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Determination of the compressive strength parallel to the grain of resinous yellow pine heartwood

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Abstract: *Determination of the compressive strength parallel to the grain of resinous yellow pine heartwood*. The compressive strength parallel to the grain of resinous yellow pine heartwood was determined as a part of this study. The interdependencies between the load and deflection of yellow pine under compression test were established. The average density of resinous yellow pine wood in an air-dry condition was 855 ± 10 kg/m^3 and it was 30% greater than the density of non-resinous yellow pine wood. Despite a considerable increase in density, which was due to the saturation of wood with resin, a 4% decrease in the compressive strength parallel to the grain of yellow pine heartwood was recorded and the differences were statistically significant. The load-deflection curves of yellow pine wood showed a similar direction of changes for resinous and non-resinous heartwood. Nevertheless, significant differences in the deflection values between resinous and non-resinous yellow pine heartwood were demonstrated, depending on the load.

***Key words*:** compressive strength parallel to the grain, density, deflection, load, resin, resinosis, yellow pine

INTRODUCTION

Yellow pine (*Pinus ponderosa* Douglas ex C. Lawson) is the most common pine species in North America. In the countries where it is harvested, yellow pine wood has similar uses as Scots pine wood (*Pinus sylvestris* L.). Yellow pine is the most commercially valuable and productive timber tree used for the production of boards or cabinets or for construction products moulding (Thieret 1993).

One of the most common wood defects in the case of coniferous species is saturation with resin, known as resinosis. Resinosis occurs near wounds caused by mechanical damage and may also be an effect of a tree being attacked by fungi. The extraction of resin from a tree also results in resin accumulating in the cells at the resin blaze area. Resinosis near a resin blaze area is, however, removed in the process of obtaining edged sawn wood and does not hinder further woodworking.

Resinosis predetermines physical, mechanical, technological and functional wood characteristics (Cown et al. 2011). An effect of resinosis is a change in colour, an increase in density, and the improvement of the biological resistance of wood (Ruel et al. 1998). García - Iruela et al. (2016) stated that resin produced by tapping decreased swelling, probably by reducing accessibility to the –OH groups and decreasing the available spaces during the capillary condensation phase. Resinosis also significantly affects the mechanical properties of wood. It makes drying and impregnating processes, mechanical working (sawing, planing, circumferential peeling), gluing and wood surface finishing difficult. In many cases resinosis is a defect which eliminates such wood from use or results in the need to apply additional technological operations.

The compressive strength parallel to the grain is a property frequently defined when describing the characteristics of wood (Wagenführ 2007, ISO 13061-17:2017). The following are the primary factors contributing to the compressive strength of wood: anatomical structure, early- and latewood share, moisture content, type and layout of knots or other defects (slope of grain) and flaws (Green et al. 2007, Rocha et al. 2018). In determination processes, the influence of the chemical structure (cellulose and lignin) is usually ignored, and so is the influence of non-structural compounds (resin).

The aim of the study was to determine the compressive strength parallel to the grain of resinous yellow pine (*Pinus ponderosa* Douglas ex C. Lawson) and comparing the data with the values obtained for non-resinous yellow pine.

MATERIAL AND METHOD

Samples of yellow pine heartwood (*Pinus ponderosa* Douglas ex C. Lawson) coming from the USA were used for the study. The moisture content of the wood was determined in accordance with ISO 13061-1 (2014). Once the samples were brought to an air-dry condition, the density of the yellow pine wood was determined using the stereometric method as required under ISO 13061-2 (2014).

Microscopic preparations of resinous yellow pine wood were made. 15–20 μm thick preparations were cut from plasticised wood soaked in a solution of water, alcohol and glycerine (1:1:1) with the use of a microtome. The preparations were tinted with safranine. Photographs showing three basic anatomical sections were taken using an Olympus BX41 (Olympus Corporation, Tokyo, Japan) microscope coupled with a digital camera and the Cell*B software.

Tests of the compressive strength parallel to the grain (CS) of yellow pine were carried out in accordance with ISO 13061-17 (2017). The tests of the compressive strength parallel to the grain were carried out by using a computer programme coupled with an Instron® testing machine, model 3382 (Norwood, USA). The wood properties were determined for 60 samples of resinous and non-resinous yellow pine heartwood.

A statistical analysis was performed using the STATISTICA version-12 software of StatSoft, Inc. (Tulsa, USA). The statistical analysis of the results based on the t-test was carried out at a significance level of 0.05.

RESULTS AND DISCUSSION

The microscopic pictures of resinous yellow pine heartwood are presented in Figure 1. Numerous vertical and horizontal resin canals with local resin accumulations could be seen.

a) b) c)

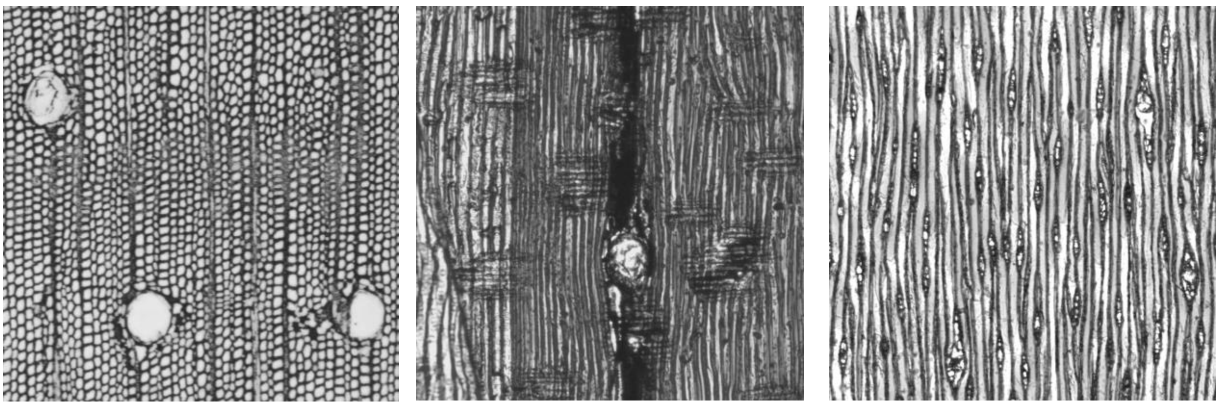

Figure 1. Transverse (a), radial (b) and tangential (c) section of resinous yellow pine heartwood

The average density of non-resinous yellow pine was 656 ± 9 kg/m^3. The compressive strength parallel to the grain was 70 ± 8 MPa (Tab. 1). As can be seen from data available in literature, the average density of yellow pine wood with a moisture content of 12–15% ranges from 340 to 500 kg/m^3, whereas its compressive strength parallel to the grain ranges from 28 to 43 MPa (Wagenführ 2007). Much lower literature values are due to the fact that they presumably refer to the averaged sapwood and heartwood values for yellow pine, whereas the subject of the study was yellow pine heartwood. These differences may be due to a number of other factors e.g. anatomical structure, annual ring width, share of latewood (Glass and Zelinka 2010).

Table 1. Selected properties of resinous and non-resinous yellow pine heartwood

Yellow pine heartwood	Properties			
	density (kg/m^3)			
	mean	min	max	std. dev.
non-resinous	656	516	895	9
resinous	855	657	976	10
	compressive strength parallel to the grain (MPa)			
non-resinous	70	51	82	8
resinous	67	62	76	3

Generally, it can be concluded that the average density of resinous yellow pine heartwood in an air-dry condition (with the determined moisture content of 8–10%) was 30% higher than the density of non-resinous yellow pine wood. The compressive strength parallel to the grain of resinous yellow pine heartwood was 4% lower than the compressive strength parallel to the grain of non-resinous yellow pine heartwood and the differences were statistically significant ($p < 0.050$). Despite a considerable increase in density which was due to the saturation of wood with resin, a decrease in the compressive strength parallel to the grain of yellow pine heartwood was recorded. This leads to the conclusion that the presence of resin in yellow pine wood has a negative impact on compressive strength parallel to the grain. Opposite interdependencies were demonstrated by García - Iruela et al. (2016) when examining *Pinus pinaster Ait* wood.

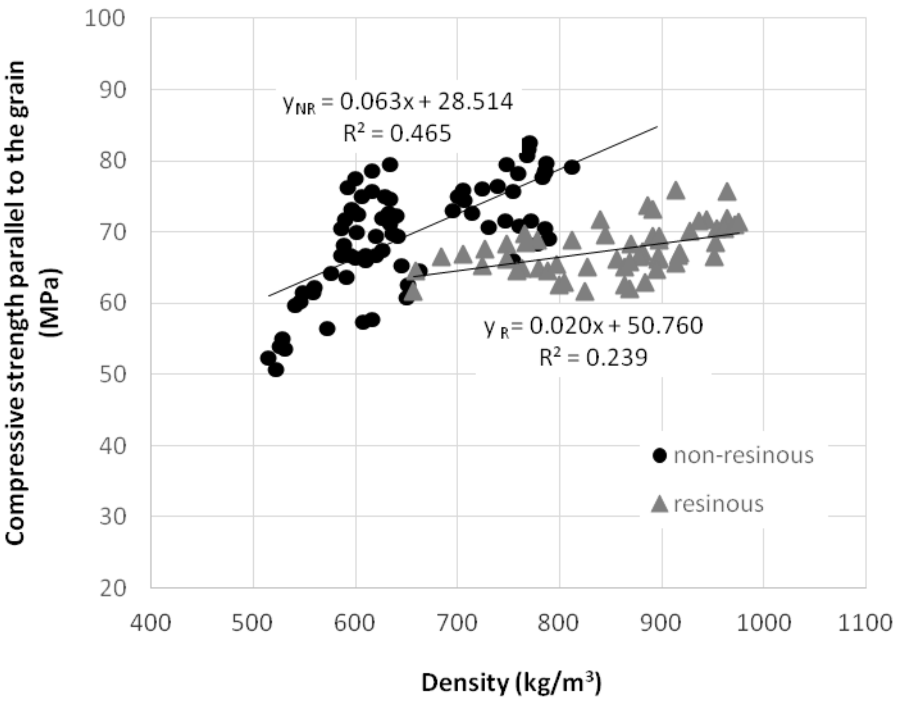

Figure 2. Compressive strength parallel to the grain of resinous and non-resinous yellow pine heartwood

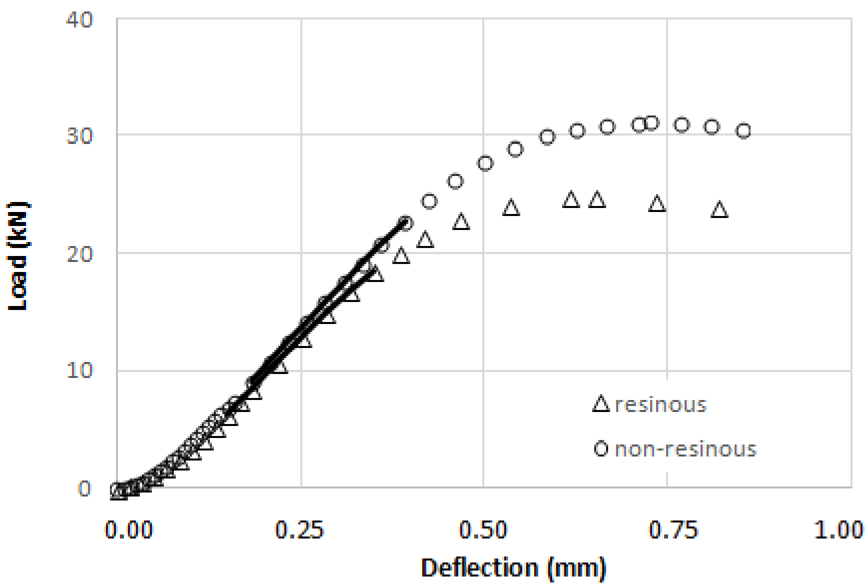

Figure 3. Load-deflection curve of yellow pine wood under compression test

The interdependencies between compressive strength parallel to the grain and density are described by the y_{NR} formula for non-resinous yellow pine wood and the y_R formula for resinous yellow pine wood (Fig. 2). The R^2 values were relatively low, reaching 0.465 and 0.239, respectively. The load-deflection curves of yellow pine wood showed a similar direction of changes for resinous and non-resinous heartwood (Fig. 3). Nevertheless, significant differences were noted in deflection changes under the influence of load, depending on whether it was non-resinous or resinous heartwood. For example, for non-resinous yellow pine heartwood, with a maximum load of 30 kN, deflection was ca. 0.85 mm. For resinous yellow pine heartwood, on the other hand, with a maximum load of 25 kN, deflection was ca. 0.80 mm. It is worth noting that in the case of non-resinous yellow pine heartwood, with a load of 25 kN, deflection was ca. 0.42 mm, so it was half its value compared with resinous yellow pine heartwood. This shows that resinosis has a significant impact on load-deflection interdependencies.

CONCLUSIONS

1. The density of resinous yellow pine heartwood in an air-dry condition was 30% higher than the density of non-resinous yellow pine wood.
2. The compressive strength parallel to the grain of resinous yellow pine heartwood was 4% lower than the compressive strength parallel to the grain of non-resinous yellow pine heartwood (the differences were statistically significant).
3. Significant differences were noted in deflection changes under the influence of load, depending on whether it was non-resinous or resinous heartwood. In the case of non-resinous yellow pine heartwood, with a load of 25 kN, deflection was two times lower than for resinous yellow pine heartwood.

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Streszczenie: *Badanie wytrzymałości na ściskanie wzdłuż włókien przeżywiczonego drewna twardzieli sosny żółtej.* W ramach badań oznaczono wytrzymałość na ściskanie wzdłuż włókien przeżywiczonego drewna sosny żółtej ze strefy twardzieli. Celem porównania zbadano wytrzymałość na ściskanie wzdłuż włókien nieprzeżywiczonego drewna twardzieli sosny żółtej. Określono zależności pomiędzy obciążeniem i odkształceniem sosny żółtej w teście wytrzymałości na ściskanie. Gęstość średnia przeżywiczonego drewna sosny żółtej w stanie powietrzno-suchym wynosiła 855 ± 10 kg/m^3 i była o 30% większa od gęstości nieprzeżywiczonego drewna sosny żółtej. Pomimo znacznego wzrostu gęstości wynikającego z przesycenia drewna żywicą odnotowano spadek wytrzymałości na ściskanie wzdłuż włókien o 4% i różnice te były statystycznie istotne. Zależności obciążenie - odkształcenie prezentowały podobny kierunek zmian dla twardzieli przeżywiczonej i nieprzeżywiczonej. Wykazano jednak istotne różnice w wartościach odkształceń w zależności od obciążenia pomiędzy nieprzeżywiczoną i przeżywiczoną twardzielą sosny żółtej.

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