Eliminating Set-recovery in Densified Wood using a Steam Heat-treatment Process

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ABSTRACT

Above the glass transition point, solid wood can be compressed without breaking the cell walls. It is well known that compressed wood will spring back in humid conditions without certain treatments because of the relaxation of internal stresses. The aim of this study was to evaluate the suitability of an industrial scale steam heat-treatment process in reducing or eliminating set-recovery in densified Scots pine. There are different methods in use for the industrial heat treatment of wood in Europe. With some modification, in principle, all could be used to reduce or eliminate set-recovery in compressed wood, with some modification. With certain processes steam is used as a shielding gas for the wood, which means that the densification starts to recover immediately the heat-treatment process begins. This problem could be avoided if the densified wood were kept in the compressed state whilst being heat-treated or, alternatively, if the steam injection process began at a higher temperature than it normally does. Scots pine boards, 100 x 100 x 37 mm (length x width x thickness) were densified by 30% in a hot press at a temperature of 200 ^{o}C. The densified boards were then subjected to a high temperature steam heat treatment at 200 ^{o}C. The steam injection starting temperatures were 140, 170 and 200 ^{o}C. Subsequently, the boards were soaked in water for 7 days at 60 ^{o}C. Set-recovery, measured as the amount the densified boards recovered, was measured after the steam treatment process and again following water soaking. None of boards showed significant evidence of set-recovery immediately after the steam treatment process, and moreover, the treated samples did not spring back after 7 days soaking in water at 60 ^{o}C, followed by drying. This process shows good promise as an industrial scale method for eliminating set-recovery in densified wood and further work is ongoing to optimise the process conditions.

INTRODUCTION

It is well known that mechanical properties of wood, such as hardness, are correlated with its density. Moreover, wood can be compressed without breaking the cell walls above glass transition point. Only slight densification can increase hardness values significantly (Rautkari *et al*. 2008a,b). Unfortunately, densified wood recovers its original dimensions under humid conditions. The elimination of this so called set-recovery with heat treatment of the wood, after densification, is well studied. Navi and Heger (2004) explain set-recovery as follows; after wood has been compressed, it has a lot of inner stresses in the helical semi-crystalline microfibrils. These stresses have to be relaxed to avoid set-recovery. This relaxation can be done by post-treatment at high temperature in saturated steam. The treatment time reduces exponentially with increasing steam temperature (Navi and Heger 2004). Various studies on compressed solid wood (Inoue *et al*. 1993, Navi and Gigardet 2000, Ito *et al*. 1998, Welzbacher *et*

al. 2008, Morsing 1997) have, however, reported that set-recovery can be totally, or, almost totally, eliminated if a high temperature (180-200 ºC) post treatment is carried out, particularly in a closed press system under humid conditions. These high humidity/temperature conditions are only possible in closed system with high air pressure (Simpson and Rosen 1981, Ishikawa *et al*. 2004). The aim of this study was to examine the suitability of an industrial steam heat-treatment process for eliminating the set-recovery of densified wood, where the pressure is constant, at approximately 1 ATM. The relative humidities at 1 ATM at high temperatures are low (Simpson and Rosen 1981), therefore the wood does not recover during the process. It has to be consider that the steam injection temperature has to be enough high to avoiding set-recovery during the process. Approximated maximum RH values at temperatures above 90 ºC are presented in Figure 1.

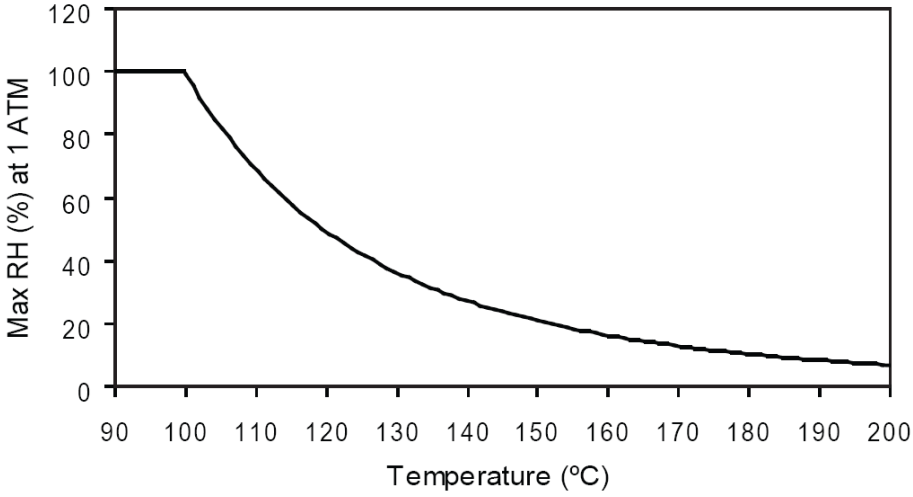

Figure 1: Approximate maximum possible relative humidities at temperatures exceeding 90 ºC (Simpson and Rosen 1981)

MATERIALS AND METHODS

Scots pine boards, 100 x 100 x 37 mm (length x width x thickness) were densified by 30% in a hot press for 4 hours at a temperature of 200 ^{o}C. Before the densification the samples were soaked in water for 24 hours. The densified boards were then subjected to a high temperature steam heat treatment at 200 ^{o}C and 1 ATM in steam heat-treatment chamber. The temperatures of which steam injection began were 140, 170 and 200 ^{o}C. The schedule of the process is presented in Figure 2. Subsequently, the boards were soaked in water for 7 days at 60 ^{o}C. Set recovery, measured as the amount the densified boards recovered, was measured after the steam treatment process and again following water soaking.

Set-recovery was evaluated using Eqn 1.

$$S_r = \frac{T_r - T_c}{T_0 - T_c}, \text{ when } T_r \geq T_c \text{ and } T_0 > T_c \qquad (1)$$

where T_r is the oven dried thickness of the specimen after soaking, T_c is the thickness of the compressed specimen (oven dried) and T_0 is the initial thickness of the specimen (oven dried).

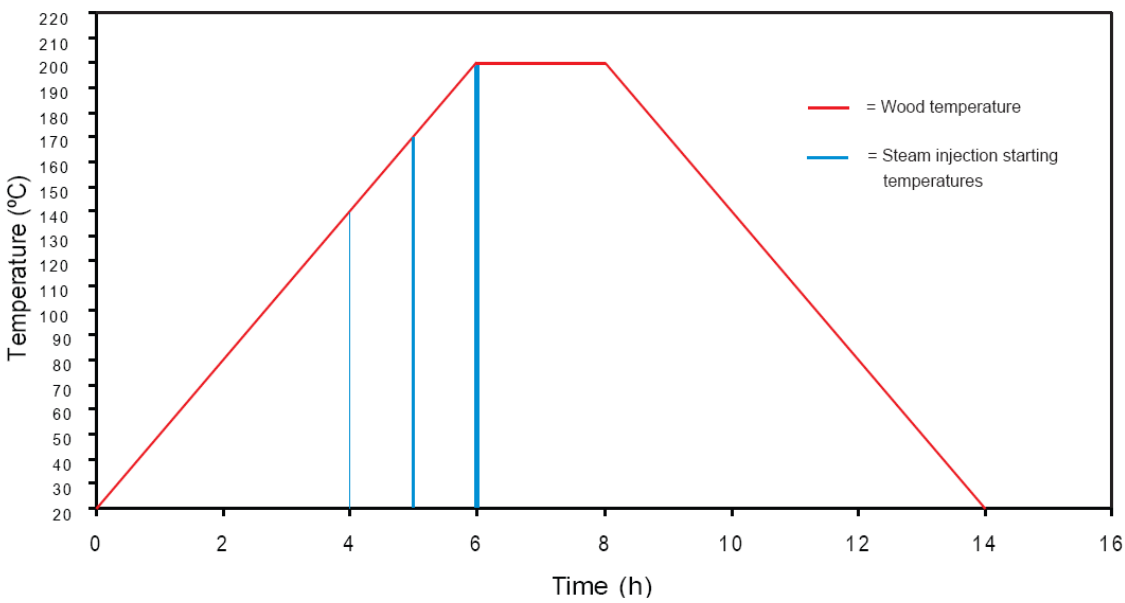

Figure 2: The schematic of the steam heat-treatment process. The steaming started at 140, 170 and 200 ºC. Samples were always heated ~2 hours at 200 ºC and then cooled

RESULTS

The results show that the steam heat-treatment process eliminates the set-recovery almost totally. Set-recovery (SR) in the heat-treatment process was less than 0.5% irrespective of the steam injection starting temperatures (Table 1). This indicates that the steam injection temperature can be less than 140 ºC, but more than 100 ºC. The maximum relative humidity is ~25 % (Simpson and Rosen 1981) at 140 ºC and 1 ATM. The recovery occurs mainly in the RH range RH 90-100% (Tarkow and Seborg 1968). Further work is ongoing to optimize the steam injection temperature.

Table 1: The set-recovery (SR) in heat-treatment process and after soaking

Steam injection starting T (ºC)	140	170	200
SR in heat-treatment process (%)	<0.5	<0.5	<0.5
SR in heat-treatment process (mm)	<0.05	<0.05	<0.05
SR after soaking (%)	<1	<1	<1
SR after soaking (mm)	<0.2	<0.2	<0.2

CONCLUSIONS

High pressure autoclaves are not cost efficient at an industrial scale and large volumes of wood. Densified wood processes are not yet widespread in Europe because of the technical difficulties and high prices of the process. Steam heat-treatment shows good promise as an industrial scale treatment for eliminating set-recovery in densified wood and further work is ongoing to optimise the process conditions.

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