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The possibility of using bacterial cellulose in particleboard technology

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Abstract: *The possibility of using bacterial cellulose in particleboard technology.* The paper presents the results of the influence of bacterial cellulose multiplication on industrial pine particles (used in wood materials technology), and then the use of the obtained biomass in the production of particleboards with reduced density LP1 type. Based on previous preliminary studies it was determined that the most effective growth of bacterial cellulose occurs using 5% wood particles in the breeding mixture. Two series of particleboards were produced: control and containing bacterial cellulose. Selected mechanical properties of produced particleboards (modulus of rupture, modulus of elasticity and internal bond) and selected physical properties (swelling and water absorption after 2 and 24 hours of soaking in water) were determined in turn. The boards made with bacterial cellulose had lower MOR and MOE values. Swelling after 2 and 24 hours was lower for boards with bacterial cellulose. The presented tests allow to state that bacterial cellulose can be a potential raw material ingredient in the production of particleboard while meeting the minimum requirements of the technical specification for boards with reduced density LP1.

Keywords: particleboard, low density, bacterial cellulose, Kombucha, physical and mechanical properties

INTRODUCTION

There is currently a deficit of wood resources in the world. The reason for this phenomenon is the constantly increasing demand for this raw material and mass deforestation for arable land [Oral, 2020]. In order to reduce the demand for wood raw material, newer and newer solutions are sought that can be used in the production of e.g. wood-based materials. One of the solutions introduced may be the use of bacterial cellulose (BC). Cellulose is the most common and available natural polymer. It is an unbranched polymer containing from 1000 to 1 million D-glucose units connected by β-(1-4) glycosidic bonds [Sánchez, 2009, Szymańska-Chargot et. al., 2017]. Bacterial cellulose, unlike its plant counterpart, is characterized by a higher degree of purity, which is due to the lack of copolymers such as lignins and hemicelluloses occurring along with cellulose in the structure of plant cell walls. [Ul-Islam et al., 2019]. In chemical terms, cellulose of plant origin is no different from BC [Zhao et al., 2018]. In addition, it should be noted that bacterial cellulose, unlike plant cellulose, has greater crystallinity, a higher degree of polymerization, greater ability to absorb and retain water, higher tensile strength, and good biocompatibility [Fax et. al., 2016, Ul-Islam et. al., 2012]. The listed BC properties can be useful when modifying technical materials. Modification of wood-based materials through the use of BC could not only improve their strength parameters, but also reduce the consumption of the main raw material used in their production, i.e. wood [Betlej et. al., 2020].

BC is synthesized by bacteria belonging to the genus *Acetobacter, Acanthamoeba, Achromobacter, Aerobacter, Agrobacterium, Alcaligenes, Azotobacter, Escherichia, Pseudomonas, Rhizobium, Salmonella, Sarcina,* and *Zooglea* [Skočaj, 2019]. *Acetobacter xylinum* is the best recognized BC synthesizing microorganism [Shoda and Sugano, 2005]. This bacterium can synthesize two structurally different types of cellulose. Cellulose type I is characterized by the occurrence of linear β 1-4 glucan chains, and type II cellulose by randomly arranged chains [Betlej et. al., 2020, Gallegos et. al., 2016, Yu and Atalla, 1996]. The Kombucha strain, whose microorganisms also produce bacterial cellulose, is used in the production of a popular drink obtained by fermenting sweetened tea. Symbiotic bacteria and yeast forming a "tea fungus" called Scoby (short for symbiotic bacterial and yeast colony) are its main component [Dufresne and Farnworth, 2000, Kalaiappan et. al., 2019]. The Kombucha microorganism ecosystem includes bacteria such *as Komagataeibacter xylinum, Acetobacter xylinoides, Gluconobacter oxydans, Gluconacetobacter hansenii, Oenococcus oeni, Komagataeibacter europaeus, Lactobacillus sp.* and *yeast Saccharomyces sp., Schizosaccharomyces pombe, Zygosaccharomyces kombuchaensis Torulaspora delbrueckii*, *Brettanomyces sp*. [Villarreal-Soto et. al., 2019].

BC is used in many industries. It has found application, e.g. in the paper industry, cosmetics industry, medicine, food industry, electronics industry [De Amorim et. al., 2020, Gallegos et. al., 2016, Wang, 2019]. Currently, a lot of research is carried out relating to the topic of BC, as evidenced by the number of records received when searching for bacterial cellulose in the Web of Science database. One of the possibilities of using BC in material engineering is to use it as an additional reinforcement for the fibers of fibrous materials used in the production of fibrous composites. Interest in BC in this area is due to its high Young's modulus estimated at 114 GPa. This value is comparable to the Young's modulus for glass fibers. It has been found that by growing cellulose-producing bacteria on natural fibers an additional layer of bacterial cellulose can be generated on the surface of these fibers, which significantly improves strength [Lee et. al., 2013]. In addition, research was carried out showing that production could be increased and BC synthesis costs reduced. For this purpose, various wastes from the food industry are used, added to the culture medium. BC synthesized on food waste was characterized by a uniform, well crosslinked structure and a level of crystallinity of 82.5% [Abdelraof et. al., 2019]. Unfortunately, there are no publications indicating the direct use of BC for the production of wood-based materials.

The paper presents preliminary results of the assessment of the possibility of using bacterial cellulose synthesized by Kombucha microorganisms on industrial pine particles, in the production of particleboards with reduced density LP1 type. To the best of our knowledge, it is the first work which develop research of particleboard with BC and wood particles.

MATERIALS AND METHODS

Initial tests were carried out during which the percentage content of each of the components needed to establish a bacterial colony of the Kombucha strain was determined. It was found that bacteria of the Kombucha strain most effectively multiply cellulose in a mixture with 5% particle content compared to 10% and 15% particle content variants, which eliminated these variants from further research. Initial research allowed at a later stage to create an effective culture of bacterial cellulose on wood particles. The moisture content of grown cellulose was also checked during the tests. Cellulose samples weighing about 5 g, were dried in a laboratory drier at 60°C until constant weight. The moisture content of the samples was calculated based on the formula:

*(pulp weight before drying [g] - pulp weight after drying [g] / pulp weight before drying [g]) * 100%*

In order to multiply cellulose by the microorganisms of the Kombucha strain, a medium consisting of water, animal peptone and sucrose was used. Research in this area was conducted based on the methodology provided by Betlej and Krajewski [2019]. The medium was modified and contained 6.5% sucrose and 0.25% peptone, respectively.

The colony was founded on a mixture consisting of industrial pine particles used for the production of the inner layer of particleboards (the amount of particles used was suitable for making particleboards in succession) immersed in the previously prepared medium. The weight of particles was 5% relative to all components of the mixture. An 8% suspension of Kombucha microorganisms was also added to the mixture. The mixture was placed in 60-liter casters. The cultivation time of the microorganisms during which they synthesized cellulose was 14 days. After a cultivation period of 7 days, the expanded cellulose was weighed, ground with a hand blender, and then returned to the casters. After this period, the particles along with the bacterial cellulose propagated were drained from the medium and dried to 3% humidity. The drying process was carried out at 60°C. Microbial propagation and cellulose synthesis were carried out in non-sterile conditions at 24°C ± 4°C and 55% ± 15% air humidity. The dry matter gain was also determined by comparing the weight of dry particles before placing them in the mixture with the dried biomass obtained after the bacterial cellulose multiplication process on the particle mixture.

In the next stage of research, single-layer particleboards were produced in 2 different variants. Control panels that did not contain bacterial cellulose were the first variant. The second variant was made using biomass on which bacterial cellulose had been previously grown. The boards were characterized by a density of 550 kg / m3, a thickness of 10 mm, dimensions of length and width 320 x 320 mm, a degree of particle gluing at the level of 10%. The boards were made using an adhesive based on urea-formaldehyde resin (the working concentration of the adhesive resin was 64%). The resin hardener was a 30% ammonium sulfate solution (added in an amount of 1% based on the dry weight of the adhesive). Paraffin was also added as a 50% paraffin emulsion (1% on dry particle basis). In order to produce particleboards, the biomass was placed in a sizing machine. During the sizing operation, the adhesive mixture and paraffin were applied to the introduced biomass. A carpet was made from the stuck biomass in the forming box. The carpets were pressed on a plate press at 180°C, with a unit pressing pressure of 2.5 N/mm^2, for 180 seconds (the pressing factor was 18 s/mm of board thickness). After removal from the press, the particleboards were seasoned for 7 days at 20°C (± 2° C) and 65% (± 5%) air humidity.

The plate samples were successively prepared and tested based on European standards (EN 310: 1994; EN 319: 1999; EN 317: 1999) to determine the effect of the modification used on static bending strength (MOR), modulus of elasticity in static bending (MOE) , stretching perpendicularly to the planes of the plate (IB), swelling and water absorption after 2 and 24 hours of soaking in water. MOR, MOE and IB tests were carried out on a testing machine manufactured by OBRPPD Ltd. in Czarna Woda. Water absorption after 2 and 24 hours soaking in water was carried out on 50 x 50 x 10 mm samples. The samples were placed in a container with water at room temperature for 24 hours. They were weighed after 2 and 24 hours of soaking in water. The water absorption of the boards was calculated on the basis of the formula:

*water absorption [%] = (particleboard mass after soaking [g] - particleboard mass before soaking [g] / particleboard mass before soaking [g]) * 100%*

RESULTS AND DISCUSSION

Bacterial cellulose increases from day 3 and 7 are shown in Figure 1.

Based on the visual assessment, BC was found to grow on the particle surface by contacting the external environment. After 14 days of cultivation, it was found that the weight of the synthesized BC on the particles corresponds to an average of 35% of the initial weight of dry pine particles used in establishing the culture. On the basis of the study determining the moisture content of freshly obtained BC, it was found to be at the level of 94,4%. Thus, the dry weight of BC produced under the assumed test conditions after a 14-day cultivation period was 5,6%.

An analysis of the mechanical properties of particleboards made with BC (Figure 2) showed that both modified and control panels met the requirements in terms of MOR, MOE and IB for LP1 panels according to prEN 16368: 2011. The tested panels did not meet the strength requirements for MOR and MOE for P1 type panels according to EN 312: 2011. In the case of MOR, panels with BC were 25% lower in strength compared to control panels. It should be noted that the value of the coefficient of variation for the obtained MOR results was 17% for control panels and 13% for BC panels, respectively. Boards with BC participation were also characterized by a lower MOE value - by 31% compared to control boards. The coefficient of variation in this case was 15% for control panels and 11% for BC panels, respectively. The differences between the control panel and modified BC variants in the obtained MOE values are statistically significant, so the modification introduced negatively affects the examined feature. It should be noted that the tested panels were single-layer, which means that they have lower strength properties than three-layer panels. At the same time, it is well known that the outer layers of three-layer boards carry 2/3 of the bending loads and the inner layers only 1/3 [Keywerth, 1958]. It can be presumed that the reduced values of the MOR and MOE test results obtained for boards containing BC relative to control boards result from the effect of the low pH of the medium on the wood particles contained in it. Shorting boards BC during the internal bond (IB) test were characterized by a 5% higher value of the tested characteristics compared to control boards (with a coefficient of variation of 15% for control boards and 9% for cellulose boards). In addition, the differences obtained with respect to IB values for control and BC containing plates were not statistically significant. Analyzing the IB values, it can be seen that in the case of both tested variants of the panels, the results obtained were characterized by a significantly higher IB value compared to the values given for P2 type panels according to EN 312: 2011. Obtained IB values were higher than the requirements of the EN 312: 2011 standard (P2 type panels) by 56% respectively for the control variant of panels and 58% for the variant of panels with the addition of BC.

a) b)

Figure 1. Growths of bacterial cellulose on a substrate with wood particles: a) after 3 days of synthesis, b) after 7 days of synthesis

The results of the tests of swelling of panels for thickness after 2 hours of soaking in water are presented in Figure 3. The panels containing BC were characterized by swelling by 31% lower compared to control panels. The coefficient of variation for the control boards was 22%, and for boards containing BC it was 17%.

Analyzing the physical properties of control panels and BC containing panels, it was found that swelling of BC containing panels was 35% lower compared to control panels. The coefficient of variation for BC modified panels was 16%, for control panels 13%. In the case of testing the absorbability of panels after soaking in water for 2 hours, it was noticed that the panels containing BC had 22% higher absorbability compared to the control panels. The coefficient of variation was 15% for control panels and 17% for BC containing panels, respectively. Based on the results of the absorbability test after 24 hours, it was found that boards containing BC have a 5% lower absorbability compared to the control panels. Taking into account the coefficient of variation, which is respectively 4% for control panels and 8% for BC panels, it should be noted that these differences were not statistically significant.

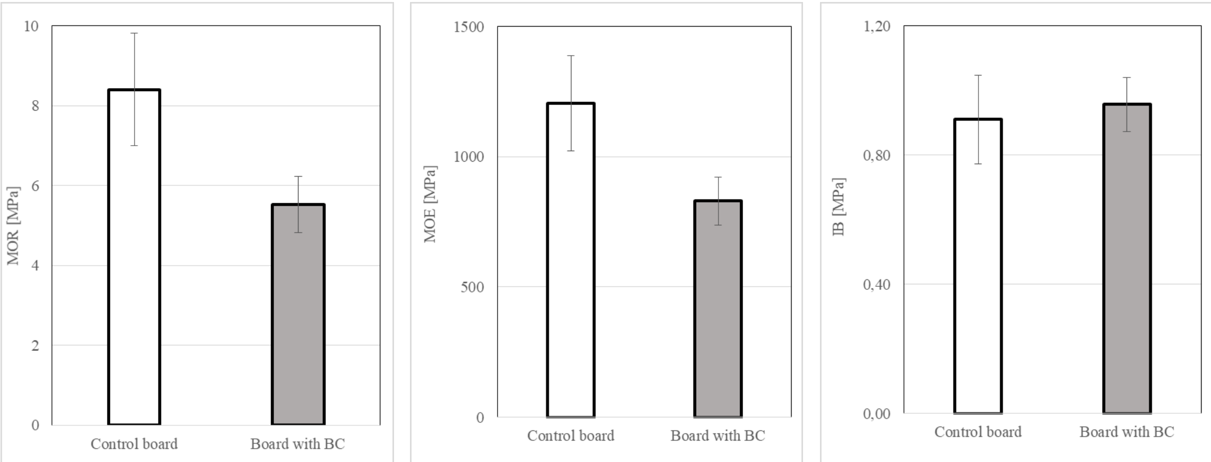

Figure 2. Differences in mechanical properties (modulus of rapture (MOR), modulus of elasticity (MOE), and internal bond strength (IB)) of the tested boards

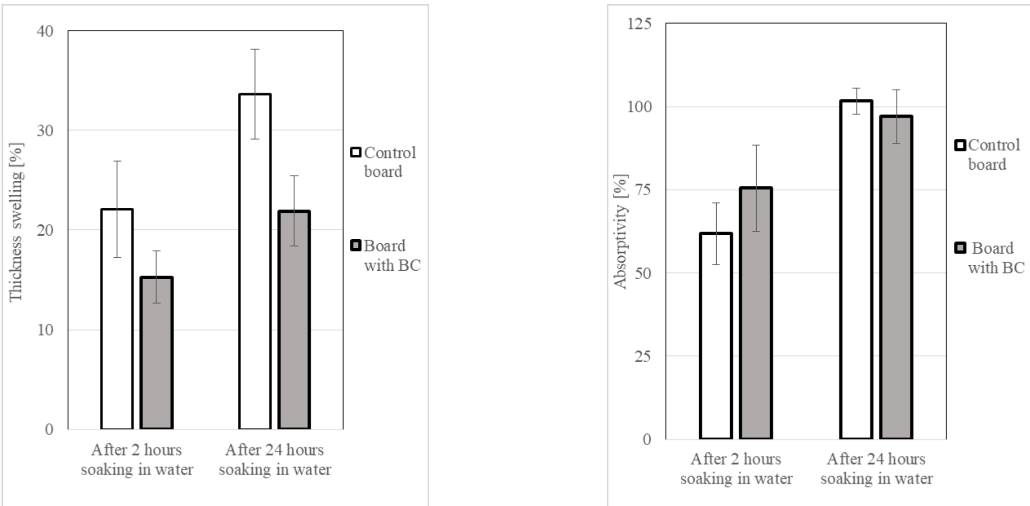

Figure 3. Differences in physical properties (thickness swelling after 2 hours of soaking in water and absorptivity) of the tested bords

In recent years, there has been an intensive increase in research on the use of nanocellulose fibers in the field of material engineering. Based on the results of research by Kojima et al. [2018] it was found that the use of 20% nanocellulose additive enables the production of particleboards with similar mechanical properties to control boards and with better hydrophobic properties along with the increase in the share of nanocellulose in particleboards. However, these plates were characterized by a relatively low value of the IB parameter. The particleboards containing BC obtained as part of this work were characterized by relatively good strength parameters, meeting the requirements of prEN 16368: 2011. The above-mentioned tests are pioneering and do not find equivalents in tests in the production of particleboards using BC.

CONCLUSION

Based on the conducted research, the following conclusions were formulated:

1. Single-layer particleboards containing an additive in the form of BC are characterized by lower MOR, MOE values compared to control panels, although it should be stated that they meet the strength parameters specified in the technical specification prEN 16368: 2011 for LP1 type panels.
2. The addition of bacterial cellulose to single-layer particleboards causes their swelling to decrease in thickness after 2 and 24 hours soaking in water compared to control boards.
3. The addition of bacterial cellulose to single-layer particleboards does not affect the level of water absorption after soaking for 2 and 24 hours compared to control boards.

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Streszczenie: *Możliwość wykorzystania celulozy bakteryjnej w technologii płyt wiórowych.* W pracy przedstawiono wyniki wpływu namnażania celulozy bakteryjnej na przemysłowych wiórach sosnowych (wykorzystywanych w technologii tworzyw drzewnych), a następnie wykorzystanie otrzymanej biomasy przy produkcji płyt wiórowych o obniżonej gęstości typu LP1. Na podstawie wcześniejszych badań wstępnych określono, że najefektywniejszy przyrost celulozy bakteryjnej następuje przy zastosowaniu 5% zawartości wiórów drzewnych w mieszaninie hodowlanej. Wyprodukowano dwie serie płyt wiórowych: kontrolną oraz zawierających celulozę bakteryjną. Kolejno określono wybrane właściwości mechaniczne wytworzonych płyt wiórowych (wytrzymałość na zginanie statyczne, moduł sprężystości przy zginaniu statycznym oraz wytrzymałość na rozciąganie w kierunku prostopadłym do płaszczyzn płyty) oraz wybrane właściwości fizyczne (spęcznienie i nasiąkliwość po 2 i 24 h moczenia w wodzie). Płyty wykonane z udziałem celulozy bakteryjnej charakteryzowały się niższymi wartościami MOR oraz MOE. Spęcznienie po 2 i 24 godzinach było niższe w przypadku płyt z udziałem celulozy bakteryjnej. Przedstawione badania pozwalają stwierdzić, iż celuloza bakteryjna może stanowić potencjalny ingredient surowcowy w produkcji płyt wiórowych spełniając przy tym minimalne wymagania specyfikacji technicznej dla płyt o obniżonej gęstości typu LP1.

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