# Experimental Testing of the Strength of Wood Subjected to Higher Temperature and Moisture Conditions - Tension

I. Malujda, K.Talaśka

*Abstract*— **The purpose of this paper is to present the methodology of experimental strength testing of wood at higher temperature and moisture conditions. The subject of research has been inspired by practical engineering experience in design of machines for processing of natural materials, specifically wood. Wood is a material with complex structure and investigating of its strength characteristics is indispensable in developing of machine design practice. The results relate to the process involved in treatment of the thin surface layer of the material by hot rolling. Some test results are also presented.**

*Index Terms*— **tensile strength, testing methodology, wood**

## I. INTRODUCTION

The methods of modelling the softening processes occurring in raw and waste materials play an important role in the development of the new organic waste processing methods. On this basis it is possible to develop theories leading to effective design and construction of machines used to implement these processes. Such machines are incorporated in production lines in factories producing carpentry and construction materials. The present research has been inspired by the practical engineering experience and still insufficient definition of plastic processing, strength and plastic limit load of the materials concerned [1,2,4].

Modification of materials with the purpose to confer the desired properties, especially in their surfaces is always a complex process, an example of which is thermal softening of the surface layer of wood by hot rolling. Bonding of two skins of wood to the chipboard base by rolling improves the appearance and the smooth surface obtained in this way facilitates subsequent processing. Fig. 1 provides a schematic diagram of the process of softening of natural wood veneer applied on both sides of a wood chipboard. When this product is completed it is used as component of furniture. The wood chipboard (3) clad on either side with natural wood veneer (4) and (5) is drawn by two, specifically oriented rollers - bottom roller (1) and top roller (2).

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The rollers apply the desired pressure on the surface of the furniture material. Moreover, the rollers are heated. Adjustment of temperature and pressure to the appropriate levels are critical to obtaining the desired effect. For optimisation, improving of output and performance of the production machines the above-mentioned processes must be modelled and analysed with the highest practicable accuracy.

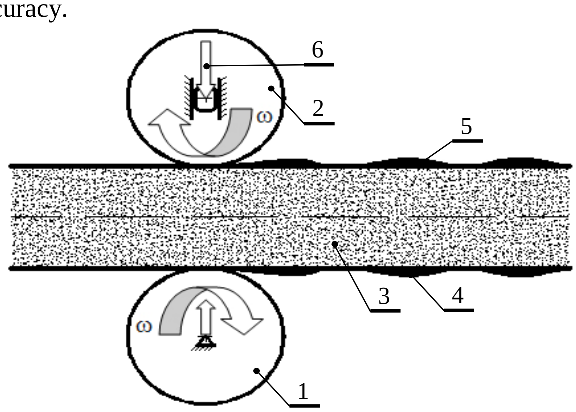


Fig. 1 Treatment of the surface layer of natural material by hot rolling 1 – bottom roller, 2 – top roller, 3 – chipboard, 4, 5 – top and bottom layers of natural veneer, 6 – applied pressure

The parameter defining the critical stress of anisotropic fibrous materials, such as wood, is the tensile strength determined during the tension test [1,2,4]. The technical value of the material is assessed on the basis of this strength, which depends on the direction of force in relation to the anatomic direction of wood. The limit load value depends on the effect of heat and moisture on the material. As a prerequisite to reliable modelling of these processes it is necessary to investigate the effect of temperature and moisture on the strength properties of the material.

This paper presents the testing methodology aimed at establishing the strength properties of wood, in particular through the tension test.

## II. DEFINITION OF THE TESTED MATERIAL

The specimens were made of two varieties of wood beech - as a representative of hardwood, and pine - as a representative of softwood. The number of samples was sufficient for carrying out tension tests on either of these two varieties in three anatomic directions: longitudinal, tangential and radial. Fig. 2 presents the orientation of fibres in a piece of wood. The dimensions of specimens are given in Fig. 3 and the anatomy of tested woods viz. annual growth

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rings is shown in Fig. 4 for the two varieties respectively. The specimens were made from selected wood logs in order to obtain representative and repeatable results of testing as per the Polish Standards: PN – 81/D-04107 and PN – 81/D-04107. Specimens with structural defects, such as knots, were rejected.

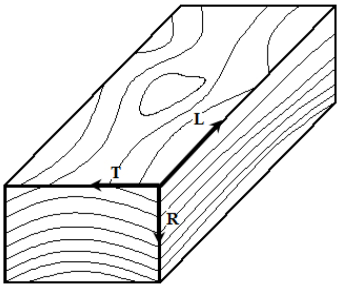


Fig. 2 Orientation of wood fibres L – longitudinal, R – radial, T – tangential

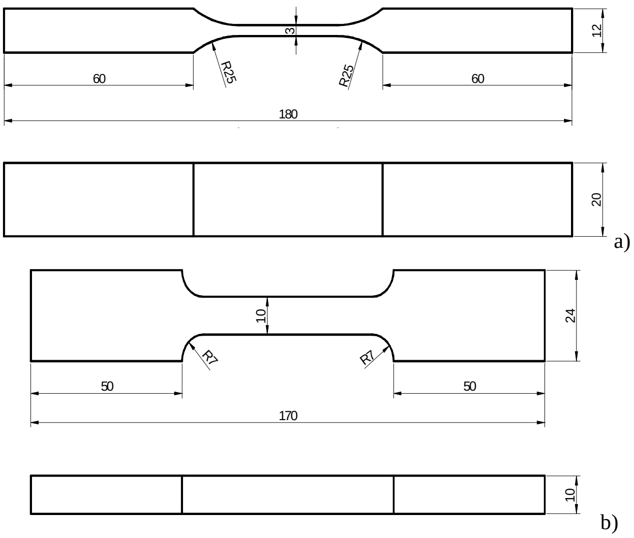


Fig. 3 Dimensions of specimens a) longitudinal direction, b) tangential and radial directions


Fig. 4 Specimens: a) pine - longitudinal direction, b) pine - tangential direction, c) pine - radial direction, d) beech - longitudinal direction, e) beech - tangentialt direction, f) beech - radial direction

## III. TESTING MOTHODOLOGY

The next step following preparation of specimens was preparation of the testing program. The objective was to obtain the results of tension tests which could be used to define the effect of temperature and moisture on the properties of wood. The tests were carried out at three temperatures: $20^0$C, $50^0$C, $80^0$C and three moisture content levels: 10%, 20% and 30%. The highest test temperature was $80^0$C as above this point chemical reactions take place both in beech and pine wood, which bring unrecoverable changes in the internal structure of wood. The maximum value of the other test parameter, namely 30% moisture content is the highest content of moisture, which may be absorbed by wood in natural conditions. The testing program for one variety of wood and one direction is presented in Table 1.

TABLE 1
TESTING PROGRAM FOR ONE VERIETY OF WOOD AND ONE DIRECTION

| | | Temperature | | |
|---|---|---|---|---|
| | | $20^0$C | $50^0$C | $80^0$C |
| Percent moisture | 10% | 3 | 3 | 3 |
| | 20% | 3 | 3 | 3 |
| | 30% | 3 | 3 | 3 |

In order to eliminate major errors, resulting for example from defective structure of wood at least 3 No. tests have been planned per each percent moisture and temperature, this giving in total at least 162 No. tests for the two varieties of wood and all the anatomical directions.

The specimens were conditioned before testing. The desired percent moisture was obtained in desiccators containing water (30%) or saturated solution of NaCl in water (20%). Desiccator containing specimens is presented in Fig. 5.

Fig. 5 Species placed inside the desiccator

Specimens with 10% moisture content are called air-dry, meaning that 10% is the maximum moisture content in wood stored in room conditions. The point at which the respective specimens have achieved the desired percent moisture was determined by weighing the specimens at pre-defined intervals. The specimens were weighted every month for the first three months and every week for the next 3 months. Thus, it took ca. six (6) months in total to obtain the desired percent moisture of 10%, 20% and 30% respectively. The point when the increase in weight stopped was defined as the point when the specimen has acquired the desired moisture content. Weight was checked with 0.001g accuracy in METTLER Toledo moisture analyser.

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As soon as the specimens have reached the pre-defined moisture values temperature curing was done as final preparation for tension test. The temperature curing took place in a stationary climate chamber built specially for this research. The climate chamber is presented in Fig. 6 below.

Fig. 6 Stationary climate chamber

The chamber presented in Fig. 6 above enables conditioning of samples at max. temperature of 250$^0$C. However, for the above stated reasons, the specimens were conditioned at the temperature of 80$^0$C and 100% air humidity inside the chamber, which ensured the desired parameters in view of the planned testing. As the first step the time needed for stabilisation of temperature throughout the whole volume of specimen was determined. For this purpose a temperature sensor was placed in the specimen during heating up to the pre-defined curing temperature. The required conditioning time varied between 6 and 12 hours, depending on situation.

The tension tests were carried out using strength tester with 50 kN load cell and mechanical extensometer suitable for high temperature and moisture content conditions. An additional climate chamber was mounted on the MTS tester in order to maintain the desired conditions during the tension tests. The strength tester including climate chamber is presented in Fig. 7. The conditioned specimen was gripped in this apparatus and subjected to the tension test.

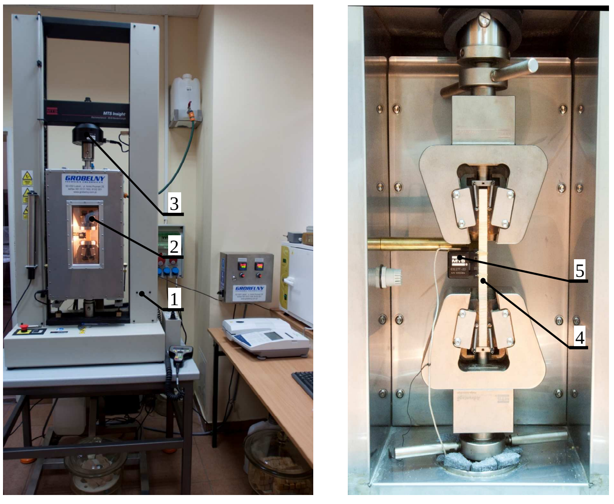


Fig. 7 MTS strength tester including climate chamber 1 – strength tester, 2 – climate chamber, 3 – load cell (measuring the applied force), 4 – specimen, 5 – mechanical extensometer

## IV. TESTS RESULTS AND THEIR ANALYSIS

Each of the respective tests produced a tensile stress-strain curve. Detailed notes were taken on each specimen. The surface area subjected to tension was measured just before the test and the specimen temperature and moisture content were measured immediately after the test. The stress-strain curve obtained during tension of beech specimen in tangential direction is presented in Fig. 8.

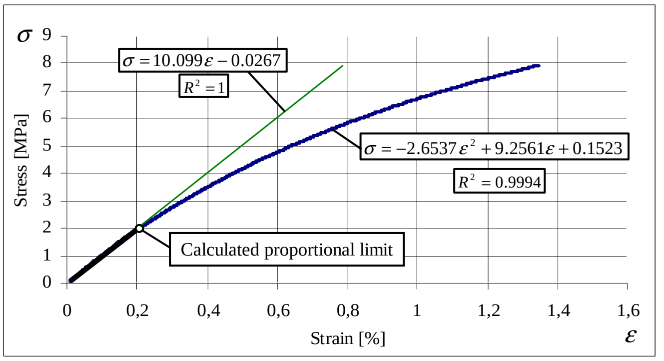


Fig. 8 The stress-strain curve for beech specimen tensioned in tangential direction at 20$^0$C and 10% moisture content

The obtained results were subjected to measuring error analysis. The following equation may be used to establish the error in determination of *y* value [3]:

$$dy = \frac{\partial F}{\partial x_1}\Delta x_1 + \frac{\partial F}{\partial x_2}\Delta x_2 + \ldots + \frac{\partial F}{\partial x_n}\Delta x_n = \sum_{i=1}^{n}\frac{\partial F}{\partial x_i}\Delta x_i \qquad (1)$$

This is based on the assumption that the reading error values $\Delta x_i$ are significantly small in relation to $x_i$. Finally, the equation takes the following form:

$$dy = |y|\sum_{i=1}^{n}\left|\frac{a_i}{x_i}\Delta x_i\right| \qquad (2)$$

Taking the accuracy of ultimate force measurement at $\Delta F = 5N$ and accuracy of dimensional measurements used in calculation of the surface area at 0.01mm we get the measuring error in the order of 0.8 – 1%.

Additionally, a statistical analysis was carried out, including calculation of the arithmetic mean, mean standard deviation and mean error of arithmetic means.

The proportional limit has been used as a characteristic criterion of the strength of wood in formulation of constitutive equations describing the softening model. It is the point where the tangent “departs” from the curve by more than 1% of the ultimate strength value. This point was in turn found by solving a system of equations describing the tangent to the breaking curve and the breaking curve respectively (Fig. 8). Proportional relation between stress and strain has been assumed in this region. This has also allowed determination of the proportionality factor. Moreover, the test enabled ultimate strength determination. The curves obtained in three tension tests on beech specimens in tangential direction are presented in Fig. 9.

With all the results in hand, it was possible to define the relation between strength and temperature for the respective moisture content levels. Fig. 10 presents the stress values corresponding to the ultimate strength vs. temperature for the respective three moisture content levels. As shown in the diagram the strength decreases with the increase of moisture and temperature. The results allowed to formulate the equations describing these relationships. Similarly the relations between ultimate strength and other parameters related to the tension tests were determined for the other

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directions of force application for beech and all directions for pine specimens.

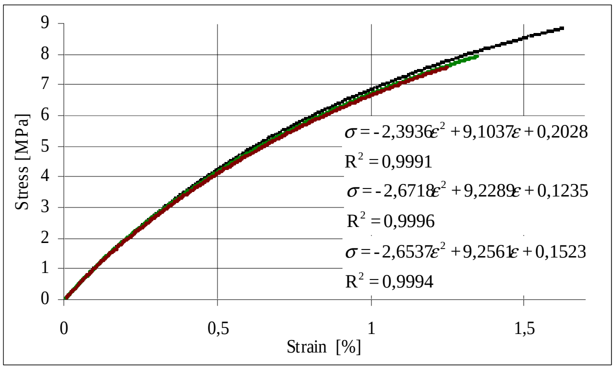


Fig. 9 The stress-strain curve for three beech specimens tensioned in tangential direction at $20^0$C and 10% moisture content

The boundary value problems have been solved on the basis of a mathematical model defined by constitutive equations and yield criterion using specialist FEM software program Abaqus. In this method the accuracy and effectiveness of results is determined by the reliability of material functions established during the tests.

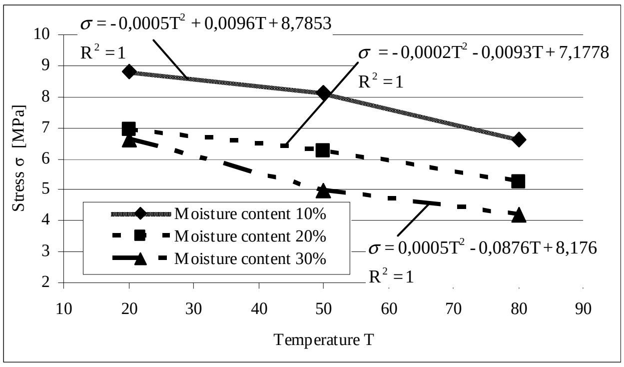


Fig. 10 Ultimate strength vs. temperature for three moisture content levels - beech, tangential direction

## V. FINAL CONCLUSIONS

The results of research presented in this report are used for modelling the process of thermal softening of the surface layer of natural materials, the example of which, and quite prominent one, is wood. The results presented in this paper are part of a wider wood strength testing scheme, including compression and shear tests. The testing methodology presented in this paper may be used as a reference in planning of strength testing of similar materials. Moreover, the results given in this paper may help understand how the tensile strength of wood changes with the increase of temperature and moisture content.

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