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Continuous Wood Surface Densification – Chemical Treatments to Reduce the Set-Recovery

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Abstract

The hardness of the outer surface of solid wood can be improved by densification, and this opens up new fields of application for low-density species. So far, surface densification is carried out in time- and energy-consuming batch processes, and this means that potential advantages over more expensive hardwood species or non-renewable materials are lost. One of the crucial problems in all densification processes is to reduce the moisture-induced set-recovery of the densified wood cells. In a previous study, a new high-speed continuous surface densification process was introduced, where the surface of solid Scots pine boards could be densified at speeds of up to 80 m/min by a roller pressing technique. The aim of the present study was to integrate the roller pressing technique with different pre- and post-treatment methods to reduce the set-recovery. An aqueous solution of sodium hydroxide was used as a pre-treatment agent to activate the wood surface prior to densification, and a methacrylate ester monomer solution was used as an impregnation agent, both before and after densification. After densification and impregnation, the methacrylate monomers are polymerized by curing in an oven at 100°C in order to stabilize the compressed wood cells. The results show that the different treatments had no significant effect on the set-recovery, probably due to insufficient penetration into the wood material. Future work will focus on improving the treatment process and integrating all process steps into a fully continuous and automatic process.

Keywords: compression, sodium hydroxide, methacrylate, impregnation, roller pressing

Introduction

Surface densification of solid wood is a concept that has gained popularity in the past years. Even though the first studies into this subject originate from the 1960s [1], recent interest was perhaps triggered by a similarly renewed interest in bulk densification of wood [2-4]. The densification of wood increases its hardness and abrasion resistance, and this opens up new fields of use, especially for low-density wood species. Compared to bulk densification through the whole thickness of a wooden board, surface densification offers certain advantages. Densifying only a few millimeters deep into the wood surface reduces the process time, costs and energy consumption, and also simplifies treatments to eliminate the shape memory effect of the densified wood cells when they are exposed to moisture. For certain applications, the combination of a hard surface and a relatively soft core is an asset. In the case of wooden flooring, a surface-densified board provides a durable surface while maintaining favorable dampening characteristics.

Past studies into surface densification of wood were aimed mainly at exploring different process approaches. Before performing the actual densification in a hot press, Inoue et al. [5] cut grooves into the wood surface and filled them with water, and subsequently exposed the surface to microwave radiation to plasticize the surrounding wood cells. Pizzi et al. [6] used a friction-welding machine to densify two pieces of wood at the same time, separated by a layer of oil to avoid bonding. A similar approach was adopted by Rautkari et al. [7], but the vast majority of further studies used a rather simple surface densification process in a hot press [8]. Usually the press is equipped with a cooling system to cool the wood below its glass-transition temperature before the press is opened, and this greatly reduces the springback once the pressure is released. Several studies were carried out to examine the influence of the press temperature, softening time, pressing time and level of compression on the resulting wood properties, such as the density profile tin the direction of compression, the hardness and the set-recovery [9-11].

The latter is in fact one of the main obstacles in the way of commercialization of surface-densified wood products, and different approaches to eliminate the set-recovery, ranging from thermal post-treatment and steam treatments to impregnation with chemicals have been studied with varying degrees of success. Westin et al. [12] impregnated the wood with furfuryl alcohol and achieved a reduction of the set-recovery to 17%. Kutnar et al. [13] were able to achieve a reduction to 6% by densifying wood specimens under saturated steam conditions at 170°C. Similar results were obtained by Laine et al. [14] after a combined heat and steam post-treatment at 200°C, with process times of several hours. In a recent study, Laine et al. [15] were able to reduce of the set-recovery to 25% when densifying acetylated radiata pine.

The reported studies clearly show that it is possible to achieve a significant improvement in several wood properties with surface densification, and to stabilize the densification effectively, even upon repeated exposure to moisture. However, these approaches rely on time- and energy-consuming batch processes, and this means that potential advantages over more expensive wood species or non-renewable materials are lost. Using fossil-based plastics or applying wood densification processes with a high energy consumption has an adverse effect on the environment.

For this reason, it is necessary to develop a high-speed surface densification process that is both cost- and energy-efficient. In a previous study, a continuous roller pressing approach was adopted to successfully densify the surface of Scots pine boards at a process speed of up to 80 m/min [16]. The experiment focused, however, only on the actual densification stage. The plasticization was done in a batch process, while additional stabilization treatments were completely omitted.

The objective of the present study was to integrate the roller pressing technique with different pre- and post-treatment methods to reduce the set-recovery. An aqueous solution of sodium hydroxide was used as a pre-treatment agent to activate the wood surface prior to densification, and a heat-curing methacrylate ester monomer resin was used as an impregnation agent either before or after densification.

Materials and Methods

The specimens were cut from locally sourced Scots pine boards with an initial cross-section of 125 mm x 25 mm. The target dimensions before densification and after conditioning at 20°C and 65% RH in a climate chamber were 900 mm (L) x 40 mm (T) x 20.5 mm (R). The moisture content (MC) of the specimens was between 14 and 15 %.

The specimens were cut so that the densification and chemical treatment were performed on sapwood cells.
Figure 1 shows an overview of the four-stage process flow, including the chemical treatments to reduce the set-recovery. Table 1 presents an overview of the treatment combinations that were tested. Each specimen group consisted of 10 replicates.
The softening of the surface was carried out by putting the specimens on a hot iron slab, which was kept at a temperature between 140 and 150°C, for 90 s. To assure proper contact, a cold steel bar was placed on top of the wood specimens. After the softening stage, the specimens were turned, so that the softened surface was in contact with the heated roller during the densification stage (Figure 1). The specimens were densified in the radial direction of the wood with a gap between the rollers of 15 mm. The speed was 20 m/min and the temperature of the heated roller was 150°C. Due to the lack of a cooling stage, a considerable springback after densification was expected. In order to mimic a cooling stage, the group DL was fed through additional sets of cold (20°C) leveling rollers immediately after the main densification stage. These rollers were set to successively smaller gaps between the rollers, starting with 17.5 mm for the first set, followed by 16.5, 15.5, and 15.0 mm.

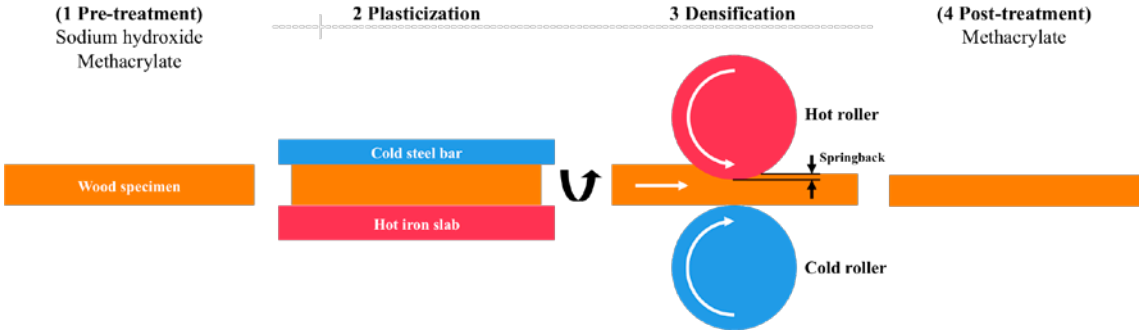

Figure 1 – Overview of the surface densification process. The first process stage was an optional pre-treatment with either sodium hydroxide or methacrylate (1). Afterwards the wood surface was softened by heating (2). Before densification, the specimens were turned to be in contact with the heated roller during densification (3). In an optional post-treatment stage, the specimens were impregnated with methacrylate (4).

Table 1 – Overview of the treatment combinations.

Specimen group	Pre-treatment	Plasticization	Densification	Heated roller	Post-treatment
R	No	No	No	No	No
D	No	Yes	Yes	Yes	No
DH	No	Yes	Yes	No	No
D-M	No	Yes	Yes	Yes	Methacrylate
DS-	Sodium hydroxide	Yes	Yes	Yes	No
DSM	Sodium hydroxide	Yes	Yes	Yes	Methacrylate
DM-	Methacrylate	Yes	Yes	Yes	No
DL	No	Yes	Yes	Yes	Leveling rollers

The pre-treatment with sodium hydroxide (Merck 1.06495.0250) was carried out by brushing an aqueous solution with a concentration of 8% onto the specimen surface with a paper towel until it was completely wetted. The subsequent process stages were performed after a waiting time of 20 minutes. Regardless of whether it was applied as a pre- or post-treatment, the impregnation with methacrylate (TurnTex Woodworks Cactus Juice Resin) was carried out by soaking the wood surface in a bath with a depth of approximately 5 mm for 10 minutes at 20°C. For the post-treatment with the methacrylate resin, the specimens were soaked immediately after densification, in order to exploit the suction effect caused by the temperature difference between the hot

specimens and the cold resin. To cure the methacrylate resin after the densification and treatment process and trigger its polymerization, the respective specimens were placed in an oven at 100°C for 1 h.
The set-recovery of the specimens was measured after one and two cycles of soaking in water at 20°C for 24 h, followed by oven-drying at 103°C for 24 h. The set-recovery is defined as:

$$\text{Set-recovery} = \frac{(\text{oven dry thickness after soaking- oven dry thickness after compression})}{(\text{initial uncompressed thickness-oven dry thickness after compression})}$$

Results and Discussion

Figure 2 presents a summary of the results. Even though the distance between the rollers was set to a target thickness of 15 mm, the actual thickness after densification was about 18 mm for most of the specimens. This is equal to an effective thickness reduction of approximately 2.5 mm. The large difference between the actual thickness and the target thickness is the springback of the densified wood cells, mainly due to a lack of cooling to solidify the softened wood while it remains under pressure. The springback of the group DL could be reduced with the post-treatment of feeding them through the leveling rollers after the main densification stage.
At first glance, it appears that the chemical treatments led to a small but significant reduction of the set-recovery. However, in reality this was not the case. As the initial, uncompressed thickness of the specimens was measured at an MC of approximately 14%, the oven-dry thickness after wet/dry-cycling will be lower than the initial thickness, resulting in set-recovery values below 100%, even in the case of full recovery of the densified wood cells. The fact that the oven-dry thickness after two wet/dry-cycles is essentially the same for all the specimen groups indicates that this actually occurred. For this reason, the apparent difference in set-recovery between the specimen groups is misleading. In reality the chemical treatments had no significant effect on the set-recovery.

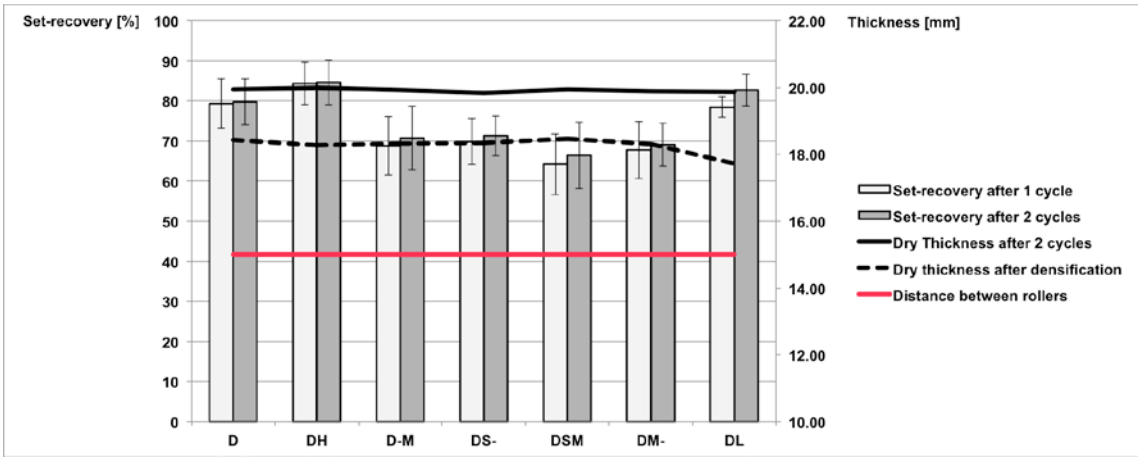

Figure 2 – Set-recovery after one and two wet/dry cycles, oven-dry thickness after two wet/dry cycles, oven-dry thickness after densification, and the distance between the rollers. The error bars show the standard deviation. The difference between the red line and the dashed line is the immediate springback caused by the lack of a cooling stage.

Prior to the roller pressing experiment, a small pre-study was carried out using an ordinary hot press to determine the method and parameters for the chemical treatments. In this pre-study, the treatment with methacrylate in particular had a significant effect on the set-recovery. Although the pre-study included only a small number of samples, it seemed to indicate that the method of densification affects the efficacy of the chemical

treatment. In contrast to the roller-pressing approach, densification in a hot press provides continuous contact and pressure throughout the process, in this case for about 90 s. This could have a positive effect on the level of penetration of the methacrylate resin.

Conclusion

Except for the rather large and expected springback, the roller pressing densification approach worked well. The achieved thickness reduction was about 2.5 mm for all but one specimen group. A post-densification between cold rollers led to less springback, resulting in a thickness reduction of 3 mm.
The chemical treatment with either sodium hydroxide or methacrylate resin, or with a combination of both, had no significant effect on the set-recovery.
Additional experiments will be carried out to examine whether the densification method has an effect on the level of penetration of the chemical into the wood. If this were the case, it would be interesting to test a continuous densification method that also provides continuous contact for a prolonged period of time, such as a belt press, similar to those used in the production of MDF boards.

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