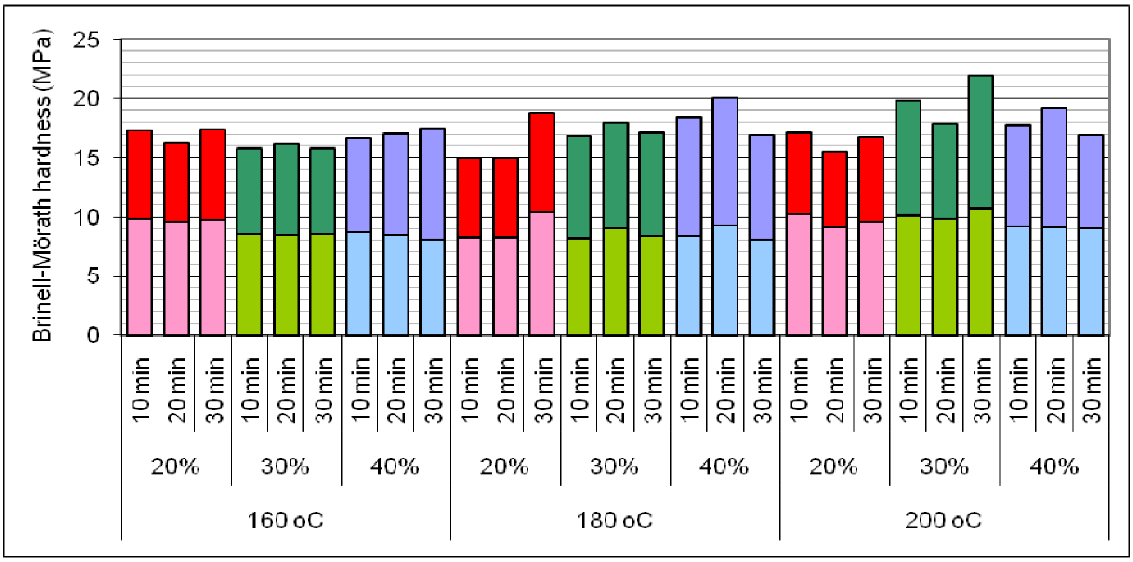

Figure 2: The effect of treatment parameters on the Brinell-Mörath hardness (light column before and dark column after the treatment respectively)

3.5. Results - shrinking

The shrinking ability was determined in three directions: parallel to the grain, across the grain and parallel to the pressing force (thickness), across the grain and perpendicular to the pressing force (width). The shrinking coefficients (treated and control) in thickness and width are shown on Fig 3.

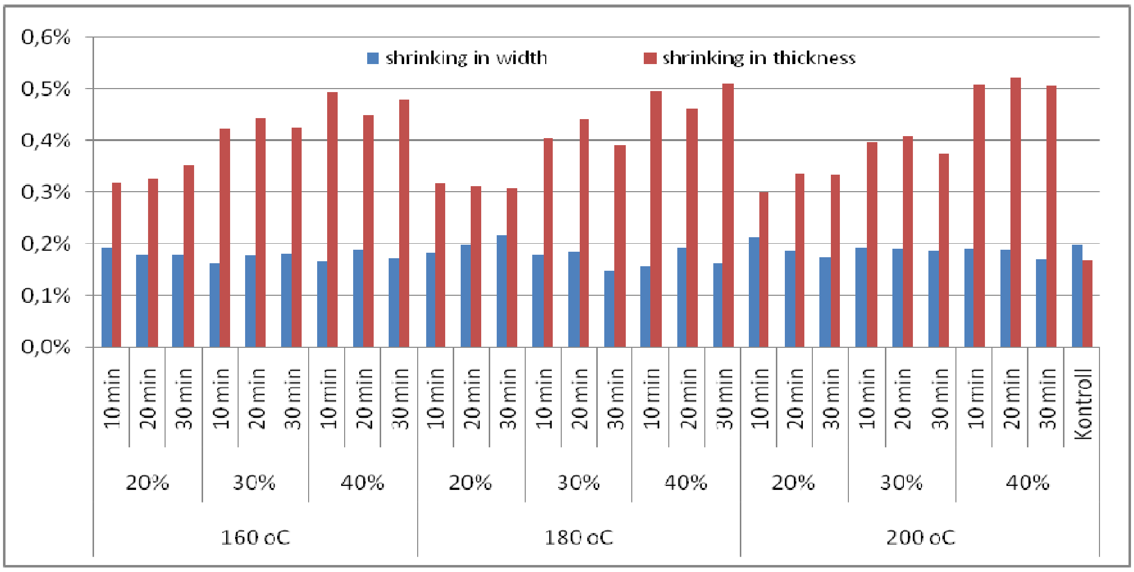

Figure 3: The effect of treatment parameters on the shrinking coefficient in width and in thickness

No differences could be found for shrinking parallel to the grain and in width, while in thickness considerable increase in shrinkage could be proved. At all investigated temperatures the higher densification grade resulted in higher shrinkage. Because of the relative short treatment time, the thermal treatment modified the surface only, even at the highest value (200°C). Thus no thermal degradation occurred in the inner layers; therefore no stabilisation effect could be aimed.

3.6. Results – ovendry density

Studying the data shown on Fig 4, it can be seen that there is a positive correlation between the densification grade and the ovendry density. The final density value is determined by the initial density of the laths.

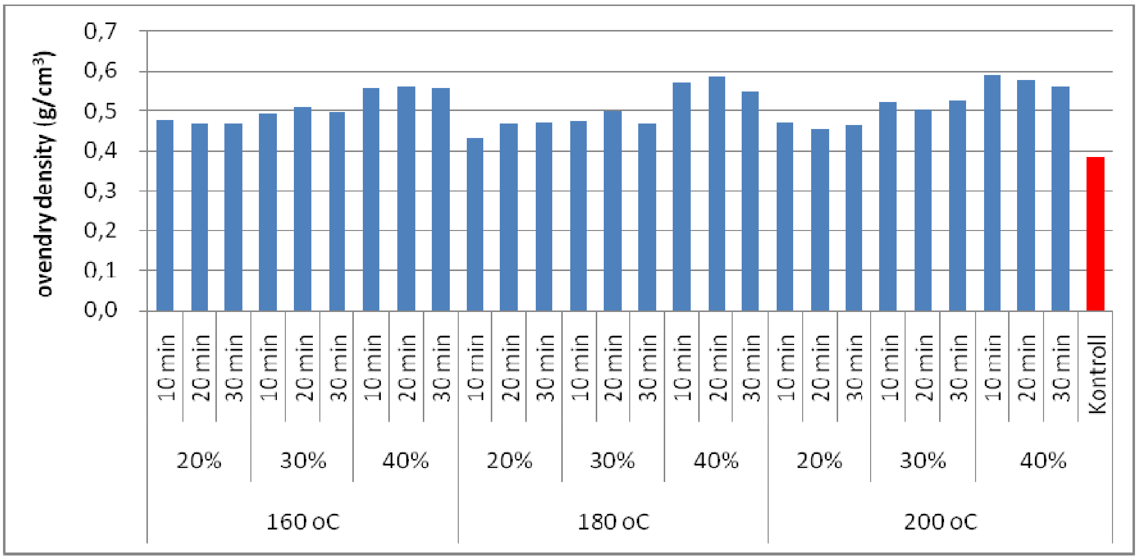

Figure 4: The effect of treatment parameters on the ovendry density

3.7. Results – densification grade across the thickness

It should be mentioned that the densification grade is not evenly distributed across the whole thickness. Studying the deformations of the straight lines which were drawn on the side surface of the laths prior to the treatment we can get information concerning the distribution of the densification across the (half) thickness. Applying the lowest bulk densification grade of 20% the local densification of the upper 1/3 layer amounts to 40%, while the inner parts show rather slow 0-10% local densifications. Applying the moderate densification grade of 30% the local densification of the upper 1/3 layer amounts to 45-50%, the second 1/3 layer shows 30% densification, while the inner part densifies ca. 10-15%. Applying the highest densification grade of 40% the local densification of the upper 1/3 layer amounts to 50-55%, the second 1/3 layer shows ca. 30%-40% densification, while the inner part densifies about 20-25%.

4. CONCLUSIONS

The specific aim of our research work was to enhance the surface hardness, and the colour of poplar wood (*Populus x euramericana* cv. 'Pannonia') in order to make it suitable for utilisation in the furniture industry (fronts) and flooring industry (parquet).

Thermo-mechanical densification schedules using different temperatures (160°C, 180°C, 200°C), densification grades (20%, 30%, 40%), and durations (15 min, 30 min, 45 min) were applied to poplar wood.

After the treatments the colour, the average density, the density profile, moisture related properties, modulus of rupture and the surface hardness were analysed.

The colour of the surface became more and more vivid by longer durations and higher temperatures. The well visible changes are reflected in the CIELab colour coordinate as it follows: Δa^* (0 -+6), Δb^* (+3 -+11), ΔL^* (-2 - -22). The total colour change ΔE reached values between from 4 to 25, thus the treatment caused well visible changes.

A major positive result is the upgrading of the surface hardness, as the values could be raised by 60-130% (ca. 9 MPa for control and ca. 22 MPa for densyfied wood). The MOE could be increased by 15-60% and MOR by 10-45%.

The density of the surface could be enhanced significantly, whilst the density in the core of the boards changed only in small extent. The higher densification rate resulted in higher swelling, but no clear influence of temperature and duration of densification could be proved. Because of the relative short treatment time, the thermal treatment modified the surface only, even at the highest temperatrure (200°C). Thus no thermal degradation occurred in the inner layers; therefore no stabilisation effect could be aimed.

Further research is needed to enhance the water-related properties of the densified poplar wood. Different starting MCs and higher temperatures are subject for future investigations.

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