ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 60(2): 25−32, 2018
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2018.60.2.02

INVESTIGATION OF MODIFIED WOOD AS A MATERIAL POWER TRANSMISSION POLE PRODUCED BY SELF-PRESSING METHOD

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ABSTRACT

Studies of modified wood as a material for power transmission poles obtained using the self-pressing method are presented in the paper. Results of the experiment on swelling, density change, and change in the geometric dimensions of wood samples are provided. Testing was carried out on small samples of birch and aspen wood. Physical and mechanical properties and microstructure of modified birch and aspen wood obtained using the self-pressing method are studied. Comparative analysis of the microstructure of modified and natural aspen wood were conducted. Dependence of the number of moistening cycles and wood drying on the length and diameter of samples are illustrated in the paper. The maximum density of birch wood obtained using the self-pressing method is 1200 kg/m^3, the maximum density of aspen wood is 1300 kg/m^3.

Keywords: Wood modification, self-pressing, power transmission poles, microstructure, density.

INTRODUCTION

Wood is one of the principal materials used in production and economy of any state, so, due to its numerous advantages; wood is the most used structural material in the history of mankind. As it is known, wood as a building material has a number of positive properties: it is environment-friendly, has high aesthetic values and it is easy to process and renewable, valuable from aesthetic point of view material. Wood density and its strength is different and depends on the species and the tree growth environment, high strength parameters also give the opportunity to apply wood as a structural material in various fields of industry, agriculture, and so on. However, there is a significant disadvantage of wood - when it is exposed to a moist environment, it swells easily and partially loses its properties. In this case, formation of various types of destruction can occur in the structure of the wood: cracks, molds, rot, which adversely affects the strength and aesthetic parameters and others, at the same time, limits its use in various areas (SHANSHAN *et al*. 2016).

Today there are many different technologies to make poles for power (transmitting) lines in the world and communications from various materials, for example, wood, reinforced concrete, metal, various composites. Poles have a number of disadvantages while exploiting them.

So, it is necessary to modify (preserve and improve properties) wood in various ways, some of them were used from ancient times (coatings and impregnation of logs with various resins, wood straining, etc.), but the greatest technological scope in the development of wood modification began in the mid-twentieth century. Now, to the previously pursued purposes to protect wood from moisture, new technological indicators of fire - and bio protection have been added. One of the types of wood modification since the early 90s of the 20th century is its heat treatment (TJEERDSMA *et al*. 1998, KOCAEFE *et al*. 2008). Thermal modification of wood was developed as an industrial method to increase wood formability, allowing expanding the scope and life of wood products (YANG *et al*. 2017). Despite the positive effect of heat treatment on wood, a number of negative factors are appearing then: hardness and tensile strength decrease and others. Today double influence of temperature on wood as a modifier has been proved (GUNDUZ *et al*. 2008, KASEMSIRI *et al*. 2012, KORKUT *et al*. 2009). It has been found that thermal treatment of certain wood types reduces moisture and water absorption, but compression strength along the fibers is significantly reduced (BALKIS *et al*. 2013, PALERMO *et al*. 2014, JOFFRE *et al*. 2014, SANDAK *et al*. 2015). A number of negative properties appears (roughness is formed on the workpieces surfaces, strength of adhesive seam is reduced while shearing along the fiber, etc.), but these negative properties can be eliminated by introducing various modifiers into the wood (MIKLEČIĆ *et al*. 2017).

There is a wide-spread way to modify wood by influencing it with mechanical pressure. This method along with the wood structure compaction allows to introduce various compositions of modifiers into it to improve the desired wood properties (BAZANT *et al*. 2014, CANDAN *et al*. 2013, CIESIELSKI *et al*. 2014, JI *et al*. 2015, MZHACHIH *et al*. 2006, STEPINA – KLYACHENKOVA 2014). Such modification methods allow the wood use as a material instead of expensive metal, reinforced concrete and other structural materials. A good example of modified wood use is the construction of power (transmitting) lines (PTL).

For many reasons, depending on the application area, wooden poles for power (transmitting) lines are much better comparing to other pole types and in some cases wood poles are unchangeable. Wooden poles are much cheaper than metal ones and cheaper for 40 per cent as for reinforced concrete poles. Transporting and installing them is much cheaper, because wood is much lighter than metal or reinforced concrete. It is possible to transport about 60 poles for one trip when transporting wooden poles. Wooden poles of power lines are indispensable in seismic zones. They are bend-resistant, so they easily tolerate ice and wind loads. The effect of "dominoes" is absent, as wires easily hold the wood, and so neighboring poles do not collapse. Naturally, the number of emergency shutdowns is reduced. Wood is an excellent dielectric, even in the case of a breakdown of the insulator, one can not be afraid of accidental contact with the pole. For the same reason, lines on wooden poles consume fewer insulators than on reinforced concrete or metal supports. Wooden poles of power lines serve for 45 years in average, while concrete poles for 25–35 years.

The best species for the production of wooden pole is pine, which is perfect because of geometric parameters and, besides, it is well impregnated, it makes it possible to protect wood from decay and other destructive factors. Poles are made from larch, spruce and fir-tree as well. But they are rarely used because these species are poorly impregnated with antiseptics.

Wooden poles have a great disadvantage - its strength is much lower than the strength of metal and reinforced concrete poles. Wood strength can be improved by impregnation and pressing.

Special poles are made for power (transmitting) line structures according to outdoor air temperature up to −65 ° C and are one of the main structural elements of power (transmitting) line; they fix and suspend electric wires at a certain level.

The choice of the material is based upon economic reasons as well as the availability of appropriate material in the area of line building.

The aim of the article is to substantiate the method of wood self-pressing by cyclic moistening and drying in a closed volume, i.e. to use forces of swelling and shrinkage to increase the density of wood. This purpose becomes relevant for obtaining hardened wood blanks of large dimensions, for example, power transmission poles.

Our technology has no analogues in Russia and abroad, the development makes it possible to improve operational performance of power (transmitting) lines and communications by increasing the wood density and its hardness.

MATERIALS AND METHOD

The disadvantage of technology is that the wood length to be modified can be no more than 3 m. Bonding of blanks 8–12 m long is a labor- consuming operation, but the main thing is that the adhesive layer becomes old quickly during the operation, and after 10–12 years it loses its strength. So, it is necessary to harden cylindrical blanks 8–12 m long. Uniaxial or contour pressing methods are impossible for this operation.

At the same time, it is possible to use the wood compaction forces, i.e. the force of swelling and shrinkage. For this purpose, the workpieces were installed in a cage, its inner contours corresponded to the workpiece outside contours, the workpieces were moisturized until the water absorption limit was reached, they were dried then to constant weight, after it all the operations – placing into the cage, humidification and drying were repeated until the required wood density. When the wood was placed in the antiseptic solution, its absorption process starts, and swelling forces had being developed in it. These forces increased the wood volume, but the metal cap of the cage prevented wood from increasing. Therefore, the swelling forces caused a decrease in the cell cavities; still there was a self-pressing of wood, which was fixed by subsequent shrinkage. Workpieces were kept in water until water absorption limit had been reached. Then the workpieces in the cage were placed in a drying chamber (kiln) and were dried at a temperature of 95 - 100 ° C to constant weight. Then the workpieces were taken out from the cage and placed into another cage of a smaller size, its internal dimensions corresponded to the outer lateral dimensions of the workpiece after shrinkage. Further, humidifying and drying operations were repeated in the cages with correspondingly decreasing internal dimensions until the wood density reached 900–1,300 kg/m^3.

Moisture absorption and its evaporation occurred through free end surfaces of the workpiece.

Logs with the three diameters types (16, 18, 20 cm) were dried in a microwave dryer (kiln) to a moisture content of 3–5% during 3 days according to special modes. A hydraulic cylinder placed the dried workpieces into steel pipes with the diameters of 14.5, 16.2, 17.6 cm respectively, then they were put into the autoclave of WRC-40 type. The impregnating solution was prepared on the basis of difficult-to-wash water-soluble antiseptics of the CCA group, i.e. ULTAN, ElemeSept or XM - 11 according to 20022.2 - 80 State Standard with the addition of fire retardants (diammonium phosphate and ammonium sulfate). Fire retardant additives were used for the power line poles in taiga or other coniferous forests. A stabilizer and reinforcing agents were added into the antiseptic solution and flame retardants. The finished solutions were pumped into the autoclave, where the impregnation was made by airborne penetration method according to 20022.6 - 93 State Standard with the antiseptic absorption norm of 16 kg/m^3.

After impregnation was over, pipes with workpieces were dried in heat chambers at a temperature of 120 ° C during 5 days up to 12‒15 per cent moisture content. Then dried poles were easily removed from the pipe and have diameters of 12, 13.5, and 14.5 cm respectively, and at that time their density was 720‒730 kg/m^3, this was the oak wood density. The estimated service period of these poles is 70 years; this is a longer period than the service period of pine poles, P 56879-2016 State Standard (TECHNICAL CONDITIONS 56879-2016).

To produce power (transmitting) lines poles, a stabilizer - the precondensate of the urea-formaldehyde oligomer (its amount is 1.5% as for the weight) and a hardenizer - hydrogel solution of nanocrystalline cellulose (the amount of 0.5% as for the solution weight) is added into the solution of the standard antiseptic. Round logs 8‒12 m long made of birch wood and diameters shown in Table 1 are used as a raw material.

Tab. 1 Dependence of the number of cycles on the diameter of the workpiece.

Number of cycles	Length of blanks, m by grades					
	6–7,5 m		8,5–11 m		12–13 m	
	Before modifying	After modifying	Before modifying	After modifying	Before modifying	After modifying
0	16	14.5*	18	16.2*	20	17.6*
1	14.5	12	16.2	13.5	17.6	14.5

Note:* For the zero cycle, the diameters after drying are indicated

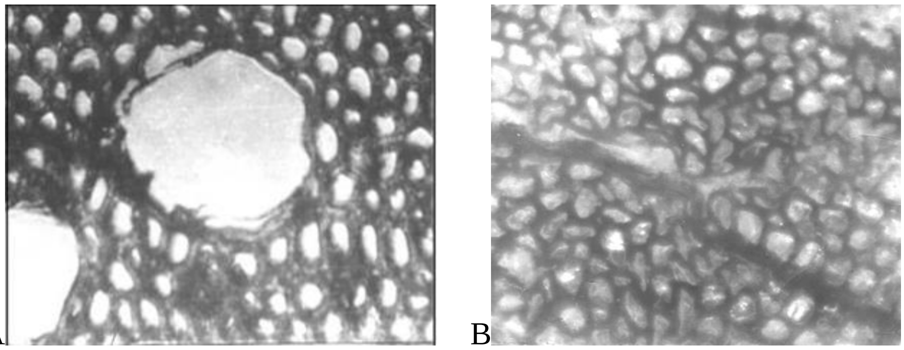
Wood density increased with each moisturizing cycle and drying process during wood self-pressing (Table2).

Tab. 2 Changes in density and geometric dimensions of wood during cyclic moistening and drying.

Number of cycles	Ultimate water absorption	Density of wood, kg/m^3	Cross-section of workpieces (diameter), mm
0	-	610/500	100/100 × 100
1	80	800/720	86/90 × 96
2	58	890/850	83/84 × 92
3	47	970/930	80/80 × 88
4	40	1,050/1,010	77/76 × 84
5	34	1,130/1,090	74/72 × 80
6	25	1,200/1,170	72/70 × 78
7	20	- /1,240	- /68 × 76
8	17	- /1,300	- /61 × 73

Note: numerator is birch; denominator is aspen.

Microstructure of wood obtained by self-pressing method differs very much from microstructure of pressed wood. Thus, in aspen wood, obtained by the self-pressing method and moistening and drying, the structure hardly differs from the structure of natural hardwood species (Fig. 1), i.e. it has natural structure.



A B

Fig. 1 Microstructure of the end surface of aspen wood (zoom. × 400). A – cut of natural aspen wood; B – cut of modified aspen wood obtained by self-pressing method.

EXPERIMENTAL PART

Earlier, a technology has been developed to make power (transmitting) lines poles and railway sleepers with raw wood impregnating, drying and pressing, the process is carried out in the same device (SHAMAYEV *et al.* 2007).

The green log of softwood species has been treated with oily anticeptic under pressure, then drying and pressing processes are made. This method is different in anticeptic mixture – healthy wood has been treated with the mixture of oily anticeptic but the defective part has been treated with the mixture of oily anticeptic and a hardenizer of kerosene/petroleum spirit. The hardenizer has been chosen from rubber production wastes, or toluene rectification, phenol-alcohols, the amount has been calculated according to:

$$M = k\frac{H_h}{H_d}\cdot C\cdot V\ , \qquad (1)$$

Where M - amount of hardening solution, l ,

H_h - hardness of healthy part, N/mm^2 ,

H_d - hardness of defective part, N/mm^2 ,

C - concentration of reinforcing solution in defective part, l/m^3 ,

V - volume of defective part, m^3 ,

k - the diameter decrease coefficient of defective part from the root of the log up to the top one, $0.8 \le k \le 1$.

In a raw cylindrical workpiece of aspen wood with a diameter of 25 cm and a length of 275 cm, containing 15 cm diameter of defective zone in butt and top part, the ratio of hardness of healthy zone to the hardness of defective zone is defined: $Hh/H_d = \frac{7.1H/mm^2}{4.4H/mm^2} = 1.61$. The correction index k, which takes into account the decrease in the diameter of defective zone from the butt part of the log to the top one, is 1. We determine the volume of defective zone $V = 0.049\,m^3$. We determine the amount of hardening solution having a concentration 200 l/m^3.

$M = 1\cdot 1.6\cdot 200l/m^3\cdot 0.049m^3 = 15.7kg$ by the formula $M = k\frac{H_h}{H_d}\cdot C\cdot V$. On the basis of the volume of defective zone, we determine the amount of impregnating mixture equal to 39 l.

RESULTS AND DISCUSSION

The described method to produce modified wood seems to be long and time-consuming. However, if the first wood drying is combined with its impregnation, placing the workpieces in the antiseptic solution, then this operation takes 0.5 up to 1 hour. If the wood is moistened with pressure, then this operation will take the same 0.5–1 hour. Finally, if wood is dried with vacuum-pulse method, then the drying process will take 4 or even 6 hours. As a result, the total duration of the process is about 7–8 hours per cycle or 35–40 hours for 5 cycles until the optimal wood density - 1100 kg/m^3 - is reached. Producing of pressed wood with the help of preheating or steaming methods takes the same time period.

Wood pipes at self-pressing do not flatten as the modified wood pipes do, i.e. receive with the mechanical influence. As a result, the dynamic characteristics of wood greatly increase. Table 3 illustrates the static strength index, it is 1.5 times higher, and the dynamic strength, it is 3–3.5 times higher than indices of pressed wood (SHAMAYEV *et al*. 2013).

Actually, the greatest density increase takes place after the first cycle of moistening and drying (190–220 kg/m^3). So, it is possible to produce a modified birch wood similar to beech wood without the expensive equipment.

Tab. 3 Physical and mechanical properties of modified wood.

Index	wood		
	Birch*	Aspen*	Birch**
Density, kg/m^3	1200	1300	1200
Moisture, %	3.2	3.0	5.0
Compressive strength, MPa	171	188	125
Face hardness, MPa	166	173	102
Impact strength,10^{3}J/m^2	179	189	114
Tensile strength under dynamic loads, MPa	65	69	21
Water absorption for 30 days	31	36	52

Note: * – self-pressing method; ** – pressed method (control).

The proposed method of self-pressing wood can be used in power (transmitting) line and communications poles production, the method makes it possible to increase the wood strength characteristics by increasing its density, thereby increasing the service period of wooden poles. Power (transmitting) lines made from modified wood are similar to reinforced concrete as for their characteristics. The given material after qualitative impregnation, can serve as long as a concrete poles can do.

CONCLUSIONS

1. The method of "self-pressing" of wood by means of cyclic moistening and drying in a closed circuit is developed, which allows us to obtain pressed wood without mechanical impact.
2. Using the forces of swelling and shrinkage allows us to get pressed wood without flattening the cells, decreasing only the volume of cell cavities.
3. The mechanical properties of wood obtained by the method of self-pressing is higher than that of conventional pressed wood by 15–20% in static and 3 times higher in dynamics.
4. Due to one cycle of moistening and drying, the density and hardness of soft hardwoods increases by an average of 25% and we have obtained aspen wood with the strength of

beech wood, and obtained birch wood has oak strength. This method can find the use in the manufacture of power transmission poles.

REFERENCES

BALKIS F., HIZIROGLU S., TAHIR P. 2013. Properties of some thermally modified wood species. In Materials & Design, 2013, 43: 348–355.

BAZANT P., MUNSTER L., MACHOVSKY V., SEDLAK J., KURITKA I. 2014. Wood flour modified by hierarchical Ag/ZnO as potential filler for wood - plastic composites with enhanced surface antibacterial performance. In Industrial Crops and Products, 2014, 62: 179–187.

CANDAN Z., KORKUT S., UNSAL O. 2013. Effect of thermal modification by hot pressing on performance properties of paulownia wood boards. In Industrial Crops and Products, 2013, 45: 461–464.

CIESIELSKI P.N., WANG W., CHEN X., VINZANT T.B., TUCKER M.P., DECKER S.R., HIMMEL M.E., JOHNSON D.K., DONOHOE B.S. 2014. Effect of mechanical disruption on the effectiveness of three reactors used for dilute acid pretreatment of corn stover Part 2: morphological and structural substrate analysis. In Biotechnol. Biofuels, 2014, 7: 1–12.

GUNDUZ G., KORKUT S., KORKUT DS. 2008. The effects of heat treatment on physical and technological properties and surface roughness of Camiyani Black Pine (*Pinusnigra* Arn. subsp pallasiana var. pallasiana) wood. In Bioresource Technol, 2008, 99: 2275–2280.

JI Z., ZHANG X., LING Z., ZHOU X., RAMASWAMY S., XU F. 2015. Visualization of Miscanthus × giganteus cell wall deconstruction subjected to dilute acid pretreatment for enhanced enzymatic digestibility. In Biotechnol. Biofuels, 2015, 8(103): 1–14.

JOFFRE T., NEAGU C., BARDAGE S., GAMSTEDT K. 2014. Modelling of the hygroelastic behavior of normal and compression wood tracheids. In Journal of Structural Biology, 2014, 185(1): 89–98.

KASEMSIRI P., HIZIROGLU S., RIMDUSIT S. 2012. Characterization of heat treated Easternredcedar (*Juniperus virginiana* L.). In Mater Process Technol., 2012, 212: 1324–1330.

KOCAEFE D., SHI J., YANG D., BOUAZARA M. 2008. Mechanical properties, dimensionalstability, and mold resistance of heat-treated jack pine and aspen. In Forest Product, 2008, 58: 88–93.

KORKUT S., HIZIROGLU S. 2009. Effect of heat treatment on mechanical properties ofhazelnut wood (*Corylus colurna* L.). In Mater Des, 2009, 30(5): 1853–1858.

MIKLEČIĆ J., TURKULIN H., JIROUŠ-RAJKOVIĆ V. 2017. Weathering performance of surface of thermally modified wood finished with nanoparticles-modified waterborne polyacrylate coatings. In Applied Surface Science, 2017, 408: 103–109.

MZHACHIH E., SUKHAREV L., YAKOVLEV V. 2006. Bio-corrosion and physico-chemical methods to improve the durability of the coating. The practice of corrosion protection. 2006, 1: 55–58.

PALERMO M., LATORRACA F., MOURA L., NOLASCO F., CARVALHO A., GARCIA R. 2014. Surface roughness of heattreated Eucalyptus grandis wood. In Maderas-Cienc. Tecnol., 2014, 16(1): 03–12.

SANDAK A., SANDAK J., ALLEGRETTI O. 2015. Quality control of vacuum thermally modified wood with near infrared spectroscopy. In Vacuum, 2015, 114: 44–48.

SHAMAYEV V., NIKULINA S., MEDVEDEV I. 2013. Modification of wood. Moscow: Science, 2013. 448. ISBN 978-5-9765-1605-2.

SHAMAYEV V., MEDVEDEV I., ZLATOUSTOVSKAYA V., ANUCHIN A.2007. Method for obtaining modified wood. Patent Russian Federation, no P2346809. 04.04.2007.

SHANSHAN J., MING L., YIQIANG W., SHA L., HAIBO C. 2016. Facile and scalable preparation of highly wear-resistance superhydrophobic surface on wood substratesusing silica nanoparticles modified by VTES. In Applied Surface Science, 2016, 386: 115–124.

STEPINA I., KLYACHENKOVA O. 2014. Biostability of Wood in the Presence of Boron-Nitrogen Compounds. Procedia Engineering, 2014, 91: 358–361.

TECHNICAL CONDITIONS 56879-2016, Modified wood. Blanks for sleepers and poles of power lines, 2016.

TJEERDSMA B., BOONSTRA M., PIZZI A., TEKELY P., MILITZ H. 1998. Charactisation of thermally modified wood: molecular reasons for wood performance improvement. In Holz Roh Werkst, 1998, 56:149–153.
YANG M., XIANFENG C., WANG Y.,YUAN B., ZHANG Z. 2017. Comparative evaluation of thermal decomposition behavior and thermal stability of powdered ammonium nitrate under different atmosphere conditions. In Journal of Hazardous Materials, 2017, 337: 10–19.

ACKNOWLEDGEMENT

The research materials presented in this article were obtained as a part of the state task of the Ministry of Education and Science of Russia № 11.3960.2017/4.6.

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