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Mechanical behaviours of wood before and after heat-treatment. Part 1: Properties in compression of beech and of poplar

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ABSTRACT

Wood is sensitive to biologic attacks and this vulnerability may require heat-treatment to improve its biologic resistance. This operation is not neutral for the physical properties of wood but also for its mechanical behaviour. In this work two wood species, beech and poplar, were characterized in compression at room temperature to study the effect of heat-treatment on the compression properties, by comparison to the not heat-treated state. It was found that heat-treating beech and poplar led to the enhancement of stiffness and an improvement of the compression resistance, in both cases. The Young's modulus as well as the ultimate compression strength were significantly increased.

KEYWORDS

Woods;
Heat treatment;
Mechanical behaviour;
Compression.

INTRODUCTION

Wood is a material characterized by its low cost, a low density, easy to supply and, naturally, biodegradable. However it presents a general rather complex behaviour because its high degree of anisotropy and a hygroscopic character. Obtaining sufficient and sustainable properties requires notably high resistance against biological attacks (mushrooms, insects…). Many works aimed to enhance the biologic resistance of wood by modifying it by applying heat treatments[1-3]. Heat treatment, also called pyrolysis, allows modifying wood without using external chemical products. Heat induces physicochemical modifications in wood. Such heat treatment is generally performed in inert atmosphere and under controlled temperature and gas pressure, with as results a decrease in hygroscopic character[4,5], an improved dimensional stability[2] and a better biologic resistance[3]. However heat treatment may additionally cause colour changes, mass loss or decrease in density. Recently it was found that the heat treatment may induce a lowering of the Young's modulus, and of the rupture modulus[6-9].

In the present work it is was in the case of wood samples coming from two types of trees, beech on the first hand, and poplar on the second hand, that the effect of a heat treatment on the mechanical properties was investigated. In this first part this is the properties in compression which are studied, while the second part will deal with the behaviour in flexion.

EXPERIMENTAL DETAILS

Preparation of the wood samples

The planks used for the study were provided by Prodeo S.A. (Avenches, Switzerland). They were sawed to obtain small boards easier to manipulate. Their dimensions were 33 cm (length) × 20 cm (wideness) × 3 cm (thickness). Some of the latter ones were kept in their present state while the other ones were heat-treated. The heat treatment was achieved in a parallelepiped electrical furnace in stainless steel, under a flow of nitrogen coming from a bottle. The heating was progressively done until reaching pyrolysis (230°C). This

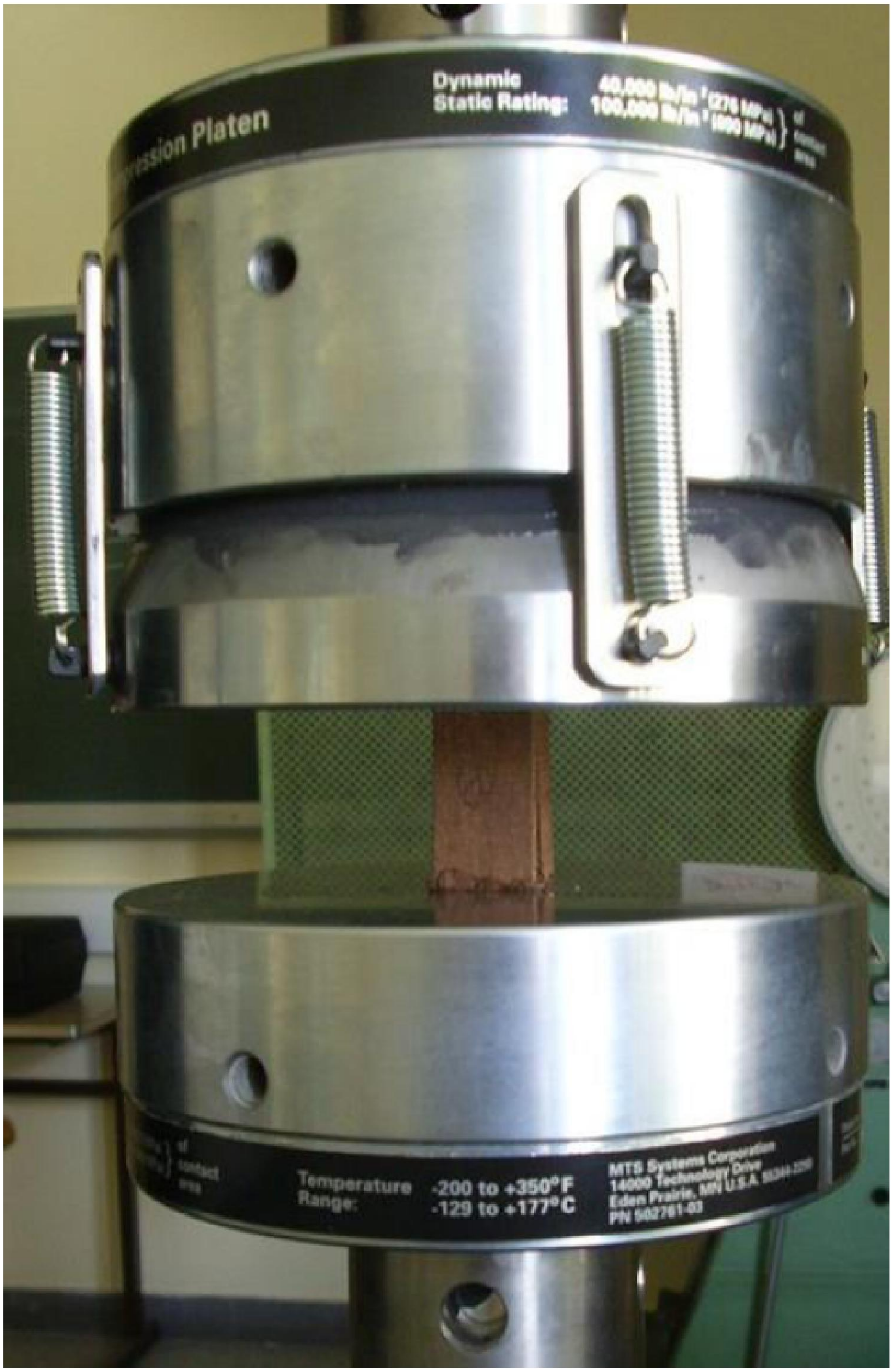


Figure 1 : A heat-treated wood sample between the two platens of the testing machine

was followed by a cooling down to ambient temperature. The gases issued from drying were trapped in a water condenser which was thereafter burned. The part which was not condensable, principally composed of CO_2 and N_2, can be recycled to be used as inert atmosphere for the furnace.

The not heat-treated boards as well as the heat-treated ones underwent sawing then planed to obtain the samples. Sixteen samples were thus available for the compression tests:

- Eight samples of beech: four not heat-treated samples and four heat-treated samples
- Eight samples of poplar: four not heat-treated samples and four heat-treated samples

The dimensions of all of them were: 60 mm × 20 mm × 20 mm.

Determination of the density and the humidity degree

The volume mass of each type of wood (beech and poplar) for the two conditions (not heat-treated and heat-treated) was calculated by simply dividing the mass (balance Mettler PC440, precision: 0.01g) of sample by its volume (dimensions measured by an electronic calliper, precision: 0.01mm). These measurements were done for the samples in the laboratory conditions (temperature: 22°C and ambient humidity: 10%).

The humidity level of each sample was determined by weighing them before (m_{hum}) and after (m_{dry}) a dry-

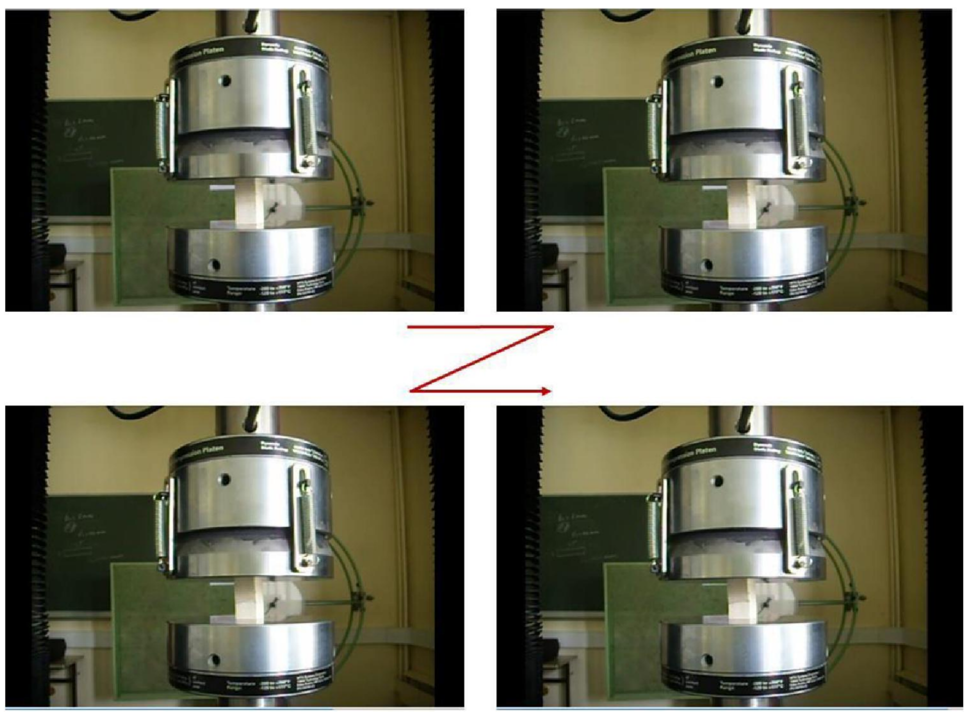


Figure 2 : Successive views of the compression test of one of the wood samples; (here: not heat-treated poplar)

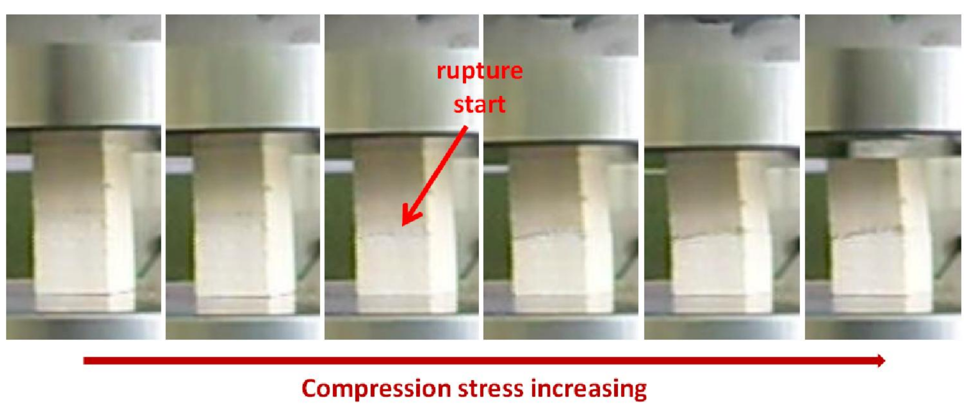
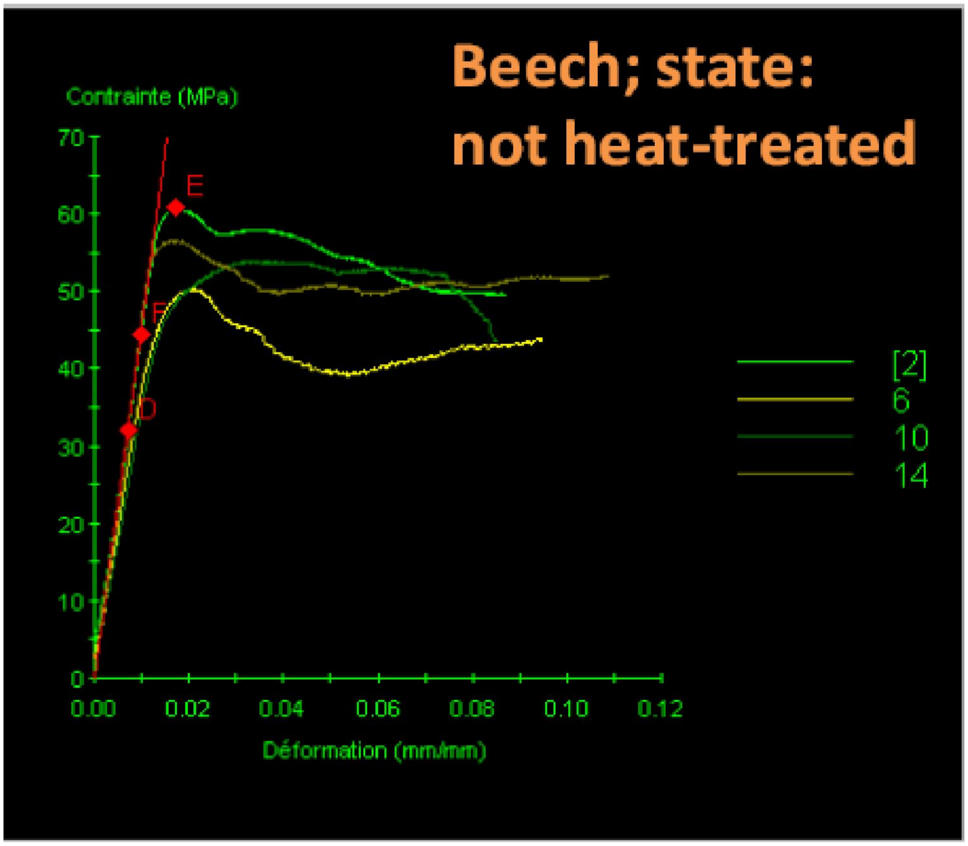


Figure 3 : Progressive deformation of a sample during compression test; (here: not heat-treated poplar)



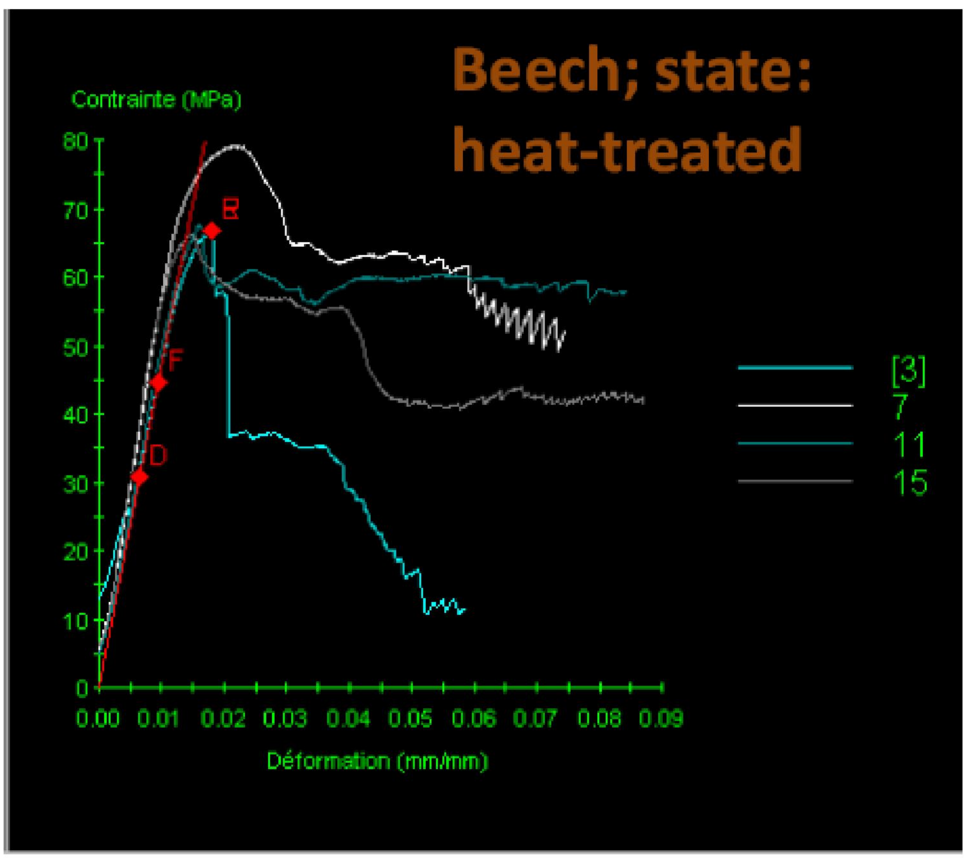


Figure 4 : The compression curves obtained for beech; (top: not heat-treated beech, bottom: heat-treated beech)

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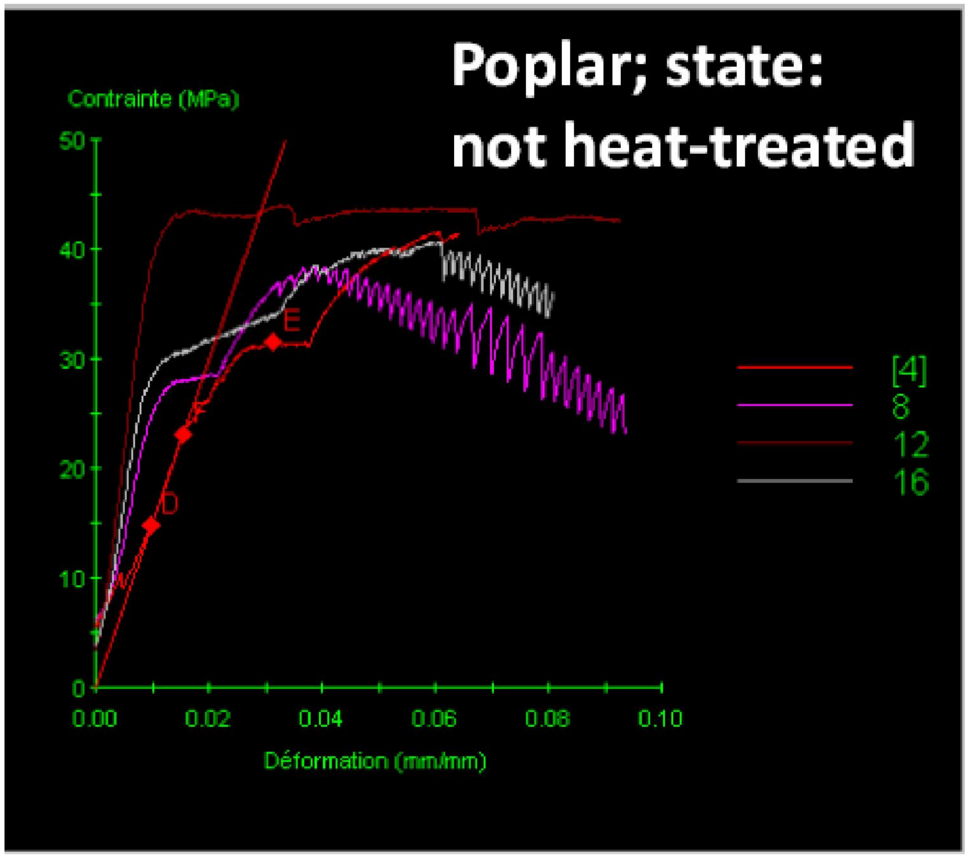

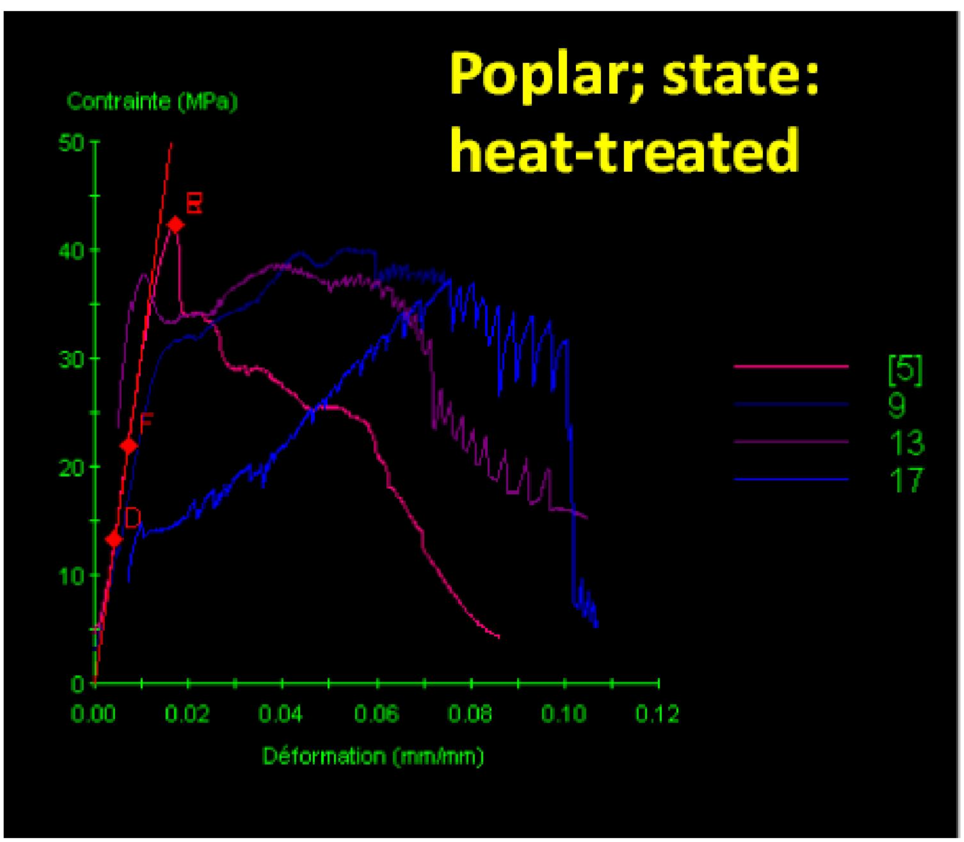

Figure 5 : The compression curves obtained for poplar; (top: not heat-treated poplar, bottom: heat-treated poplar)

TABLE 1: Compression properties and physical properties of the beech samples in the two conditions; (heat-treated or not)

BEECH	Mechanical properties		Physical properties	
	Young's modulus(GPa)	Rupture modulus(MPa)	Density (kg / m^3)	Humidity (%)
Not heat-treated	8.35±1.64	53±7	726±25	7.6±0.2
Heat-treated	13.15±0.37	67±2	679±14	3.2±0.3

TABLE 2 : Compression properties and physical properties of the poplar samples in the two conditions; (heat-treated or not)

POPLAR	Mechanical properties		Physical properties	
	Young's modulus (GPa)	Rupture modulus (MPa)	Density (kg / m^3)	Humidity (%)
Not heat-treated	3.98	40	437	7.3±0.9
Heat-treated	7.64±0.13	42±5	371±17	2.6±0.2

ing cycle done in a stove (initial temperature: 103°C), and calculated by $h(\%) = 100 \times (m_{hum}-m_{dry}) / m_{dry}$.

The compression tests

The testing machine which was used for the compression tests was an electro-mechanical one: a MTS ALLIANCE RT/100 (capacity: 100kN) driven by the TESTWORKS 4 software of MTS. It was equipped two platens with auto-alignment. A sample placed between the two platens is shown in Figure 1.

The continuous measurement of the applied force was done with the cell (capacity: 100kN too) present between the horizontal mobile part and the upper platen. The continuous measurement of the compressive strain was deduced from the position of the horizontal mobile part.

The compression runs were done with a rate of 5 mm / min, until rupture. The elasticity modulus (Young's modulus) and the rupture modulus (ultimate strength) were determined from the obtained strain-stress compressive curves.

RESULTS AND DISCUSSION

The compression tests were performed on all the prepared samples (illustration in Figure 2), until rupture occurred. The compressive strain was recorded in the same time as the increasing force applied. The progressive deformation in compression of the samples is illustrated in Figure 3.

The compression runs were done until rupture. The elasticity modulus (Young's modulus) and the rupture modulus (ultimate strength) were determined from the obtained strain-stress compressive curves. These curves are presented in Figure 4 for the beech samples in their not heat-treated (top) and heat-treated conditions (bottom) and in Figure 5 for the poplar samples in their not heat-treated (top) and heat-treated conditions (bottom).

The exploitation of these curves led to the results presented in TABLE 1 for the not heat-treated beech and the heat-treated one, and in TABLE for the not heat-treated Poplar and the heat-treated one.

General commentaries

The first effects of the heat treatment on the wood properties are on the density and on their humidity. Indeed by comparison with the not heat-treated state the heat-treatment induces a little decrease in density and a significant fall in humidity, for beech as well as for poplar.

Heat-treatment had also an influence on the compression behavior of these two wood species. This can be first seen by looking at the obtained curves which first present a worse reproducibility after heat-treatment than before, for the two wood species. Further, after the tensile strength is reached the applied stress falls more rapidly for the heat-treated state than for the not heat-treated one. In contrast the Young's modulus is higher after heat-treatment than before, and the rupture strength (i.e. the maximal strength) is also higher in the heat-treated state than in the not heat-treated one.

CONCLUSION

Thus, as demonstrated here for a typical heat-treatment which can be applied to wood for increasing its biologic resistance, heat-treating wood logically decreases its density and its humidity degree, but is also not neutral for its mechanical properties. As shown here for beech and poplar, stiffness and resistance in to compression are significantly increased, as a matter of fact more for the Young's modulus that for the ultimate strength. This study will continue for the flexion behavior, in the second part of this work[10].

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