Further Treatment Option after Longitudinal Wood Compression

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ABSTRACT

The longitudinal compression is an eco-friendly wood modification treatment, which makes the wood lastingly bendable. Right after the compression process, the compression ratio can be kept for a predetermined time (relaxation). Both increasing compression ratio and increasing relaxation time causes the wood to become more flexible. By the treatment the modulus of elasticity decreases, the deflection at maximum load increases and the needed bending force decreases. Different relaxation times were tested, and it has been proven that after 1 minute of relaxation, the property changes slow down but do not cease. Relaxation time can be up to a daylong and this produces very different properties with at least 6 times higher maximum deflection during 4 point bending tests, compared to the control samples, still without breaking. The treatment produces 3-6 times greater shrinkage in the longitudinal direction during the drying process, depending on the relaxation time. The new properties of the wood can be explained by cell wall deformations.

INTRODUCTION

The longitudinal compression of wood is a combined thermo-hydro-mechanical treatment, also known as pleating (Báder and Németh 2018). By longitudinal compression the bending modulus of elasticity (*MoE*) and the required bending force decrease dramatically and provide great flexibility to the wood (Báder and Németh 2017, Kuzsella 2011). These property changes of the wood can be explained by cell wall deformations (Kollmann 1951, Sandberg and Navi 2007). The wood will bend more easily and in smaller radii compared to steam bending, even when it is cold. Thus, there can be found some innovative, high added value of the bent wood. The products are mostly used in furniture industry for example as chairs and skirting, furniture rim, mattress coil springs. It can be also used in interior design as wooden handrails, coat hooks, applied arts, etc. (Báder 2015). Other applications are also possible, e.g. vibration dampening tool shafts, car panels, wood toys, medical aids, etc. (Báder 2015). In areas where corners have to be avoided, it can be an excellent raw material for product design, for example, ship and aircraft furniture (Vorreiter 1949, Báder 2015).
The procedure (like the Thonet-method) requires high quality hardwood material. Before compression, the wood has to be plasticized by steaming (Ivánovics 2006, Sandberg and Navi 2007). The sample is usually compressed by 20% compared to its original length. Following the method, the specimen is wet at the beginning, and as long as the moisture content is high, it can be bent more easily (Báder and Németh 2017). The compressed

materials are ready to use immediately after the treatment, but they can be also stored, preferably in foil at cold temperatures.

EXPERIMENTAL

The raw material was Sessile Oak (*Quercus petraea* (Matt.) Liebl.), from the Sopron region, Hungary. The dimensions of the samples were 20×20×200 mm (Radial × Tangential × Longitudinal). We used steaming at atmospheric pressure in saturated atmosphere. After steaming, the samples were longitudinally compressed, while the temperature was kept at 90 °C to 100 °C degrees. Longitudinal compression can be achieved as the workpiece is kept straight during the compression process, through supports on the sides. The device is developed to operate in an Instron 4208 (Instron Corporation, USA) universal material testing machine. All samples were compressed by 20% compared to their original lengths, at a rate of 30 $mm \cdot min^{-1}$. After compression, the 20% compression ratio was kept for a predetermined time, allowing the wood to undergo viscoelastic relaxation. During relaxation, the force required to keep the sample in compressed state decreased (Báder and Németh 2018). All relaxations were made in the laboratory compression chamber (Table 1).

Table 1: Test methods and labelling of oak samples.

Marking	Pieces	Sample marking explanation
OC	20	Control
OSC	20	Steamed Control
O0m	20	Compressed without relaxation
O1m	20	Compressed with 1 minute of relaxation
OLm	3	Compressed with a long-time relaxation (averagely 900 minutes)

At the OLm samples the heating was switched off during the relaxation. In this case, the compression device cooled down with the sample, and thus the moisture loss was eliminated. After treatment, the samples were dried at a temperature of 40 °C for 48 hours, then conditioned at 20°C and 65% relative humidity (*RH*) until a constant weight was reached.

Based on the method described by Báder and Németh (2017), the height of the samples (*h*) was 12.5 mm, and the width (*b*) was left the original size. An Instron 4208 material testing machine was used for 4 point bending tests. The loading rate was 20 mm/min, except for control samples (8 mm/min), according to the Hungarian standard MSZ 6786-5 (2004). Tests were stopped when the load dropped with no recovery. The determination of the *MoE* comes from the work of Báder and Németh (2017), using the loading span displacement (Δw) corresponding to the difference between the 10% and the 25% of the maximum load (ΔF) (Eqn. 1).

$$MoE=(\Delta F \cdot a^2 \cdot (3 \cdot L-4 \cdot a))/(b \cdot h^3 \cdot \Delta w) \quad (1)$$

where *a* is the distance between the loading span and the nearest support span (50 mm), and *L* is the distance of the support spans. The maximum deflection of the sample (y_{max}) came from Eqn. 2, based on Báder and Németh (2017).

$$y_{max}=1.1563\cdot(w\cdot(3\cdot L^2-4\cdot a^2))/(4\cdot a\cdot(3\cdot L-4\cdot a))-0.7345 \quad (2)$$

where *w* is the highest displacement of the loading span till the fracture of the sample. Eqn. 2 is applicable for materials with high bendability.

RESULTS AND DISCUSSION

Mechanical changes

The *MoE* for the control samples averaged 10.0 GPa and the stress change at 5 mm load span displacement for the control samples averaged 100.0 MPa. The results of the longitudinal compression and short-time relaxation are shown in Figure 1.

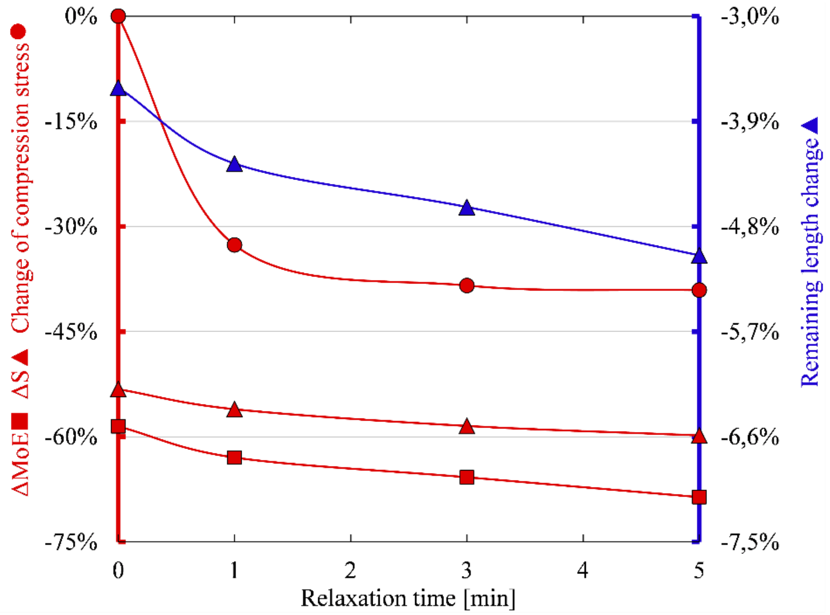

Figure 1: Change of the mechanical and physical properties after compression with the increasing relaxation time. Abbreviations: ΔMoE - change of Modulus of Elasticity; ΔS. - Stress change at 5 mm load span displacement.

The differences between the mechanical properties of control and steamed control samples are negligible so it is not necessary to discuss them separately. The stress at 5 mm load span displacement shows us the first advantage of the pleating method. It decreased to half or less by the treatment (Figure 1). The longitudinal compression resulted in a decrease of *MoE* with 59.0%. While the deflection of control samples averaged 9.3 mm till the break, both compressed and short-time relaxed samples had at least 3 times higher deflection (Figure 2a), and almost the same force needed for the bending process. Furthermore, with a large increase of relaxation time (*OLm* samples) the deflection ability increased so much that the samples did not break during the bending tests. The high deflections mean high bendability, which is the most important property for utilization of this material (Figure 2a). For *OLm* samples the maximum deflection is at least 6 times higher than in case of control samples.
The point of the maximum force and the break move away from each other with the increasing relaxation time. This indicates an increasing ductility due to increased relaxation time. The deformability has a strong inverse correlation with *MoE* (Ashby and Jones 2003). Figure 2b represents the change of the *MoE*. The slope at the beginning of

each graph decreases with the increased relaxation time. At the greatest force peaky graphs can be observed on Figure 2b for the control samples. These peaks gradually become rounded both by compression and increasing relaxation time. Finally, *OLm* samples can undergo significant plastic deformation before fracturing: they show ductile properties (Hayden et al. 1965), as also represented in Figure 2c. All these changed properties led to a new material with the major advantage of easy bendability.

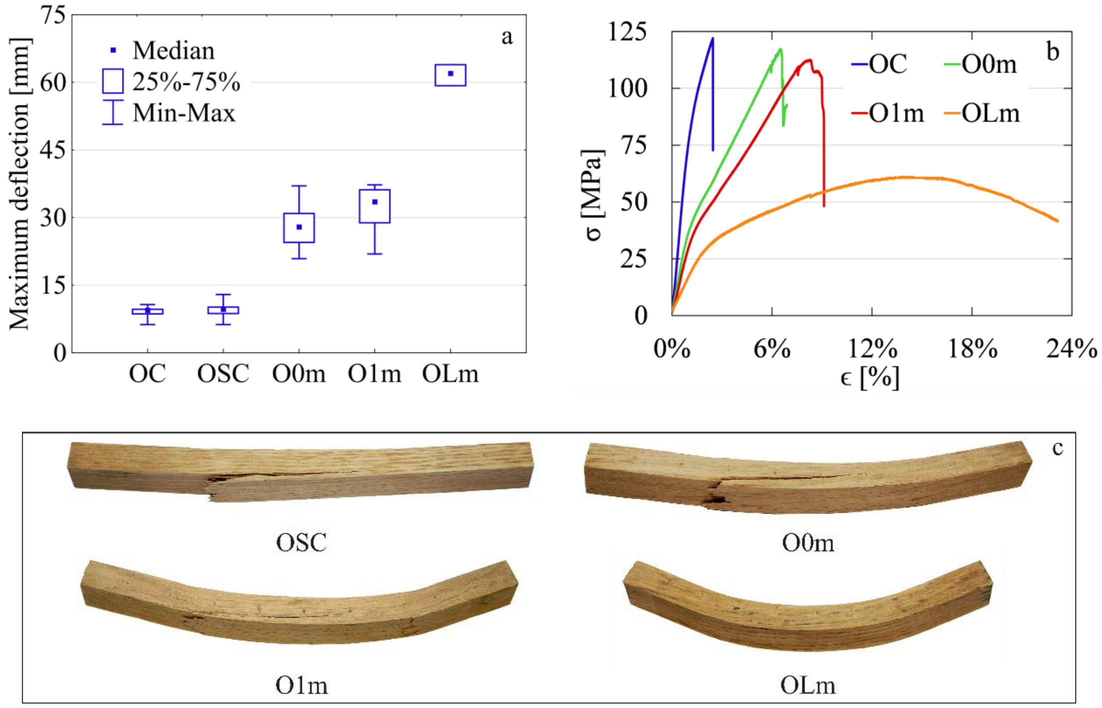

Figure 2: The maximum deflections during 4 point bending test (a), typical Relative deformation – Bending stress graphs for the different treatments (b) and images of crack patterns for different modification methods (c). Abbreviations: OC-control sample; OSC-steamed control sample; O0m, O1m - longitudinally compressed samples with 0 and 1 minute of relaxation time; OLm - compressed and long-time relaxed sample.

Physical changes

The remaining shortening after pleating represents the resistance of wood against the compression, and the remaining shortening is proportional with the force needed to bend the wood (Segesdy 2003). The length change after drying to 0% moisture content was calculated from the difference of length changes under wet and normal conditions. After longitudinal compression, shrinkage is 3 times higher during the drying (Figure 3a). The relaxation process increases the shrinkage too, from 0.51% to 0.68% in the first minute. With the long-time relaxed samples, the shortening amounts to 0.94% during drying. Compared to control samples, this means about 6 times higher shrinkage. The explanation of this phenomenon can be due to the curved cell walls, because this way a part of the far greater transverse shrinkage is added to the longitudinal shrinkage. This is also evidenced by the remaining length change after the treatment (Figure 3b).

Optimal relaxation time

Analyzing the change of compression stress during relaxation, in the first 2 seconds, the compression stress falls by 12.1%. In the next 2 seconds, the compression stress falls by

4.7%, then only by 3.1% and by 2.4%, and so on, compared to the starting value. After 1 minute relaxation time, the changes slow down considerably. If we are looking for the optimal relaxation time based on the mechanical changes, 1 minute relaxation is suggested. After 1 minute relaxation time, the maximum deflection increases to 110% compared to the compressed wood without relaxation, and to 353% compared to the control samples, in accordance with the decrease of *MoE* (89.3% and 37.0%, respectively). Bending stress at 5 mm load span displacement decrease to 43.9% by longitudinal compression and 1 minute relaxation time, compared to the control samples (Figure 1). Of course, to meet individual demands, longer relaxation times can be chosen. A higher compression ratio (Buchter et al. 1993) or a long-time relaxation is needed to further enhance the deflection, but this results in a very slow process both for industrial and laboratorial production. However, maximum deflection increases a lot, just as shrinkage increases during the drying process.

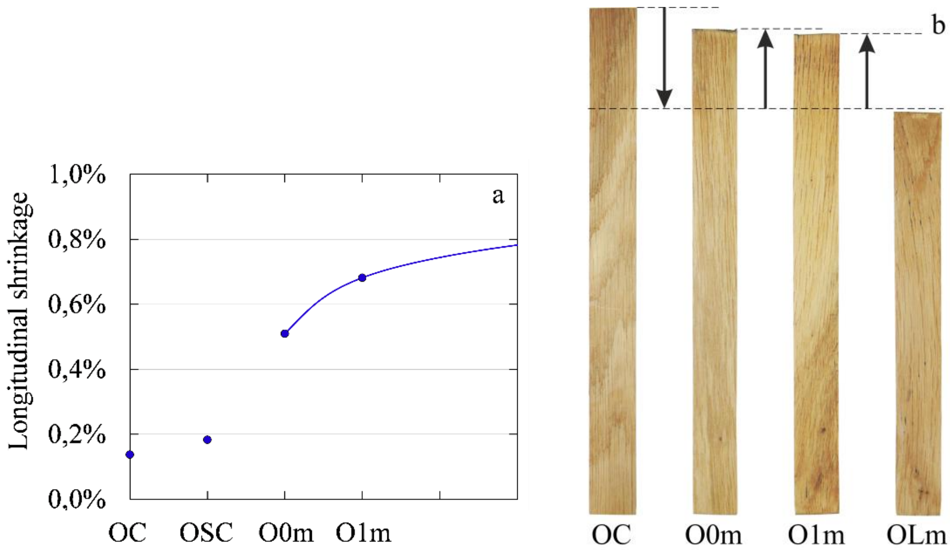

Figure 3: Length change during the drying process, depending on the relaxation time (a) and remaining shortening of the samples after different treatments (b). Abbreviations: OC - control sample; OSC - steamed control sample; O0m, O1m - longitudinally compressed samples with 0 and 1 minutes of relaxation time.

CONCLUSIONS

This study was performed to determine some mechanical properties such as *MoE* and some physical properties such as deflection of the longitudinally compressed Sessile Oak, produced with different relaxation times.

Higher compression stress reduction during relaxation means greater remaining shortening of the material, and these are indicators of higher deflection ability and higher relative deformation, and lower *MoE*. Furthermore, pleating produces 3-6 times greater shrinkage in the longitudinal direction during the drying process, depending on relaxation time.

Different relaxation times were tested, and it has been proven that after 1 minute relaxation time, the change of the material properties slows down extremely, so the generally recommended relaxation time is 1 minute as an ideal combination of economic relaxation time and increasing of bendability. This results in an increase in maximum deflection during 4 point bending tests to 353%, and in a decrease to 37% in *MoE* and to 44% in bending stress at 5 mm load span displacement, compared to the control samples.

To meet special requirements for the product, both the compression ratio and the relaxation time can be changed. A long relaxation time results in a wood material with plastic properties with a 6 times higher deflection compared to the compressed samples without relaxation, still without breaking, but this slows down the production and increases its costs.

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