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DEVELOPMENT OF A CONTINUOUS WOOD SURFACE DENSIFICATION PROCESS – THE ROLLER PRESSING TECHNIQUE

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Abstract

The hardness of the outer areas of solid wood can be improved by surface densification, and this opens up new fields of application for low-density species. So far, surface densification relies on time- and energy-consuming batch processes, and this means that potential advantages over more expensive hardwood species or non-renewable materials are lost. Using fossil-based plastics or applying wood densification processes with a high energy consumption has adverse effects on the environment.

The purpose of this project has been to study the viability of a high-speed continuous wood surface densification process on Scots pine boards using roller-pressing equipment. Based on the process parameters used in existing research into the surface densification of wood, an experiment was conducted to study the potentials and limitations of the roller pressing approach.

Densification with a roller pressing technique resulted in a densified surface at feed speeds up to 80 m/min, but there is a complex relation between the roller pressing process parameters and the properties of the densified wood surface. Even though immediate springback was observed, the peak density increase reached up to 40%. The data indicate that a short heating time at a high temperature to soften the wood yields the best results.

Future work will continue on optimization of the densification process, and also on improving the process from an economic and an environmental perspective.

Key words**:** wood modification, compression, thermo hydro mechanical processing

Introduction

Increasing the hardness of wood by densification is not a new approach. Sixty years ago, Seborg et al. (1956) presented a heat-stabilized compressed wood product, called Staypak. The increase in hardness opens up new fields of application for low-density species, e.g. highly durable wood flooring or kitchen counters.

Staypak and other compressed wood products have in common that the level of densification is more or less constant throughout the thickness of the piece of wood, indicated by the term *'through densification'*.

Densifying only the area close to the surface of a piece of wood has several advantages over through densification: it has a higher material input efficiency from a strength perspective, similar to that of an I-beam. For some applications it can be advantageous that the undensified core has better dampening characteristics than a densified core, e.g. in flooring.

In contrast to through densification, surface densification of wood became a research topic only more recently. Even though some experiments were reported already in 1968 (Tarkow & Seborg), research on surface densification became more popular only about ten years ago (Navi & Sandberg 2012). One can say that the majority of recent research into the surface densification of solid wood originates from Aalto University in Finland. In his doctoral thesis, Rautkari (2012) explored various approaches to surface densification of solid wood. Laine (2014) focused on surface densification in a hot press, examining the effects of the process parameters on the resulting properties of the surface-densified wood.

Rautkari et al. (2010) investigated one of the crucial obstacles that prevent surface-densified wood from being a marketable product: set-recovery, the moisture- or heat-induced "swelling" of the densified wood back to its original thickness. Without additional treatment, set recovery reaches almost 100%. Gong et al. (2010) and Laine et al. (2013) showed that set-recovery can be reduced by a thermal post-treatment stage.

Even though past research offers solutions for most of the problems encountered, the major obstacle that remains is how to improve the economic viability of the surface densification process. So far, surface densification relies on time- and energy-consuming batch processes. Post-treatment stages to eliminate set-recovery work in principle, but consume a lot of time and energy. This eliminates the potential advantages over more expensive species or non-renewable materials with a higher inherent hardness, for both economic and environmental reasons. So far, continuous processes have only been investigated in other contexts, for example for a novel impregnation process (Inoue et al. 2008).

The aim of this research project is to develop a continuous wood surface densification process, which fulfills the requirements of being fast and economic, together with a low environmental impact.

This paper covers the first experimental study of the roller-pressing technique, and the influence of the process parameters on the resulting density and density profile of the densified wood samples.

Materials and Methods

The study was conducted in collaboration with the Swerea Mefos in Luleå, Sweden, who provided the roller pressing equipment and expertise regarding the roller pressing of steel and other metals.

The densification process

19 Scots pine (*Pinus sylvestris*) samples with a length of 1000 mm, a width of 40 mm and a thickness of 20 mm were compressed in the radial direction. The samples were cut from boards so that the densified surface would consist only of sapwood, and the samples were conditioned to a moisture content of 13% before the treatment started. The mean density of the samples before densification was 470 ± 100 kg/m^3.

The densification process consisted of two stages: 1) softening of the wood samples under heat, and 2) densification of the wood samples between two rollers (Fig. 1). The samples were softened between two steel plates of which one was heated in an oven to a constant temperature, in order to soften only one of the surfaces. The densification of the samples was achieved by feeding them through a pair of rollers of which one was heated (Fig. 2). The diameter of the rollers was 160 mm. The roller pressing equipment is usually used in the steel industry, which means that the forces developed during wood densification are much below the limit of the capabilities of the equipment.

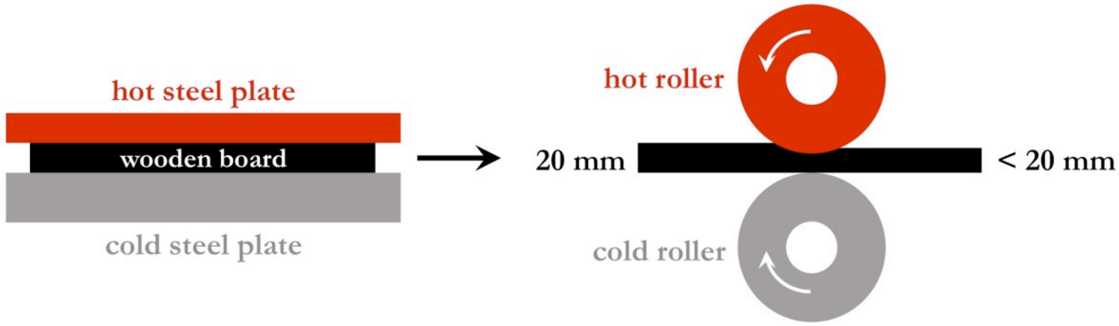

Figure 1: The roller pressing process: a) softening of one surface of the wood between one hot and one cold steel plate (left), and b) densification between one heated and one cold roller (right).

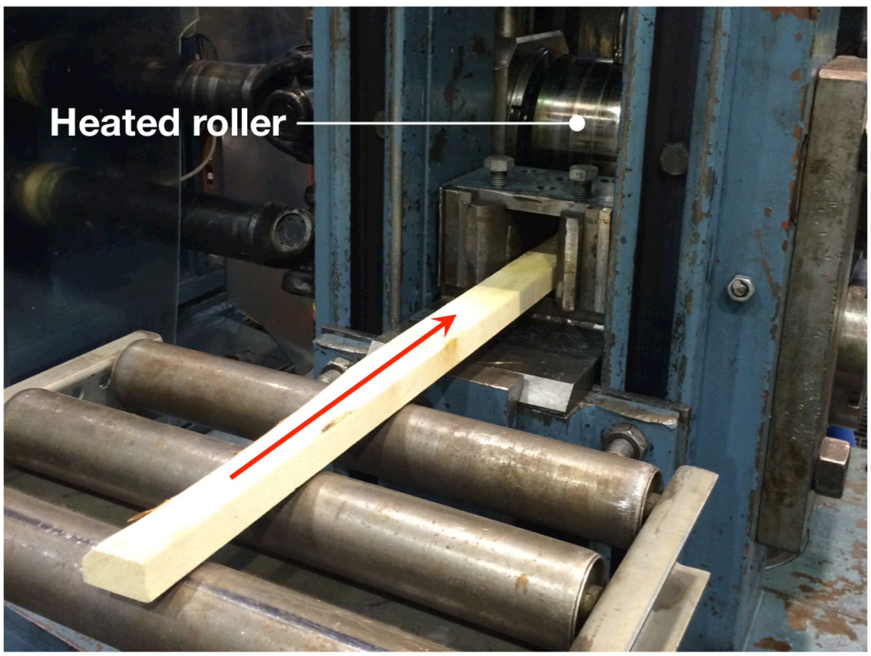

Figure 2: The roller pressing equipment. The upper roller was heated. The lower roller is not visible in the photograph.

Table 1 shows the process parameters used in the test. The temperatures of the heated steel plate and the heated roller were determined with a pyrometer.

The heating time and temperature of the steel plate, and the targeted thickness reduction under compression were based on the results reported by Rautkari et al. (2011). For the first sample, a low feed speed was chosen, and the feed speed was thereafter increased stepwise in order to test the limits of the process.

Table 1: Sample overview and process parameters.

Pre-heating	Densification process

Sample No.	$T_{steel\ plate}$ [°C]	Heating time [s]	$T_{heated\ roller}$ [°C]	Feed speed [m/min]	Target thickness reduction [mm]
1	180	90	140	0.083	5
2	180	90	140	0.8	5
3	180	90	140	8	5
4	180	90	140	80	5
5	180	90	140	80	5
6	130	90	140	80	5
7	130	90	150	20	5
8	130	90	150	20	5
9	140	90	150	20	5
10	150	180	50	20	5
11	190	180	50	20	5
12	180	90	45	20	5
13	170	90	45	20	5
14	180	90	130	20	5
15	175	90	130	20	1
16	170	90	170	20	2
17	160	90	145	20	3
18	20	0	140	20	3
19	20	0	130	20	3

Determination of the sample thickness, density and density profile

The density and density profile of all samples were measured before and after densification with an X-ray computer-tomography (CT) scanner. Cross-sectional CT images were taken every 100 mm in the length direction of the samples, evenly distributed over the length of each sample. The image processing software ImageJ was used to extract density values and density profiles from the CT images. The density profiles were measured through the center of the cross-sectional images (Fig. 3).

The grey scale data were calibrated and expressed in kg/m^3 in the range from 0 to 1000 kg/m^3. The density calibration was achieved with the aid of the known density of air and water (Kalender 2011). Light grey areas indicate high-density values, and dark grey areas indicate low-density values.

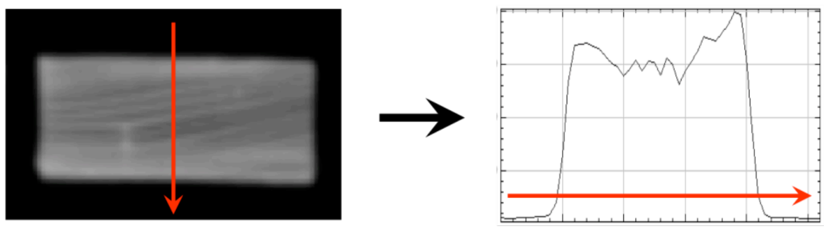

Figure 1: Principle of measurement of the density profile. The density profile is measured through the centre of the cross-sectional CT images. The lighter areas in the CT image indicate a higher density than the darker areas.

Results and Discussion

To explore the possibilities of a continuous wood surface densification process, various process parameters were tested with regard to their influence on the resulting sample density and density profile. The goal was to obtain density profiles with a pronounced peak close to the heated surface.

It was not possible to detect significant interactions between the heating temperatures during softening and densification and the resulting density profile. For example, the data do not show whether a pre-heating temperature of 180°C and a roller temperature of 140°C provided a better result than a pre-heating temperature of 130°C and a roller temperature of 150°C. The data do show however that if heat is not applied in either the softening or the densification stage, an undesired density profile is obtained.

Figure 4 shows that the feed speed has only a small influence on the density profile, with a slightly less pronounced density peak at a feed speed of 80 m/min. A feed speed of 20 m/min was found to be a good compromise between process speed and resulting density profile.

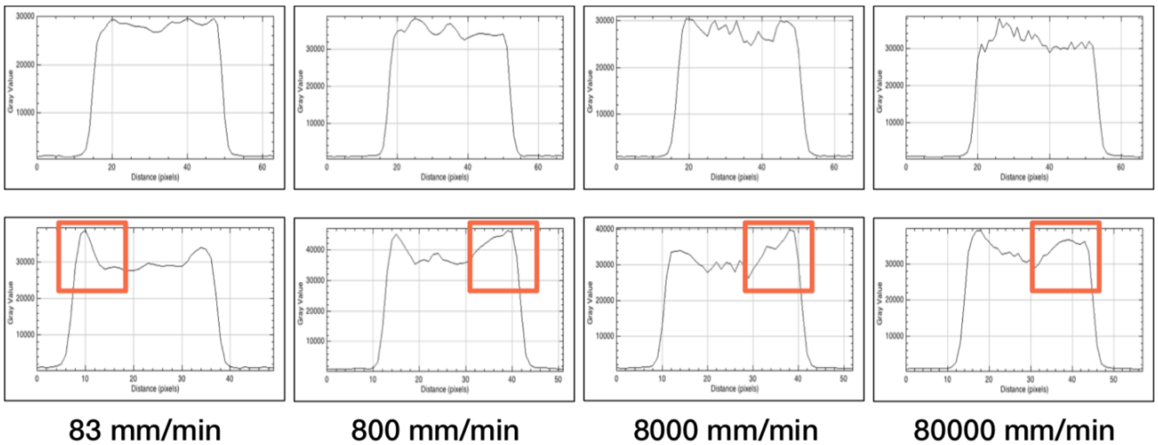

Figure 2: Influence of feed speed on the density profiles. Sample numbers from left to right are 1, 2, 3, and 4. The upper row of images shows the density profile before densification. The lower row of images shows the same samples after densification. The values on the axes in each graph are not meant to be read. The squares show the increased density of the softened wood cells of the samples.

A heating time of 180 s led to density profiles with less pronounced peaks than a heating time of 90 s. With a longer heating time, the samples were probably softened too deep into the core, resulting in a flatter density profile. This result is in agreement with the findings of Rautkari et al. (2011). The results suggest that a short but intense softening stage will yield the best results.

Calculating the densities from the CT images at various locations within each cross-sectional image revealed that the core of the samples with a pronounced density peak was not compressed at all. The average peak density increase in these samples was between 25% and 40%. Taking into consideration an immediate spring-back of approximately 50%, which can probably be avoided by an additional cooling stage, the potential for a strong increase in density is high.

Conclusions

The purpose of this project was to study the viability of a high-speed continuous wood surface densification process on Scots pine boards using roller-pressing equipment. It was shown that the roller-pressing approach works, even though it was not possible to clearly relate the outcome to the heating temperatures. However, the results suggest that the softening/heating time should be rather short, with a high heating temperature rather than a low heating temperature.

The feed speed only has a small influence on the resulting density profile. Even at high speeds, which are required to achieve an economically viable process, the roller pressing approach resulted in a clear density increase close to the surface and an undensified core.

Now that the promising potential of densifying the surface of solid wood with roller pressing equipment has been shown, further tests will focus on introducing a more controlled softening stage and on introducing a subsequent cooling stage. Perhaps the most crucial issue to tackle in the future will however be the elimination of the set-recovery in as fast a way as the actual densification process.

Acknowledgement

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