IRG/WP 05-40303

THE INTERNATIONAL RESEARCH GROUP ON WOOD PROTECTION

Section 4 **Processes and properties**

Influences of the hydro-thermal treatment on physical properties of beech wood (*Fagus orientalis*)

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Paper prepared for 36th Annual Meeting
Bangalore, India
24 – 28 April 2005

IRG SECRETARIAT
SE-100 44 Stockholm
Sweden
www.irg-wp.com

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Abstract

Influences of the hydro-thermal treatment on physical properties of beech wood were studied. Wood specimens (2×2×2cm) were treated in two steps. At first step, samples were treated at 160,180 & 200ºC for 4, 5 & 6 hours. At second step, treated samples were cured based on their first step treatment temperatures (160,180 & 200ºC) for 16 hours. The treated samples were soaked in water and oven dried for 24 hours. The soaking-drying cycles were repeated for seven times. Oven dried density (initial and final), swelling (initial and final), water absorption (initial and final) and density loss were analyzed. Results revealed that swelling was decreased due to the hydro-thermal treatment; while the water absorption was increased in wood. And oven dried density was slightly lost due to the treatment. The density loss and increase of water absorption are related to initial pyrolysis of wood which consequences with increase of wood porosity due to the treatment.

Keywords: thermal wood modification, hydro-thermal treatment, oven dried density, swelling, water absorption, Anti-Swelling Efficiency (ASE)

Introduction

Wood and lignocellulosic materials are composed of three major polymers; cellulose, hemicellulose and lignin. Their all physical, chemical and mechanical properties are influenced of them. Wood is an engineering material**.** In spite of its good technological properties, it has some limiting properties that can affect its applications; e.g. dimensional instability, flammability, degradation due to UV and biodeterioration.

Different techniques have been used to improve those properties; such as, wood preservation by using preservatives and pesticides, UV-absorbent paints, etc. However, many of them have environmental impacts. For this reason, their applications are being restricted in different countries due to laws and media pressures (Mohebby, 2003a). Since the last decade, scientists are looking for techniques to modify wood structure and lignocellulosic materials chemically to enhance higher properties.

Wood modification has been found as a better solution. Different techniques have been studied or used for wood modification. Heat (thermal) treatment is known as one of the oldest, easiest and cheapest methods, which improves water repellency, dimensional stability and bio-resistance in wood.

Since the last decade, different techniques have been invented for the thermal wood modification; e.g. PLATO (Tjeerdsma *et al.*, 1998, 2000; Boonstra *et al.*, 1998), Le Bois de Perdure (Vernois, 2001; Gohar & Guyonnet, 1998), Retification (Militz, 2002), VTT (Syrjänen & Oy, 2001; Jäsmä & Viitaniemi, 2001) and OHT (Rapp, 2001; Rapp & Sailer, 2002; Thévenon, 2002). Some techniques have been industrialized in different countries; such as France, Germany, The Netherlands and Sweden. Annually 165000 m^3 of thermally treated woods are produced (Militz, 2002).

According to the reports, the thermal treatment of wood improves its different properties; such as water repellency, dimensional stability, anti-swelling efficiency (ASE), UV resistance (Militz, 2002). After using different chemicals and improving dimensional stability of wood, Stamm *et al.* (1946) reported that achieving dimensional stability is neither due to applying heat during the treatment nor using the chemicals.

It was reported that the thermal treatment increases bio-resistance of wood against rot fungi (Kamdem *et al.*, 2002; Welzbacher & Rapp, 2002; Mazela *et al.*, 2003; Momohra *et al.*, 2003).

Kamdem *et al.* (2002) suggested that the thermal treatment of wood decreased modulus of rupture (MOR) about 10-50%. Reports indicate that any raised treatment temperature and duration increase modulus of elasticity in beech wood (Yildiz *et al.*, 2002; Repellin & Guyonnet, 2003).

Since, there is no report about the influences of the hydrothermal treatment on Persian beech wood; the current research has been set up to study its effects on density, swelling, water absorption of beech wood.

Material and methods

Wood blocks (5×5×20cm) were prepared from oriental beech wood (*Fagus orientalis* Lipsky) and cut into sizes 2×2×2cm. Samples were dried in an oven for 24h at 103±2ºC to determine dry weights before treatment. Thereafter, the treatment was carried out in two steps, hyrothermal and curing respectively.

Samples (20 replicates) for each treatment were placed in a stainless steel chamber and filled with water ($^{Liquid}/_{Dry\ Wood}$=10 g/g) and heated at 160, 180 and 200ºC for 4, 5 and 6 hours. After the hydrothermal treatment, they were cured in an oven for 16 hours based on their initial treatment temperatures (160, 180 and 200ºC). Oven dry weights of the treated samples and their initial dimensions were measured to determine the density loss due to the hydrothermal treatment and samples' initial dimensions before any soaking-drying cycles. Afterwards, they were dipped in water for 24h to determine anti-swelling effect (ASE) of the hydrothermal treatment. Wet weights and dimensions were measured to determine the water absorption and swelling after soaking. At next step, samples were oven dried and their dry weights and dimensions were also determined. The soaking-drying cycles were carried out for 7 times. At each step, the mentioned measurements were done to determine the ASE and density loss. ASE and swelling were calculated based on the following equations:

Eq. 1 $$\mathbf{ASE\ (\%) = (S_2-S_1)/S_1 \times 100}$$

Where:

ASE (%) = Anti-Swelling - Efficiency
S_1 (%) = Swelling Coefficient after each soaking-drying cycle
S_2 (%) = Swelling Coefficient before each soaking-drying cycle

Eq. 2 $$S(\%) = (V_2 - V_1)/V_1 \times 100$$

Where:

S (%) = Volumetric Swelling

V_1 (cm^3) = Volume after soaking in water

V_2 (cm^3) = Volume in dry condition (before soaking)

Oven dried densities before and after the hydrothermal treatment, and also during the soaking-drying cycles, water absorption during the soaking-drying cycles, swelling and also anti-swelling efficiency during the soaking-drying cycles were measured to determine any changes which were occurred due to the repeated cycles.

Results and discussions

Changes of the initial and finial densities (after first and seventh step of soaking-drying cycles) are shown in Fig. 1. It was revealed that density is decreased due to raised treatment temperatures and durations. Comparison between initial and final densities showed that finial oven dried density was slightly lost after soaking-drying cycles in comparison with the initial density. Also Fig. 2 indicates that percentage of density loss increased due to the raised treatment conditions (temperature and time).

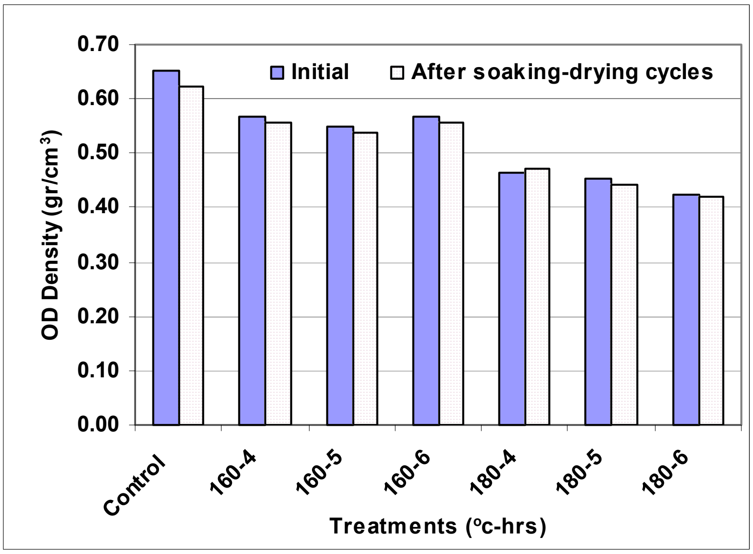

Fig. 1- Initial and final swelling in hydrothermally treated beech wood

As the thermal treatments were occurred at higher temperatures, it could be suggested that the increased oven dried density losses probably related to slight pyrolysis and/or deterioration of the cell wall polymers; especially hemicelluloses, which was sequenced by a mass loss in wood. Allen *et al.* (2002) studied thermo-chemical behavior of spruce (*Picea abies*) and indicated that the thermal treatment degrades hemicelluloses; while pyrolysis of cellulose and lignin is negligible.

Lower density of the treated samples after final step of soaking-drying cycle could be related to leached extractives that were formed during the hydrothermal treatment. Mayes and Oksanen (2002) reported that thermally treated Scots pine wood losses its weight after soaking-drying cycles. They suggested that leaching of the formed extractives during the thermal treatment was the main reason.

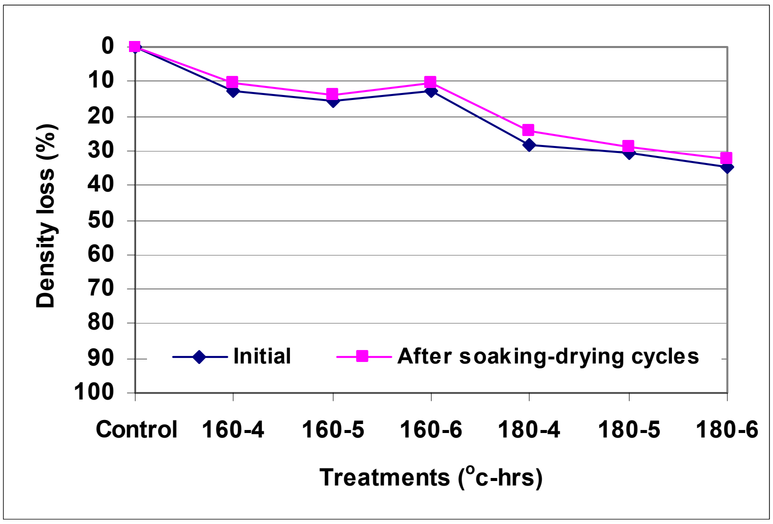

Fig. 2- Comparison between initial and finial density loss in in hydrothermally treated beech wood

Figs. 4 & 5 show volumetric, axial, radial and tangential swelling of the treated beech after the initial and final steps of soaking-drying cycles. Results revealed that initial volumetric swelling of the samples was decreased at raised temperature. The highest initial volumetric swelling was measured in untreated samples as 17.31% and the lowest percentage of swelling was determined in treated samples (180ºC for 4h) as 7.86% (Fig. 3) with an ASE of 45.4%. Also, it was revealed that the highest final volumetric swelling was determined in untreated samples as 13.29% and the lowest in treated samples at 180ºC for 6h as 8.09% with an ASE of 60.87% (Fig. 4).

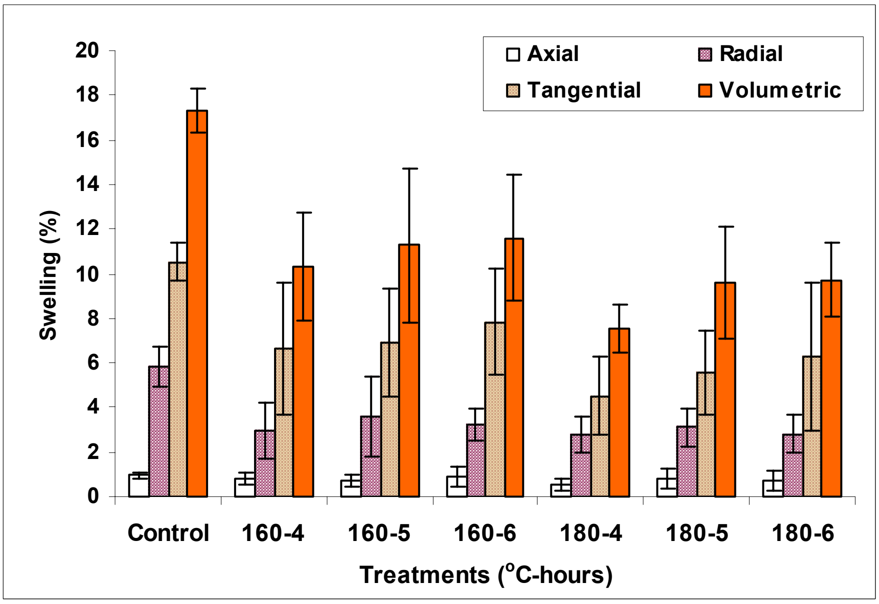

Fig. 3- Initial swelling of treated beech wood after the first soaking-drying cycle

Fig. 5 indicates ASE in the hydrothermally treated beech wood. The results revealed that ASE was increased at raised temperature.

Shrinkage and swelling are the phenomenon, which are happened under fibre saturation point (FSP) due to moisture absorption. It sequences with dimensional changes in wood. Above the FSP, no dimensional changes and swelling occur due to the water absorption.

Chemical structure of wood becomes altered due to the thermal treatment, which is followed by cross-linking in cell wall polymers and slight pyrolysis. It could be suggested that OH groups of the cell wall polymers are removed or cross-linked during the hydrothermal treatment and the curing step. Therefore, wood absorbs less moisture and becomes much water repellent.

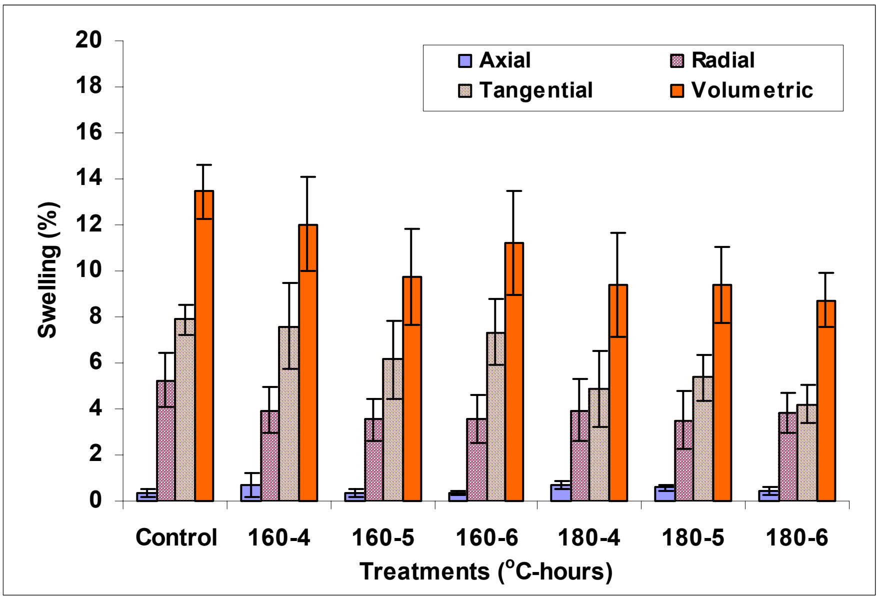

Fig. 4- Final swelling of treated beech wood after the last step of soaking-drying cycle

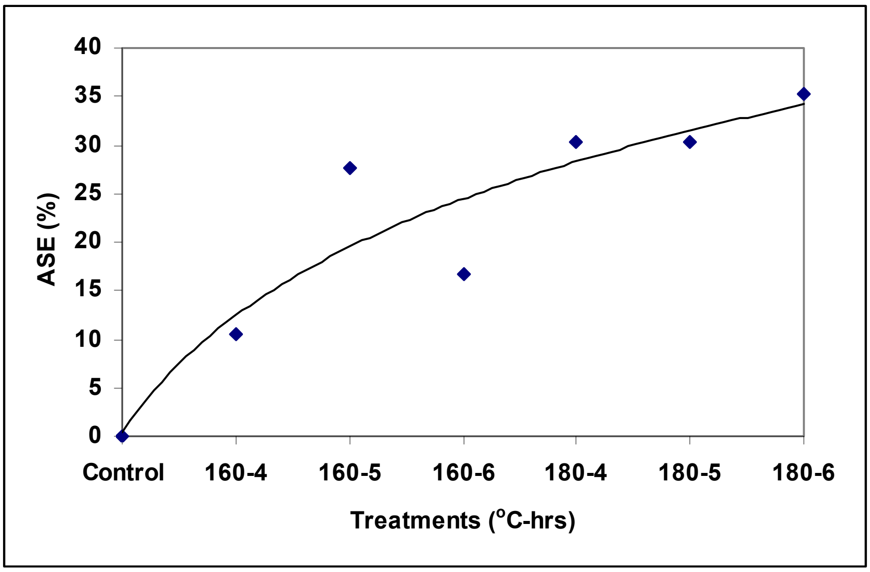

Fig. 5- Anti-Swelling-Effect of the hydrothermal treatment on beech wood

Leaching of the extractives during the soaking-drying cycles could be related to pyrolysis of the hemicelluloses that was occurred during the hydrothermal treatment and curing step. Not only removal of the hydrophilic hemicelluloses influences slightly wood mass, but also its hygroscopy. Therefore, increased ASE could also be related to removal of the hemicelluloses and cross-linked cell wall polymers. Yildiz *et al.* (2002) reported an ASE of about 47.64% in the thermally treated beech wood at 180ºC for 2, 4 and 10h of soaking-drying cycles. Viitanen *et al.* (1994) reported also an ASE between 50-80% based on applied thermal treatment.

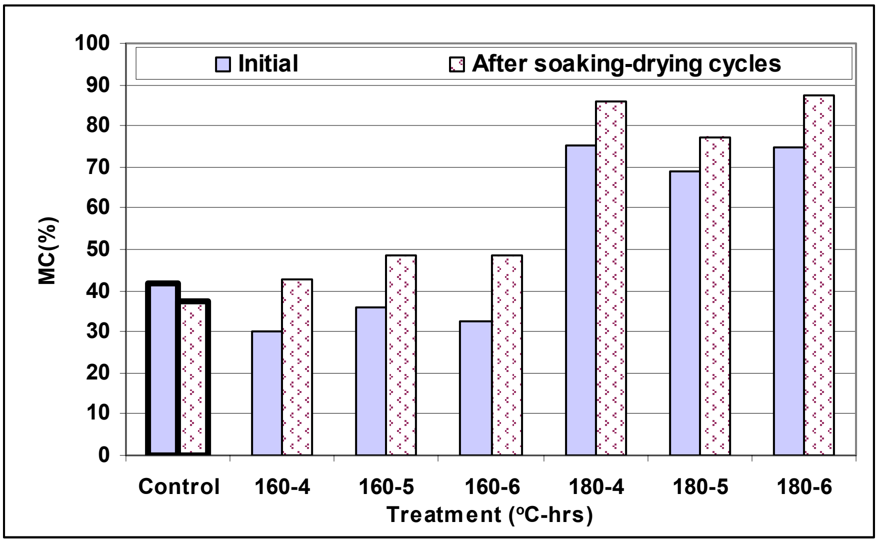

Fig. 6- Water absorption after initial and final steps of soaking-drying cycles

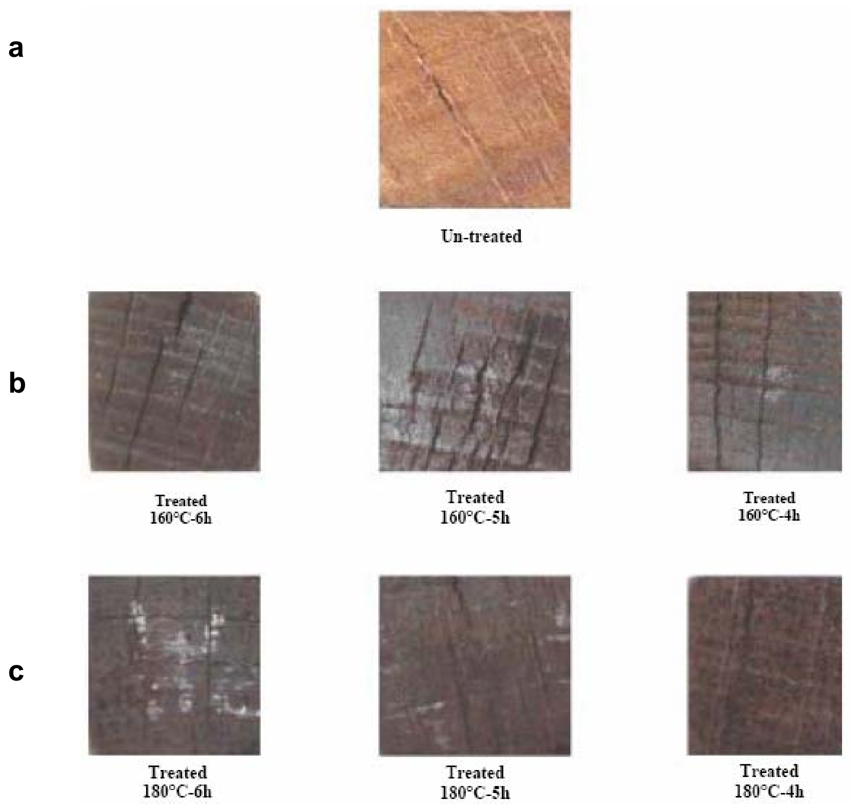

Fig. 7- Checks in hydrothermally treated beech wood; a: untreated, b: treated at 160ºC, c: treated at 170ºC

The influence of hydrothermal treatment on moisture absorption is shown in Fig. 6. Results revealed that the moisture absorption was increased due to raised temperature. In spite of the lower ASE at higher temperatures, the water absorption was increased due to the treatment. The water absorption was also increased after soaking-drying cycles (Fig. 6). The highest absorption was determined in treated beech wood at 180ºC for 4 and 6 hours (76.75% and 74.97% respectively). The lowest moisture absorption was measured in the treated samples at 160ºC for 4h (31.86%). Comparison between the absorbed moisture after initial and final soaking-drying cycles indicated that untreated beech wood absorbed less moisture than the treated samples after soaking-drying cycles.

Visual analysis also showed small checks in the treated woods (Fig.7). The checks were mostly appeared in wide and multiseriate rays due to their lower strengths.

The increased moisture absorption in the treated beech wood can be related to appeared checks due to the thermal treatment. Wood became porous due to broken wide rays and removal of the hemicelluloses. Decreased moisture absorption in untreated beech wood is related to hystersis that was occurred in wood after soaking-drying cycles.

It was observed that the treated samples at 200ºC were deteriorated during curing step because of highly applied temperature. Therefore, they were removed from this experiment.

References:

Alen R., R. Kotilainen & A. Zaman ; 2002: Thermochemical behaviour of Norway Spruce(*Picea alba*) at 180- 225°C; Wood Science and Technology; 36: 163-17.

Kamdem D.P., A. Pizzi & A. Jermannaud; 2002: Durability of heat-treated wood; Holz als Roh- und Werkstoff; 60: 1-6.

Mazela B.; R. Zakrzewski; W. Grzeskowiak; G. Cofta & M. Bartkowiak; 2003: Preliminary Research on the Biological Resistance of Thermally Modified Wood; European Conference on Wood Modification; 3-4th April, Ghent, Belgium: 113- 119.

Militz H.; 2002: Thermal treatment of wood: European Processes and their background; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 02-40241.

Boonstra M. J., B. F. Tjeerdsma & H. A. C. Groeneveld; 1998: Thermal modification of non-durable wood species 1. The PLATO technology; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 98-40123.

Gohar P. & R. Guyonnet; 1998: Development of the retification process of wood at the industrial scale; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 98-50101-16.

Jämsä S. & P. Viitaniemi; 2001: Heat treatment of wood: Better durability without chemicals; COST Action E22.

Mayes D. & O. Oksanen; 2002: ThermoWood handbook; ThermoWood; Finnforest; StoraEnso.

Mohebby B.; 2003a: Biological attack of acetylated wood; Ph.D. Thesis; Göttingen University; Göttingen: p. 147.

Mohebby B.; 2003b: Wood modification of wood and lignocellulosic materials and their technologies; The First Conference on Processing of Cellulosic Materials;

30th Sep.-1st Oct., Tehran University, Rezvanshahr, Iran: 405-412 (*In Persian Language*).

Momohara I.; W. Ohmura; H. Kato & Y. Kubojima; 2003: Effect of High-Temperature Treatment on Wood Durability against the Brown- rot Fungus *Fomitopsis palustris* and the Termite *Coptotermes formdsaus*; 8th Int. IUFRO Wood Drying Conference- 2003: 284- 287.

Rapp A.O; 2001: Review on heat treatments of wood; State of the art; COST Action E22

Rapp A.O. & M. Sailer; 2002: Heat treatment of wood in Germany- State of the art; COST ACTION E22.

Repellin V. & R. Guyonnet; 2003: Evaluation of Heat Treated Beech by Non-destructive Testing; European Conference on Wood Modification. 2003: 73-82.

Stamm A.J., H.K. Burr & A.A. Kline; 1946: Heat stabilized wood (Staybwood); Rep. No. R-1621; Madison; Forest Products Laboratory.

Syrjänen T. & K. Oy; 2001: Heat treatment of wood in Finland: State of the art; COST Action E22.

Thévenon M.F., 2002: Oils and water repellents in wood protection: Research and development in France; COST ACTION E22.

Tjeerdsma B.; M. Boonstra; A. Pizzi; P. Tekely & H. Militz; 1998: Characterisation of thermally modified wood: molecular reasons for wood performance improvement; Holz als Roh- und Werkstoff; 56:149- 153.

Tjeerdsma B.F.; M. Stevens & H. Militz; 2000: Durability aspects of (hydro) thermal treated wood; The International Research Group on Wood Preservation; IRG Document No: IRG/WP 00- 40160.

Vernois M.; 2001: Heat treatment of wood in France: State of the art; COST Action E22.

Viitanen H., S. Jämsä, A. Nurmi & P. Viitaniemi; 1994: The effect of heat treatment on the properties of spruce: A preliminary report; The International Research Group on Wood Preservation; IRG Document No: IRG/WP 94-40032.

Welzbacher C.R. & A.O. Rapp; 2002: Comparison of thermally modified wood originating from four industrial scale process-durability; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 02-40229.

Yildiz S.; 2002: Effect of Heat Treatment on Water Repellence and anti-Swelling Efficiency of Beech; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 02- 40223.

Yildiz S.; G. Colakoglu; U. Yildiz; E. Gezer & A. Temiz; 2002: Effects of Heat Treatment on Modulus of Elasticity of Beech Wood; The International Research Group on Wood Preservation; IRG Document No. IRG/WP 02- 40222.