Production of compressed wood with target quality indicators from different parts of tree trunk

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Abstract. Wood species has great influence on the service life and quality of compressed wood. Currently, the industry lacks high-quality wood, so one of the solutions to this problem is the possibility of expanding the species composition used for the manufacture of compressed wood. The predominant group of species is soft hardwoods. It is advisable to use birch wood for the production of compressed wood. This conclusion is made on the bases of wood species stock and its physical and mechanical properties. Information on the nature of raw materials is needed to implement the pressing wood technology. Wood is a biological material whose properties change in the tree trunk. Changes in moisture content and wood density in the height of the tree trunk have been studied. The necessary degree of pressing has been determined on the basis of these data. It takes into account the required final density of compressed wood. Initial thickness of the specimens has also been calculated. This has made it possible to obtain a uniform density of compressed wood. It also reduces raw material consumption, taking into account from what part of the tree trunk the wood was taken.

1. Introduction
Wood is a very promising structural material for many industries. Currently, there is steady, constantly growing demand for wood, especially valuable hardwoods. The lack of high-quality wood in the production of railway sleepers is a critical problem.

It is possible to expand the industrial application of low-value wood to meet the ever-growing demand for wood in conditions of a sharp decline in the stock of both high-quality softwoods and hardwoods. They are not widely used. Low-value species include soft broadleaved species. The stocks of this wood are significant (birch, aspen, alder, etc.).

Service life of wooden products largely depends on the quality of wood. Significant disadvantages of soft deciduous species are their low density and low biostability. One of the promising directions for solving the problem of replacing valuable hardwood with low value species is improving its quality by pressing [1]. The higher the density, the higher the strength and biological properties of wood are, and the higher its service life is.
Density is a characteristic of all manufactured materials (plastics and metals) in various fields of application.

Consumer properties of pressed wood largely depend on the conditions and parameters of the compaction process. Production conditions affect the properties of pressure-treated wood. A number of scientific papers are devoted to the studies of influence, direction, speed and compression ratio, the influence of compression on the speed of decompression, and mechanical properties of wood [5-9]. There are studies in the field of the influence of deformation transformations on the character of restructuring in the nanostructure of wood. They are aimed at improving the shape stability of wood, performed on small and clear specimens [10].

Raw materials from various parts of tree trunk are used in the production of pressure-treated wood. Wood is an anisotropic material of biological origin, the properties of which are variable in height and cross section of the trunk [2, 3]. However, there is no exact information in literature about the degree and nature of the influence of wood density variability along the height and cross section of the trunk. This complicates the production of compressed wood with uniform density and quality for the entire batch of manufactured products.

In connection with it, the aim of the research has been formulated: to obtain compressed wood with target quality indicators from different trunk parts.

One of the main indicators of wood quality is its density and hardness.

Density is a characteristic of the given species. It affects all the physical and mechanical properties of wood [11]. It largely determines the quality and service life of products. Density should be taken into account when planning the work of further processing of the material. It largely determines the service life of products and their quality. The density of wood is determined by physical and mechanical properties of wood and its structure.

The features of wood species anatomical structure do not have a significant impact on this relationship (1). On the basis of this dependence P. N. Khukhryanskiy put forward the main position of the pressing theory, which is that "the strength of wood of all the species can be increased by compacting it. It can be done only when this compaction is not connected with the destruction of cells. Wood of any tree species should not be deformed" [2]. In order to increase the density of soft hardwoods, they must be compacted by pressing. Increased service life of pressed wood products will make its use efficient and competitive [3, 4].

Production of pressed wood on an industrial scale is an urgent task (both theoretical and practical), the solution of which enables more rational use of wood resources.

The choice of species for the production of compressed wood largely depends on physical and mechanical properties of wood and its stock.

According to the state forest register as of January 1, 2015, wood stock in the forests of the Russian Federation is about 80-81 billion m³. 75 % of which is coniferous wood, soft deciduous plantations are 19.6 %, hardwoods – 2.4 % and other – 9.8 %. The main soft deciduous diffuse-porous species are birch, aspen, linden, alder, willow, poplar, walnut, etc. The percentage of the soft deciduous species in the forests of Central Russia is as follows: the share of birch is 13%, the timber stock is 248.2 million m³; aspen - 3.5%, the timber stock is 66.8 million m³; linden is 0.3%, the timber stock is 5.7 million m³; alder is 0.2%, the timber stock is 3.8 million m³. The stock of these species is insignificant that limits their industrial use. In addition, the wood of some of these species has a number of unique properties. It is recommended for the use in special industries. It is advisable to use birch wood for the production of pressed wood. This conclusion has been made on the basis of the volume stock of tree species and its strength indicators [1].

Compaction of wood of diffuse porous species proceeds simultaneously over the entire thickness of the annual layer during the pressing process. It provides the production of pressed wood with uniform density and strength throughout the annual layer.

Compressed wood made of soft deciduous species successfully replaces the wood of valuable hardwoods. It also competes with various types of structural and technological materials (plastics and metals) in various fields of application.

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The formula for determining the density of wood is as follows:

\[
\sigma = a + b\rho
\]

Where \( \sigma \) – strength of wood, MPa;
\( a, b \) – constant coefficients depending on the species;
\( \rho \) – wood density, kg/m³.

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into account when using wood as structural and technological raw materials.

Hardness characterizes the quality of wood as a structural and technological material in a whole way. Hardness value gives the information on the degree of difficulty of mechanical wood processing, etc.

Density distribution of wood inside a tree trunk is of great practical interest. Data on the density variation in the different parts of the tree trunk (butt, midline and top) enable to justify the initial dimensions of the specimens and the degree of their pressing. Different degree of wood pressing enables to obtain a material with predetermined homogeneous indicators of density, and, consequently, with given indicators of quality and operational characteristics.

### 2. The methodology of the experiment

The research was carried out using warty birch, growing in the territory of the Voronezh region.

To determine the variability of changes in the density of wood in the height of the trunk, trees with a diameter of 26 cm or more were selected and cut into blocks. Each tree was sawn in 9 blocks with a length of 1 meter. A smaller block with a thickness of 3.0-3.5 cm was cut at the beginning of every large block. Then the bark with bast layer was taken off and the density and moisture content of each disk was determined according to 16483.1-84 and 16483.7-71 State Standards. This method of sampling at relative heights enables to determine the nature of changes in density and humidity of wood along the height of tree trunk.

The initial thickness of the boards and the necessary degree of compression was calculated. The calculations were made using the data of moisture content and density from the butt, middle and top parts of the trunk. The required final density of compressed wood (750 kg/m³) and thickness of the sleepers (180 mm) were taken into account. The initial thickness of the bars from the butt end of the trunk, taking into account the allowance for shrinkage was 198 mm, from the middle part – 217 mm and from the top – 230 mm. Degree of pressing of the bars from the butt end of the trunk was 7.2 %, from the middle part – 15.1 %, from the top – 20.3 %.

Then the bars were subjected to atmospheric drying from the moisture content of freshly chopped wood to the final moisture content of 22 %. After atmospheric drying, the bars were heated in an autoclave with water vapor at a temperature of 125 ºC for 3.5 hours. As a result of heating, the moisture content of the bars increased by an average of 3 %. After heating, the bars were pressed and fixed in the mold and subjected to atmospheric drying for 12 days, until a humidity of 22 %. Size fixing was made. Then, 30 cm blocks were cut from the middle part of pressed timber bars. Static hardness in the radial direction and the average density of pressure-treated wood were determined using these blocks.

The study of static hardness of wood was performed in accordance with 16483.17-81 State Standard. Static hardness was determined in the transverse direction.

### 3. The results of the experiments

The change in the density of natural birch wood along the height of the tree trunk was determined by the thickness of 3.0-3.5 cm blocks, cut through each meter starting from the butt end (table 1). The results of experimental studies of changes in moisture content and density of birch wood along the height of the tree trunk are presented in table 1.

| Table 1. Distribution of moisture and density birch wood along the height of the tree trunk. |
|----------------------------------|---|---|---|---|---|---|---|---|---|
| Height, m                        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Initial moisture content, W, %   | 52.0 | 52.5 | 50.2 | 50.4 | 54.1 | 56.9 | 66.0 | 67.6 | 62.5 |
| Density ρₘₚ, kg/m³               | 890.0 | 840.6 | 828.0 | 819.6 | 801.0 | 794.2 | 790.0 | 781.2 | 767.1 |
| Density ρ₁₂₃, kg/m³              | 719.0 | 680.0 | 679.0 | 640.5 | 635.5 | 620.8 | 609.0 | 589.3 | 582.0 |
The reduction in the density of natural birch wood along the height of the trunk from the butt to the top is 15.2 kg/m$^3$ or 2.11 % per meter. These data were obtained for density determination on the blocks cut at every meter height of the trunk.

Based on the research, it is possible to determine the average density for the production of pressure-treated wood, taking into account their location in the trunk of the tree (butt, middle and top of the trunk).

Figure 1 shows the average density of birch specimens from the butt, middle and top parts of the trunk. The density of compressed wood obtained from these specimens is also shown.

The diagram presented in figure 1 shows that the block cut from the butt of the trunk has the highest density of 697 kg/m$^3$ at a moisture content of 22 %; the block from the middle part of the trunk has a density of 648 kg/m$^3$ and the block from the top part has a density 585 of kg/m$^3$. Decrease in the wood density (in comparison with the most dense butt part of the trunk) is 7.0% in the middle part of the trunk, and 16.1 % in the top.

The density of pressure-treated birch wood, taking into account the calculated degree of pressing and the initial size of the sleeper bar, was 754 kg/m$^3$ from the butt end of the trunk, 749 kg/m$^3$ from the middle, 759 kg/m$^3$ from the top. The deviation of density of the pressure-treated wood from the set value was 0.1-1.2 %, i.e. compressed wood with equal density, and, consequently, quality was produced from various parts of a tree trunk.

Figure 2 shows the results of the study of the static hardness of pressure-treated wood in the transverse direction.

The static hardness of birch wood from the butt, middle and top of the trunk is different. The difference in the static hardness of wood between the butt and the top parts of the trunk is 16.2 % (figure 2). Pressure-treated wood from different parts of the tree trunk has more uniform static hardness. The difference in static hardness of compressed wood from the butt and top parts of the trunk does not exceed 3.8 %.

Considering the initial density of the raw materials, depending on their position in the tree trunk, as well as their degree of pressing, it is possible to obtain compressed wood of the same density. Hence, it is homogeneous in strength and performance properties (figure 3-1).

According to the recommendations of R 56879-2016 State Standard, the initial size of the bars in thickness is 265 mm. The thickness of the pressure-treated wood should be 180 ±5 mm regardless of the place of cutting. Based on the initial thickness of timber before pressing and final thickness after pressing, the degree of pressing is calculated, this is 32.1 %. This degree of pressing is the same for all the bars of the butt, middle and top parts. The density of pressure-treated wood obtained according to
The density of bars from the butt part was 960 kg/m³, from the middle - 875 kg/m³ and from the top - 821 kg/m³. It does not meet the requirements of R 56879-2016 State Standard (720–800 kg/m³). Sleepers made from butt, middle and top parts of a tree trunk have different density, strength and performance.

The density of pressure-treated wood obtained in an industrial plant, taking into account the density, degree of pressing and the initial dimensions of the birch bars from the butt, middle and apical parts of the tree trunk, is presented in figure 3. The density of sleepers from the butt part was 754 kg/m³, from the middle - 749 kg/m³, and from the top part - 759 kg/m³. Deviation of the density of compressed wood from the given was 0.1–1.2 %, i.e. wood with equal density, and, consequently, homogeneous quality indicators, i.e. improved performance, was produced.

![Figure 2](image)

**Figure 2.** Average static hardness of wood in the radial direction at normalized moisture content (W = 12 %).

![Figure 3](image)

**Figure 3.** Estimated density of compressed sleepers made of birch wood.
4. Conclusions
The value of density reduction of natural birch wood growing in the Voronezh region in the height of the trunk from the butt to the top was found. By an average it is 15.2 kg/m$^3$ or 2.11 % per meter.

The variability of the static hardness of natural wood along the height of the trunk was found. It is 16.2%. Variability of the static hardness of pressure-treated wood obtained from various parts of the tree trunk does not exceed 3.8%.

Degree of birch wood pressing was substantiated based on the variability of wood density in the tree trunk. It makes it possible to determine the initial thickness of the blocks, which provides equal density of pressed wood sawn from butt, middle and top parts of the tree trunk.

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