ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 642-649

MECHANICAL PROPERTIES OF PICEA ABIES AFTER VACUUM AND ATHMOSPHERIC MICROWAVE DRYING

Wilfried BEIKIRCHER
DI Dr.nat.techn. – University of Innsbruck – Department of Engineering Science- Timber Engineering Unit
Address: Technikerstr. 13, 6020 Innsbruck, Austria
E-mail: wilfried.beikircher@uibk.ac.at

Christian LUX
DI – University of Innsbruck – Institute of Ion Physics and Applied Physics
Address: Technikerstr. 25/3, 6020 Innsbruck, Austria
E-mail: christian.lux@uibk.ac.at

Michael FLACH
Univ. - Prof. DDI – University of Innsbruck – Department of Engineering Science- Timber Engineering Unit
Address: Technikerstr. 13, 6020 Innsbruck, Austria
E-mail: michael.flach@uibk.ac.at

Abstract:
The knowledge of the influence of the drying process on mechanical properties of timber is very important in structural applications. In this study, Norway spruce (Piceaabies L.) timber was dried to pre-determined moisture contents.The wood was dried in air at ambient temperature, in a conventional laboratory oven at elevated temperatures and in a microwave oven at two different power settings. The drying experiments were performed at clear wood specimens which were prepared for the mechanical tests. After drying, the mechanical properties as the three-point bending test, the compression strength parallel to the grain and the Brinell hardness were determined. The results of this systematic investigation show no significant influence by the microwave drying process on the mechanical properties as the modulus of rupture and the modulus of elasticity out of tree-point bending test and the compression strength parallel to the grain. The influence of drying rate and internal cracking affect the mechanical properties more as the drying process. Regarding the Brinell hardness significant differences could be found within the artificial drying processes but in comparison to the natural dried Norway spruce wood most test series does not differ at 5% significant level.

Key words: *microwave wood modification; wood drying; mechanical properties; Norway spruce (Piceaabies L.).*

INTRODUCTION

The drying of wood can be a time - and energy - consuming process. The timber industry has been using several methods for drying; these include drying the wood at elevated temperatures in conventional kilns, which is the most common method, drying in radio frequency or microwave ovens, or a combination of the two. In timber drying, mechanical properties may be changed due to treatment temperature and treatment duration. In general when increasing the kiln temperature, drying time is decreased and some timber properties are negative affected. The occurrence of cracks and loss of mechanical properties are major problems in wood drying. Attention should be given on the control of drying conditions in order to avoid these forms of defects.

Investigations on microwave drying of wood have been performed since the late fifties. A comprehensive review on the drying wood with high frequency electric current is given by Resch (2009). Studies by many authors Antti (1992), Turner (1994), Lehne *et al.* (1999), Oloyede and Groombridge (2000), Lee (2000) Masakasu Miura *et al.* (2003) and Taskini (2007) emphasize the advantages of microwave drying over convective drying.

A literature review where different drying methods and investigated wood species are presented is given by Oltean (2007). This report deals with different temperature ranges and drying methods, but little information is available to quantifying the effect of the microwave drying method on the mechanical properties of the wood. In general the mechanical properties at the temperature below 100°C are not affected. The scientific papers differ on the effect of the microwave drying process on the mechanical properties of the wood. As Oloyede and Groomebridge (2000) found up to 60% lower strength properties, Hansson and Atti (2006) found no change in the temperature range at 60-100°C. Taskini (2007) found that microwave dried wood lead to higher strength as infrared and convectional drying processes. Due to these inconsistencies research work will be necessary for this topic and this study should support the actual knowledge.

In this study the changes in MOE, MOR and the compression strength parallel to the grain related to the drying process are investigated. In the present paper, the tests were carried out using laboratory - size – specimens with the dimensions of 30x30x500mm³ that were dried to a target moisture content (MC) of 12% and 0%. Due to the small size, short drying times were used and the results should therefore not be directly compared on full size studies.

MATERIALS AND METHODS

Drying experiments

In this study, freshly sawn Norwayspruce (Piceaabies L.) from upper Austria was used for the investigations. The raw material was preparedin the way to get twin samples for optimal comparison of the microwave drying effect. For having an adequate material range the starting material selected was out of six trees, presented sapwood and heartwood. From each tree one core board and one side board was used. Out of the boards three bars were cutted and from each bar one sample were randomly selected for the different drying processes (s. Fig. 1). As result, in sum 36 samples for every drying process were used. All drying samples had the dimension of 30x30x500mm³. After cutting, the bars were sealed on both cross sections with epoxide-adhesive, in order to prevent drying from the cross sectional ends. Due to the material from the sawn mill the starting moisture content (MC) varied between 15 to 25 %. The mean value of the starting MC was 22%. As the material has not the required range of the MC, additional two series were prepared and stored in water before drying; this two series had a mean starting MC of 47% (s.Table 1).

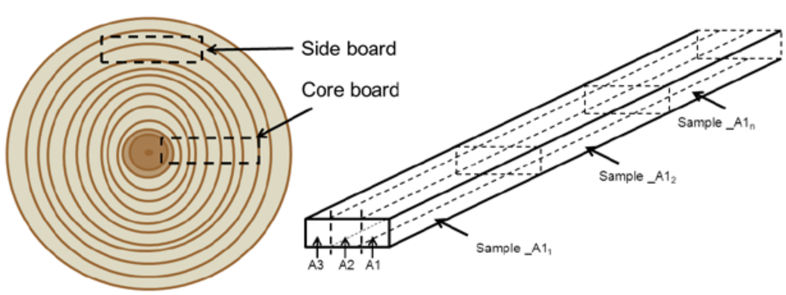

Fig. 1
Sample preparation.

The methods applied were vacuum-microwave drying, microwave and laboratory oven drying under atmospheric pressure and natural dried material was used as reference material. The drying schedules are summarized in Table 1.

Table 1

Drying schedules applied for the Norway spruce timber

Identification	Description	Starting MC (%)	Target MC (%)	Drying Temperature
MWA_100°C_12%	*MW-drying under ambient pressure*	*16-25*	*12*	*100 ± 2*
MWA_100°C_0%	*MW-drying under ambient pressure*	*16-25*	*0*	*100 ± 2*
MWV_65°C_12%	*MW-drying under vacuum (200mbar)*	*16-25*	*12*	*65 ± 2*
MWV_65°C_0%	*MW-drying under vacuum (200mbar)*	*16-25*	*0*	*65 ± 2*
FLA_20°C_12%	*Natural-drying in the storage room*	*16-25*	*12*	*20 ± 5*
TSA_100°C_0%	*Laboratory oven drying under ambient pressure*	*16-25*	*0*	*103 ± 3*
TSA_100°C_0%_w	*Laboratory oven drying under ambient pressure*	*28-67*	*12*	*103 ± 3*
MWA_100°C_0%_w	*MW-drying under ambient pressure*	*28-67*	*12*	*100 ± 2*

Experimental equipment

Drying experiments were carried out with laboratory MW-drying equipment (see Fig. 1). For the drying tests the first five Magnetrons of the MW-kiln were used. The laboratory plant is equipped with 12 spirally positioned magnetrons at the whole length of 3m. Each magnetron has a maximum power of 800W and the working frequency is 2.45GHz.

During the drying the core temperature was measured with a fibre optic sensor (FOTEMP1 Fa. OPTOcon GmbH), which was inserted to the core of one of the samples. The surface temperature was measured with an infrared spectral pyrometer. The core temperature was used for the manual regulation of the intensity of the MW-power. The drying started by using 50% of the MW-power and then the power was manually regulated for holding the target core temperature. The core temperatures were regulated in the range of 100 ± 2°C for the atmospheric drying process and 65 ± 2°C for the vacuum drying process at 200mbar.

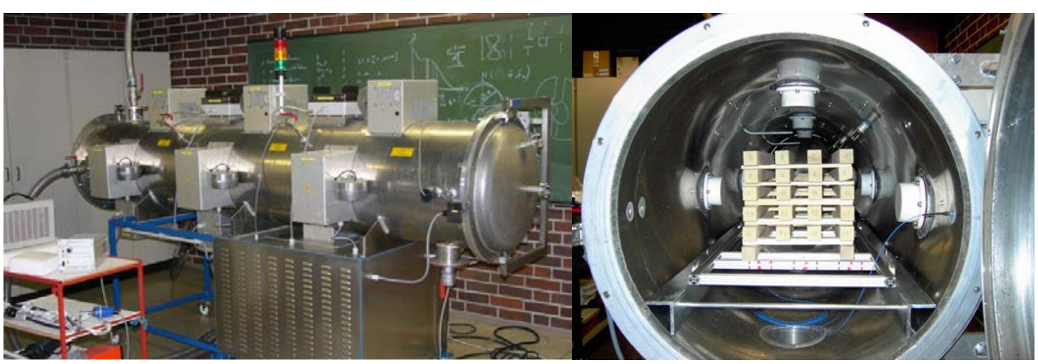

Fig. 2
Microwave laboratory equipment and position of the samples.

For the comparison of the MW-dried timber, natural dried and in a laboratory oven dried samples were used. The natural dried material was stored in a storage room at about 15-25°C until the MC of about 12% was reached. The drying steps for the laboratory oven were 24 hours with 50°C following of 24 hours with 80°C and finally until the target MC was reached the temperature of 103°C were settled. The different drying experiments were carried out to get final target moisture content of 12% and 0% (see Table 1). With exceptions of the natural dried material, this was only dried at the target MC of 12%.

After drying all samples were conditioned in a climate chamber at 20°C and 65% relative humidity prior to testing until constant moisture content was reached.

Preparation of test specimens

The test material consisted of microwave dried, laboratory dried and natural dried control specimens according to the schedules described above. For the determination of the mechanical properties defect free specimens were produced after the drying at the final dimension of 20x20x360mm³ for the bending tests and 20 x 20 x 60mm³ for the compression strength and 20x20x30mm³ for the Brinell hardness in radial and tangential direction. In total 863 samples (one sample was not usable) were prepared for the mechanical testing, the numbers used for each mechanical test are presented inTable 2.

Mechanical testing

The determination of the material properties were performed according to the Standards for defect free small wood samples. The material properties to be determined were: the density, the moisture contend, modulus of elasticity and bending strength, compressive strength and Brinell hardness. The specified standards which were followed, the number of specimens used for each mechanical test, as well as the devices and some remarks are presented in Table 2. The material tests were performed at the TVFA (TechnischeVersuchs - und Forschungsanstalt) of the University of Innsbruck. All tests were performed after storage the material in a climate chamber at 20°C and 65% RH until the equilibrium moisture content (EMC) was reached.

Table 2

Details concerning the standards followed, number of samples involved for each test and the devices used

Test	Standards	No. samples	Devices	Remarks
Density	*DIN 52182 (1976)*	*575*	*digitalmeasuringslide, balance*	*balance accurateness 0,001g*
Moisture content	*DIN 52183 (1977)*	*779*	*balance*	*accurateness 0,001g*
Compression test	*DIN 52185 (1976)*	*288*	*Shimadzu Autograph AG-100kN Testing Maschine*	*cross head speed 0,7mm/min*
Three point bending test	*DIN 52186 (1978)*	*287*	*Shimadzu Autograph AG-100kN Testing Maschine*	*cross head speed 7mm/min*
Brinell hardness	*EN 1534 (2000)*	*288*	*Shimadzu Autograph AG-100kN Testing Maschine*	*max. load 500N*

RESULTS AND DISCUSSION

The statistical processing of the data obtained is presented in Table 3. For the drying processes carried out mean values were recorded between 76,67 and 93,97MPa for MOR and from 9.67 to 11.53GPA for MOE in the tree point bending test. In the case of compression tests parallel to the grain mean values of compression strength were recorded between 32.97 and 44.76MPa. Remarkable lower values for the water stored material can be recognized for the MOE, the MOR and the compression strength s. Table 3. For the Brinell hardness in the radial direction HB 10/500 mean values are between 11.26 to 14.70N/mm² and for the tangential direction between 13.90 to 18.94N/mm². After the drying macro cracks could be recognized within the water stored test series (TSA_100°C_12%_w and MWA_100°C_12%_w). Those cracks influence the mechanical properties of the wood (Oltean *et al*. 2007). The testing results with lower values for the water stored material at about 8-11% for the MOR and MOE and lower values of 19-24% for the compression strength in comparison to natural dried material are in agreement to this. The reason for the cracks can be assumed as result of the drying rate as the similar processes were used as for the material with lower MC (Shahverdi *et al*.2012).

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 642-649

Three-point bending tests

The diagrams in Fig. 3 and Fig. 4 show the influence of the drying schedules applied for Norway spruce wood at low and moderate temperature ranges on MOR and MOE in three-point bending tests. Distinct lower mean values for the MOR and the MOE can be seen for the both processes TSA_100°C_12%_w and MWA_100°C_12%_w in comparison to the other processes (s. also Table 3). Statistical analyses (one way ANOVA and Tukey test analyses) were performed and no significant differences (at 5% significance level) between the natural dried material and the artificial dried material were found for the MOE and MOR in three-point bending tests. Between the artificial drying processes as the diagrams (s. Fig. 3 and Fig. 4) let expect, significant differences were found for the MOR in between the MWV_100°C_0% series and the series of MWV_65°C_12%, TSA_100°C_12%_w and MWA_100°C_12%_w. Also in between the TSA_100°C_12%_w series and the two series MWA_100°C_0% and TSA_100°C_0% were found significant differences by analyzing the mean values of the MOR. Significant differences for some artificial processesregarding the MOE were found. The mean values of the MOE differ significant in between the TSA_100°C_0% and the processes TSA_100°C_12%_w, MWA_100°C_12%_w. Additionally for the MOE in between the series of MWA_100°C_0% and TSA_100°C_12%_w significant differences could be assessed.

Table 3

Number of samples, mean values and standard deviation values for density, bending strength in three-point bending test (MOR, MOE), compression strength and for the Brinell hardness in radial and tangential direction for the drying processes investigated

Three point bending tests							
Test Series	*n*	*Density (kg/m³)*		*MOR (MPa)*		*MOE (GPa)*	
		Mean	*Std.dev.*	*Mean*	*Std.dev.*	*Mean*	*Std.dev.*
MWA_100°C_12%	*35*	*469*	*35.79*	*86.65*	*11.94*	*11.31*	*1.70*
MWA_100°C_0%	*36*	*477*	*28.96*	*93.97*	*14.18*	*11.18*	*2.40*
MWV_65°C_12%	*36*	*481*	*37.61*	*83.81*	*9.76*	*11.05*	*1.71*
MWV_65°C_0%	*36*	*469*	*38.61*	*84.93*	*14.42*	*11.01*	*2.15*
FLA_20°C_12%	*36*	*483*	*36.81*	*85.29*	*12.11*	*10.87*	*1.69*
TSA_100°C_0%	*36*	*478*	*34.95*	*87.97*	*19.41*	*11.53*	*2.12*
TSA_100°C_12%_w	*36*	*458*	*56.56*	*76.67*	*12.16*	*9.67*	*1.88*
MWA_100°C_12%_w	*36*	*457*	*55.29*	*79.06*	*13.00*	*9.96*	*1.86*
Compression strength parallel to the grain							
Test Series	*n*	*Density (kg/m³)*		*compression strength (MPa)*			
		Mean	*Std.dev.*	*Mean*	*Std.dev.*		
MWA_100°C_12%	*36*	*468*	*38.5*	*42.79*	*6.43*		
MWA_100°C_0%	*36*	*477*	*28.96*	*44.76*	*5.90*		
MWV_65°C_12%	*36*	*481*	*37.61*	*40.31*	*5.19*		
MWV_65°C_0%	*36*	*469*	*38.61*	*41.59*	*5.72*		
FLA_20°C_12%	*36*	*483*	*36.81*	*43.34*	*5.34*		
TSA_100°C_0%	*36*	*478*	*34.95*	*43.63*	*6.38*		
TSA_100°C_12%_w	*36*	*457*	*53.87*	*32.97*	*4.53*		
MWA_100°C_12%_w	*36*	*452*	*54.43*	*35.36*	*4.45*		
Brinell Hardness HB 10/500							
Test Series	*n*	*Density (kg/m³)*		*HB rad. (N/mm²)*		*HB tang. (N/mm²)*	

ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 9 N° 4 2013
pp. 642-649

		Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
MWA_100°C_12%	*36*	*468*	*38.5*	*11.35*	*1.67*	*14.56*	*2.01*
MWA_100°C_0%	*36*	*477*	*28.96*	*14.70*	*3.49*	*18.94*	*4.92*
MWV_65°C_12%	*36*	*481*	*37.61*	*12.59*	*1.07*	*14.22*	*2.24*
MWV_65°C_0%	*36*	*469*	*38.61*	*13.65*	*1.82*	*15.13*	*2.07*
FLA_20°C_12%	*36*	*483*	*36.81*	*13.67*	*1.73*	*14.84*	*1.82*
TSA_100°C_0%	*36*	*478*	*34.95*	*13.91*	*3.85*	*17.73*	*3.54*
TSA_100°C_12%_w	*36*	*458*	*56.56*	*13.28*	*2.72*	*14.62*	*3.15*
MWA_100°C_12%_w	*36*	*457*	*55.29*	*11.26*	*2.37*	*13.90*	*3.60*

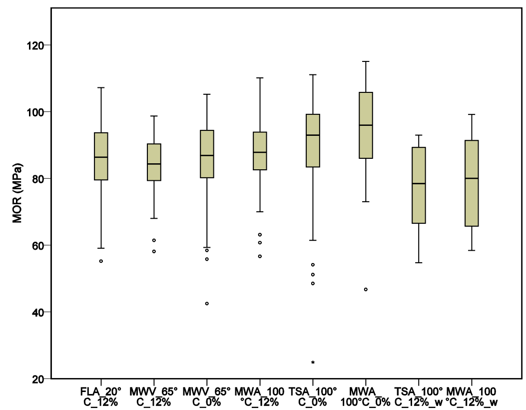

Fig. 3
Relationship between the drying processes and the MOR in tree-point bending test. The box represents the median and the 25- and 75-percentile. The whiskers represent the smallest or the highest values except outliers.

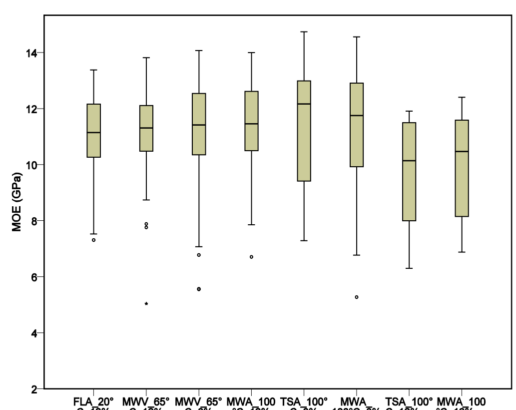

Fig. 4
Relationship between the drying processes and the MOEin tree-point bending test. Explanation of box- and whiskers s. Fig. 3.

Compression strength

The compression strength of the eight drying processes is presented in Fig. 5. Also the compression strength show remarkable lower values for the two processes TSA_100°C_12%_w and MWA_100°C_12%_was

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 9 N° 4 2013
pp. 642-649

the other processes (s. Table 3 and Fig. 5). The compression strength of those two series differs significant from the natural dried material FLA_20°C_12% by the Tukey test analysis. Out of the statistical analysis the series TSA_100°C_12%_w and MWA_100°C_12%_w show significant differences to the otherseries with exception to the MWA_100°C_12% process regarding the compression strength.

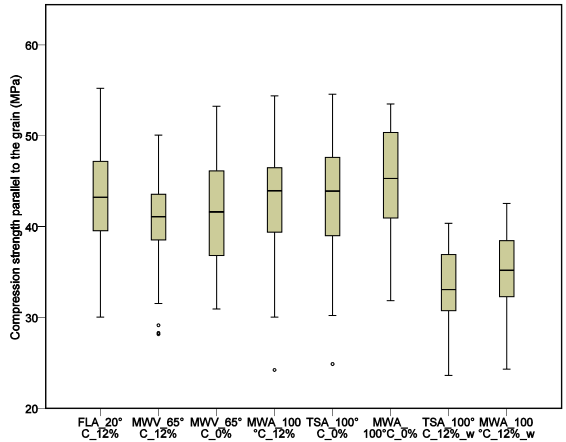

Fig. 5
Relationship between the drying processes and the compression strength parallel to the grain. Explanation of box - and whiskers s. Fig. 3.

Brinell hardness

The boxplot diagram for the Brinell hardness in radial and tangential direction is presented in Fig. 6. The statistical analysis (oneway ANOVA) shows significant differences at 5% level for both tested directions. By facing natural dried material FLA_20°C_12% to the other series the Tukey test show significant differences to the MWA_100°C_12%_w series in radial direction and to the series MWA_100°C_0% and TSA_100°C_0% in the tangential direction for the Brinell hardness. By considering the Brinell hardness in both directions (radial and tangential) significant differences in between the artificial drying processescould be found by the statistical analysis using the Tukey test.

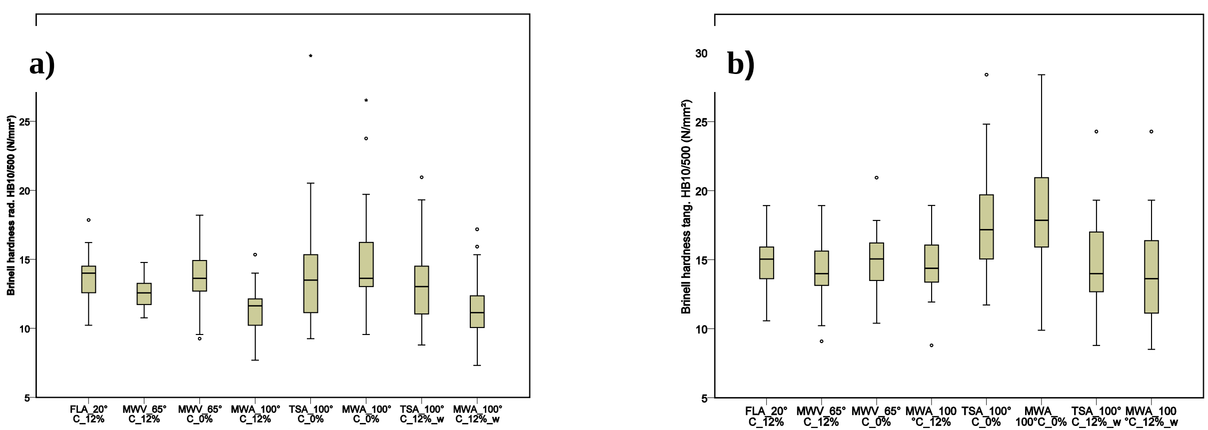

Fig. 6
Relationship between the drying processes and the Brinell hardness in radial (a) and tangential (b) direction. Explanation of box- and whiskers s. Fig. 3.

CONCLUSION

As a conclusion it can be stated that the mechanical properties of Norway spruce wood investigated, namely: the tree-point bending strength and the compression parallel to the grain are not influenced by the moderate temperature microwave and oven drying processes applied. Significant differences could be found for the mechanical properties of water stored material with a high starting MC due to cracks as result of the drying stresses by comparison with the natural dried material. For the Brinell hardness significant differences could be found in same cases in comparison to the natural dried material for the radial and tangential direction. Most of the artificial dried series differ significant at 5% level from each other by comparing the Brinell hardness in radial and tangential direction.

ACKNOWLEDGEMENT

The presented work is financially supported by the “TirolerStandortagentur” under the project “Physikalisch - chemischeUntersuchungen der silikat - ischen Nano - Infiltration von HölzernnachMikrowellentrocknung” within the Translational - Research program.

REFERENCES

Antti A L (1992) Microwave drying of wood: simultaneous measurements pressure, temperature, and weight reduction, Forest Products J. 42:49–54

DIN 52182 Prüfung von Holz; Bestimmung der Rohdichte, 1976

DIN 52183 Prüfung von Holz; Bestimmung des Feuchtegehalts, 1977

DIN 52185 Prüfung von Holz; Bestimmung der Druckfestigkeit parallel zur Faser, 1976

DIN 52186 Prüfung von Holz; Biegeversuch, 1978

EN 1534 Parkett und andere Holzfußböden – Bestimmung des Eindruckwiderstandes (Brinell) – Prüfmethode, 2000

Hansson L, Antti AL (2006) The effect of microwave drying on Norway spruce woods strength: a comparison with conventional drying, Journal of Materials Processing Technology 141:41-50

Lee HW (2003) Combined microwave and convective drying of Koreanwood species, in: Proceedings of the 8th International IUFRO Wood Drying Conference, 2003, pp. 146–149

Lehne M, Barton GW, Langrish TAG (1999) Comparison of experimental and modelling studies for the microwave drying of ironbanktimber, Drying Technol. 1999, pp. 2219–2235

Masakasu M, Harumi K, Akihiko S, Toyoji K, Keji T (2003) Rapid pyrolysis of wood block by microwave heating, J. Anal. Appl. Pyrol. 2003, pp. 1–13

Oloyede A, Groombridge P (2000) The influence of microwave heating on the mechanical properties of wood, Journal of Materials Processing Technology 100, pp. 67-73

Oltean L, Teischinger A, Hansmann Ch (2011) Influence of low and moderate temperature kiln drying schedules on specific mechanical properties of Norway spruce wood, Eur. J. Wood Prod. 69, pp. 451-457

Oltean L, Teischinger A, Hansmann Ch (2007) Influence of temperature on cracking and mechanical properties of wood during wood drying – a Review, Bio ressorces 2(4):789-811

Resch H (2009) Drying Wood With High Frequency Electric Current, Society of Wood Science and Technology, Madison WI 53726-2398 (USA), ISBN 978-0-9817876-1-9

Shahverdi M, Tarmian A, Dashti H, Ebrahimi G, Tajvidi M (2012) Mechanical properties of poplar wood (Populus alba) dried by three kiln drying schedules, Bio ressources 7(1):1092-1099

Taskini J (2007) Effect of Drying Methods on wood Strength: A comparison Between Microwave, Infrared and Conventional Drying, Mech. & Areospace Eng. J. 3(1):83-90

Turner IW (1994) A study of the power density distribution generated during the combined microwave and convection drying of softwood, in: Proceedings of the 9th International Drying Symposium, Gold Coast, Australia, August, 1994, pp. 1–4