Increasing the service life of sleepers made from birch wood

A D Platonov1*, T K Kuryanova1, M A Mikheevskaya2 and S N Snegireva1

1Timber Industry faculty, Voronezh State University of Forestry and Technologies named after G.F. Morozov, 8 Timiryazev st., Voronezh 394087, Russian Federation
2Chair of Technology and Logging Machines, Ukhta State Technical University, 13 Pervomaiskaya st., Republic of Komi, Ukhta 169300, Russian Federation

*E-mail: aleksey66@yandex.ru

Abstract. In construction of railway bed, sleepers of various materials are used: wooden, ferro-concrete, steel and polymer ones. Of all the sleeper types, wooden ones have the greatest distribution, possessing some performance characteristics inherent only in wood. The disadvantages of wooden sleepers are: short service life; using commercial timber of valuable species, the reserves of which are severely depleted. It is possible to meet the demand for wooden sleepers using wood of soft leaf-bearing species. These species are of low cost, but inferior to hardwood in density. It is possible to increase wood density by its modification (compressing). The predicted service life of sleepers from modified wood is higher than that of sleepers from natural wood. Considering its significant reserves and physical-mechanical properties, the most suitable of all soft leaf-bearing species is birch. Reducing the cost price of sleepers from modified wood and increasing the efficiency of their production is possible when compressing several billets simultaneously by height in the compression mold. This research studies the density and compression ratio of wood with uniaxial compression of four billets, regarding their location, the duration of exposing them in the compression mold after pressing, and the initial moisture content of wood.

1. Introduction

Wood is a unique material, which has an exceptional value for almost all branches of the national economy, and is available on an industrial scale.

Multipurpose use of wood is determined by its unique properties. First of all, it is a restorable natural resource. The variety of wood species makes it possible to satisfy almost any requirements imposed on this material. Wood has high specific strength, performance and durability characteristics, which allows using it as a building material. Unique amortization properties, such as impact bending strength, ability to suppress vibrations, make wood very valuable the main material for the production of sleepers.

Russian railway transport system is one of the largest railway networks in the world. In terms of freight turnover, Russia is the leader in Europe and the second in the world.

Sleepers are the elements of the upper structure of any railway track, and they are designed to provide the consistency of the track width, the transfer of the load from the rail to the ballast cushion, and fixing the track to the roadbed. The choice of material for manufacturing sleepers is based on such major factors as cost counting for all the service life and performance characteristics [1].

On the railways of the world, several types of sleepers are mainly used: ferro-concrete, steel, polymer (plastic) and wooden. The main flaws of ferro-concrete sleepers include: the absence of
damping properties, which leads to the destruction of wheel sets; increase in cases of electric shock due to high conductivity of the current by ferro-concrete; forced replacement of worn out shock-absorbing gaskets every 7-8 years, resulting in high costs when operating a railway. Steel sleepers - aside from advantages, are prone to corrosion, and have a high cost, so their use is limited. The use of plastic sleepers, despite their advantages: ensuring homogeneity and resilience of the roadway throughout the railway track, the possibility of their re-use, is also strongly limited by the high cost and the lack of a raw material base in the required volumes.

Wooden sleepers have received the greatest application, due to a number of unique performance characteristics inherent only in wood. These sleepers, unlike other types, have no restrictions in their use. The main flaws of wooden sleepers are a short service life and using expensive commercial timber.

Price comparison of different types of sleepers on the national market of the Russian Federation is as follows [2]: wooden sleepers - from 950 rubles up to 1200 rubles apiece; ferro-concrete sleepers - from 3500 to 4000 rubles apiece; metal sleepers - from 3000 to 4000 rubles apiece, polymer sleepers from 3500 to 4500 rubles [1].

The service life of pine sleepers is no more than 12-15 years; sleepers made of hard wood - about twice as high; ferro-concrete, metal and plastic sleepers - about 30-50 years [2].

Originally, wood was of prime use for the production of railway sleepers - it is a highly available industrial material that can be easily processed. In most developed countries of Western Europe, Japan, the United States, that have a large length of railways, the reserves of commercial timber for the production of sleepers are almost exhausted. Wooden sleepers in these countries are made from imported hardwood.

In Russia, the main raw material for the production of sleepers is provided by coniferous species, primarily pine, logged in the regions of the Northern Ural and Siberia. Such wood is optimally suitable in geometric parameters and physical-mechanical characteristics, significantly exceeding the wood from the central part of European Russia. In addition, it can be easily impregnated, which allows protecting it from decay and other destructive factors. A significant flaw of this wood using is that the stocks of such wood in the Central Zone and in Ural region are practically depleted, and in Siberia and the North, where there are significant reserves, very few access roads are available to transport wood.

However, the main impediment in the selection of wooden sleepers is a depleted raw material base. At the same time, a large amount of soft leaf-bearing species (birch, aspen, alder, poplar, etc.) annually rot in the cutting areas of Russia. With a deficit of coniferous wood, sleepers can also be made from wood of soft leaf-bearing species. The cost of raw materials of these species is lower than that of conifers.

Wood, like other products of biological origin, is subject to biological lesions.

Soft leaf-bearing species are considered to have a low class of biostability, so sleepers made from this wood quickly rot, that reduces service life of products. To increase the biostability and form stability of products, wood needs to be impregnated with antiseptics.

For the most effective use of wood of soft leaf-bearing species for engineering purposes, it is necessary to take into account the indices of their physical and mechanical properties. The most important indicator of the properties of wood is its density, which determines the durability of wood products. The disadvantage of wood of soft leaf-bearing species is its lower density, and consequently, the durability of some of these species is lower than that of conifers.

There is the closest correlation between density and durability - as the density increases, so durability is increased too. Increase in density can be achieved by compressing the wood and biological durability and form stability - by impregnation of wood with the mixture of antiseptics and a stabilizer.

Sleepers made of modified wood of leaf-bearing species with high-quality impregnation, in terms of their physical and mechanical properties, are not inferior to sleepers made from natural coniferous wood. After compressing, the dielectric properties of the wood increase, and the damping-depreciation properties remain at the level of natural wood. The predicted service life of sleepers from modified...
wood is about 30-50 years, which is significantly higher than that of wooden sleepers made from natural coniferous wood [2].

The choice of species for the production of railway sleepers is primarily determined by the properties of the wood species and its reserves in the forests of the Russian Federation.

Of all soft leaf-bearing species in the Central Federal District, birch stands at 13 %, timber stock - 248.2 million m$^3$; aspen is 3.5 %, timber stock is 66.8 million m$^3$; linden is 0.3 %, timber stock is 5.7 million m$^3$; alder is 0.2 %, timber stock is 3.8 million m$^3$; the remaining soft leaf-bearing species are 0.1 % or less each. The reserve of these species is insignificant, which limits their industrial use.

Moreover, the timber of some of these species has a number of unique properties and is recommended for use in special manufactures. Considering the significant reserves of birch wood and its physical and mechanical properties, it is expedient to use this species for the production of modified timber.

Reducing the prime cost of railway sleepers from modified wood and increasing the efficiency of their production is possible when compressing simultaneously four or more sleepers. Voronezh State University of Forestry and Technologies has developed the theoretical foundations of the technology for producing railway sleepers from modified wood. The main equipment for this technology is an installation for simultaneous compression of four billets by height from wood of soft leaf-bearing species [3].

A number of scientific researches have studied the effect of the ratio, direction and speed of compression, the effect of compression on the speed of decompression, and the mechanical properties of wood [4-6]. There are researches of the effect of deformation transformations on the nature of restructuring in the wood nanostructure aimed at improving the form stability of wood, performed on small, clean samples [7]. In literature sources, there are no data on the compression ratio of billets laid in a compression mold in the amount of four pieces by height. These data are necessary for the development of technology for the production of modified timber with an identical density and quality.

To obtain the data on the compression ratio of billets, taking into account their stacking in the compression mold by height, it is necessary to conduct experimental research. Thus, the purpose of this work is to determine the compression ratio of billets considering their initial moisture content, the location of their stacking and the duration of exposing them in the compression mold.

2. The methodology of the experiment

For the experiments, quarter sawn samples from green birch wood with dimensions of 30 × 56 × 150 mm were cut out. Then in the laboratory, the moisture content of the samples was brought to 66%, 34% and 20%. Four samples with the same moisture content were stacked into the compression mold according to the scheme shown in Figure 1.

After that, the samples were being compressed in the compression mold in the transverse direction using the method of uniform uniaxial pressing at a speed of 0.25 mm/s. The total average compression ratio of all the samples in the compression mold made 29% at different initial humidity of the samples (66%, 34% and 20%).

Then the samples of wood in the compression mold were placed into a drying chamber and dried to the moisture content of 15 % at the temperature of 115 °C. After drying, the samples were kept in the compression mold under room conditions for 1, 3 and 7 days according to the experiment plan. After exposing, the samples were taken out of the compression mold and their compression ratio was determined.

The compression ratio under uniaxial compressing was determined by the formula

$$\varepsilon = \frac{h_0 - h}{h} \cdot 100\%,$$

where $\varepsilon$ is the compression ratio,%.

$h_0$ and $h$ are the initial and final dimensions of the billet in the compression direction, mm.
3. The results of the experiments
The results of the experiments are presented in Table 1 and Figure 2.

![Figure 1. Arrangement scheme of the samples in the compression mold.](image1)

![Figure 2. Compression ratio of birch wood.](image2)

The compression ratio of the samples according to the scheme of their arrangement in the compression mold is irregular. Analysis of the curves shown in Figure 2 allows us to conclude that Samples 2 and 3, located in the middle of the mold, had the smallest compression ratio. Sample 1 from the side that transmits the pressure of the site (P) (Figure 1) and Sample 4 located at the bottom of the mold had a higher compression ratio than Samples 2 and 3. The difference between the compression ratio of Samples 1 and 4 depends on the moisture content of the wood. At an initial moisture content of 66% (experiment 1), the difference in the compression ratio was about 3.2%, at an initial moisture content of 34% (experiment 2 and 3), the difference in the compression ratio was 2.8%, at an initial moisture content of 20%, the difference in the compression ratio was 4.4% (experiment 4). Consequently, the higher the initial moisture content of wood while pressing, the more compressed the wood, regardless of its location in the mold.

In experiments 1, 2 and 3 free moisture in the wood while compressing acts as a plasticizer, even at room temperature. Therefore, the difference in the compression ratio of wood at a humidity of 66%
and 34% is insignificant (3.2% and 2.8%). In the absence of free moisture (experiment 4 Figure 2), air-dry wood is in the state of natural glazing, and it is characterized by only elastic deformation, so the difference in the compression ratio between Samples 1 and 4 was 4.4%. The upper Sample 1 from the side of the application of pressing force was deformed more under the action of the load. For the lower Sample 4 at the bottom of the mold the pressing force was less, hence the compression ratio was less.

The presence of free moisture in the wood requires less pressing force than that for wood with only bound moisture to achieve the same compression ratio. While compressing the green wood in experiment 1 (initial moisture content 66%), the pressing force made 0.053 MPa, in experiments 2 and 3 (initial moisture content 34%) 0.055 MPa, in experiment 4 (initial moisture content 20%) 0.063 MPa.

To reduce the energy consumption of the wood compressing process, moisture content should be close to the saturation limit of the cell walls - about 30%.

**Table 1.** Variation of compression ratio and density of samples of birch wood by height of the compression mold.

| No. of samples in the compression mold | Compression ratio,% | Average value of density $\rho$, kg/m$^3$ | Exposing time in the compression mold $\tau$, days | Moisture content of samples,% |
|---------------------------------------|----------------------|------------------------------------------|-----------------------------------------------|-------------------------------|
|                                       |                      | before compression $\rho_0$ | after compression $\rho_{15}$ |                                      |
| Experiment 1                          |                      |                             |                                      |                               |
| 1                                     | 34.4                 | 840.3                      | 909.2                                | 1                             | 66                            |
| 2                                     | 26.4                 | 806.8                      | 781.9                                | 3                             | 34                            |
| 3                                     | 22.1                 | 884.1                      |                                      |                               |
| 4                                     | 33.3                 |                            |                                      |                               |
| Experiment 2                          |                      |                             |                                      |                               |
| 1                                     | 31.0                 | 722.3                      | 739.5                                | 3                             | 34                            |
| 2                                     | 24.8                 | 720.0                      |                                      |                               |
| 3                                     | 26.2                 | 737.0                      |                                      |                               |
| 4                                     | 31.9                 | 740.9                      |                                      |                               |
| Experiment 3                          |                      |                             |                                      |                               |
| 1                                     | 35.4                 | 687.0                      | 889.4                                | 7                             | 34                            |
| 2                                     | 27.8                 | 817.7                      |                                      |                               |
| 3                                     | 27.1                 | 815.5                      |                                      |                               |
| 4                                     | 35.4                 | 886.5                      |                                      |                               |
| Experiment 4                          |                      |                             |                                      |                               |
| 1                                     | 29.4                 | 671.3                      | 849.1                                | 1                             | 20                            |
| 2                                     | 24.3                 | 807.9                      |                                      |                               |
| 3                                     | 23.9                 | 791.8                      |                                      |                               |
| 4                                     | 28.1                 | 827.1                      |                                      |                               |

The effect of the duration of exposing the samples in the compression mold after drying is shown in Figure 2 (curves 2 and 3). At an exposing time of 7 days, curve 3, the compression ratio of samples 1 and 4 is the same. At an exposing time of 3 days, the difference in the compression ratio made 2.8%. Long-term exposure of the samples in the compression mold with fixed dimensions ($\varepsilon = \text{const}$) leads to relaxation, i.e. release of stresses. Taking into account the time factor, wood under load manifests rheological properties, with constant deformation ($\varepsilon = \text{const}$), stress relaxation occurs; with
constant stress (\(\sigma = \text{const}\)), the fluidity of the material occurs depending on the direction of the applied force (compressing or stretching).

As a result of the research performed, it was established that the compression ratio of the samples depends on their location in the compression mold and the direction of the pressing force. The density of wood in the tree trunk decreases from the butt to the apical part. Therefore, assortments cut from different parts of a tree should be placed in the compression mold considering their initial density. The densest samples from the butt end are placed in the center of the mold. The least dense samples from the apical part should be placed on the side of the applying of pressing force. Samples with medium density from the middle part of the stem should be placed on the bottom of the compression mold. Such stacking of assortments that takes into account their initial density, will allow receiving the pressed wood of homogeneous density, i.e. quality.

4. Conclusions
Based on the experimental researches, it is established that the compression ratio and the density of the modified wood depend on the density and initial moisture content of raw materials and the location of samples by height in the compression mold. The exposing time for the samples in the compression mold in the fixed state (deformation \(\varepsilon = \text{const}\)) under room conditions affects the relaxation time (release of stresses), that is, the stabilization of the pressed wood size. The results of the research can be used for rationalization of compressing wood technology.

This will allow obtaining compressed wood with uniform quality indicators regardless of the location of the raw materials in the tree trunk.

Acknowledgments
The work is carried out within the framework of the state assignment No. 11.3960.2017 / 4.6.

References
[1] Railway transport in Russia: current status, problems and prospects development [Electronic resource] Access mode: http://viperson.ru, free (Date 07.06.2017)
[2] Advantages of thermally modified wood [Electronic resource]. – Mode access: http://www.teletap.org, free. (Date of circulation on May 24, 2017)
[3] Kuryanova T K, Platonov A D, Mikheevskaya M A, Snegireva S N and Pervakova E M 2018 Theoretical foundations for the production of modified wood Forestry Journal [Lesotekhnicheskiy zhurnal]. 8/1(29) 146-154 DOI: 10.12737/article_5ab0dfc30d6f83.06547595
[4] Zhao Y 2017 Studies on pre-treatment by compression for wood drying III: the reduction of moisture content, the recovery rate, and mechanical properties of wood compressed at different moisture content conditions Journal of Wood Science 63(3) 209–215
[5] Zhao Y, Wang Z, Iida I, Huang R, Lu J and Jiang J 2016 Studies on pre-treatment by compression for wood drying II: effects of compression ratio, compression direction and compression speed on the recovery rate and mechanical properties of wood Journal of Wood Science 62(3) 226–232
[6] Zhao Y, Wang Z, Iida I, Huang R, Lu J and Jiang J 2015 Studies on pre-treatment by compression for wood drying I: effects of compression ratio, compression direction and compression speed on the reduction of moisture content in wood Journal of Wood Science 61(2) 113–119
[7] Gorbacheva G A, Ugolev B N, Sanaev V G and Belkovsky S Yu 2016 Characterization of the memory effect of beech wood form by thermomechanical methodspec trometry Bulletin of the Moscow State Forest University - Lesnoy Vestnik [Buliten Moskovskogo Gosudarstvennogo Universiteta Lesa - Lesnoy Vestnik] 20(4) 10-14