Railroad ties produced from modified wood for cold climate regions

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Abstract. Cold climate regions need railroad ties with improved operational characteristics during the construction and repair of railroad tracks. The aim of the study is to create a technology and equipment allowing the manufacture of such sleepers. Low-value soft hardwoods, oily antiseptic, and drying press chamber are needed for the production of sleepers with improved performance characteristics. Technological modes for producing sleepers with high performance characteristics of softwood have been tested using the installation which enables to combine technological operations - drying, treatment, and wood pressering. The resulting sleepers can be used in the Extreme North conditions. The half ties have been laid at Chistye Prudy metro station in Moscow, and the ties have been laid at Scherbenka station on the experimental ring of Russian Railways (JSCo «RZD»). The tests have been carried out for four years in underground railway system and for two years on the ring of Russian Railways. The test results have found that wear of modified sleepers and half ties is about 3 times less than wear of pine sleepers and the average service life of sleepers made of modified wood will be about 50 years. An experimental batch is currently being manufactured.

1. Introduction

In the Russian Federation, at least 10% of the areas are located in the conditions where low temperatures (less than 50°C) are observed for more than half a year, and only the surface layer of the ground thaws out in summer time, the rest part is perpetually frozen soil. It is not possible to use reinforced concrete sleepers on main railways in cold climates, since reinforced concrete cracking takes place at low temperatures due to moisture freezing in micro cracks.

The main use is found for sleepers made of pine, but their service life is short (10-15 years) [1, 2]. A technology for producing sleepers from modified birch and aspen wood has been developed to meet the country's need for railway sleepers for cold regions (about 200 thousand units per year). These are low-demand species and millions of cubic meters of this wood are rotting in the cutting areas. This technology is based on compaction of soft hardwood with two-fold increase in strength and wear resistance (up to oak wood) [3, 4]. Hardwood is used to produce sleepers in Western Europe, the USA, and Japan (oak, beech, and wood from Africa, Southeast Asia, and Latin America) [5].

Many alternative technologies for the production of railway ties have been developed. Currently, the production of polymer composite railway sleepers made from recycled plastics [6], ties made of polymer concrete with reinforced fibers has become widely used [7, 8].

However, all these new technologies do not take into account the possibility of using sleepers at very low temperatures.
Traditional technology for producing railway sleepers consists in treatment of pre-forms (dried to a moisture content of 30 ± 5% in autoclaves at a pressure of 8…15 atm and a temperature of 100…110°C) with oily antiseptics (coal oil, shale oil, absorbing oil, thermal cracking fluid, anthracene oil, etc.) or aqueous solutions of salts (chromium copper, arsenic, sodium pentachlorophenolate fluoride and others) [9-12]. A common drawback of these methods is the need to pre-dry the work pieces to the moisture content of 25% by the method of atmospheric drying (6-9 months) or chamber drying (10-14 days), and when it is impregnated with water antiseptics. There is still a necessity to re-dry the sleepers to the moisture content of 22% [13-15]. At the same time, wooden sleepers are most suitable for use in the regions with cold climate.

New opportunities have appeared after justifying the method of end-grain through-treatment of large-sized work pieces under pressure, by analogy with the movement of fluid in a growing tree from butt (root) to the crown (top) [16, 17].

The objectives of the study are to create a technology for the production of railway ties from soft hardwoods suitable for use in cold regions.

2. Methods and materials

The schematics of the experimental installation for through-treatment of sleeper work pieces is shown in Figure 1. Birch wood (*Betula verrucosa* L.) was used for the experiments. Thermocatalytic cracking fluid (TCF) was used as an antiseptic coming to coal oil according to its characteristics.

![Figure 1](image1.png)

**Figure 1.** The scheme of the experimental installation for through-treatment of sleeper work pieces: 1 – receiver for impregnating fluid; 2 – receiver for harvesting; 3 – pump station tank; 4 – drain tank; 5 – pipeline; 6 – control panel; 7 – electric dosing plunger unit.

The 3D model of the experimental installation for the production of sleepers is shown in Figure 2. The production of sleeper work pieces at the experimental installation included three main technological operations - drying, treatment, and pressing. The first operation was drying of birch sleeper bar with an initial moisture content of 70-80% in oily antiseptic. A bar was laid in the thermally insulated working bath 1 (figure 2). The TCF antiseptic required temperature of 130°C and the antiseptic was pumped into the working bath 1 with the help of the pump unit 8 through the pipeline from the tank 6. Further the antiseptic was pumped back to the tank 6 along the parallel pipeline with the pump unit 9. At the same time, the antiseptic temperature decreased sharply. It was necessary to heat the antiseptic carried out due to the work of heating elements installed in the double bottom of the tank 6. The antiseptic circulation continued throughout the whole time of sleeper work piece drying. The drying process was controlled by the temperature inside the sleeper work piece using thermocouples mounted in it in the amount of at least three parts of TCF antiseptics. As soon as the temperature inside the wood reached 100°C, the moisture content of the work piece was not more than 35%, and the bound moisture begins to evaporate - the duration of the evaporation process of bound moisture, depending on the ambient temperature, was 25 hours. The temperature in the sleeper...
The vapors (resulting in the process of sleeper work piece drying) were condensed in a heat exchanger 7 (figure 2).

![3D model of experimental installation for modified wood ties](image)

**Figure 2.** The 3D model of an experimental installation for the production of modified wood ties: 1 – working bath, 2 – frame, 3 – hydraulic station, 4 – hydraulic cylinders, 5 – tank for cold antiseptics, 6 – tank for hot antiseptics, 7 – heat exchanger, 8 – pump unit for pumping hot antiseptics, 9 – pump unit for pumping cold antiseptics.

Uniaxial pressing of sleeper bar was carried out due to the impact of the pressure plate (punch) located inside the working bath 1 to improve the performance characteristics of sleepers. The pressure plate was driven by hydraulic cylinder rods 4 mounted on the frame 2. The pressing process was carried out stepwise and controlled along the stroke of the hydraulic cylinders rods (the stroke of the rods is not more than 5 cm), which enabled to increase the work piece density to 750-800 kg/m$^3$. The work of hydraulic cylinders was provided by hydraulic station 3 (figure 3). The next process step was an additional surface treatment. Treatment of bars on the experimental installation was carried out by the method of hot-cold bathing. The antiseptic in the cold bath 3 (preheated to a temperature of 40°C) was pumped through the pipeline by the pump unit 7 into the working bath 5, at the same time hot antiseptic was pumped out of the working bath 5 into the hot antiseptic tank 1 (figure 2). The working bath was controlled so that the level of antiseptic did not fall below the height of the work piece, so that air suction was not take place.

Treatment was carried out according to the following procedure: hot liquid was replaced with cold one in 5 minutes, followed by wood conditioning in cold liquid for 4 hours.

To determine the humidity, antiseptic content and depth of impregnation methods described in State Standard were used.

The photo of experimental installation for the production of modified wood sleepers is presented in figure 3. The photo of produced ties using modified wood is in figure 4.
3. Results and discussion

Figure 5 shows the graphs of technological process results for the specimen sleeper. To increase the drying rate of the specimen sleeper, the diameter of the mesh laid between the pressure plate and the specimen and between the bottom of the working bath and the specimen is changed from 1 mm to 2.5 mm.

![Graph of changes in temperature, pressing and moisture content of wood specimen sleeper](image)

**Figure 5.** Graph of changes in temperature, pressing and moisture content of wood specimen sleeper: 1 – curve of moisture values of the work piece during the drying process, W,%; 2 – curve values of the pressing degree in the pressing process, E, %; 3 – temperature curve in the process of modified wood production, $t$, $^\circ$C.

The results of studies on the depth of TCF end-grain treatment of railroad ties are presented in table 1. As it can be seen from Table 1, the content of antiseptic is 5.57% even at a distance of 200 mm from each end, which meets the requirements of State Standard 78-2004 of Russia [18].

**Table 1.** The antiseptic content in specimens indicated in the figure 5.

| Distance from the end of the railroad tie, mm | The content of TCF antiseptic, % |
|---------------------------------------------|---------------------------------|
| 0                                           | 17.5                            |
| 200                                         | 5.57                            |
| 500                                         | 8.22                            |
| 800                                         | 20.4                            |
Table 2 shows the depth of penetration of TCF antiseptic in the work piece across the fibers. Measurements have been taken every 200 mm length of the sleepers on the surface of the plates. As it can be seen from Table 2, the depth of treatment across the fibers ranges from 9.1 mm to 40.65 mm, which exceeds the standard value (5 mm).

As it can be seen from Table 3, wood density of sleepers corresponds to State Standard R 56879-2016 [19]. There is an excess of 6% in terms of moisture content, i.e. drying time is necessary to be increased.

Tests for ultimate compressive strength along the fibers have showed that $\sigma_{\text{comp}}$ is 41.5 MPa for wood with a moisture content of 22% and 65.5 MPa - for wood with a moisture content of 12%.

Table 2. Depth of wood treatment across the fibers.

| Distance from the end of a railroad tie, mm | Depth of treatment, mm |
|-------------------------------------------|------------------------|
| 0                                         | 40.65                  |
| 200                                       | 10.3                   |
| 400                                       | 9.1                    |
| 600                                       | 16.87                  |
| 800                                       | 38.9                   |
| 1,000                                     | 24.83                  |
| 1,200                                     | 13.27                  |
| 1,400                                     | 10.29                  |
| 1,600                                     | 15.9                   |
| 1,750                                     | 30.17                  |
| The average value for the railroad tie length | 21.03                 |

On the basis of the obtained results, a technological regulation for drying, treatment and pressing wood has been developed using a combined method of sleepers’ production.

The work piece is loaded into the working bath of the pilot unit SPK-1M manually by operators. After loading, the hydraulic station is turned on, and the hydraulic cylinder rods are lowered until the pressure plate touches the upper part of the work piece. The bath cap is attached to the bath manually. Heating elements are turned on in containers with a hot antiseptic, the temperature of which is brought up to 120°C four hours before the start.

The pump unit is turned on and hot antiseptic is fed into the working bath from the tank with hot antiseptic. From the working bath the antiseptic is pumped back to the tank with the hot antiseptic by the second pump unit. The circulation of antiseptic is carried out for 68 hours, when heating elements are turned on in a hot container.

After the drying process is completed, the treatment process starts by pumping out hot antiseptic and simultaneously pumping cold antiseptic from the tank with cold antiseptic at a temperature not lower than 40°C.

Table 3 presents the results of testing on wood specimens with dimensions 20×20×30mm (the last dimension is along the fibers) to determine the density and moisture content in the resulting sleeper. It can be concluded that specimens taken from the edges and ends of sleepers have the highest density. Also, specimens taken from the ends of sleepers have less moisture content. The average moisture content and density of the specimens is 29.4% and 694.8 kg/m³. The treatment process takes 4 hours from the time of antiseptic change.

Further, according to the technological regulations, the process of wood pressing with simultaneous circulation of hot antiseptic follows. The pressing process continues for 7 hours after the application of pressure on the work piece.

The end of the process is cooling and conditioning. Cooling takes place in a hot antiseptic for 10 hours. Air conditioning is carried out on the roller table for 2 hours.

The finished sleeper is obtained with a section of 180×250 mm and a length of 2,750 mm with moisture content of 22%, density of 720-780 kg/m³.
The obtained parameters of the technological regimes make it possible to produce railroad ties made of modified wood with improved performance characteristics (figure 6).

According to the developed technology an experimental batch of half ties for underground railway system and a batch of sleepers to carry out tests have been produced on the pilot plant. Based on the tests, Russian Railways JSC has approved Specifications No. 5888-001-34017041041-2012M "Modified wood sleepers". An experimental batch of broad gauge sleepers is currently being prepared for testing in the Extreme North.

4. Conclusion
Low-value soft hardwoods, oily antiseptic and drying-press chamber are needed for the manufacture of rail road ties according to the proposed technology. A technology has been developed, a pilot plant has been tested and a batch of modified wood sleeper has been produced corresponding to State Standard R 56879-2016 “Modified wood. Work pieces for sleepers and power line poles” in Russia. The optimal modes of treatment, drying and pressing of wood have the following values: hot antiseptic temperature – 120°C, warm-up and drying time of wood – 38 h, treatment time – 4 h, pressing time – 17 h, specific pressure – 0.8 MPa, cooling time – 6 h, pressing degree – 22%.

Modified wood, obtained in optimal conditions, has the following characteristics: density – 700 kg/m³, moisture content – 22%, compressive strength along fibers – 41.5 MPa, treatment depthare 5.5 and 110 mm, respectively, across and from the end of the fibers.

| Specimen | Density, kg/m³ | Moisture content, % |
|----------|----------------|---------------------|
| 1        | 756.4          | 22.9                |
| 2        | 658.0          | 28.1                |
| 3        | 661.2          | 36.4                |
| 4        | 675.8          | 36.6                |
| 5        | 749.6          | 31.0                |
| 6        | 721.6          | 25.3                |
| 7        | 641.3          | 25.5                |
| Average  | 694.8          | 29.4                |

The obtained parameters of the technological regimes make it possible to produce railroad ties made of modified wood with improved performance characteristics (figure 6).
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References
[1] Durability of Modified Wood – Laboratory vs Field Performance. Westin Mats, Technical Research Institute of Sweden, Boras, Sweden, 142 (2010).
[2] Official Website of Kebony Company – Mode of access: http://kebony.com/en/products/ – title from screen 2014/02/21.
[3] Shamaev V, Medvedev I and Parinov D (2018) Study of modified wood as a bearing material for machine-building international conference on aviamechanical engineering and transport (Avia ENT). Adv. Eng. Res. 158 478
[4] Shamaev V, Medvedev I, Parinov D, Shakirova O and Anisimov M (2018) Investigation of physical and mechanical properties and microstructure of modified wood produced by self-pressing method Acta Fakultatis Xylologiae Zvolen, 10 25
[5] Ovchinnikov V and Zobov S (2010) Increase of service life of wooden sleepers Path and Track Facilitie 8 9
[6] Ferdous W, Manalo A, Erp G, Aravinthan T, Kaewunruen S, and Remennikov A (2015) Composite railway sleepers – recent developments, challenges and future prospects. Compos. Struct. 134 158 10.1016/j.compstruct.2015.08.058
[7] Ferdous W, Manalo A, Erp G, Aravinthan T and Ghabraie K (2018) Evaluation of an innovative composite railway sleeper for a narrow-gauge track under static load. J. Compos. Constr. 22 04017050 doi.10.1061/(ASCE)CC.1943-5614.0000833.
[8] Ferdous W, Manalo A, Aravinthan T, and Fam A (2018) Flexural and shear behaviour of layered sandwich beams. Constr. Build. Mater. 173 429 10.1016/j.conbuildmat.2018.04.068
[9] Taymarov M, RF Patent No. 2481430 (29 December 2011)
[10] Medvedev I, Shamaev V and Parinov D (2018) Resource-saving production of modified wood sleepers Path and Track Facilities, 11 30
[11] Lekounougou S, Kocaefe D, Oumarou N, Kocaefe Y and Poncsak S (2011) Effect of thermal modification on mechanical properties of Canadian white birch (Betula papyrifera), International Wood Products Journal 2 101
[12] Tshabalala M, Mc Sweeney J and Rowell R (2012) Peat treatment of wet wood fiber: a study of the effect of reaction conditions on the formation of furfurals. Wood Material Science and Engineering 7 202
[13] Sandberg D, Haller P and Navi P (2013) Thermo-hydro and thermo-hydro-mechanical wood processing: an opportunity for environmentally friendly wood products. Wood Material Science and Engineering 8 64
[14] Rowell R, Andersone I and Andersons B (2012) Heat treatment. in Handbook of Wood Chemistry and Wood Composites. 2nd Ed., (Madison: CRC Press) chapter 14, p 511
[15] RF State Standard No. 20022.0-93 Wood Protection. Security Settings (Moscow: Standards Publishing House)
[16] Shamaev V, Manaev V, Kondratyuk V, Voskoboynikov I, Schelokov V and Konstantinova S Varnakov, RF Patent No. 2511302 (10 April 2014)
[17] Shamaev V and Parinov D, RF Patent No. 2646612 (02 March 2017)
[18] RF State Standard 7No. 8-2004 Wooden Sleepers for Broad Gauge Railways (Moscow: Standards)
[19] RF State Standard R No. 56879-2016 Modified Wood. Workpieces for Sleepers and Power Lines Poles. Technical Conditions. (Moscow: Standartinform)