Densification of Wood – Chemical and Structural Changes Due to Ultrasonic and Mechanical Treatment

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This paper presents the state of the art of wood surface densification method by pressing with ultrasound. The properties of ultrasound and its effects on the structure and properties of wood, as well as ultrasound-induced chemical changes in wood material, are described. The following research results were analyzed: the effects of acoustic cavitation in wood material, plasticization of wood lignin by processing with ultrasound, the influence of ultrasound on the wood anatomical structure, the combined effect of ultrasound and wood pressing, and the sterilization of wood using ultrasonic action. Ultrasound causes conversion of lignin from glassy into a quasi-rubbery state, which facilitates compaction of the workpiece surface. Additionally, under ultrasound, growth and collapse of gas bubbles (cavitation phenomena) occur within a liquid medium of wooden substance accompanied by high local temperatures and production of chemically active radicals. This contributes to the destruction of the former and the formation of new bonds in the wood substance, which is important for increasing the stability of the workpiece size after densification. The conclusions made about the ultrasound can be effectively used for the wood plasticization and about prospects of joint use of wood pressing and ultrasound for wood surface densification.

Keywords: Surface densification; Wood plasticization; Softening lignin; Pressure with ultrasound; Hardness of wood; Surface quality

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INTRODUCTION

In recent decades, the issue of using different types of wood as non-metallic structural materials capable of replacing ferrous and non-ferrous metals, textolite, and some plastics has become topical. The production of other structural materials (steel, alloys, plastics, *etc.*) is associated with the consumption of a lot of raw materials, whose reserves are not renewed, but are continually depleted. Additionally, the creation of most construction materials requires a large expenditure of energy, the deficit of which, especially in recent years, is particularly acute.

The production of number wooden details requires wood with high physical and mechanical characteristics, mainly the wood density. Wood of higher density has higher additional mechanical characteristics and overall wood quality. For example, density of wood strongly correlates with its hardness and strength (Wangaard 1950; Fang *et al.* 2012). Wood surface hardness determines its resistance to abrasion. This is especially important for parts such as flooring, parquet, countertops, and facial surfaces of furniture.

Therefore, hardwood (for example, oak, ash, beech, hornbeam, and maple) are used in the production of, for example, flooring and building structures. The total volume of roundwood removals (under bark) in all 27 countries of the European Union is about 550 million m^3 per year. Meanwhile, the total volume of industrial roundwood is more than 324 million m^3 per year (European Commission 2019).

Environmental problems associated with the decline in the production of high-quality wood in forestry are growing. This motivates the use of lesser quality wood species (spruce, pine, birch, aspen, poplar, alder, and others) as a substitute for high-quality wood materials and materials based on fossil fuels (Kutnar and Sundberg 2015). The development and improvement of methods for increasing the hardness of wood blanks from soft and hard woods are of great importance for increasing the completeness and efficiency of natural resources use.

Wood densification is an emerging process technology. This technology is realized by bulk and surface densification, bending, and molding of shells and tubes. These methods make it possible to increase the density of wood to about 1000 kg/m^3 (spruce before densification – density 430 kg/m^3, after densification – density 1230 kg/m^3; local Japan timber – density from 430 kg/m^3 to greater than 900 kg/m^3). This makes it possible to expand the field of application of wood as soft and hard (Navi and Sandberg 2012; Kutnar *et al.* 2015). The most widely used improvement in the mechanical properties of wood blanks is the compression of only their surface (surface compaction) (Laine 2014).

Densification of softwood surface will make it possible to expand its use to produce floors, doors, and windows. Densified wood has begun to replace bushings and plain bearings, which were previously made from expensive alloys (babbitt, bronze) and polymers (caprolactam, polyamide, and textolite) (Postnikov and Kamalova 2015). The demand for such products is constantly growing due to the development of mining, oil and gas production, and metal processing industries.

To date, the process of wood densification involves the various combinations of wood treatment in presence of moisture, chemical reagents (solutions of ammonia or uric acid), at high temperature (pre-steaming at 120 °C to 220 °C for up to 20 min, thermal treatments at 150 °C to 200 °C for 1 to 3 min, post-steaming of compressed wood at 165 to 235 °C for up to 30 min), under mechanical loading (13 to 25 MPa), impregnation with chemicals (carbamide-formaldehyde resin, alkyd, alkyd-urethane, and acrylic resins and acids), and under the influence of high-frequency electromagnetic radiation (frequency 5 to 9 MHz) (Solar and Melcer 1980; Dwianto *et al*. 1999; Shamaev 2003; Esteves and Pereira 2009; Inoue *et al*. 2008a; Kosheleva and Sheikman 2014; Kutnar *et al.* 2015; Angelski 2017; Sadatnezhad *et al.* 2017).

Such combined methods of wood treatment are classified as thermo-mechanical, thermo-hydromechanical (Kutnar *et al.* 2015; Angelski 2017; Balasso *et al*. 2020; Sandberg *et al*. 2017), chemical-mechanical processes (Shamaev 2015; Mania *et al.* 2020, Meethaworn *et al*. 2020; Jakob *et al*. 2020), densification using heat, pressure and pre-softening with steam (viscoelastic-thermal-compression), densification using temperature, pressure, and vibration as a new application (Thermo-Vibro-Mechanic) (Şenol and Budakçi 2016), and high-pressure treatment (Yong *et al.* 2020). In the process of thermo-, hydro-, mechanical, and chemical exposure for densification the surface of the wood can change color, partially undergo thermal decomposition, and be damaged mechanically (Uhmeier *et al.* 1998; Winandy and Krzysik 2007). Parts with densified surfaces can restore their size before densification when exposed to a humid environment, as well as in an environment with increased temperature. These phenomena are called spring-back and shape memory (Navi and Sandberg 2012; Kutnar *et al.* 2015).

High-frequency electromagnetic radiation is used to heat wood too. This is because the water dipoles in the wood undergo intensive motion. It is a result of their aim to follow the rapidly changing by sign poles of the electric field.

Internal thermal generation creates the circumstances for the occurrence of unilateral propagation of moisture and heat in the volume of the material from the center to the surface. This is the main difference between this method and the widespread methods of heating wood (contact, convective), where the surface temperature is higher than the temperature at the center. This method is used for the plasticization of wood before its volumetric deformation - bending. This is one of the fastest methods of heating wood. In a high-frequency field, a beech wood detail with measures 35 mm × 50 mm × 850 mm, could be bent and dried from 40% down to 10% moisture for 150 s, and from 20% moisture down to 10% only within 1 min (Inoue *et al.* 1998; Angelski 2017).

However, fast deformation and drying of beech wood detail in a high-frequency field leads to many processing defects, such as internal cracks and surface burns. Serious difficulties are also caused by a natural uneven distribution of moisture in the wood, which leads to uneven heating. This method is not suitable for wood species with many cell barriers (membranes). They prevent the free access of steam from wood, which leads to internal ruptures. These and other reasons (as the high price of the high-frequency generators, their hard maintenance, and the potential danger of radiation) create limitations for the practical implementation of the high-frequency electromagnetic radiation for wood plasticization (Angelski 2017).

The tasks of reducing the energy costs of the wood densification, improving the quality of the surface of the treated wood, increasing the productivity, ensuring environmental safety, and improving the dimensional stability of densified parts in the process of their use, is topical and is of great practical importance.

One of the promising methods of wood densification is simultaneous treatment of wood billet by pressing and ultrasound. This paper is a review on the state of the art and the knowledge on this topic.

Ultrasound and the Effect of Acoustic Cavitation

Ultrasound is acoustic energy that is considered as mechanical, nonionizing, and nonpolluting; it is widely used in engineering and has great potential (Raj *et al.* 2004). Acoustic waves are a vibrating disturbance of the environment with a frequency of 20 kHz to 1 GHz (not audible for humans) and need a means of propagation to travel and transmit, unlike electromagnetic waves that can propagate in any medium, including vacuum. Because of this, acoustic waves are also called mechanical waves (Agranat *et al.* 1987).

In the wood industry, ultrasound is successfully used for wood drying, debarking of wood, surface cleaning, increasing the efficiency of wood impregnating, and for finding defects in wood raw materials and for controlling the quality of wood products (Gasparyan 2013; Fang *et al.* 2016). The effects of ultrasound on materials are manifold. Even separate branches of science are distinguished, studying physics and chemical phenomena accompanying ultrasound (sonophysics and sonochemistry) (Crum 1994; Ashokkumar and Mason 2000).

Many physical and chemical effects of ultrasound on materials are associated with the phenomenon of acoustic cavitation (Leighton 1994; Franc and Michel 2010), which occurs under rapidly alternating high-amplitude pressure waves and consists of the growth and collapse of gas bubbles within a liquid medium. The bubbles grow in areas of low pressure, collapsing violently when passing to high-pressure areas and produce local temperatures close to 5000 K, as well as pressures above 1000 atm (Soria and Villamiel 2010) due to the release of the energy stored during expansion. A result of the high local temperatures after the collapse of the bubbles is the production of chemically active radicals (Moholkar *et al.* 2015). The energy provided by cavitation in this so-called sonochemistry is approximately 10 to 100 kJ/mol, which is within the hydrogen bond energy scale (Suslick 1990; Tischer *et al.* 2010). With the phenomenon of cavitation, the sound-capillary effect of ultrasound is also associated (Agranat *et al.* 1987).

This effect consists in a multiple increase in the depth and rate of penetration of liquid into the capillary channels of porous materials under the influence of ultrasound. The movement of the liquid in the capillary is carried out under the action of a pressure pulse that appears at the mouth of the capillary when the cavitation cavity is slammed shut.

The effect of cavitation is also associated with the effect of an increase in the permeability of porous bodies under the action of ultrasound (up to 10 to 12 times) (Annenkov 1974). It is established by calculations that the emergence of cavitation under the influence of ultrasound is possible in wood capillaries and interfibrillar cellulose space due to the presence of bound water (Kiprianov 2002).

Unique effects of ultrasound are a prerequisite for its application in the process of effective wood densification, since the destruction of chemical bonds in a wood substance, the appearance of free radicals, an increase in capillary permeability can create favorable conditions for the process of creating and maintaining permanent deformations of wood during densification. However, the influence of the phenomenon of cavitation requires additional study.

Plasticization of Wood by Processing Samples with Ultrasound

One of the most important stages of wood densification is softening (plasticization) of wood structure in a region that is to be compressed (Kutnar *et al.* 2015). At the molecular level, the wood can be simplified by modeling it as partially crystallized regions of cellulose macromolecules, as if "dissolved" in amorphous lignin (Erinsh 1977). Under normal conditions, the lignin of the wood is in the glassy state and it is necessary first to "soften" the lignin, that is, in some way, converting it into a quasi-rubbery state (Lamason and Gong 2007). Wood plasticization can be completed using various procedures (treating wood with temperature, moisture, or chemicals).

The application of steam as a heating and softening medium is the most traditional method used for wood softening. Unfortunately, due to mechanisms of heat and mass transfer during steaming of wood, time consumption and energy requirements are important issues of this method.

The plasticization of wood by chemical methods (treatment with ammonia in the presence of water, carbamides, *etc.*) (Solár and Melcer 1980; Yamashita *et al.* 2009; Fekiač *et al.* 2015; Shamaev 2015) leads to partial destruction of cellulose fibrils, which in turn negatively affects the physical characteristics of the compacted wood (Postnikov and Kamalova 2015). Studies in recent years have shown the possibility of effective softening lignin by processing samples with ultrasound (Postnikov *et al*. 2010).

Changes in the structure of lignin are caused by chemical effects that arise under the influence of cavitation from the action of ultrasound. Cavitation is most intense at the boundary of the "water-sorbent" phases (Antonova *et al.* 2006). Some authors suggest two possible mechanisms of ultrasound absorption during wood treatment (Postnikov and

Kamalova 2013). First, this process can occur due to the appearance of mechanical friction at the boundary of the ultrasound tip and the sample surface. Due to frictional forces, the contact region of the sample can be heated. The second mechanism of absorption is the resultant ultrasonic action of viscous friction in the middle of the region where two adjacent cell walls are in contact, which consists mainly of lignin.

Plasticization of birch wood with an ultrasonic energy flow of 25 to 30 W/cm^2 for 90 to 100 s and its subsequent pressing made it possible to increase in hardness from 42 to 200 MPa. This same hardness was previously achieved by pressing the wood after plasticizing lignin with a complex, long-term, and unsafe method for impregnating samples with ammonia solution. Therefore, the processing of wood by ultrasound allows plasticizing lignin as efficiently as under the action of highly toxic ammonia (Postnikov and Kamalova 2013).

Cavitation in wood material because of ultrasound leads to the formation of many hydroxyl radicals and hydrogen peroxide. These substances also change the structure of wood and lignin (Antonova *et al*. 2014).

Therefore, the effect of an ultrasonic field with a power of 25 to 30 W/cm^2 results in the plasticization of wood samples sufficient for subsequent optimum compaction (with a minimum degree of destruction of wood fibers). This result proves that the action of ultrasound translates lignin samples from the vitreous to the viscous flow state (Kalchenko 2011).

Thus, ultrasound can be effectively used to realize the most important stage of densification, namely, for the plasticization of wood. Another important stage of wood densification is the stage of fixing the dimensions of densification.

The Influence of Ultrasound on the Wood Anatomical Structure

It is known that elements of early oak (*Quercus robur* L.) wood are relatively resistant to the action of ultrasound, but small and wide vessels, as well as libriform fibers, react to the influence of ultrasound differently. The most active effect of ultrasound is on small vessels and libriform fibers. Under the influence of ultrasound, the porosity of the libriform fibers and the cross-sectional area of small vessels increased almost two-fold, possibly due to the presence of absorbed water, the presence of which enhances the process of cavitation (Antonova *et al.* 2009).

Ultrasound of high power (80 W/cm^2) has a particularly strong destructive effect on lignin after prolonged exposure to oak wood in air (Antonova *et al.* 2009). The most active effect of ultrasound is on small vessels and the libriform fibers. Under the influence of ultrasound, the porosity of the libriform fibers and the cross-sectional area of the small vessels increase. This is due to the presence of absorbed water, the presence of which enhances the process of cavitation.

The influence of ultrasound on the anatomical structure of oak wood was studied by placing wood in a water-ethanol mixture and directly contacting the generating device with wood in the air (Konovalova *et al.* 2003). The anatomical structure of the oak wood is disturbed, the morphological parameters of its elements, especially the libriform fibers, and the intermolecular bonds of its components change under the influence of ultrasound both in the air and water-alcohol medium. Lignin in wood undergoes changes after ultrasonic exposure in air and water-ethanol mixture according to histochemical and spectral (infrared spectroscopy) studies of wood (Konovalova *et al.* 2002, 2003, 2006).

The Combined Effect of Ultrasound and Mechanical Stress on Several Parameters of Wood

Wood is a complex polymer material. Vibrational deformations of wood cells and high-molecular compounds contained in them occur because of alternating stresses during the processing of wood by ultrasound. Intensive ultrasound action on polymers causes destruction of macromolecular chains, rotation of segments of these chains, and rupture of bonds between fibers.

One of the fundamental properties of macromolecules of polymers is their transition into a state of molecular flow or a sol state under the action of a time-varying temperature field (Antonova *et al.* 2014). In this case, a deformation jump phenomenon occurs if the polymer is under load. Molecular "flow" of polymer takes place by reducing the elastic modulus and destroying of its physical network (Antonova *et al.* 2014).

It is known that in elastomers, to which lignin can also be classified as its physical characteristics, at high values of external pressure, the rate of high-elastic deformations decreases, while the velocity of viscous-flow deformations increases and reaches a maximum value (Bartenev and Zelenev 1983). In addition to sonochemical reactions occurring under the action of ultrasound, tribochemic reactions are also known (Stefanovich *et al.* 2014). They occur with intensive mechanical action on the material, because of which new chemical bonds in polymers are destroyed and formed.

Joint application of wood pressing and acoustic impact showed the possibility of effective plasticization of even a damp, freshly cut wood (Krivonogova 2016). It is established that acoustic influence significantly reduces the frictional force between the wood billet and the form of the press during wood pressing (Birman *et al.* 2015).

When the wood is compacted in the field of ultrasonic vibrations (intensity of 3 to 10 W/cm^2, amplitude of oscillations of 30 to 70 μm and a frequency of 22 kHz), its density can reach up to 1.4 g/cm^3 to 1.45 g/cm^3. With this density, the wood becomes almost isotropic and perceives forces almost equally in all directions. Such wood is recommended for manufacturing of friction parts (sliders of presses, sawmills, loose leaves of large bearings, or thrust bearings). Parts that perceive vibrations and shocks (gears, fingers of couplings, cams of lunettes, vibration damping pads and pads in different mechanisms and machines, or fingers of couplings) (Ivanov *et al.* 2007).

When the wood is compacted in an acoustic field, the ultrasonic action increases the plasticity of the wood, reduces the force of pushing the billet through the die, reduces the number of microdefections of the billet, *i.e.*, increases the quality of the surface of the densified wood (Novolokin 2002). Under the ultrasound action, the process of samples deformation from various materials occurs with a reduction in the forces necessary for deformation (Rodimov *et al.* 2013).

From Sun-Tae (2000), it is known to heat a wooden workpiece by ultrasound and to compress it afterward, whereby the volume of the wooden workpiece is by and large reduced, and the wood is dehydrated and compacted. In doing so, the cells of the wood are not destroyed.

An experimental installation for wood densification was created at the Department of Electroacoustics and Ultrasonic Engineering of the St. Petersburg State Electrotechnical University (Russia). They have a rich experience in developing of ultrasound equipment and its applications for material processing (Vyuginova and Vyuginov 2013; Vyuginova *et al*. 2014).

A wood sample with a width of up to 200 mm is densified during the passage between two ultrasonic waveguides. The distance between the two waveguides less initial thickness of the workpiece and determines the degree of wood compaction. Ultrasound reduces friction when the workpiece passes through the treatment zone. This make it possible to increase treatment performance (speed of feed at least 3 m/min).

As a result of the experiments, it was possible to increase the Brinell hardness of the Canadian cedar billet up to 3 times (from 1,6 to 5,1), Aspen up to 2.5 times (from 1,86 to 4,98), and Oak up to 1.5 times (from 3,7 to 5,62). At the same time, the surface is closer to polished by the parameters of roughness (Fig. 1, Fig. 2).

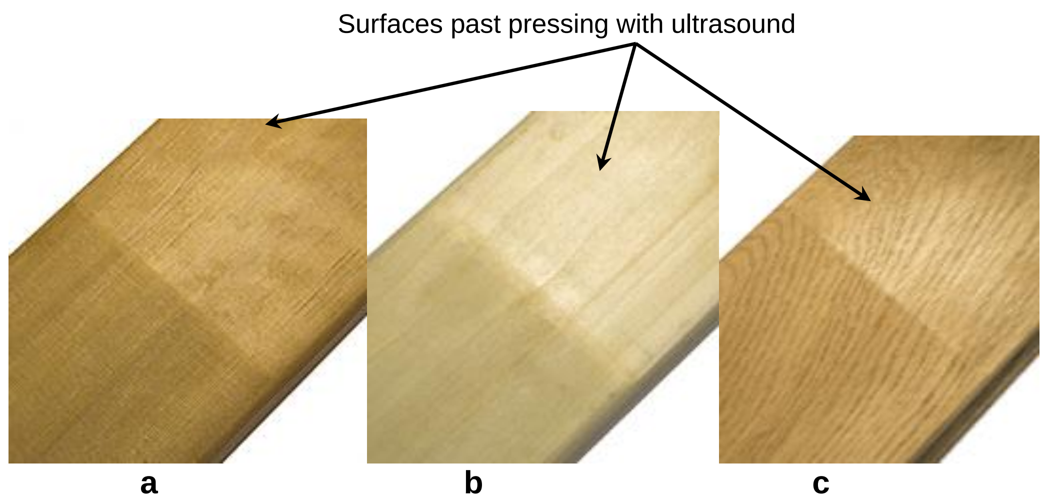

Fig. 1. Photographs of wood surfaces past pressing with ultrasound and untreated: Canadian Cedar (a), Aspen (b), and Oak (c) (Chizhkov 2017)

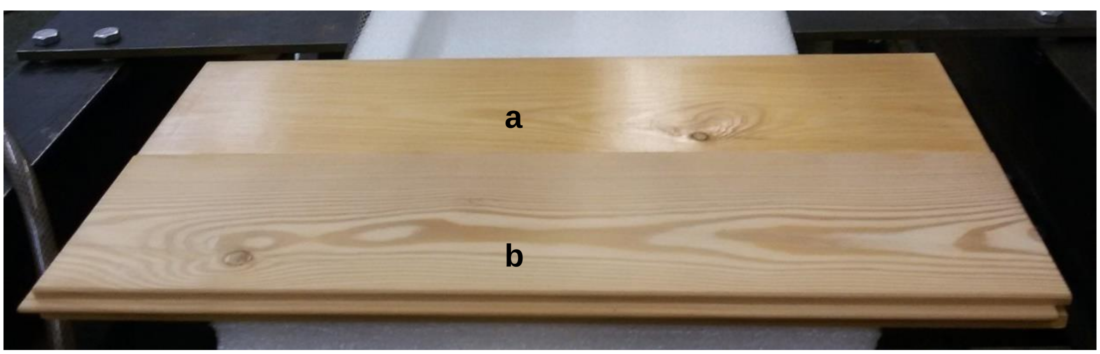

Fig. 2. Floorboards from larch: processed by pressing with ultrasound (a) and untreated (b) (Chizhkov 2017)

The surface treated with ultrasound may have a lower absorbency, which is good for saving finishing materials. In addition to the established increase in the hardness of the compressed with ultrasound surface, other studies of their properties have not been conducted. The main attention of the researchers is focused on the characteristics of an ultrasonic acoustic system improving.

Application of Ultrasound for Permanent Fixation of Densified Wood Dimensions

There are three main ways for achieving a permanent fixation of the densified wood dimensions (Inoue *et al.* 2008b; Kutnar *et al.* 2015): 1. The formation of cross-links between molecules of the wood matrix; 2. Relaxation of the stresses stored in the microfibrils and the matrix; and 3. Ensuring the hydrophobicity of wood.

Ultrasound affects all three of these ways. The fact that the ultrasonic effect on wood not only destroys the bonds between lignin macromolecules but also facilitates the formation of new bonds has been confirmed experimentally (15 W/cm^2, 21.5 kHz, and ultrasonication for 120 s), using thermomechanical spectroscopy methods (Antonova *et al.* 2014).

It is known that under the influence of ultrasound even of low power, depolymerization of lignin and a change in its structure occur (Saidalimov *et al.* 1977). The intramolecular bonds of lignin macromolecules break down, and free functional groups appear that promote interaction between fragments of the degraded polymer (ultrasonic flow 4 W/cm^2, frequency 22 kHz, and the time of ultrasonic treatment on oak wood in the air was 15 min to 35 min) (Antonova *et al.* 2006). The effect of cavitation and the local increase in the temperature of the wood substance under the influence of ultrasonic action are considered as a reason for changing the lignin structure.

Short-term exposure to high-power ultrasound causes changes in the chemical composition of oak wood. Moreover, the content of cellulose and the spatial distribution of lignin in the morphological structures of the wood do not change. Under the influence of ultrasound, structural changes occur in the lignin, which are accompanied by a decrease in the content of macromolecular and an increase in the low molecular weight fraction (Antonova *et al.* 2009).

During sonication, the wood is exposed to the combined action of local high pressures and temperatures. This destroys the lignin-carbohydrate bonds and breaks the bonds between the subunits of lignin. Consequently, the lignin network decomposes, increasing the available surface area of the cellulosic core without impairing the ordering (Koutsianitis *et al.* 2015; Qiu *et al*. 2016). The given irradiation conditions lead to enhanced delignification, and increased amorphous cellulose degradation due to radical formation (Koutsianitis *et al.* 2015).

Zhengbin He and colleagues performed ultrasound at a frequency of 28 and 40 kHz with an intensity of 10 W·cm^{-2} on wooden samples of poplar (*Populus cathayana*) sapwood in distilled water for 30 to 90 min. Wood becomes less hygroscopic after being subjected to ultrasound (He *et al*. 2016). Increased dimensional stability makes it possible extending its use into high-temperature and high-humidity surrounding in which wood products normally shrink and swell easily.

It was found that ultrasound pretreatment decreased the hydroxyl content in the wood. The hydrogen bonds in the moisture in the wood samples were broken down during ultrasound treatment. Ultrasonic action leads to decomposition or dehydration of hemicelluloses and extractives that contain many hydroxyl groups. In the wood samples treated with ultrasound for 30 min, some of the pit membranes had broken down. There were some collapsed structures and microchannels on the pits (He *et al.* 2016).

The Sterilization of Wood Using Ultrasonic Action

The sterilizing effect of ultrasound also has a high practical value. The disinfecting effect of ultrasound, for example, on water, is well known. Increasing the power of ultrasound leads to greater efficiency in the destruction of bacterial cells. High-frequency ultrasound is more beneficial than low frequency in the disinfection of water (Phull *et al.* 1997).

The application of high-intensity ultrasound for cleaning wood of wine barrels (including spoilage yeast *Brettanomyces*) has been investigated, and a commercial system for sanitizing wood wine barrels has been developed (Yap *et al.* 2008; Taylor *et al.* 2011).

Certain combinations of timing and frequency of ultrasonic waves and produced heat are effective in killing pinewood nematodes (*Bursaphelenchus xylophilus*), thus resulting in phytosanitized wood (mortality of nematodes reaches 100%) (Sohi *et al.* 2016).

Due to the impact on the wood of the oak ultrasound of high power, complete sterilization of the wood was achieved concerning the filamentous fungi. This is due to the local thermal effect of ultrasound (Antonova *et al.* 2009).

An anti-mold effect of ultrasound is established in experiments with Chinese moso bamboo (Guan *et al.* 2013). The mold rate of bamboo decreased after ultrasonic treatment, which was inversely proportional to the power and duration of treatment time. Scanning electron microscopic analysis revealed that the starch granules largely disappeared after ultrasonic treatment, which likely occurred because the ultrasonic wave broke or gelatinized the starch and widened the pits of the cell wall so that the starch could easily flow out resulting in reduced mold growth.

However, some organisms and their forms (for example spores) are established, to which ultrasound has less effect (Piyasena *et al.* 2003). For example, Gram-positive bacteria in oak wood were not destroyed by ultrasound (Antonova 2009).

It is advisable to combine ultrasound with heating or applying mechanical pressure to effectively sterilize the wood (Taylor *et al.* 2011). Thus, the sterilization of wood using ultrasonic action is promising and requires further study.

Thus, the effect of ultrasound on living organisms is known. Much also is known about the effect of ultrasound on the human body. Ultrasonic exposure, when sufficiently intense, to result in a syndrome involving nausea, headache, vomiting, disturbance of coordination, dizziness, and fatigue, and might cause a temporary or permanent hearing impairment (Pawlaczyk-łuszczyńska and Dudarewicz 2020).

To protect against the negative effects of ultrasound in industrial plants, it is recommended to use remote control, interlocks providing automatic shutdown in case of opening of soundproofing devices, as well as the use of soundproofing casings, semi-housings, screens. Direct contact of a person with the working surface of the source is prohibited. ultrasound and with a contact medium during the excitation of ultrasound in it (Geppa 2020).

SUMMARY

1. The development and improvement of methods for increasing the hardness of wood blanks from soft and hard woods are of great importance for increasing the completeness and efficiency of natural resources use.
2. The tasks of reducing the energy costs of the wood densification, improving the quality of the surface of the treated wood, increasing the productivity, ensuring environmental safety, and improving the dimensional stability of densified parts in the process of their use, is topical and is of great practical importance.
3. Studies of recent years have shown the possibility of effective softening lignin by processing samples with ultrasound. Thus, ultrasound can be effectively used to realize the most important stage of densification, namely, for the plasticization of wood.

4. Ultrasound produces changes in the physical, chemical, and functional properties of wood.
5. The sterilization of wood using ultrasonic action is promising and requires further study.
6. The use of combined ultrasound and pressing action for wood surface densification is very relevant.

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