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X-RAY METHODS

Physical Nondestructive Methods for the Testing and Evaluation of the Structure of Wood-Based Materials

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Abstract—The processing modes and operating properties of wood-based materials depend in many respects on the structure, density, and moisture of wood, the determination of which by traditional methods in production conditions presents great difficulties. Therefore, in recent years there has been an interest in applying physical nondestructive methods of testing in the area of manufacturing wood-based materials and investigations of their properties. The performed studies showed that it is possible to use computer tomography and magnetic-resonance imaging methods for evaluating latent defects of wood, its density, and moisture. The joint use of these methods is of special interest, which is intended to increase the reliability of evaluation of wood density, based on which the strength of future lumber is forecast.
The application of radiography enables one not only to determine the structure of wood and glued layers but to indirectly evaluate the strength of gluing.

Keywords: wood, lumber, structure, density, moisture, computer tomography, magnetic resonance imaging, radiography

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INTRODUCTION

Wood, as a natural vegetable polymer, has a number of disadvantages as a structural material. On the one hand, these drawbacks can be detected using physical inspection methods and, on the other hand, they require taking the peculiarities of the structure and properties of wood into account that are capable of affecting the reliability and accuracy of the results that are obtained by these methods. The basic natural signs of wood include the heterogeneity of its structure, anisotropy of properties, and existence of defects. The heterogeneity of the structure and variability of properties relate not only to wood from different species that grow in different types of forests, but one kind, even one tree, as well.

The physical and mechanical properties of wood, when measured on small specimens, depend on the location of sampling specimens from the trunk and the direction of effort with respect to the grain direction; on large specimens they depend not only on the grain direction but on the quantity and the state of wood defects, in the first place, knots. This is the result of the heterogeneous structure of wood at the macro-, meso-, micro-, and nanolevels.

Nanostructured differences are typical of the cell wall, which consists of beams of cellulose micromolecules that are combined into microfibrils, which form shells of the cell wall with both oriented and unoriented layers.

At the micro- and mesolevels different species of wood differ in the kinds, shapes, sizes, and properties of cells, on which physicomechanical properties of wood depend, including its density and moisture.

Differences at the macrolevel are specified by several zones of the wood trunk (core, kernel (ripe wood), sapwood, and bark), which fulfill different functions and are characterized by different properties, and by defects, which substantially affect the mechanical properties of wood.

Traditional nondestructive visual evaluation using universal and measuring tools allows one to determine sizes and shapes of saw logs, and evaluate surface knots, based on which it is impossible to forecast the quality grade of future lumber and their strength.

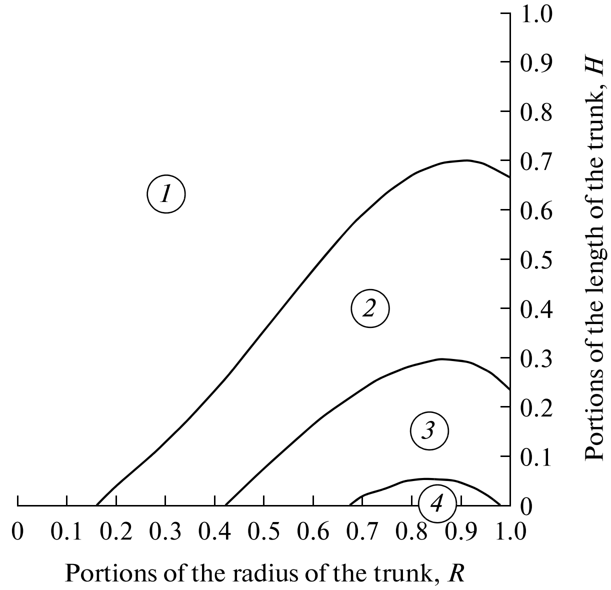

Fig. 1. Density distribution over a pine trunk at a moisture of 12%, kg/m^3: (*1*) 400–450; (*2*) 450–500; (*3*) 500–550; and (*4*) 550–600.

The basic physical wood properties, which determine their load-carrying capacity and processing technology, are density and moisture [1, 2], which are substantially different in different parts of the tree trunk (Fig. 1). Therefore, in woodworking processes in real time it is necessary to control the state of wood samples and sort them into groups that differ in moisture and density.

The use of traditional inspection methods (Fig. 2) for determining wood density and moisture is not possible due to their duration and the necessity of destruction of the samples that should be tested.

The development of new principles for evaluating the physical properties of round lumber and forecasting the properties of products will allow one to change the approach to the determination of the quality of samples. In addition to the visually determined dimensionally qualitative characteristics and species composition of the raw materials on timber enterprises, it is necessary to divide samples according to the application and type of production for which they can be used. This approach will increase the qualitative commercial yield and will meet requirements of rational nature management, since it will allow one to significantly decrease the specific consumption of the raw materials in the production of structural wood materials.

In industrialized countries, laser scanning is used to evaluate the shape and sizes of lumber (Fig. 3) and the computer tomography (CT) is used for identification of the internal structure of lumber [1].

The studies that we performed demonstrated that it is possible to use physical investigation methods (radiography, computer tomography, and magnetic resonance imaging (MRI)) to evaluate the structure and the state of wood and wood-based materials in wood processing.

MATERIALS AND METHODS

Pine and white wood from the Leningrad oblast, at ages of 80–100 years, was used during the performance of these investigations.

Prepared whips were cut along their length into 0.5-m sections.

The internal structure, density, and moisture over the volume of samples were determined for the obtained sections by the computer tomography and magnetic resonance imaging methods. Then, 20 × 20 × 30-mm-size sections were obtained from the specimens; the same parameters were determined by the standard methods at different moisture levels.

The density distribution over the volume of round lumber and the internal structures were evaluated by the computer tomography method on a PHILIPS BRILLIANCE 64 multislice computer X-ray tomograph, which outputs visual data on the internal structure on a display, while simultaneously fixing the X-ray attenuation on the Hounsfield scale.

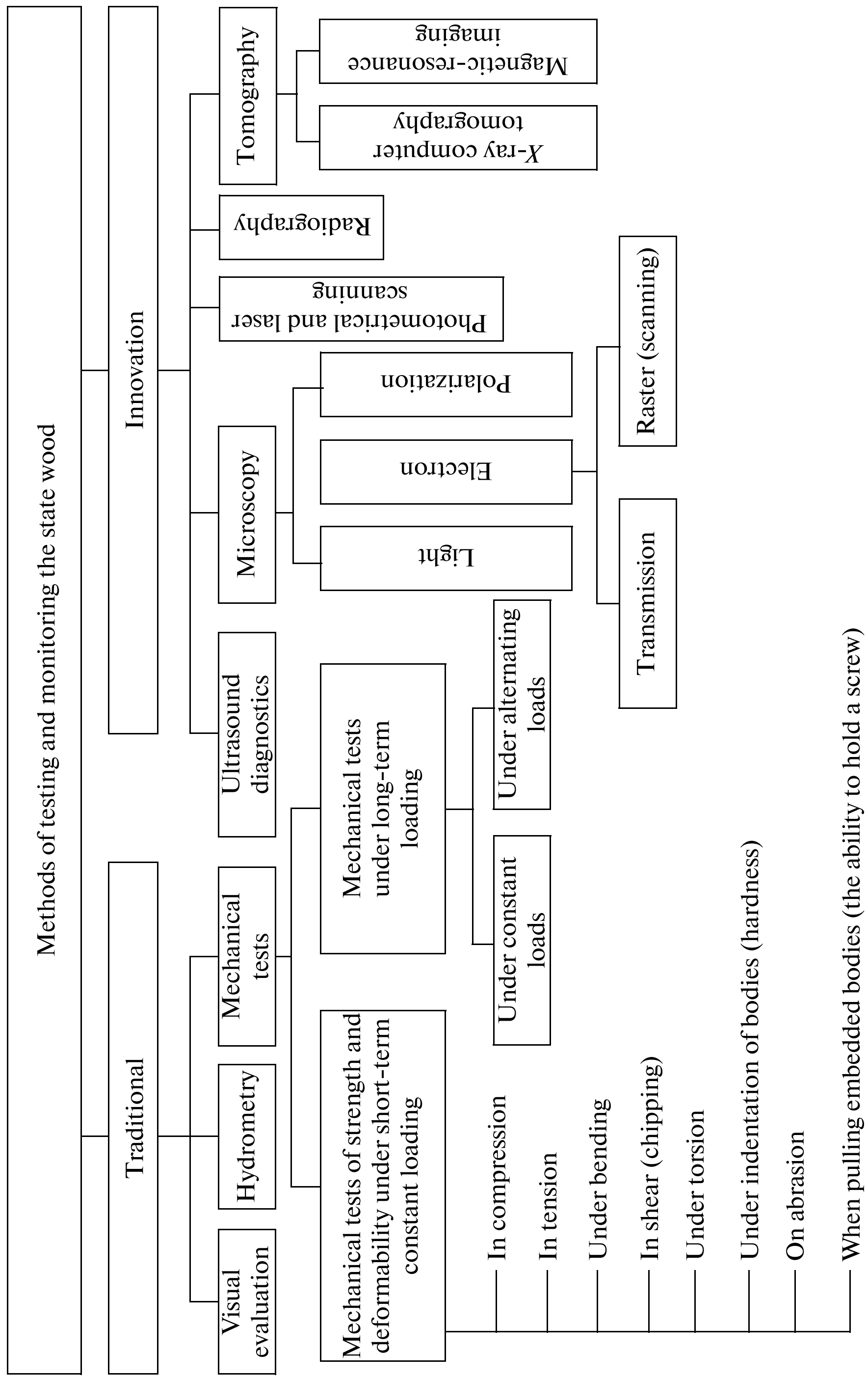

Fig. 2. Classification of the methods of testing and monitoring the state of wood [1–11].

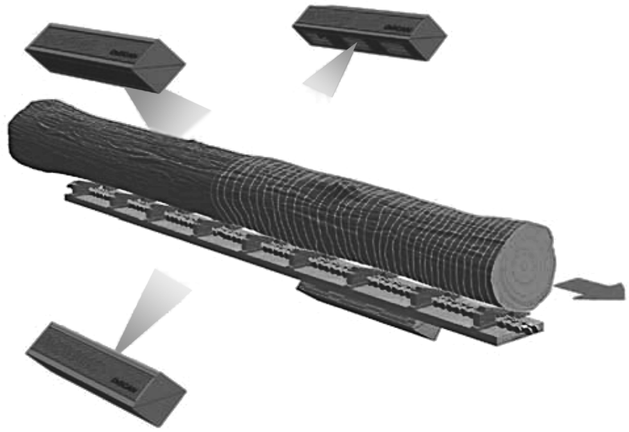

Fig. 3. Laser scanning of the surface of a log using the MiCROTEC measuring tools.

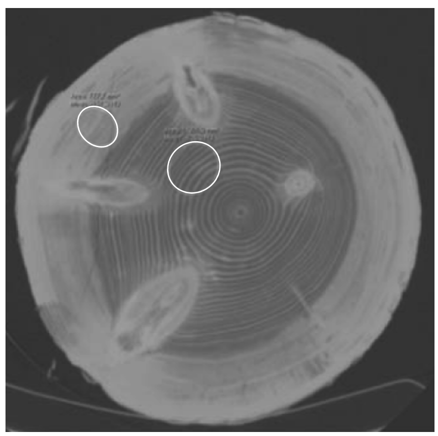

Fig. 4. A cross section of pine wood that was obtained by the CT method (detection of latent knots).

The internal structure of the samples and the moisture distribution over the volume were evaluated by the magnetic-resonance imaging method, which is based on measurements of the electromagnetic responses of hydrogen atoms to excitation by a certain combination of electromagnetic waves in a high-intensity constant magnetic field. The studied objects in the form of round pieces of lumber were placed in a constant magnetic field with a 1.5-T intensity with the subsequent production of the pulse sequence (PS) PD/T2 to obtain a visual image of the zone distribution in woods with different moisture levels [12, 13].

The properties of lumber and qualitative characteristics of glued joints were evaluated using a standard X-ray unit with a CHIRAGRAFS X-ray tube with a power of 48-kW and a 110-mm focal length; the exposure time was 0.04 s. The strength of the glued joint was determined based on its dependence on the thickness of the wood zone impregnated with glue (the thickness of the glued layer).

The penetration of the glue into the wood was studied using a JEOLJSM-35 scanning electron microscope.

RESULTS AND ANALYSIS

The results of the investigations that were performed using computer tomography and magnetic resonance imaging are shown in Figs. 4–7.

The analysis of these results shows that it is possible to use the CT and MRI methods for detecting latent defects of round lumber, as well as their density and moisture, based on the intensity of the signal absorption.

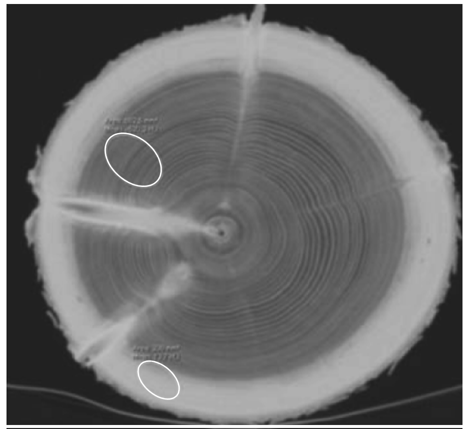

Fig. 5. A cross section of white wood obtained by the CT method (determination of wood structure on the cross cut).

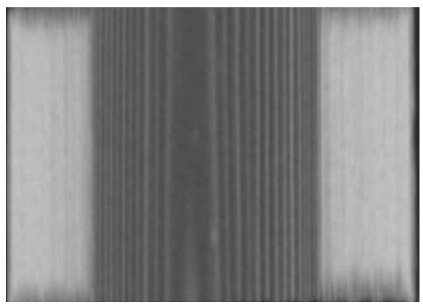

Fig. 6. The longitudinal size of pine wood obtained by the CT method (determination of wood texture during the planing of a veneer sheet).

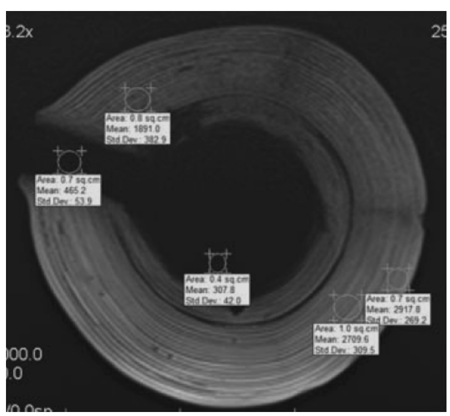

Fig. 7. Determination of the signal-intensity change as function of the moisture of different parts of a tree trunk (in studies by the MRI method).

In spite of the high information density of the results using computer tomography, they do not allow one to directly determine the strength of lumber based only on the wood structure (annual ring width) and the latewood contents in it. This method enables one to determine the total sample density, i.e., the total density of wood with the moisture contained in it, which is distributed unevenly over the volume of the tree trunk and contained predominantly in its sapwood part.

The use of magnetic resonance imaging also allows one to determine the structure and dimensioning specifications of the samples; but in this case, it is not the density but rather the moisture content in the entire volume of round lumber that is evaluated (Fig. 7).

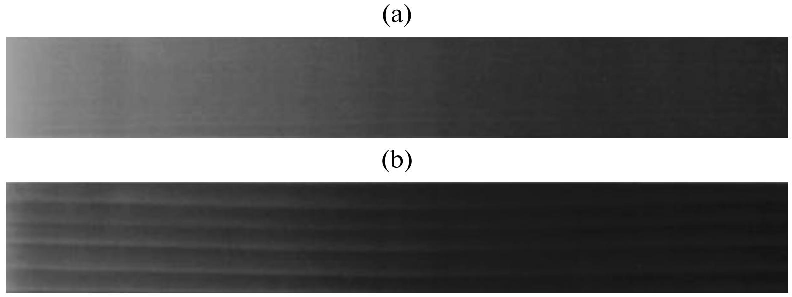

Fig. 8. An X-ray photograph of two wooden boards from one lumber lot with a density of (a) 520 and (b) 470 kg/m^3.

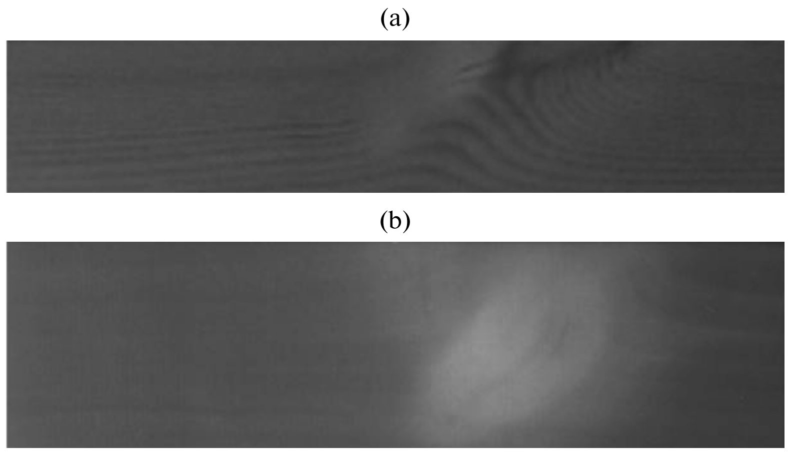

Fig. 9. Evaluation of the sizes and locations of knots: (a) visually on the upper face; and (b) by the radiography method at right angle to the edge.

Knowing the density and moisture distribution over the volume of the round lumber, evaluated respectively by the CT and MRI, it is possible to authentically determine the density and strength of wood-based materials that are formed from different parts of a sample at a preset technological level of humidity. These data allow one to optimize the cutting plan of the round lumber in accordance with the required density, location of knots in the sample, and wood-grain direction.

The application of radiography and computer tomography also opens up new possibilities for evaluating lumber (Figs. 8 and 9).

The execution of lumber sorting based on visual evaluation or using power sorting, does not allow one to authentically determine the density, which is of fundamental importance for the qualitative formation of glued joints. The use of the radiography method allows one to sort dry lumber based on both visual and strength characteristics. In this case, the wood density can be evaluated from both the technological and operating moisture.

Since even for one species the wood density can vary over a wide range (e.g., for a pine with a moisture of 12% the density varies from 400 to 600 kg/m^3, when the rated value is 505 kg/m^3), the use of only the rated data without stream diagnosis of lumber can lead to errors when wood structures are designed and destruction when they are used.

Another important factor that affects the load-carrying ability of wood is the presence of knots on the surface or inside the lumber, which act as stress concentrators and reduce the structural strength. Visual surface evaluation of knots does not allow one to authentically determine their sizes; as well, due to their conical form, only some part of a knot can be seen at the surface.

Figure 9 shows the X-ray photograph of lumber that contains a knot, the size and location of which were determined visually and by the radiography method. When assessed visually, such lumber can be given the superior quality grade, since on the surface of the board the knot is represented as a cone and the operator cannot determine its size inside the board, which in this case is virtually equal to the thickness of the lumber and reduces its strength by 30–60%.

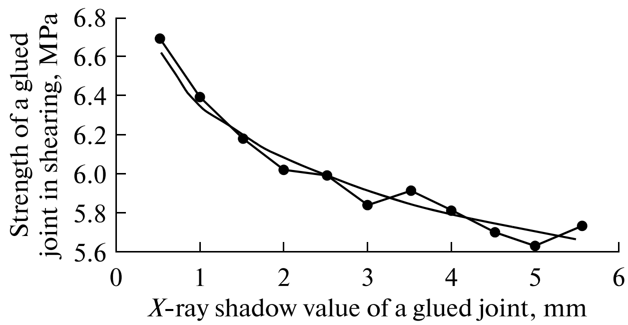

Fig. 10. The dependence of the strength of glued beams made of an entire section timber using polyvinyl acetate (PVA) binders on the X-ray shadow thickness [10].

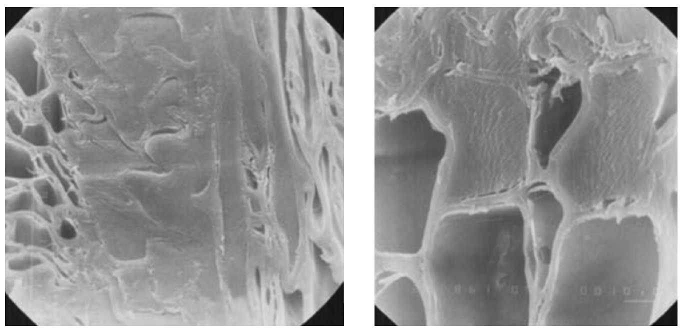

Fig. 11. Microphotographs of the larch zone that is impregnated with glue, which were obtained on a scanning electron microscope [11].

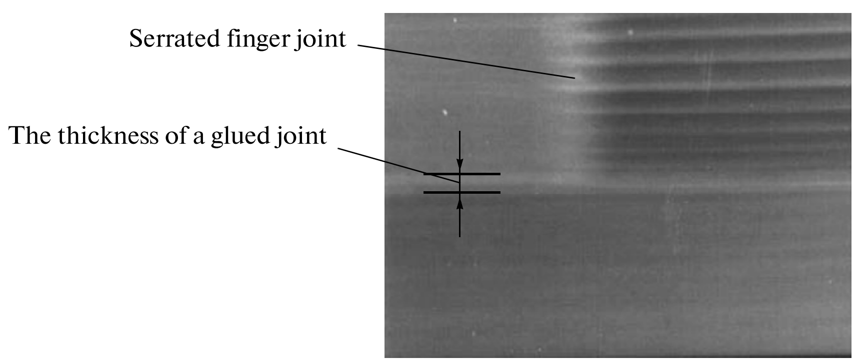

Fig. 12. Evaluation of the size of a glued joint.

Radiography can also be used for evaluating the glued joints of wood with the destruction of glued samples in order to perform the tests.

It is known that the quality of glued joints depends on the thickness of the glued layer, which includes the wood zone that is impregnated with glue (Figs. 10 and 11).

The radiography method can be used for evaluating the quality of gluing lumber both along the face and edge and the length of a serrated finger (Fig. 12). Radiography also allows one to evaluate the continuousness of a glued joint (the existence of unglued locations).

The radiography method is easy to use, does not require organizational changes of a sawmill, and units for performing complete nondestructive inspection can be built into technological lines.

CONCLUSIONS

1. The variability of the physical properties of wood over the volume of a tree trunk requires that physical nondestructive methods be used for inspection.

2. The joint use of computer tomography and magnetic resonance imaging allows one to monitor the normalized physical properties of the round lumber, enabling one to increase the qualitative yield of lumber.

3. The use of innovative inspection methods on lumber will increase the authenticity of sorting it into groups and will allow one to determine the density, which is necessary for manufacturing glued wooden objects.

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