Micro-mechanical Characterization of Compression Wood

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Abstract
In this paper are reported the results of a study carried out with the aim of characterising the mechanical behaviour of Compression wood. Tests were performed on micro-samples containing only portion of CW or normal wood that, within the growth rings, have been extracted separately from both early and late wood. After micro-mechanical tests the residual portions of the specimens have been studied at anatomical level in order to assess the presence and the severity of CW, and for measuring the average MFA.
Results have shown the dependence of tensile strength of CW from MFA, and the scarce effectiveness of the wooden colour to forecasting the presence and or the severity classes of CW.

key words : Compression wood, micro-mechanics, Microfibril Angle, Larix decidua, Pinus sylvestris

1. INTRODUCTION

The term compression wood (CW) is used to describe Softwood's wood that is formed on the underside of leaning stems, on the leeward side of trees exposed to strong winds, in crooked stems and in the lower part of trees growing on slope. Because of its different structure CW behaves in different way from normal wood, and some of its properties are not desirable for construction or processing applications, therefore it is classed as defect when present inextensive areas of a wood products.
Some anatomical features are considered typical of CW: at microscopic level tracheids present a round shape with presence of intercellular spaces between cells, whereas at ultrastructural level the secondary wall of CW is markedly different from that of normal wood showing, instead of the three layers (S_1, S_2 and S_3), only two of these (S_1 and S_2). Moreover in layer S_2 microfibril angle (MFA) is quite larger than in normal wood)up to 45° or more [1]).
Recent studies [3] have also attested that CW can be divided, according to its colour intensity, at least, in three different intensity levels, from mild to severe (severe CW should be darker and reddish than moderate and mild ones).

A consequence of these anatomical differences is represented by a different mechanical behaviour of CW as compare to the one of normal wood.
Aim of this study has been that of characterising the mechanical behaviour of pure CW tissue isolated from that of normal wood. Methodological aspects, especially about micro sample preparation, have been preliminary considered, followed by a tentative of associating CW strength according to the established severity classes (i.e. mild, severe).

2. Materials and methods.

Tests have been performed on clear micro-samples of Scots pine (*Pinus sylvestris*), coming from Sweden, and of Europen larch (*Larix decidua*) coming from Italy. Samples of normal wood and CW were selected according to the colour of the wood, assuming, as reported in literature, that as darker and reddish was the colour of the wood, as severe was the CW. Great care has been paid to sample preparation, in order to obtain specimens with the grain oriented perfectly parallel to direction of load. Starting from a small log a radial stripe, as long as the log radius, has been obtained by splitting the log along RL plane. Using a precision saw small stripes 0,3-0,4 mm thick (radial direction), 35-40 mm long (grain direction) and 10-15 mm wide (tangential direction), have been prepared from portions of annual rings located in early or late wood and constitute only by CW or normal wood. Under stereoscope specimens have been reduce to a final width of about 5 mm by cutting the sample along the grain in TL plane
Both ends of the specimens were embedded in epoxy resin in order to allow their hooking in the clamps of the tensile test machine.

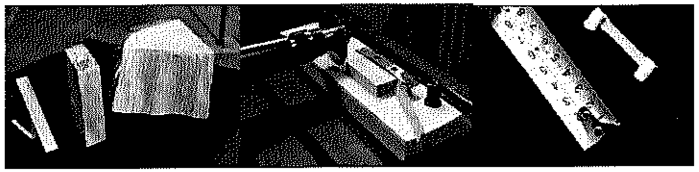

Figure 1 Phases of samples preparation.

The test device consists of a tensile test machine, provided with a DAQ system, having a maximum load capacity of 500 N and a laser extensometer for displacement measuring. Before testing the specimens were conditioned to 20°C and 65%.

After tensile tests samples were examined with an optical microscope in order to verify the real presence of CW and its relevant level of intensity. Some cross and radial microscopic sections were made in order to assess the presence of rounded tracheids, inter-cellular spaces and to measure MFA. Some colorimetric measurements in the CIE L* a* b* colour space, were also performed by means of a spectro-photocolorimeter (mod. Microflash Datacolor International), for an objective measurement of the sample's colour.

3 Results

3.1 Effects of grain direction and position within the ring

As a strong influence of grain direction and density on both strength and stiffness was supposed, preliminary tests on normal wood have been carried out in order to assess the magnitude of the effect of these variables on the mechanical behaviour of the specimens. As shows in fig. 2 values of tensile strength significantly decreases (about 50%) as the grain direction move from the one parallel to the direction of load.

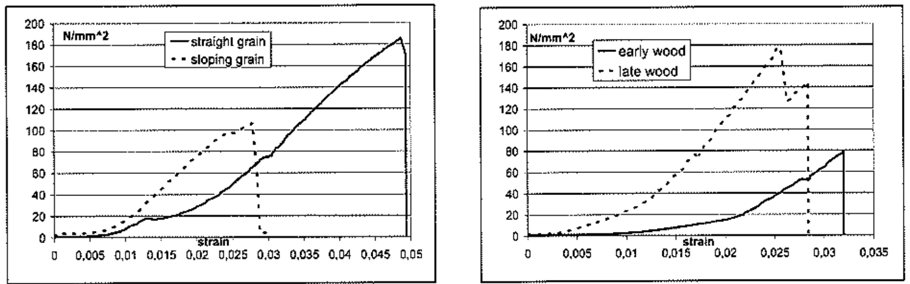

Figure 2 Influence of grain direction and wood density on tensile strength.

Also very important has resulted the influence of density, here expressed by the differences between early and late wood, which may reduce up to one third the final strength. On the base of these results, it has been decided to focus the comparative analysis between CW and normal wood to specimens obtained, within the growth ring, from late wood.

3.2 Compression wood

According to the properties that are normally ascribed to CW, and to the larger MFA in particular, a significant difference in short term tensile strength between normal and compression wood were expected. On the contrary analysis of experimental data have shown (fig.3), especially in Larch, that values of rupture were often quite close between normal and CW samples (samples were here homogeneous by specie, ring number from the pith, and position within the ring).

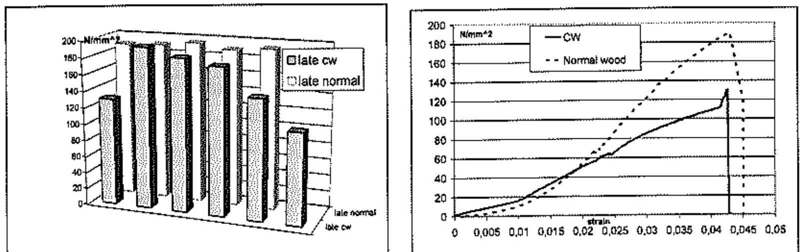

Figure 3 Strength values of late wood samples in Larch (on the left9 and an example of comparison between normal and CW within the late wood portion of the same ring.

In order to explain this apparent anomalous behaviour of compression wood, anatomical observations were carried out on the residual part of the specimens after failure. These observations have shown that in Larch the "darker" colour of the wood does not represent a definite feature for predicting the presence and the intensity of CW. In fact some "darker" specimens did not show the typical intercellular spaces or the cavities in cell walls, and it seems equivocal the association, at least in this specie, between darker colour and any CW severity class.

In Scots pine the darker colour is resulted always related to the presence of CW, as a matter of fact the inter-cellular spaces and the cavities were found, but high values of strength have been recorded in many CW specimens.

The resorting of the original dataset of tensile strength in function of MFA, has clearly evidenced the dependence of CW's mechanical behaviour from this anatomical feature. Lower values of MFA, 10°-17°, don't bias so much the tensile strength of the sample, and the values are resulted similar to those of normal wood. As MFA increases, the specimen strength decreases. Samples with MFA ranging from 21°-27° have shown breaking values about 33%-38% lower than in normal wood. For MFA between 34°-38°, the value of tensile strength decrease up to 50% (in accordance with references [3], [4]) and when MFA is larger than 45° the decrement in strength is resulted over 50% (fig 4).

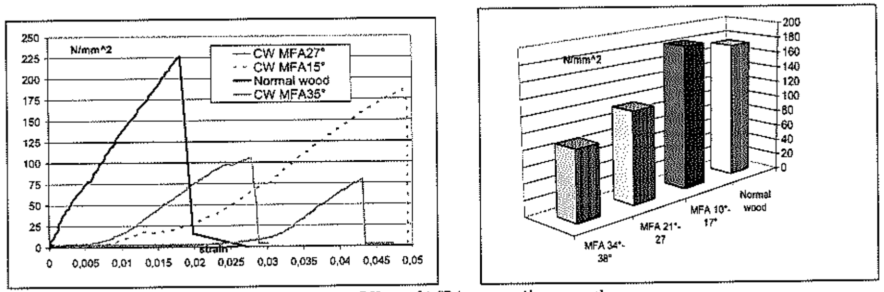

Figure 4: Effect of MFA on tensile strength.

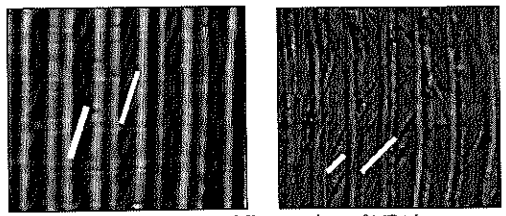

Figure 5 Radial sections showing different values of MFA between samples.

In order to assess the relation between MFA and colour intensity, colorimetric measurements have been also performed on some specimens. According to reference [1], [3], the highest severity classes of CW should be characterised by higher values of "a", "b" and lower ones of "L". By the way results reported in table 1 have evidenced that no correlation exist between the intensity of CW and the relevant values of MFA.

Sample	MFA	L	a	b
27CW5 late	11°	68,21	20,33	40,24
51CW7 late	17°	73,17	16,21	32,2
51CW5 late	21°	74,13	15,59	29,76
51CW1 late	24°	74,55	15,69	31,78
27CW9 late	27°	70,3	15,35	33,18
187CW8 late	34°	71,28	17,44	36,33
187CW8 late	38°	69,99	16,82	34,38

Table 1 Colorimetric measurement [1]. Where: MFA= measure of microfibril angle; L= luminance, position in white-black axis; a= position in green-red axis; b= position in blue-yellow axis.

Conclusion

From the experimental evidence of this study the following main conclusion can be drawn:

- from methodological point of view it is important to remark the significance, at least in micro-mechanical studies, of the alignment between specimen's grain and direction of load. If not considered this parameter could affect quite a lot measurement's results. Specimen preparation obtained by splitting along both RL and TL planes seems to avoid contamination on test results.
- MFA is resulted the parameter that, on micro samples, has shown the heaviest influence in determining the strength values of the CW samples;
- In the specie studied CW colour did not show any significant relation nor with its presence, as in Larch, nor with its intensity (mild to severe).

References

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[1] Negative values of L indicate darker colour (closer to black), values of "a" and "b" can be positive (a= red; and b= yellow) or negative (a= green; b= blue). An high positive value of L means that the object is bright, an high values of "a" and "b" means colour propensity to red the to yellow [5].

About The Cylindrical Anisotropic Model Applied To Wood

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Abstract

The wood elastic theory is based on that wood has three mutually perpendicular planes of elastic symmetry. However, the longitudinal-tangential surface is roughly cylindrical whereas the longitudinal-radial and radial-tangential are more plane. Thus, wood may be treated as a cylindrical orthotropic body. In this work, we assumed two different coordinate systems, a cylindrical coordinate system: *L*- direction parallel to axis of the tree, θ-axis parallel to annual growth rings and r-axis perpendicular to θ- direction and Cartesian one, *L*, *r* and *T*. We concluded that this procedure treats wood in more accurate form than the rectilinear model.

1. Introduction

In general, wood is considered an orthotropic material with three mutually perpendicular planes of elastic symmetry according to its internal structure. Besides this hypothesis, the material is considered homogeneous. Therefore, the longitudinal- tangential surface is not a plane, but roughly cylindrical. The other two surfaces, the longitudinal-radial and radial-tangential are, truthfully, more straight. This way, we can study wood as a cylindrical orthotropic body. We can see this configuration in Figure 1(Lekhnitskii[1]). Observe that g is an axis of anisotropy.

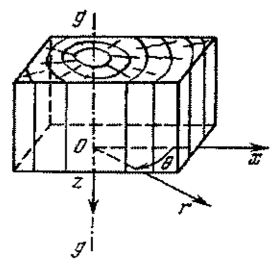

Figure 1- Block of wood

To analyze the macroscopic structure of wood we assumed two different coordinate systems to wood. Firstly, considering a cylindrical axes: *L*- direction parallel to axis of the tree, θ-axis parallel to annual growth rings and r -axis perpendicular to θ - direction. Secondly, considering Cartesian coordinate system, *L*, *r* and *T* to describe small parts, as a specimen. Figure 2 will be used to illustrate these systems.This way, wood may have both curvilinear anisotropy and rectilinear anisotropy. Apart from this, we considered the axisymmetric body in order to simplify this procedure.