Andrej JOSIFOVSKI [1]
Neda DŽOMBIĆ [2]
Igor SVETEL [3]

NON-DESTRUCTIVE DETERMINATION OF MECHANICAL PROPERTIES OF WOOD

Abstract

Mechanical properties of wood are defined by its structure. The method of using wood as an element of a constructive assembly is directly dependent on its mechanical properties, including, in particular, resistance to pressure, bending and stretching. The delicacy of restoration and conservation works very often imposes the need to obtain appropriate data on the quality wood using non-invasive testing, which does not cause physical damage to the wood. In the last decade, in the construction industry, the method of ultrasonic testing is represented, which results in the visualized structure of the scanned wood sample. The brightness of such an image, analogous to the X-ray, is defined primarily by its density. As the hardness of the wood, one of the more important mechanical properties, is the resultant of density, so the light specificity of the structural scans of a particular sample is considered in this work as the equivalent of physical and mechanical coefficients obtained by classical testing. The tonal scale of black color proved to be a complete representative of physical and mechanical properties of wood. As a result of this testing, a picture of wood is obtained, whose appearance and brightness leave the possibility of adequate selection of wood for performing even delicate restoration works. This method of testing is particularly suitable in places where preventive laboratory testing of the quality of existing wooden structures cannot be carried out.

Key words: non-destructive methods, x-ray radiation, wood structure, defects, restoration

NEINVAZIVNO ODREĐIVANJE MEHANIČKIH OSOBINA DRVETA

Rezime

Mehaničke osobine drveta su definisane njegovom strukturom. Način upotrebe drveta kao elementa konstruktivnog sklopa, u direktnoj je zavisnosti od njegovih mehaničkih osobina, među kojima prvenstveno otpornost na pritisak, savijanje i istezanje. Delikatnost restauratorskih i konzervatorskih radova, vrlo često nameće potrebu dobijanja odgovarajućih podataka o kvalitetu drveta pomoću neinvazivnog ispitivanja, čime ne dolazi do fizičkog oštećenja istog. U građevinarstvu je za te svrhe u poslednjoj deceniji zastupljena metoda ultrazvučnog ispitivanja, kojom se kao rezultat dobija vizuelizovana struktura skeniranog uzorka drveta. Svetlina takve slike, analogno rentgenskom snimku, definisana je, pre svega, njegovom gustinom. Kako je tvrdoća drveta, jedno od važnijih mehaničkih svojstava, rezultanta gustine, to je svetlosna specifičnost strukturalnog skena određenog uzorka, u ovom radu posmatrana kao ekvivalent fizičko-mehaničkih koeficijenata, dobijenih klasičnim ispitivanjem. Tonska skala crne boje, pokazala se kao potpuni reprezent fizičko- mehaničkih osobina drveta. Kao rezultat ovakvog ispitivanja dobija se slika drveta pomoću čijeg izgleda i svetline se ostavljaju mogućnosti adekvatnog izbora drveta za izvođenje i delikatnih restauracijskih radova. Ovakav metod ispitivanja posebno je pogodan na onim mestima gde se preventivno ne može vršiti laboratorijsko ispitivanje kvaliteta postojećih drvenih konstrukcija.

Ključne reči: neinvazivne metode, radijacija x-zracima, struktura drveta, defekti, restauracija

[1] Assistant, University of Belgrade, Faculty of Architecture, email: andrej.arch@gmail.com

[2] Assistant, University of Belgrade, Faculty of Architecture, email: neda.dzombic@arh.bg.ac.rs

[3] Research Associate, University of Belgrade, Faculty of Mechanical Engineering, Innovation centre, email: svetel@mas.bg.ac.rs

1. INTRODUCTION

Wood is one of the most widely used materials applied as the primary structural element, mainly in the architecture of rural areas, but also as the basic material of roof constructions, as a primary or secondary structural element. Although the performance of works on roof constructions in contemporary architectural practice, in terms of materials, is much different than before, there is still a considerable number of buildings with a classical, wooden roof construction. The oldest buildings are of particular interest, categorized as cultural monuments, in which a bearing structure is made of timber. The problem of preserving the aforementioned objects would be accelerated by timely replacement of worn parts of the construction, which would significantly contribute to the extension of the lifetime of the building itself with the minimization of the cost of the works. The question of timber selection is always resolved by experience, based on characteristics, which in certain circumstances proved to be good. However[4], it is known that the mechanical and / or utilization characteristics of wood depend directly on its structure and its inherent physical properties.

The goal of this research is to demonstrate the procedure for selecting wood of adequate mechanical properties in an uninvasive manner, with an ultrasonic scan, primarily for performing restoration works on a protected architectural heritage. In addition, this type of research is particularly suitable in places where it is not possible to take samples of certain parts of the structural assembly and test their properties in laboratories. The mentioned approach would provide the possibility of preventive monitoring of timber structures over time. Conservation and restoration, primarily of buildings of cultural and historical significance, would thus be maximally improved.

2. STRUCTURE OF WOOD

In this paper, the research was carried out on sawn timber, whose properties fully represent the characteristics of certain types of wood. The focus of this research is the density of wood[5], as the basic predictor of its hardness, and therefore as the determinant of selective air permeability of certain penetrating characteristics. Since the wavelength and frequency of such rays are unique indicators of their penetrating potential, the density of wood is here also emphasized as the basic starting point of its structural display. Thus, the density of wood as its physical property, primarily determines the characteristics of the image of such a display.

Accordingly, it is theoretically assumed that the higher-density wood has a brighter structural image and vice versa that penetrating rays of higher intensity give a darker image. X-ray and ultrasonic rays are now used for non-invasive wood testing in construction. From a technical aspect, wood is a heterogeneous, anisotropic material formed by a perennial division of the inner part of the cambium cells. This heterogeneity is expressed by the difference in composite elements and compounds, anatomical specificity, as well as the macroscopic differences in the structure of the growth rings. The percentage participation of the main constituent elements of wood, carbon, oxygen and hydrogen does not depend essentially on the type of wood. Basic, structural compounds of wood, cellulose, hemicellulose and lignin are produced by various combinations of chemical bonding of these elements. It is known that in the structure of deciduous tree there is a smaller percentage of lignin, and a greater percentage of cellulose, than in the structure of the wood of conifers.

---

[4] Šoškić, Borislav and Zdravko Popović, *Wood Properties* (Belgrade: University of Belgrade, Faculty of Forestry, 2002).

[5] "The specific wood density - Y is the ratio of the wood mass in absolutely dry state- mo and the mass of water-mw equivalent to the volume of wood with a certain moisture content. The density can be calculated in the entire area of a moisture content of the wood from an absolutely dry to a charged state of moisture. In the hygroscopic area, the density of wood is most often expressed at 12% moisture. "
Šoškić, Borislav and Zdravko Popović, *Wood Properties* (Belgrade: University of Belgrade, Faculty of Forestry, 2002), page 99.

In addition to these basic, wood also contains secondary components, such as tannins, fats, resins, essential oils. The basic organic compounds form the elemental anatomical structures of the wood, which enable the development of physiological functions. In coniferous tree species, whose structure is simpler, the basic anatomical elements are trachea (95% of wood) and parenhimic cells, while trachea, tracheids, mechanical fibers, and transient forms of tracheo-tracheids are equally represented in deciduous species. The uniformity of density is characterized by a uniform distribution of mechanical elements of the wood in the growth rings.

The degree of uniformity is usually estimated by the difference in the number of rings on two adjacent parts of one piece[6]. Structural unevenness is observed on the treated tree due to the cavities of the anatomical elements. The image of the wood structure on the cross-section in the form of concentric layers is specifically designed on the longitudinal cross-section depending on its depth. Thus, the concentric layers of the macroscopic structure of the wood consisting of the pith, the heartwood, the mature wood, the sapwood and the bark on the longitudinal radial or on the longitudinal tangential cross-section are projected in the form of parallel-arranged, laminar layers. Mechanical properties of wood, ie its technical usability, are primarily dependent on the specificity of the grouping of structural elements of wood, which are transferred to the image of its structure. In addition, the specific wood density and its mechanical properties are significantly affected by the moisture of the wood. Water in the structure of the wood can be located in the lumen of the cells - free or capillary, or water in the cell walls - bound or hygroscopic. The binding of water from cell lumens to the cell walls is of a physico-mechanical nature and the estimation of these relationships will affect the change in the density of the wood. By reducing the hygroscopic moisture of the wood, the dimensions of the wood are also reduced, resulting in stress and deformation, which affects its usability.

3. EXPERIMENTAL ANALYSIS

The subject of this work is the visualization of mechanical properties of wood, that is, its usability, and the content of water and air can, in analogy with medical experience, influence the appearance of a structural image obtained either by X-ray or ultrasound detection. Overcoming this problem, using wood samples of equal hygroscopic saturation, gives a "purified image" and enables the possibility of considering a light reflection of the mechanical properties themselves.

It is known[74] that the specific density of the early and late wood is directly perpendicular to the values of the coefficients of its mechanical properties, the tension and bending stress, as well as, in percentage expressed, volume shrinkage. As the mean values of the density of the early and late deciduous trees, as well as their relationship, unlike conifers, are the variable values[8], the research in this paper is conducted in this direction. The examination of the rheological properties of wood, related to the behavior of wood under the influence of long-term loads, is of particular interest in this paper. These stresses of the wood, due to its heterogeneity and anisotropy, are very complex in the constructions, so the approach to the examination of the mechanical properties of the wood must be specific. The selection of samples of extreme values of mechanical coefficients for a particular type of wood was used as a possible way of obtaining relevant results in this research. Tabular values of physical and mechanical properties of wood, which were already known, could logically be considered a good orientation of such a choice. The usability of wood is based on its mechanical properties and therefore the concept of this research is based on their exact determination, both by the standard methodology and photometric, based on the computer gray scale obtained structural images. The planned research was intended to be carried out two-way. In the first act, the determination of specific density and values of mechanical coefficients of a particular wood sample would be carried out by a

[6] [3] Ibid. Growth ring structure, page 46.

[7] V. E. Virhov, Growth ring structure, cited in Šoškić, Borislav and Zdravko Popović, *Wood Properties* (Belgrade: University of Belgrade, Faculty of Forestry, 2002), page 38.

[8] ibid, Wood density factors, table 3.7, page 109.

standard laboratory methodology in order to create photometric standards. The mechanical properties of the control sample would, conversely, be first estimated photometrically.

The testing was carried out on samples of deciduous and conifer wood, whose mechanical properties were taken approximately, based on the table values for certain types of wood. Wood samples were standardized in the form of test tubes, of the same shape and dimensions, according to the same principle that applies to the laboratory examination of their mechanical properties. The tested tubes were sampled from the processed for construction use. Test tubes of individual wood samples were arranged in three-layer packs, each of 4 rows of one pack, containing a certain combination of test tubes of longitudinal or transverse textures. In the vertical sequence of each raw there was one test tube, perforated perpendicularly on the longitudinal axis, alternately placed from the superficial to the deepest layer. (Figure 1) The perforation of the test tube was made using a drill bit of 1.5mm diameter.

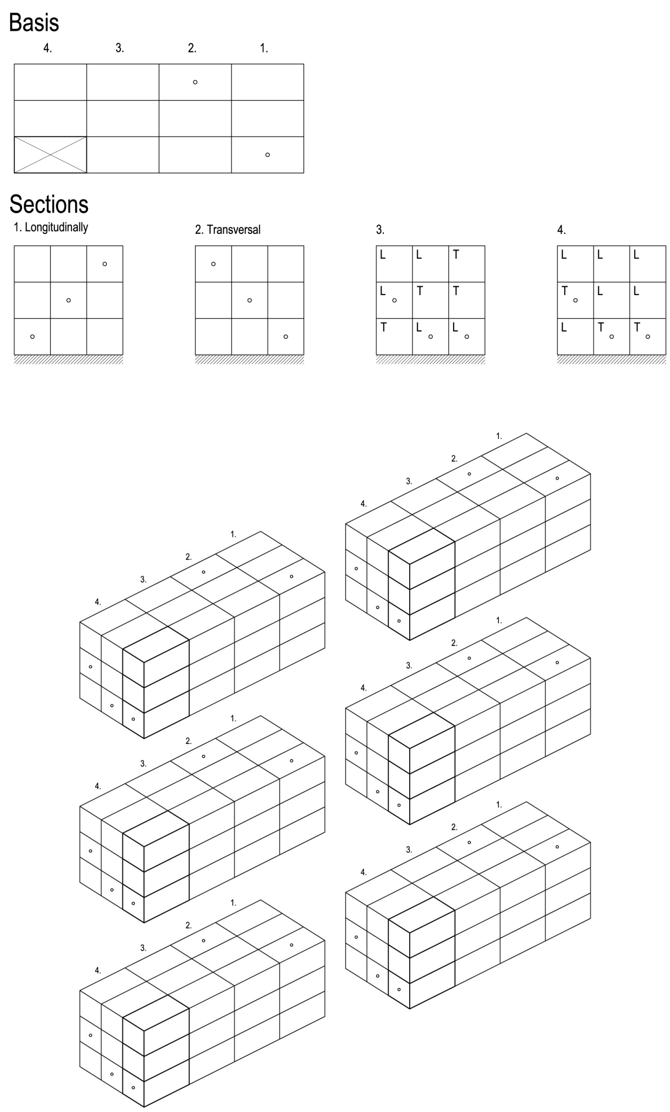

Figure 1. Schematic setting of testing samples

Testings of the same sample settings were performed both by X-ray and ultrasound. X-ray examination was performed with a device used in human medicine, and ultrasound with a device used in construction for quality control of building wood. Light standardization of the structural image, each individual wood sample obtained by X-ray and ultrasound recording, was performed by a computer program. Gray scale obtained on the basis of numerical standardization, X-ray and ultrasonic images, was used as a photometric parameter for determining the mechanical properties of wood. Parts of wooden chestnut material, objects of protected architectural heritage, those that are still in the constructive structure and as well as those that were replaced due to damage were examined as conrol samples. In order to compare the obtained results, testing was carried out on testing samples of new timber in the same way.

4. RESULTS AND DISCUSSION

Figure 2, shows the images obtained by the X-ray examination of the tested samples cut in the direction of fiber stretching (first column) and perpendicularly in the direction of the fiber stretching (second column). By observation it was noticed that the same pattern of wood gives a brighter image, if the direction of the X-ray or ultrasonic beam is directed parallel to the stretching of its structural fibers.

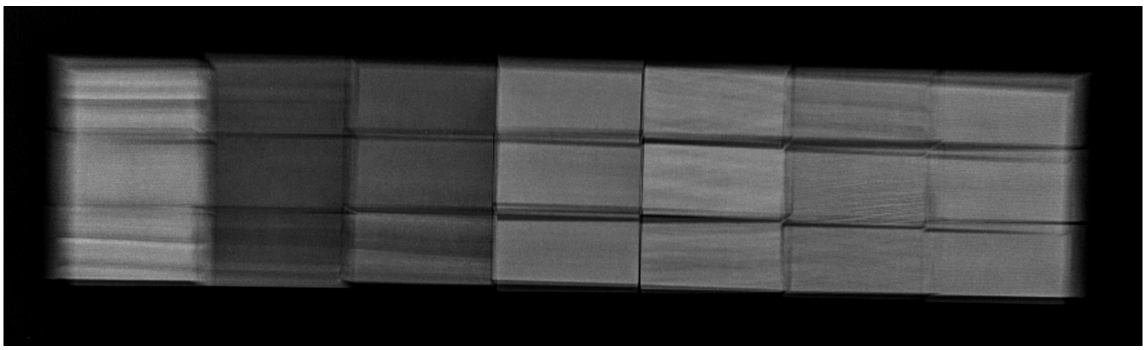

Figure 2. Tonal palette

Figure 3. shows the setting, transversally cut packs of each group, as follows:
ring porous deciduous wood, acacia (150 MPs) and oak tree (88 MPs);
diffusely porous deciduous wood, beech (123 MPs) and Canadian poplar (60MPs);
conifers, pine tree (100 MPs) and fir (73 MPs);
a sample of wild chestnut (63.5 MPs).

The packs were lined up next to each other in order from the diffusely porous deciduous of the highest coefficient of static compression stress to the conifers, ending with the packs of the control group. This setting, with regard to the differences in the coefficient of static compression stress of individual samples, gives a visual model of the zebra in the X-ray projection. The setting was recorded with X-rays of medium power (70 kV and 37 mA / s).

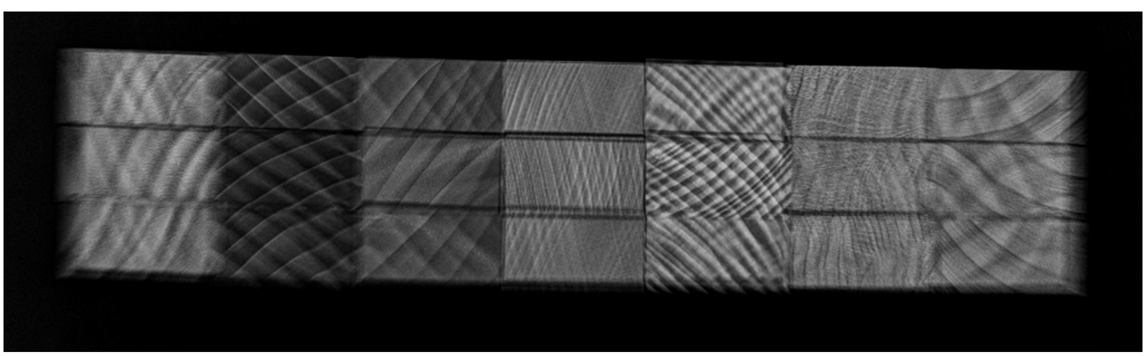

Figure 3. Setting of transversally cut packs

Figure 4. shows a chestnut stump, recorded with X-rays of medium power.
A) parallel to the stretching of structural fibers and
B) perpendicular to the stretching of structural fibers.
Since the coefficient of compression stress is ten times greater in the case of force parallel to the

stretching of structural fibers, the X-ray image of the stump in this projection is brighter. In this figure, the structural appearance of the stump is clearly visible.

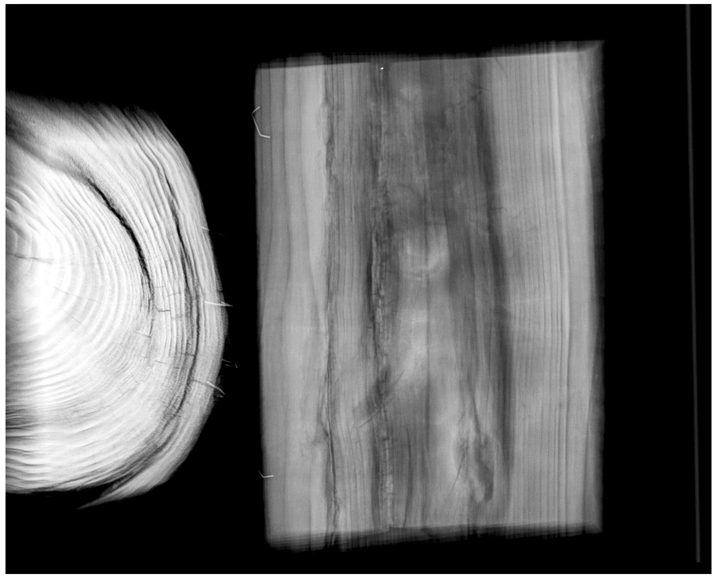

Figure 4. Transverse and longitudinal image of a chestnut stump

Based on the tested samples and the shown images, the following can be concluded:

1. Wood of higher density, ie hardness, on an X-ray or ultrasound image has a brighter picture than softer wood;

2. The permeability of the wood for X-rays and ultrasound beams is in reversed proportion to its hardness.

3. Mechanical properties of wood have their own light equivalent, expressed by an X-ray or ultrasound image.

4. The same sample of wood gives a brighter picture, if the direction of an X-ray, or ultrasound beam, is directed parallel to the stretching of its structural fibers.

5. CONCLUSION

The tonal scale of black color proved to be a complete representative of the physical and mechanical properties of wood. Based on the appearance and brightness of such an image, obtained by ultrasound examination, the internal structure, quality and some mechanical properties of the wood are examined, which enables the testing of the quality of the built-in wooden material in the construction of architectural buildings. On the basis of these results, it is shown that by ultrasonic scanning of the wood in the direction of fiber stretching, as well as in the perpendicular direction to the fibers, we can get the image of the internal structure of the wood, and thus notice the state of the built-in wooden structure. On the basis of the obtained results and images, pores and cracks can be detected in the structure of the wooden element, formed during the operation of the load, which are not noticeable by observing the element from the outside. In addition, this way we can detect the involvement of the wooden structure with fungi, bacteria, wormholes and termitas, which are one of the main causes of the decay of the structure of the wood and the loss of its physical and mechanical properties.

Bibliography

[1] Babić, Radomir. Radiology. Belgrade: Medicinska knjiga, 2002.

[2] Novelline, Robert. Squire's Fundamentals of Radiology 5. London: Harvard University Press, 1997.

[3] Purić, Jagoš and Ivan Dojčinović. Physics of Atoms. Belgrade: Zavod za udžbenike, 2013.

[4] Šoškić, Borislav and Zdravko Popović. Wood Properties. Belgrade: The Faculty of Forestry, 2002.