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Investigation of round Scots pine wood WC01 class using X-ray computer tomography

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Abstract: *Investigation of round Scots pine wood WC01 class using X-ray computer tomography*. Scots pine is the most widespread type of wood in Poland with wide industrial use. The typical starting material used for the production of layered floor elements are logs of WC01 class (class according to the Polish Standard PN-D-95008: 1992 and Order no 72 - GM-900-5 / 2013 of General Director of the State Forests in Poland). Using X-ray computed tomography, tests of fresh wood in the bark were carried out, confirming the full suitability of this technique for the precise assessment of wood density as well as its grain and distribution of anatomical defects (knots). The different level of humidity of sapwood and heartwood in fresh wood is visible in tomographic images and translates into a much higher recorded density of the wetter zone of sapwood. Calibration of the tomograph used made it possible to convert the Hounsfield density scale into actual densities expressed in kg/m^3.

Keywords: X-ray computer tomography, quality of round wood, Scots pine wood, density of wood, annual rings, moisture content of wood

INTRODUCTION

Scots pine is a species that forms solid stands and is widespread throughout Europe, covering a compact area, especially in its northern and northeastern parts. All of Poland is within the range of this species, except for alpine areas. The growing stock of standing Scots pine wood in Polish Forests is assessed on 1612 mln m^3 (GUS 2020). Scots pine, due to its extensive range of occurrence, is characterized by high variability of morphological and habitual, physiological-growth, and adaptive-immunity traits [Andrzejczyk and Żybura, 2012], which also translates into high varied properties of the formed wood. The properties of pine wood also change within the trunk of one tree. In a typical breeding cycle (artificial, one-century-old plantings), the first annual increments are wide, with low density and low strength parameters, and with the distance from the core, the rings become narrower and the wood becomes stronger. The properties of wood change not only in the radial direction, but also at the height of the trunk (Dzbeński et al., 2000). This is important for the processing and use of this wood.

Scots pine wood (the trade name according to EN 13556: 2003) is also a popular species used for the production of many items (Wagenführ, 2007; Kozakiewicz, 2019), e.g. wooden floorings (Kozakiewicz et al., 2012, Laskowska et al. 2018) and building construction (Borysiuk et al. 2019). In this application, the most important is to fully recognize the quality of the wood, which can be used by modern, non-destructive diagnostic methods. Such methods include X-ray computed tomography, which, along with the increase in resolution, speed of operation and availability of tests, has been used for over three decades in the analysis of wood, including historic buildings (Kozakiewicz and Gawarecki, 2003). Tomography has also been adopted for the needs of the wood industry, including in the assessment of the quality of the raw material: logs and logs as well as sawn timber (Zatoń et al., 2018). Currently, the resolution of industrial tomographs has approached the diameters of individual structural elements of wood, breaking the barrier of microscopic structure, which opens up new research possibilities, e.g. in dendrochronology (Zatoń et. al., 2020), and for smaller-sized objects, X-ray computer microtomography can also be successfully used

(Watanabe et al, 2008; Van den Bulcke et al. 2009; Mayo et al., 2010], also in the analysis of the quality of glue joints (Paris et al., 2015) present in wooden layered floor elements, e.g. in Barlinek planks.

This study aims to determine the density variability of WC01 class fresh round pine wood used for the production of the middle and bottom layers in three-layer floorboards and to confirm the suitability of this research method for raw material quality assessment.

MATERIAL AND METHODS

The research material consisted of 6 pine logs (*Pinus sylvestris* L.) aged 50 years with diameters from 20 to 36 cm in the thick end, class WC01 (class according to the Polish Standard PN-D-95008: 1992 and Order no 72 - GM -900-5 / 2013 of General Director of the State Forests in Poland). The logs were obtained from the Krucz Forest District, Biała Forest District (Greater Poland Voivodeship). It was wood fresh in the bark, with paraffin emulsion protected on the foreheads (14 days elapsed from its harvest to the execution of tomographic examinations). The sapwood moisture was approx. 100%, the heartwood moisture approx. 35%. Due to the limitations resulting from the dimensions of the tomograph and the permissible mass of the tested objects, the logs were cut (divided) into 24 chops with a length of 0.73 m just before the measurement. Approximately 300 tomograms were obtained for each of the charts. The description of round wood was carried out per European standards EN 844, and its quality was visually assessed following the principles of classification of coniferous wood raw material, i.e. large-size coniferous wood according to PN-D-95008: 1992, taking into account the provisions of PN-D-01011: 1979 and the GM- Ordinance 900-5/2013.

X-ray computed tomography was used for the tests: CT NeuViz 16 with an integrated detector of the DAS system (16-row tomograph - activation of 16 layers with one gantry revolution in 0.5 s - minimum resolution 0.75 mm) - with measurement settings: HFP, 120 kV, 40 mA, CTDI val.:40, 3mGy, Helical scanning mode without contrast, the thickness of the scanning layer 1 mm, the diameter of objects up to 40 cm.

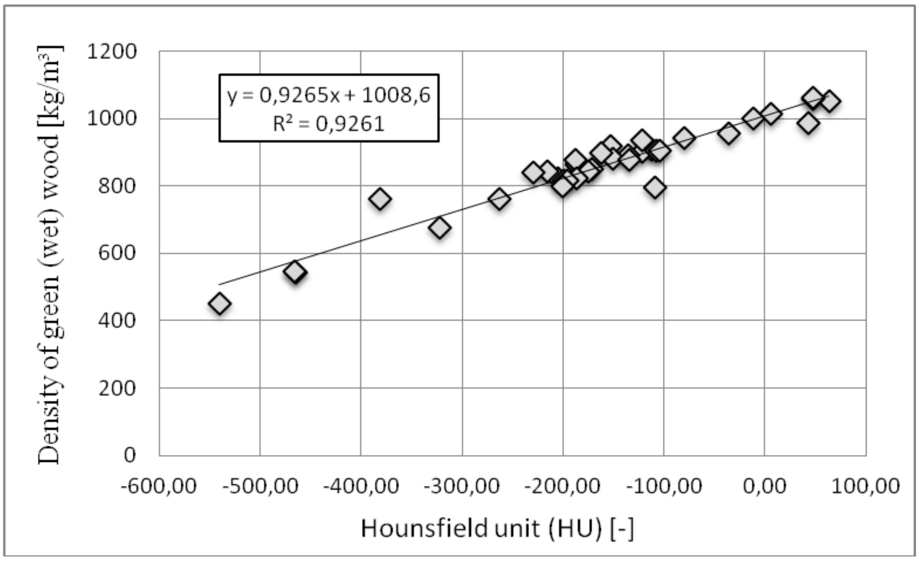

Figure 1. Model simple - the relationship between the Hounsfield density point scale and the actual density of wood in a wet state (in the CT NeuViz 16 CT CT scan used)

The obtained tomographic images were analyzed for density and grain, as well as for the types and arrangement of internal defects in RadiAnt DICOM Viewer. From the reconstructed images of pine wood (tomograms), the density given in the Hounsfield point scale (HU) was read, which was then converted to the actual density in kg/m^3, thanks to the earlier calibration of the tomograph at the set settings (identical to those used in the main tests). Equally, the conversion line (Fig. 1) was as follows:

$$\mathbf{g = 0.9265\ HU + 1008.6\ (cooficient\ of\ correlation:\ r = 0.99)}$$

where: g - density of Green (wet) wood [kg / m^3],
HU - density in Hounsfild unit (HU)

Determination of moisture by the dryer-weighing method was performed according to the ISO 13061-1: 2014 standard. As a reference point, the wood density was determined by the stereometric method according to ISO 13061-2: 2014.

RESULTS AND DISCUSSION

With the use of X-ray tomography, non-destructive simultaneous access to many "sections" of the wood (spaced - in the mode of operation used - by 1 mm from each other). Out of over 300 tomograms, this study presents three typical cross-sections (representative of the 6 tested logs): a cross-section through the knotless zone (Fig. 2), a cross-section through the zone right next to the knot whorl with visible streaks of resins (Fig. 3), a cross-section through the knotted zone (Fig. 4).

Density within single annual increments of pine wood changes even twice [Kozakiewicz 2012], which allows for capturing annual marginal overgrowths and assessing their width, especially in the zone of persistent wood (Fig. 2-4). Difficulty in recognizing uniform rings is the high moisture content of the sapwood, which "blurs" the differences between the density of early and latewood.

The humidity of freshly harvested pine logs is repeatable (Kozakiewicz et al. 2021). The humidity of the heartwood, which in living trees no longer conducts water, is lower and amounts to approx. 35%, while the sapwood is filled with water and its humidity is approx. 100%. These two different levels of moisture can be seen in the tomograms (Fig. 2-4) and allow for a precise indication of which zone of the log is sapwood and which heartwood (clearly different shades of grey). Based on the tomogram, you can also precisely determine the diameter of the log in the bark and without the bark.

Earlier calibration of the tomograph with the given settings allows for the conversion of the obtained data in the Hounsfield point scale and the actual density of the wood in the wet state. In the heartwood zone, a typical density variation is visible depending on the presence of juvenile wood and wider tri-core rings (Dzbeński et al. 2000; Kozakiewicz et.al., 2020; Konofalska et al., 2021). As the distance from the core increases (Figs. 2 and 3), the density gradually increases from the initial 500 kg/m^3 at the core to approx. 600 kg/m^3 at the boundary with sapwood. When it passes into the sapwood zone, the density increases by leaps and bounds to the level of approx. 950 kg/m^3 as a result of an abrupt increase in humidity. If the moisture content of the wood was reduced to one level (to calculate the densities, for example, according to the formulas given by Kozakiewicz 2012), the wood density would change smoothly without an abrupt increase. In whitewashed wood, there is a slight but significant tendency of increasing density along with moving away from the core, which is confirmed by the determined simple correlations and correlation coefficients (typical and given in figures 2 and 3). Summing up, the central part of the graph showing the density variation covering heartwood is similar to a parabola and in the sapwood zone, the graph has a rectilinear course.

The analysis of tomographic images allows, thanks to the significant differences in wood density, to detect the distribution of wood defects, such as gums (Figs. 3 and 4). The increase in wood density due to the presence of resin gives light areas in the heartwood area with a dark rim (the resin is a barrier to water penetration) in the wet white area. Thanks to this, the gums are visible in the entire volume of the logs.

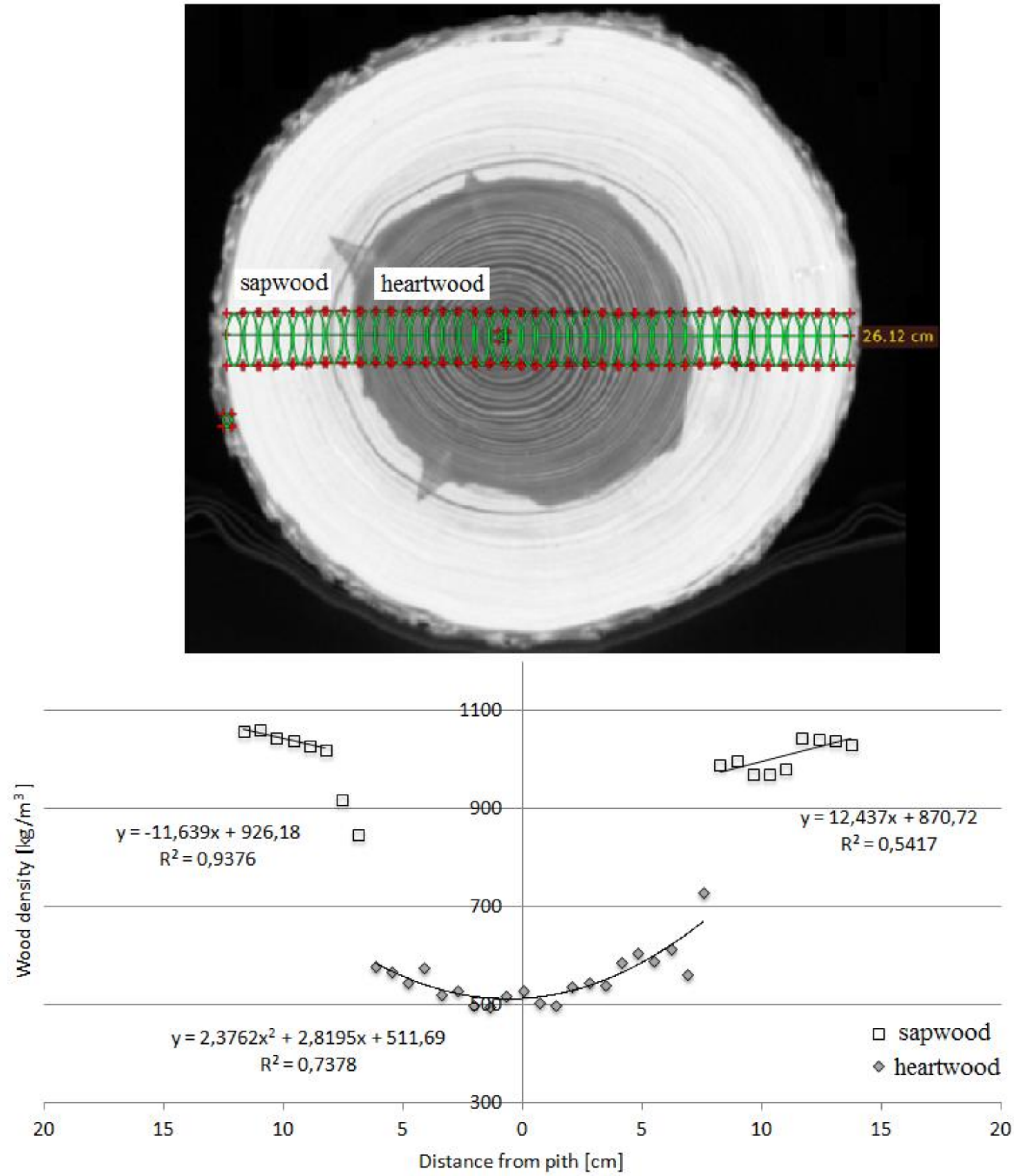

Figure 2. Relationship between pine wood density and distance from the core in log No. 2 (cross-section in a knotless zone)

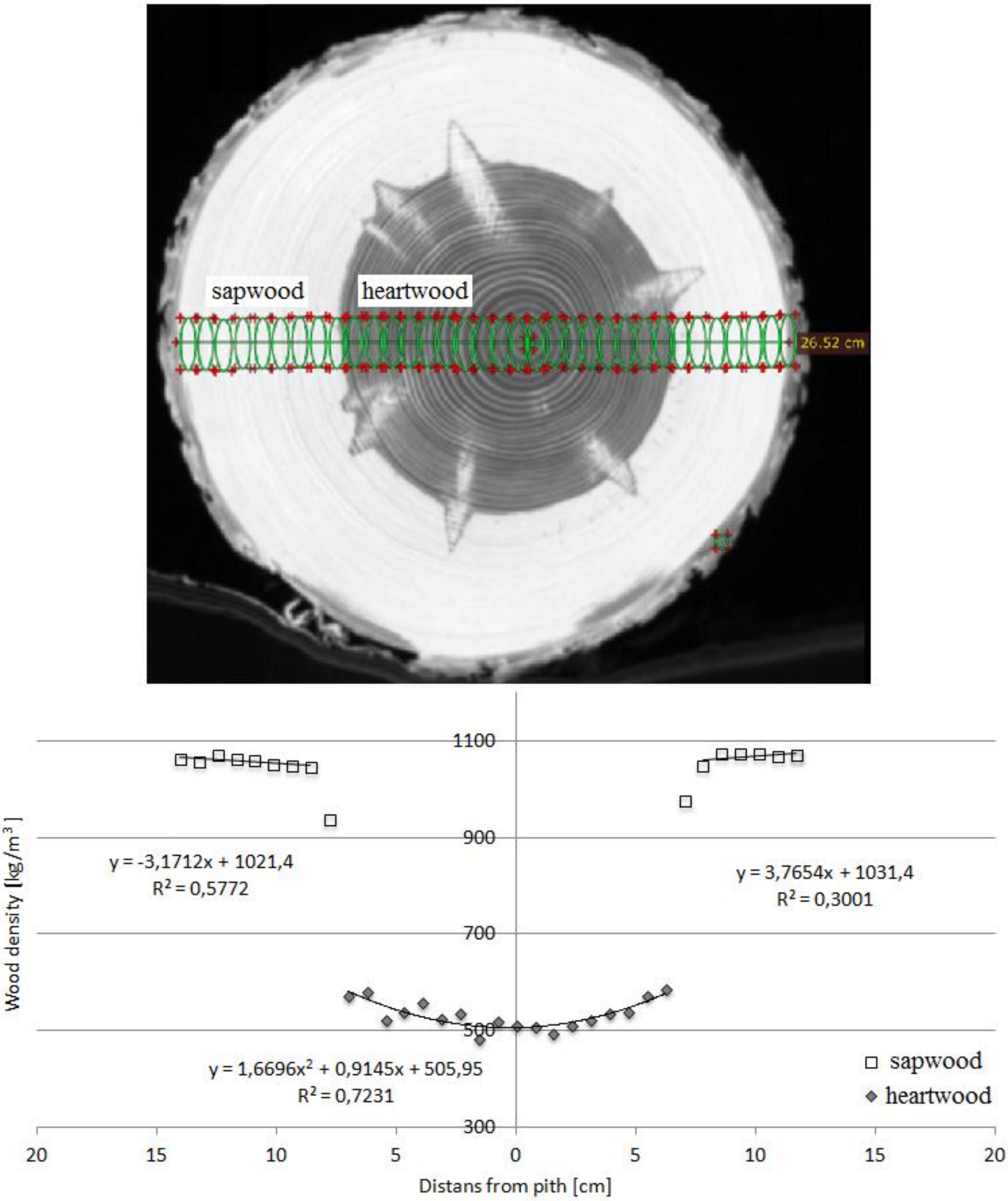

Figure 3. Relationship between pine wood density and the distance from the core in log no. 1 (cross-section just above the knot whorl - visible zones of survival)

An equally recognizable defect present in WC01 class logs is knots of different sizes. Within them, the darker (middle) zone of the heartwood and the lighter white zone are noticeable (Fig. 4). Generally healthy knots have a higher density than the surrounding wood tissue of the log (Kozakiewicz, 2012; Borysiuk et al., 2019), which is partly due to their narrowness and greater share of dense latewood as well as the presence of scleroderma wood typical of conifer knots. The ability to precisely assess the quality of pine wood intended for the production of layered flooring materials is of decisive importance in production efficiency 9Kozakiewicz et al., 20180.

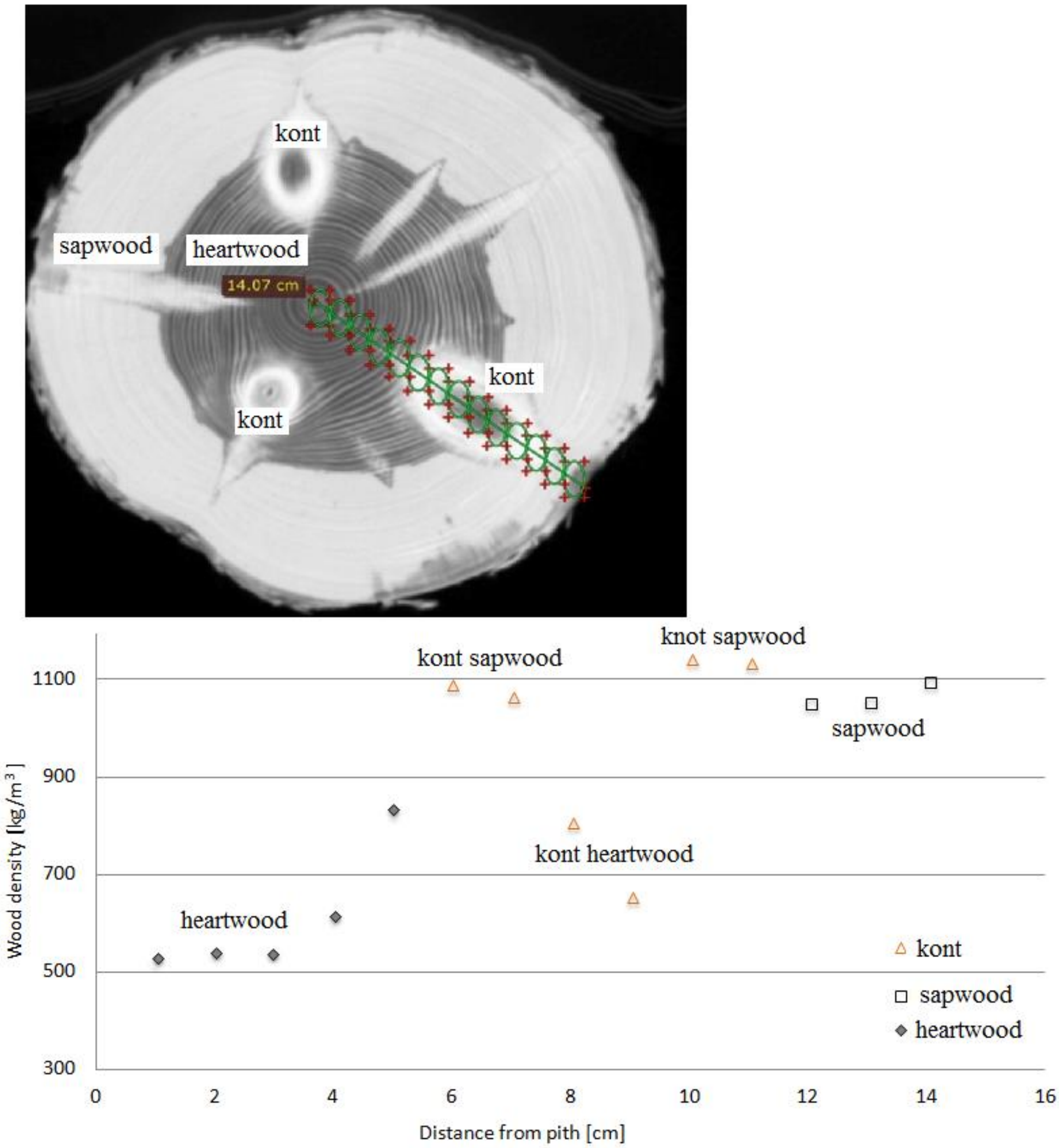

Figure 4. Relationship between pine wood density and distance from the core in log no. 3 (cross-section through the knot zone)

CONCLUSIONS

Using the CT NeuViz 16 X-ray computer tomography, it is possible to precisely determine the number and width of annual increments of pine wood in logs, especially in the heartwood zone. The high humidity of whiteness blurs the density differences and thus the distinctness of the rings.

The advantage of the computed tomography method is the readout of density in the Hunsfild point scale from the two cross-sections of the tested wood, which, thanks to the earlier calibration of the tomograph in a given mode of operation, can be converted into the real and practical wood density expressed in kg/m^3.

X-ray computed tomography is an effective tool for the precise assessment of the size and distribution of wood defects such as knots and gums, and thus the quality of the raw material. This solution, however, has its limitations and methodological requirements (e.g. it requires a proper arrangement of the wood and selection of the tomograph operating mode). In assessing the variability of pine wood density in logs, a hindering factor is the significantly different moisture levels of sapwood and heartwood, which, on the other hand, allows for the precise identification of these zones.

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Streszczenie: *Badania okrągłego drewna sosnowego klasy WC01 z zastosowaniem rentgenowskiej tomografii komputerowej*. Sosna zwyczajna to najbardziej rozpowszechniony gatunek drewna w Polsce o szerokim zastosowaniu przemysłowym. Typowym surowcem wyjściowym stosowanym do produkcji warstwowych elementów podłogowych są kłody klasy WC01. Przy wykorzystaniu rentgenowskiej tomografii komputerowej przeprowadzono badania świeżego drewna w korze, potwierdzając pełną przydatność tej techniki do precyzyjnej oceny gęstości drewna a także jego słoistości i rozmieszczenia wad anatomicznych (sęków). Różny poziom wilgotności drewna bieli i twardzieli w świeżym drewnie jest doskonale widoczny w obrazach tomograficznych i przekłada na zdecydowanie wyższą odnotowaną gęstość wilgotniejszej strefy drewna bielastego. Wzorcowanie zastosowanego tomografu w danym trybie nastaw pozwoliło na przeliczenie skali gęstościowej Hounsfilda na rzeczywiste i jednocześnie praktyczne wartości gęstości wyrażone w kg/m^3.

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