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Preparation of pleated oak samples and their bending tests at different moisture contents

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ABSTRACT

This study presents the steps and results of the longitudinal compression modification process (aka. pleating) and bending tests of sessile oak (*Quercus petraea* (Matt.) Liebl.) wood. Bending tests were done to determine properties under different moisture conditions. The stress values during compression of the specimens were nearly identical, attributed to proper pre-selection of the specimens. However, significant differences were observed during bending tests. The results of the three samples (pleated and conditioned to 12% moisture content (*MC*), pleated and frozen with *MC* above fibre saturation point (*FSP*), and untreated-conditioned to 12% *MC* showed significant discrepancies. Regarding modulus of rupture (*MoR*), the average values were averagely 103.20 MPa for the pleated samples conditioned to 12% *MC*, 63.26 MPa for the frozen samples, and 136.80 MPa for the untreated sample conditioned to 12% *MC*. In terms of modulus of elasticity (*MoE*), the average values were averagely 4.02 GPa, 1.42 GPa and 12.25 GPa, respectively. These results suggest that samples with higher *MC* can withstand less load but are significantly more flexible, whereas samples with lower *MC* can withstand greater load but are stiffer. We hope these findings can contribute to better decision-making regarding future wood utilization practices.

INTRODUCION

A purpose of longitudinally compression (or pleating) timber is to make it more flexible and pliable. Treating wood as an inhomogeneous fibre-reinforced composite, post-plasticization, and pleated it along the fibre axis result in compression. This process makes the timber more bendable with less force. Steam bending of wood was first utilized by Michael Thonet in the 1800s for mass production under industrial conditions. In Thonet's method, wood must be immediately shaped after steaming before it cools. In contrast, the advantage of longitudinal compression technology is that the treated timber can be stored and remains bendable at room temperature. Hardwood species with higher density (such as oak, beech, ash, maple) have been found to be compressible along the fibre direction. High-quality raw material is essential, as seemingly insignificant failures in the wood can often pose significant problems. Key factors determining the production of quality compressed timber include wood species, quality of raw material, *MC*, temperature, compression direction, and others. Most hardwood species with initial *MC* above 20% can be compressed. During the typically steam-plasticized longitudinal compression process, it's necessary to support the wood to prevent lateral deflection and reduce friction forces that inhibit uniform compression along the fibres. As a result of longitudinal pressing, changes occur in the cell structure of the wood, which has been softened by hydrothermal treatment and kept at a temperature of at least 80°C. The middle layer, mainly composed of lignin and hemicellulose, allows the high cellulose content, solidifying fibres, and other tissues to slide relative to each other, while the cell walls of these longitudinally oriented elongated elements become wrinkled (Figure 1). As a result of the process, the bending modulus of elasticity *MoE* the wood decreases, making it significantly more bendable compared to untreated wood (Báder 2015; Báder et al. 2017).

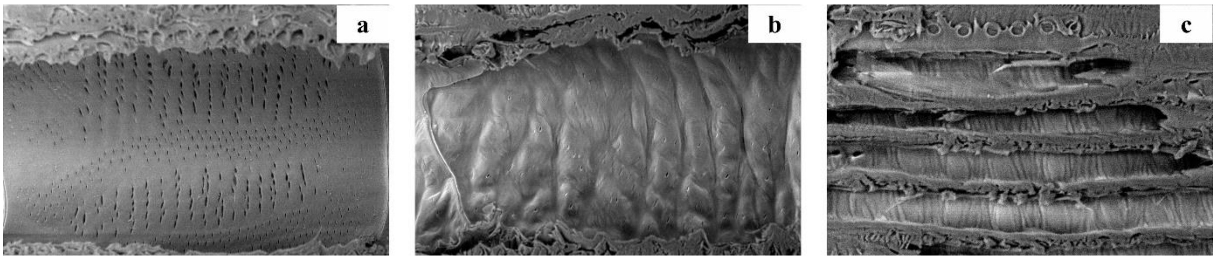

Figure 1: Changes in vessels and fibres during compression: Untreated vessels (a), pleated vessels (b) pleated fibres (c)(based on Báder and Németh 2018)

Wood contain water in two states: free water and bound water. Free water exists in the wood as liquid or vapor and has a significant impact on the wood's mass and density, particularly when the *MC* exceeds 30%. However, it does not affect the wood's shape or size changes. The removal of bound water begins only after the evaporation of free water. The point at which there is no free water left in the cell structure of the wood is called the *FSP*. While the value of the *FSP* depends on the wood species, generally, the portion of wood *MC* below 30% is considered bound water, and the *MC* threshold of 30% is referred to as the *FSP* (Fainfo.hu 2023).
Our study aims to demonstrate the changes that wood undergoes solely due to variations in *MC*. We primarily examined these changes through mechanical means. During our research, we were particularly interested in understanding the differences in load-bearing capacity and other mechanical properties of wood material in response to changes in *MC*. Moisture content in wood significantly influences the construction industry, as the load-bearing capacity of wood varies considerably with changes in *MC*.

MATERIALS AND METHODS

As a first step, we selected 10-10-10 pieces of suitable, 20×30×200 mm (thickness × width × length) dimensioned sessile oak (*Quercus petraea* (Matt.) Liebl.) specimens for each sample. Care was taken to ensure that the wood was free from failures, as these would have led to inaccuracies in the measurements. Examples of such failures include diagonal grain deviation, knots, cracks, etc. Subsequently, the specimens were numbered for tracking purposes (Figure 2), followed by the pleating of the wood. The pleating was performed using an INSTRON 4208 material testing machine (INSTRON Corp., USA). Prior to compression, the samples were steamed for 45 minutes at 100 °C. Compression was carried out by an equipment at a rate of 25%, then the specimens were kept compressed for 1 minute. After pleating, if the specimens had bent, they were manually straightened. Once pleating was complete, the specimens were cut in half, preparing them for bending test. The longitudinal dimensions of the pleated samples were on average 193.12 mm ± 0.71 mm. Thickness and width dimensions remained unchanged (20x11 mm), except for the untreated sample sample conditioned to 12% *MC*. Subsequently, the samples were conditioned. The sample with *MC* above *FSP* was stored in a freezer to maintain its green state, while the sample conditioned to 12% *MC* was stored in a climate chamber at 20 °C and 65% relative humidity until its weight stabilized. 4-point bending tests were also done on the INSTRON 4208 material testing machine. The specimens protruded at least 2-2 cm on both sides of the support span rollers. The support span was set to 140 mm, while the distance between the loading rollers was 50 mm. Bending tests were conducted at a rate of 16 mm/min for pleated specimens and at a rate of 8 mm/min for untreated specimens, with 10 specimens per sample. This was necessary to comply with the requirements of both EN 408: 2010 + A1 (2012) and ISO 13061-03 (2014) standards, which require a bending tests time between 1 and 5 minutes. Prior to each test, width and thickness parameters were measured at the centre of the sample. Upon completion of the bending tests, our subsequent task involved comparing and evaluating the collected data. Conclusions drawn from the measurements mainly involved the average results and relative deviances of the maximum compressive stress and the length of the samples after pleating.

Figure 2: Storage of the specimens in the climate room

RESULTS AND DISCUSSION

During pleating, the results of the specimens did not show significant differences. This indicated that we had performed appropriate raw material selection before pleating, ensuring that the specimens were similar anatomically and physically. With this in mind, we could state that the differences in the results obtained from the bending tests were not due to the wood itself but rather to differences in *MC* within the wood. The average *MoR* was 136.80 MPa for the sample conditioned to 12% *MC*. In comparison, the pleated sample conditioned to 12% *MC* showed 24.6% lower *MoR*, while the pleated sample frozen above *FSP* was 53.8% lower (Figure 3). We attribute the observed changes in the measurements to lignin and hemicellulose in the wood, as they behave more plastically with higher *MC* in the wood. Another reason could be that the pleated specimens were much more flexible. The average values of the *MoE* were 12.25 GPa for the untreated sample, 4.02 GPa for the pleated and conditioned sample, and only 1.42 GPa for the pleated and frozen sample. The relative deviances were under 20% in all cases. The results of these tests indicate that the higher the *MC* of the wood, the lower its *MoE*, which is in agreement with the literature. Therefore, the higher *MC* of the wood, the more pliable it becomes. Lower *MoE* of the wood exhibits more plastic properties. Our sample with high *MC* and consequently low *MoE* suffered less, or almost no damage during the bending test. During pleating, the average values of maximum compressive stress were 19.41 MPa for the pleated and conditioned sample and 21.03 MPa for the pleated and frozen sample. The relative deviations were 7.3% and 7.1%.

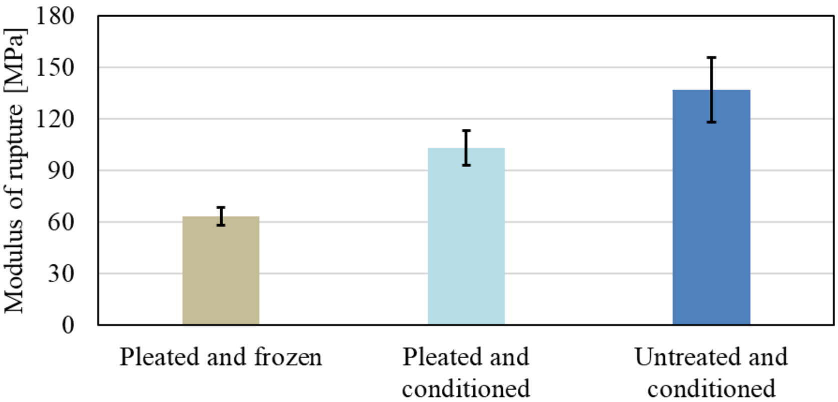

Figure 3: Modulus of rupture of the samples. The frozen sample had a moisture content above fibre saturation point, while the other two samples were conditioned to 12% moisture content

Pleating altered the cell structure of the specimens, resulting in lower *MoR* compared to untreated sample. On average, the *MoE* of sessile oak is ~10.5 GPa (Meier 2023), which may change depending on the provenance. In our case, for untreated sample, the average result was 12.25 GPa, with a relative deviance of 12.8%. However, difference was not only found in *MoE*. The bending stress measured at 4 mm deflection was 114.98 MPa for the untreated sample, 40.69 MPa for pleated and conditioned sample, and 18.60 MPa for pleated and frozen sample. The relative deviations were 12.42 MPa, 4.67 MPa and 1.46 MPa, respectively. The average deflection at maximum force was 7.51 mm, 28.45 mm and 32.54 mm with relative deviations of 11.9%, 9.5% and 7.9%, respectively. At maximum deflection, we observed that the results of the pleated samples were almost identical, with a great increase compared to the untreated sample. The maximum deflections were 7.80 mm, 35.70 mm and 35.95 mm with relative deviances of 12.2%, 20.9% and 7.3%, respectively. The maximum deflection was averagely 25.5% higher for pleated samples than their deflection at the maximum force. Here it is also evident that the wood of the pleated samples was more flexible and could withstand less load. Thus, if we want to bend two specimens with different *MC* with the same amount of force, the specimen with the higher *MC* would be easier to bend.

CONCLUSIONS

During our research, we were able to obtain numerous data from the results of untreated sample conditioned to 12% moisture content (*MC*), pleated sample conditioned to 12% *MC*, and pleated sample frozen above *FSP*. The results obtained from pleating demonstrated that the wood of the samples was available to be the post-modification tests comparable. This means that any differences in the bending test results could be attributed to the different *MC*s. The data obtained from the bending tests showed significant differences. For the untreated sample, the average modulus of rupture was 136.80 MPa, for the pleated and conditioned samples it was 103.20 MPa, and for the pleated and frozen samples was 63.26 MPa. The higher the water content in the wood, the less load it could withstand, but its plastic properties changed inversely. These changes between the samples are caused by the lignin and hemicellulose in the wood, as they behave more plastic in the presence of water. The modulus of elasticities for the samples were 12.25 GPa, 4.02 GPa, and only 1.42 GPa, respectively. After bending test, the specimens with higher *MC* typically intended to return to their initial shape, thereby reducing the bending induced in the wood by the test. Overall, our research demonstrated that pleating can significantly reduce the modulus of elasticity of wood, thereby enhancing its plastic characteristics.

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