

Ways to increase the production efficiency of hardwood blanks

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Abstract. The article presents the main results of experimental studies on the identification of the main grade defects of oak lumber by the thermal non-destructive testing method. Regression dependences of wood defects temperature display from the main factors for the studied grade defects are proposed. Indicators of infrared radiation (temperature range) of the main visible oak grade defects obtained as a result of experimental studies are presented. A conceptual scheme for the line control methods of identification of the main grade defects in lumber are proposed.

1 Introduction

Production of high-quality materials, determination of their properties today special attention is paid [1-6]. The full technological cycle is characteristic feature of the production of hardwood timber blanks in Ukraine – from round timber to finished intermediate products of final moisture content, since the manufacturing of such products from industrial wood is low cost-effective. In addition, in view of the very different size and quality characteristics of raw materials and the chaotic discrete location of wood defects in industrial wood, the technological process of cutting boards into blanks is characterized by considerable labor and material consumption, in which wood losses can reach 40 %.

The search of ways to increase the production efficiency of round oak timber blanks is a rather labor – demanding process and has traditionally been considered as two directions – cutting logs into industrial wood, and obtaining blanks from boards. The problem in the technology of the billets production at the stage of cutting freshly industrial wood is the significant complicity in predicting the useful and high-quality billets without the use of effective non-destructive methods of assessment of the size and quality parameters of boards.

Modern scientific and technological achievements in the field of electronics and computer technology have led to a decisive revolution in the field of technological processes automation of sawmilling and woodworking in general. One of such scientific and technical solutions is the assessment of forest quality and sawn products by non-destructive testing methods (NDTM) before cutting them [7].

It is now possible to obtain this or that information about wood, to reveal surface or internal defects (knots, cracks, rot, various kinds of stains) using such NDTM as:

optical scanning; laser scanning; ultrasound scanning; X-ray; ST scan; microwave scan; infrared scanning etc. It is known that the most effective NDTM for assessing the quality of lumber are: acoustic, radiation and thermal scanning methods [8]. Moreover, the acoustic and radiation methods are based on measuring the wood density, which allows us to assess the real shape, as well as the existing surface and internal defects of industrial wood without destroying the wood. However, they have a common drawback – high cost and, in most cases, are used to assess the quality of dry industrial wood [9-12].

Therefore, in order to reduce the cost of the process of non-destructive quality control of industrial wood, in this report we consider the hypothesis of possibility of using thermal NDTM to reveal and identify wood defects in industrial wood of oak of initial moisture content, based on statements regarding the different structure, heat capacity and humidity of defect-free wood and wood with defects [13, 14]. Profile densities of two types of imported solid wood flooring from lumber were quickly detected by their physical properties and basic chemical compositions using fast detection technology, X-ray scanning method and infrared spectrum with Fourier transform [15].

Scanning logs in industrial computed tomography provides detailed information about the quality of wood before sawing [16-18]. And near-infrared spectroscopy in combination with multidimensional statistical modeling can be a suitable forecasting model for determining the manufacturing quality [19].

An approach to computerized classification is proposed, which uses a hybrid approach using predicted profit-making capacity from slice-modeling and neural-network methods for increasing both accuracy and high processing speed [20]. Non-destructive logs scanning using georadar to detect defects in logs before sawing can

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significantly increase the productivity and output of high-quality defect-free industrial wood due to the optimal orientation of the saw blade and prevent damage of the saw blade from incised metals [21].

Numerous energy crop species and various processing methods provide thousands of biomass samples that need quick, low-cost analysis. Infrared methodology can provide high-throughput analysis of cellulosic biomass. The conventional method for biomass analysis is time-consuming, labor-intensive and unable to provide structural information. Use of infrared spectroscopy allows qualitative and quantitative analysis of biomass samples without destruction of samples, which is beneficial for in situ or in-field measurement. Chemometric analysis is able to make calibration models robust and reliable. The progress of infrared techniques and their applications in biomass study is introduced. A comparison of infrared methods and the conventional method is also summarized. We also review recent infrared applications in biomass analysis and discuss the prospects for applications of infrared techniques [22-24].

Raman spectroscopy is a technique that can detect and characterize a range of molecular compounds such as water, water ice, water-bearing minerals, and organics of particular interest to planetary science. The detection and characterization of these molecular compounds, which are indications of habitability on planetary bodies, have become an important goal for planetary exploration missions spanning the solar system. Using a compact portable remote Raman system consisting of a 532 nm neodymium-doped yttrium aluminum garnet (Nd:YAG) pulsed laser, a 3-in (7.62 cm) diameter mirror lens and a compact spectrograph with a miniature intensified charge coupled device (mini-ICCD), we were able to detect water (H₂O), water ice (H₂O-ice), CO₂-ice, hydrous minerals, organics, nitrates, and an amino acid from a remote distance of 122 m in natural lighting conditions. To the best of our knowledge, this is the longest remote Raman detection using a compact system. The development of this uniquely compact portable remote Raman system is applicable to a range of solar system exploration missions including stationary landers for ocean worlds and lunar exploration, as they provide unambiguous detection of compounds indicative of life as well as resources necessary for further human exploration [25-29].

Recently usage of timber in various industries is impossible without knowledge of its structure and physical and mechanical properties. It is therefore important to investigate the hardwood timber structural features and set the main parameters that characterize its quality and strength. The use of special non-destructive methods for assessing the lumber quality (ultrasonic, optical, laser scanning) allows measuring the real shape, presence of the surface and internal defects without timber destruction. Information obtained by dimensional and qualitative characteristics is considered when the introduction of CAD for optimal cutting. Comparing the results of the plate lumber cutting without the use of optimized systems and with cutting optimization (CAD), it can be seen that the output is useful when cutting plate materials without the use of CAD is 85 % and the plate lumber yield with the use of CAD is 90-95 %. Results of

work pieces yield using lumber scanning showed that yield when cutting increases up to 10 %, confirming the rational choice of method for assessing the lumber quality [30].

Thus, the research on revealing and identification of the main wood grade defects is trending.

The purpose of this work of the study was the research on revealing and identification by the thermal NDTM of the main grade defects of wood in initial humidity of industrial oak wood.

2 Raw materials and methods

Industrial oak wood was used for research.

A control scheme has also been developed to identify the main grade defects of wood in freshly sawn industrial oak wood, shown in Fig. 1.

The control circuit provides the use of photo filters (RGB) for capturing the certain infrared radiation wavelength of the industrial wood defects after being blown with hot air.

Analysis of functional dependencies of industrial oak wood stimulation.

It is known that various types of lamps, heat guns and lasers can be the methods of thermal stimulation of the studied material. A general comparison criterion for various thermal control procedures is the signal-to-noise ratio, which can be determined by the formula [31]:

$$S = \frac{\bar{T}_d - \bar{T}_{nd}}{\sigma_{nd}}, \quad (1)$$

where is the

\bar{T}_d – average temperature of the defective zone, °C;
 \bar{T}_{nd} – average temperature of the defect-free zone, °C;
 σ_{nd} – standard deviation of the defect-free region (noise variance), which is determined by the equation:

$$\sigma_{nd} = \sqrt{\frac{\sum_{i=1}^n (T_{ndi} - \bar{T}_{nd})^2}{n-1}}. \quad (2)$$

It was established that internal defects can be detected provided that upon observation the signal caused by them exceeds the noise level:

$$S > 1. \quad (3)$$

It is known that internal defects of the material can be detected by the thermal method if a combination of the following conditions is fulfilled:

$$\Delta T(\tau_m) > \Delta T_{res}, \quad (4)$$

$$C(\tau_m) > C_{noise}, \quad (5)$$

$$T_{abs}(\tau = \tau_h) < T_{destr}, \quad (6)$$

Conditions (4-6) are based on the parameters: equipment (devices), ΔT_{res} ; products, C_{noise} ; heating, T_{abs} ; defects, ΔT or C .

Thus, in order to establish the most effective method of industrial wood thermal stimulation of oak wood initial moisture, we determined the signal-to-noise ratio

criterion, S , using equations (1-2) and verified the fulfillment of conditions (3-6), for which a number of experimental studies were performed. For the experiment, uncut industrial wood from oak timber was selected in an

amount of 720 pieces with an average initial moisture content (40...50%), an actual thickness of 30 mm and a length of 1.7 m.

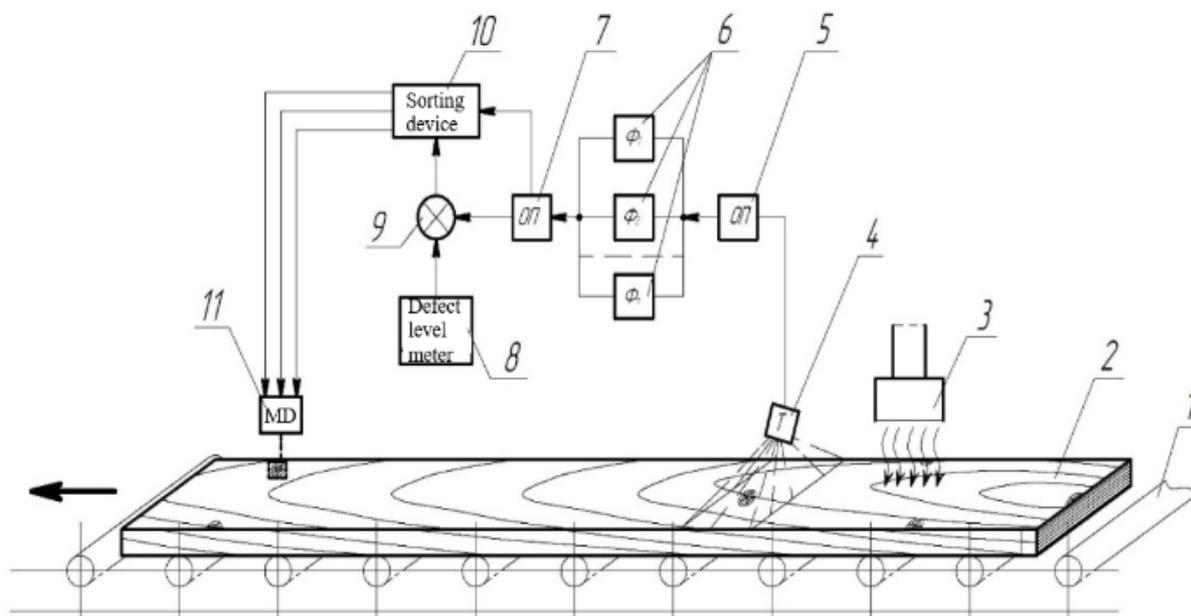


Fig. 1. Schematic diagram of the control method for identifying the main grade defects of wood in industrial wood: 1 – roller conveyor; 2 – industrial wood; 3 – installation of warm air supply; 4 – photo-video thermal imager; 5 – computing device; 6 – photo filters; 7 – computing device; 8 – defect level meter; 9 – adder; 10 – sorting device; 11 – marking device.

3 Results and discussion

To determine the most practical and inexpensive method of thermal stimulation, an experiment was conducted in which the studied industrial wood samples were heated by two methods – incandescent lamps and a heat gun (industrial hair dryer). Laser heating was not foreseen in the experiment, due to its high cost, large dimensions and low efficiency. Thermal imaging of samples heated with a heat gun for 20 s is presented in Table 1. Image of the thermal radiation of the sample after cooling for 60-180 s is presented in Table 2.

Thus, the most effective method of thermal stimulation for performing a series of experimental studies on the identification of the main wood grade defects in industrial oak wood is the method using a heat gun ($S=2.6$). In the process of research work in using thermal NDTM to identify grade wood defects in oak of initial moisture content, the following indicators of infrared radiation defects were obtained: knots – $t = 16...24$ °C, rot – $t = 22...27$ °C, cracks – $t = 24...31$ °C.

When heating industrial wood, there is a clear difference between the thermal radiation of defect-free wood and areas with violations, which can be explained by the following reasons: different heat capacity of wood and fixed defects; different humidity of individual sections of lumber; heterogeneity of the structure of wood, affects its emissivity.

The radiation temperature range of the main variety-forming wood defects at the corresponding blowing temperature (air) and blowing time is shown in Fig. 2.

Table 1. Part of the data set of experimental studies of the parameters for assessing the quality of oak lumber after heating.

Number in order	Digital image sample	Image of the thermal radiation of the sample before the experiment	Image of the thermal radiation of the sample after heating through 20 s
1			
2			
3			

As a result of experimental studies, overlapping of the infrared reflection temperature ranges of the studied wood defects was noted (Fig. 3); therefore, to clearly capture a

certain wavelength range of infrared (thermal) radiation from lumber defects, it is proposed to use RGB filters for a certain radiation wavelength spectrum.

Table 2. Part of the data set of experimental studies of the parameters for assessing the quality of oak lumber after cooling.

Number in order	Image of the thermal radiation of the sample after cooling for:		
	60 s	120 s	180 s
1	19.7°C FLI	17.0°C FLI	17.3°C FLI
2	18.5°C FLIR	17.9°C FLI	17.6°C FLIR
3	21.1°C FLIR	20.8°C FLIR	19.7°C FLIR

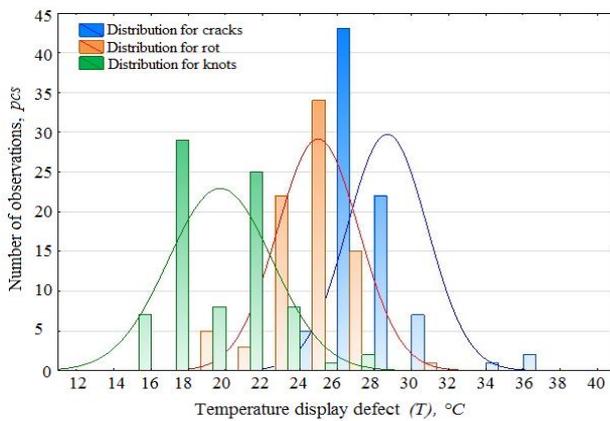


Fig. 2. Temperature range for displaying grade defects of wood when blown with air at 80 °C.

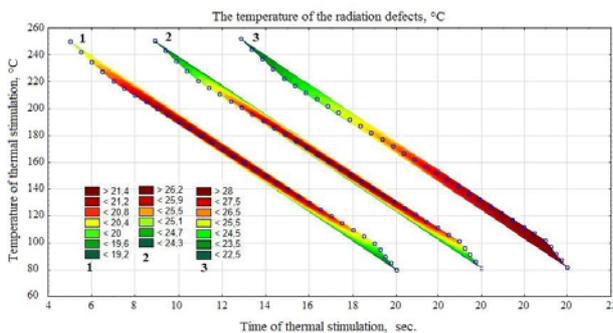


Fig. 3. The temperature distribution ranges of the display of the main variety-forming wood defects in oak lumber at a temperature of thermal stimulation: 1 – knots; 2 – rot; 3 – cracks.

Based on the research results, we obtained the regression dependences of the defects display temperatures on the main factors presented in normalized values for each of the variety-forming defects:

$$\text{– knots: } y_k = 22,23 - 3,38x_1 + 2,98x_2 - 2,13x_1x_2, \quad (F_{calc.} = 0,10; F_{tabl.} = 1,3), \quad (7)$$

$$\text{– rots: } y_r = 26,85 - 4,25x_1 + 4,40x_2 - 2,10x_1x_2, \quad (F_{calc.} = 0,11; F_{tabl.} = 1,3), \quad (8)$$

$$\text{– cracks: } y_c = 26,75 - 2,75x_1 + 5,85x_2 - 1,25x_1x_2, \quad (F_{calc.} = 0,16; F_{tabl.} = 1,3), \quad (9)$$

where is the

x_1 – temperature of thermal stimulation of industrial wood by air, °C; x_2 – duration of thermal stimulation of lumber, s.

To select operational parameters of the identification process for each of the studied oak wood defects in freshly sawn timber, the scale is proposed to determine the time of thermal stimulation (τ , s) and the temperature of the wood defects display (t , °C) depending on the temperature of thermal stimulation (T , °C) (Fig. 4).

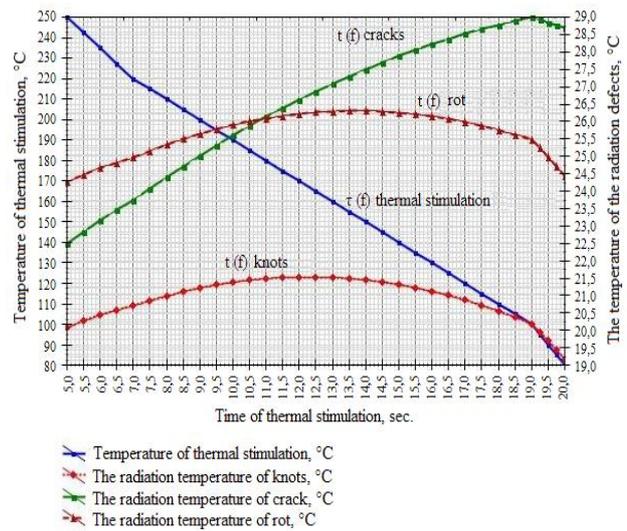


Fig. 4. The scale for determining the time of thermal stimulation (τ , s) and the radiation temperature of wood defects (t , °C) depending on the change in the temperature parameter of thermal stimulation (T , °C).

The duration of the photothermal imaging process for assessing the size and quality characteristics of industrial oak wood of initial moisture per running meter was established, which is in the range from 19 to 64 s with a fixing interval of 2 s, provided that the width of the board is not more than 350 mm and the scale factor is (K_m) – 6 (Fig. 5).

To carry out the research on the identification of oak wood defects in lumber of initial moisture content, a method and line were developed and proposed (Fig. 6) for the thermal non-destructive detection of defects, which are based on the use of photo-video thermal imaging of material surfaces and a hot air blowing lumber installation.

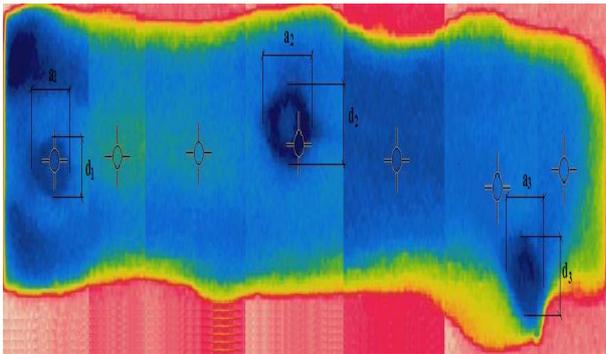


Fig. 5. An experimental study of the assessment of the quality of industrial oak wood using a thermal non-destructive testing method.

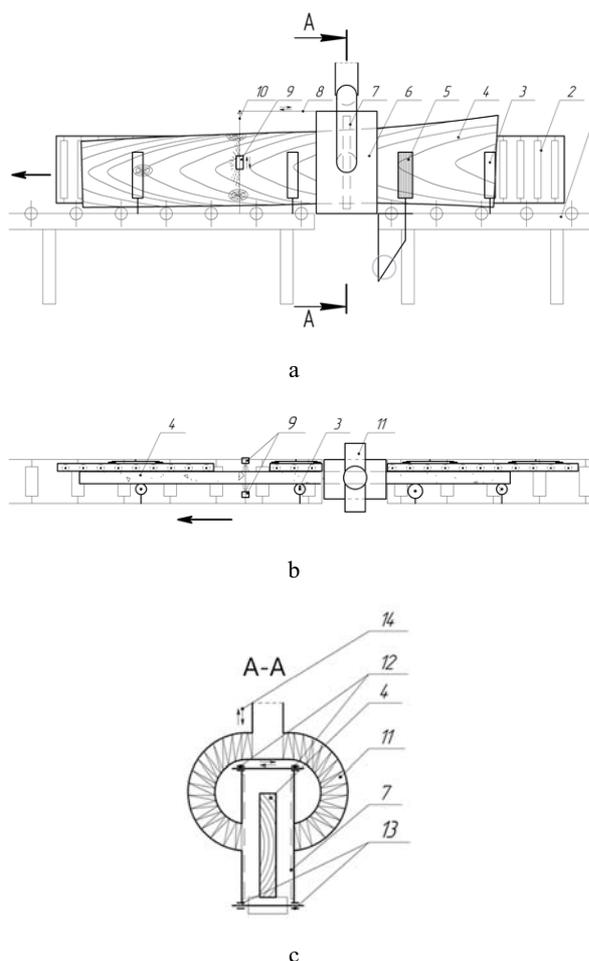


Fig. 6. The line of thermal non-destructive identification of variety-forming defects of lumber: a – frontal projection; b – horizontal projection; c – section AA frontal projection.

The line for thermal non-destructive detection of grade defects of industrial wood has: a roller conveyor 1, a support roller conveyor 2, pinch rollers 3, a drive pinch roller 5, an installation of blowing lumber 4 with hot air 6, a nozzle for the direction of air movement 7, horizontal guides 8 of the mechanism for regulating the photo and video heater 9 relative to the installation 6, the guides 10 of the mechanism for adjusting the distance of the video

and thermal imager 9 in height and width of lumber 4, corrugated pipe d 11 blowing agent supply timber (hot air), the upper guide 12 and lower guide 13 for adjusting the mounting mechanism 6 in the thickness range of timber, the guide mechanism 14 for adjusting the distance setting adjustment timber 6. Based on the results of the studies, in order to increase the efficiency of the use of wood raw materials, recommendations were developed for manufacturers of oak billets.

4 Conclusion

The results of experimental studies have confirmed the practicability of using the thermal control method to identify the main grade wood defects in oak timber by thermal imaging using heat stimulation by guns, the effectiveness of which is established by the signal-to-noise (S) criterion.

Regression dependences of the temperature of infrared radiation of grade defects of wood on the temperature and time of thermal stimulation of the board have been obtained, on the basis of which the scale for predicting the temperature of defect radiation has been developed, which allows to control the process of grade defect's identification.

The practical implementation of the research results is presented by the developed method and the line for the thermal non-destructive identification of grade wood defects in industrial wood, for which the control identification defects method have been developed and proposed.

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