ABSTRACTS

of the research works and publications of Assoc. Prof. **Viktor Petrov Savov**, PhD, for the period 2015 ÷ 2023 (after acquiring the academic position of Associate Professor) in English language, submitted for participation in the competition for acquiring the academic position "**Professor**" in the academic discipline "**Technology of Materials from Wood Fibres",** scientific area **6. Agricultural Sciences and Veterinary Medicine**, Professional Field 6.5. **Forestry**, scientific speciality "**Technology, mechanization and automation of the woodworking and furniture industry**", announced in **State Gazette, issue 26/03.21.2023**, procedure code: **WWI-P-0223-104**

1. Savov, V., Antov, P., Zhou, Y., Bekhta, P. (2023). Eco-Friendly Wood Composites: Design, Characterization and Applications. Polymers, 15, 892. https://doi.org/10.3390/polym15040892. IF: 4,967 (2021); 5-Year Impact Factor: 5,063. Квартил Q1.

Abstract: The ongoing transition from a linear to a circular, low-carbon bio-economy is crucial for reducing the consumption of global natural resources, minimizing waste generation, reducing carbon emissions, and creating more sustainable growth and jobs, the prerequisites necessary to achieve climate neutrality targets and stopping biodiversity loss. In recent years, the wood-based panel industry has faced significantly increasing demands for its various products due to the rising worldwide population, shifts in land use, and growing economies. Using wood more efficiently, optimizing natural raw material use, and sustainably converting waste into value-added products to meet projected demands for the development of wood-based composites all represent fundamental circular economy principles requiring the reuse, recycling, or upcycling of materials.

This Editorial presents a collection of 10 high-quality original research and review papers providing examples of the most recent advances and technological developments in the fabrication, design, characteristics, and applications of eco-friendly wood and wood-based composites.

2. Aristri, M.A., Sari, R.K., Lubis, M.A.R., Laksana, R.P.B., Antov, P., Iswanto, A.H., Mardawati, E.; Lee, S.H., **Savov, V.**, Kristak, L., Papadopoulos, A.N. (2023). Eco-Friendly Tannin-Based Non-Isocyanate Polyurethane Resins for the Modification of Ramie (*Boehmeria nivea* L.) Fibers. Polymers, 15, 1492. https://doi.org/10.3390/polym15061492. IF: 4,967 (2021); 5-Year Impact Factor: 5,063. Квартил Q1.

Abstract: This study aimed to develop tannin-based non-isocyanate polyurethane (tannin-Bio-NIPU) and tannin-based polyurethane (tannin-Bio-PU) resins for the impregnation of ramie fibers (Boehmeria nivea L.) and investigate their mechanical and thermal properties. The reaction between the tannin extract, dimethyl carbonate, and hexamethylene diamine produced the tannin-Bio-NIPU resin, while the tannin-Bio-PU was made with polymeric diphenylmethane diisocyanate (pMDI). Two types of ramie fiber were used: natural ramie without pre-treatment (RN) and with pre-treatment (RH). They were impregnated in a vacuum chamber with tannin-based Bio-PU resins for 60 min at 25 ◦C under 50 kPa. The yield of the tannin extract produced was 26.43 ± 1.36%. Fourier-transform infrared (FTIR) spectroscopy showed that both resin types produced urethane (-NCO) groups. The viscosity and cohesion strength of tannin-Bio-NIPU (20.35 mPa·s and 5.08 Pa) were lower than those of tannin-Bio-PU (42.70 mPa·s and 10.67 Pa). The RN fiber type (18.9% residue) was more thermally stable than RH (7.3% residue). The impregnation process with both resins could improve the ramie fibers' thermal stability and mechanical strength. The highest thermal stability was found in RN impregnated with the tannin-Bio-PU resin (30.5% residue). The highest tensile strength was determined in the tannin-Bio-NIPU RN of 451.3 MPa. The tannin-Bio-PU resin gave the highest MOE for both fiber types (RN of 13.5 GPa and RH of 11.7 GPa) compared to the tannin-Bio-NIPU resin.

3. Savov, V., Valchev, I., Antov, P., Yordanov, I., Popski, Z. (2022). Effect of the Adhesive System on the Properties of Fiberboard Panels Bonded with Hydrolysis Lignin and Phenol-Formaldehyde Resin. Polymers, 14, 1768. MDPI. ISSN 2073-4360. https://doi.org/10.3390/polym14091768. IF: 4.967 (2021); 5-Year Impact Factor: 5.063. Квартил Q1.

Abstract: This study aimed to propose an alternative technological solution for manufacturing fiberboard panels using a modified hot-pressing regime and hydrolysis lignin as the main binder. The main novelty of the research is the optimized adhesive system composed of unmodified hydrolysis lignin and reduced phenol–formaldehyde (PF) resin content. The fiberboard panels were fabricated in the laboratory with a very low PF resin content, varying from 1% to 3.6%, and hydrolysis lignin addition levels varying from 7% to 10.8% (based on the dry wood fibers). A specific two-stage hot-pressing regime, including initial low pressure of 1.2 MPa and subsequent high pressure of 4 MPa, was applied. The effect of binder content and PF resin content in the adhesive system on the main properties of fiberboards (water absorption, thickness swelling, bending strength, modulus of elasticity, and internal bond strength) was investigated, and appropriate optimization was performed to define the optimal content of PF resin and hydrolysis lignin for complying with European standards. It was concluded that the proposed technology is suitable for manufacturing fiberboard panels fulfilling the strictest EN standard. Markedly, it was shown that for the production of this type of panels, the minimum total content of binders should be 10.6%, and the PF resin content should be at least 14% of the adhesive system.

4. Valchev, I., Yordanov, Y., **Savov, V.**, Antov, P. (2022). Optimization of the Hot-Pressing Regime in the Production of Eco-Friendly Fibreboards Bonded with Hydrolysis Lignin. Periodica Polytechnica Chemical Engineering, 66(1), pp. 125-134. Published Online 26.11.2021. ISSN 1587-3765. https://doi.org/10.3311/PPch.18284. IF: 1,571, 5-Year IF: 1,680. Квартил Q3.

Abstract: This research was aimed at studying the potential of using residual lignin from acid hydrolysis as a binder in manufacturing eco- friendly, dry-process fibreboards. For that purpose, a modification of the adhesive system and hot-pressing regime was conducted. The adhesive system applied was composed of 2 % phenol-formaldehyde (PF) resin and 10 % hydrolysis lignin (based on the dry fibres). The PF resin does not only act as a binder but generally contributes to the even distribution and good retention of the main binder – hydrolysis lignin. A specific hot-pressing cycle was used. In the first stage, the pressure was 1.0 MPa, followed by an increased pressure of 4.0 MPa, and subsequent cooling. The purpose of the initial lower pressure was softening the lignin and reduction of the material moisture content. The effect of the second stage of hot-pressing on the properties of eco-friendly fibreboards was investigated. It was determined that the fibreboards produced with 2 % PF resin and 10 % hydrolysis lignin have similar physical and mechanical properties to those of the control panels, produced with 10 % PF resin at a standard hot-pressing cycle. The findings of this work demonstrate that residual hydrolysis lignin can be effectively utilized as a binder in the production of eco-friendly, dry-process fibreboards with acceptable physical and mechanical properties.

5. Shahavi, M. H., Selakjani, P. P., Abatari, M. N.; Antov, P., **Savov, V**. (2022). Novel Biodegradable Poly (Lactic Acid)/Wood Leachate Composites: Investigation of Antibacterial, Mechanical, Morphological, and Thermal Properties. Polymers, 14, 1227. MDPI. ISSN 2073-4360. https://doi.org/10.3390/polym14061227. IF: 4.967 (2021); 5-Year Impact Factor: 5.063. Квартил Q1.

Abstract: This research aimed to investigate the effects of using wood leachate (WL) powder as a cost-effective filler added to novel poly (lactic acid) biocomposites and evaluate their mechanical, thermal, morphological, and antibacterial properties. Fourier transform infrared spectroscopy (FTIR), tensile test, Charpy impact test, Shore hardness, scanning electron microscope (SEM), differential scanning calorimetry (DSC), contact angle, and bacterial growth inhibition tests were employed to characterize the developed biocomposites. The SEM results indicated a proper filler dispersion in the polymer matrix. WL powder improved the hydrophobic nature in the adjusted sample's contact angle experiment. Markedly, the results showed that the addition of WL filler improved the mechanical properties of the fabricated biocomposites. The thermal analysis determined the development in crystallization behavior and a decline in glass transition temperature (Tg) from 60.1 to 49.3 ◦C in 7% PLA-WL biocomposites. The PLA-WL biocomposites exhibited an antibacterial activity according to the inhibition zone for *Escherichia coli* bacteria. The developed novel PLA-WL composites can be effectively utilized in various value-added industrial applications as a sustainable and functional biopolymer material.

6. Solihat, N. N., Santoso, E. B., Karimah, A., Madyaratri, E. W., Sari, F. P.; Falah, F., Iswanto, A. H., Ismayati, M., Lubis, M.A.R.; Fatriasari, W., Antov, P., **Savov, V.**, Gajtanska, M., Syafii, W. (2022). Physical and Chemical Properties of *Acacia mangium* Lignin Isolated from Pulp Mill Byproduct for Potential Application in Wood Composites. Polymers, 14, 491. MDPI. ISSN 2073-4360. https://doi.org/10.3390/polym14030491. IF: 4.967 (2021); 5-Year Impact Factor: 5.063. Квартил Q1.

Abstract: The efficient isolation process and understanding of lignin properties are essential to determine key features and insights for more effective lignin valorization as a renewable feedstock for the production of bio-based chemicals including wood adhesives. This study successfully used dilute acid precipitation to recover lignin from black liquor (BL) through a single-step and ethanol- fractionated-step, with a lignin recovery of ~35% and ~16%, respectively. The physical characteristics of lignin, i.e., its morphological structure, were evaluated by scanning electron microscopy (SEM). The chemical properties of the isolated lignin were characterized using comprehensive analytical techniques such as chemical composition, solubility test, morphological structure, Fourier-transform infrared spectroscopy (FTIR), 1H and 13C Nuclear Magnetic Resonance (NMR), elucidation structure by pyrolysis-gas chromatography-mass spectroscopy (Py-GCMS), and gel permeation chromatography (GPC). The fingerprint analysis by FTIR detected the unique peaks corresponding to lignin, such as C=C and C-O in aromatic rings, but no significant differences in the fingerprint result between both lignin. The 1H and 13C NMR showed unique signals related to functional groups in lignin molecules such as methoxy, aromatic protons, aldehyde, and carboxylic acid. The lower insoluble acid content of lignin derived from fractionated-step (69.94%) than single-step (77.45%) correlated to lignin yield, total phenolic content, solubility, thermal stability, and molecular distribution. It contradicted the syringyl/guaiacyl (S/G) units' ratio where ethanol fractionation slightly increased syringyl unit content, increasing the S/G ratio. Hence, the fractionation step affected more rupture and pores on the lignin morphological surface than the ethanol-fractionated step. The interrelationships between these chemical and physicochemical as well as different isolation methods were investigated. The results obtained could enhance the wider industrial application of lignin in manufacturing wood-based composites with improved properties and lower environmental impact.

7. Iswanto, A.H., Madyaratri, E.W., Hutabarat, N.S., Zunaedi, E.R., Darwis, A., Hidayat, W., Susilowati, A., Adi, D.S., Lubis, M.A.R., Sucipto, T., Fatriasari, W., Antov, P. **Savov, V.**, Hua, L. S. (2022). Chemical, Physical, and Mechanical Properties of Belangke Bamboo (Gigantochloa pruriens) and Its Application as a Reinforcing Material in Particleboard Manufacturing. Polymers, 14, 3111. MDPI. ISSN 2073-4360. https://doi.org/10.3390/polym14153111. IF: 4.967 (2021); 5-Year Impact Factor: 5.063. Квартил Q1.

Abstract: This study aimed to analyze the basic properties (chemical composition and physical and mechanical properties) of belangke bamboo (*Gigantochloa pruriens*) and its potential as a particleboard reinforcement material, aimed at increasing the mechanical properties of the boards. The chemical composition was determined by Fourier transform near infrared (NIR) analysis and X-ray diffraction (XRD) analysis. The physical and mechanical properties of bamboo were evaluated following the Japanese standard JIS A 5908 (2003) and the ISO 22157:2004 standard, respectively. The results showed that this bamboo had average lignin, holocellulose, and alpha-cellulose content of 29.78%, 65.13%, and 41.48%, respectively, with a degree of crystallinity of 33.54%. The physical properties of bamboo, including specific gravity, inner and outer diameter shrinkage, and linear shrinkage, were 0.59%, 2.18%, 2.26%, and 0.18%, respectively. Meanwhile, bamboo's mechanical properties, including compressive strength, shear strength, and tensile strength, were 42.19 MPa,
7.63 MPa, and 163.8 MPa, respectively. Markedly, the addition of belangke bamboo strands as a reinforcing material (surface coating) in particleboards significantly improved the mechanical properties of the boards, increasing the modulus of elasticity (MOE) and bending strength (MOR) values of the fabricated composites by 16 and 3 times.

8. Kristak, L., Antov, P., Bekhta, P., Libis, M. A. R., Iswanto, A. H., Reh, R., Sedliacik, J., **Savov, V.**, Taghiyari, H. R., Papadopoulos, A. N., Pizzi, A., Hejna, A. (2022). Recent progress in ultra-low formaldehyde emitting adhesive systems and formaldehyde scavengers in wood-based panels: a review. Wood Materials Science and Engineering. Taylor and Francis Publishing House. ISSN 1748-0272. https://doi.org/10.1080/17480272.2022.2056080. IF: 2.732 (2021); 5-Year Impact Factor: 2.353. Квартил Q1.

Abstract: Traditional wood-based panels are produced with synthetic, formaldehyde-based adhesives, commonly made from fossil-derived constituents, such as urea, phenol, melamine, etc. Along with their numerous advantages, such as chemical versatility, high reactivity and excellent adhesive performance, these adhesives are characterized by certain problems, connected with the hazardous volatile organic compounds (VOCs), mostly free formaldehyde in the adhesives and the formaldehyde emission from the finished wood composites, which is carcinogenic to humans and harmful to the environment. The growing environmental concerns and stringent legislative requirements to the formaldehyde emission from wood-based panels have posed new challenges to researchers and industrial practice, related to the development of sustainable, eco-friendly wood-based panels with close-to-zero formaldehyde emission. The most common methods to reduce the formaldehyde emission from wood-based panels have been to decrease the free formaldehyde in the adhesive by modifying the adhesive (like lowering the molar ratio of formaldehyde to urea in UF resin) or by using formaldehyde scavengers, one group of scavengers being for adhesives by mixing or reacting and the second one scavengers for wood-based panels as post-treatments. Another way is to use alternative bio-based adhesives, however, there are still substantial challenges for the complete replacement of formaldehyde-based adhesives with bio- based adhesives, mainly because of their relatively low bonding strength, poor water resistance, etc. This article presents a review and analysis of the current state of research in the field of low formaldehyde emission wood adhesives and formaldehyde scavengers for manufacturing low-toxic, eco-friendly wood composites.

9. Bhakri, S., Ghozali, M., Cahyono, E., Triwulandari, E., Restu, W. K., Solihat, N., N., Iswanto A. H., Antov, P., **Savov, V.**, Hua, L. H., Agustiany, E., A., Kristak, L., Fatriasari, W. (2022). Development and Characterization of Eco-Friendly Non-Isocyanate Urethane Monomer from Jatropha curcas Oil for Wood Composite Applications. Journal of Renewable Materials, 11(1), 41–59. ISSN 2164-6341. https://doi.org/10.32604/jrm.2022.023151. IF: 2.115 (2021); Квартил Q3

Abstract: The aim of this research work was to evaluate the potential of using renewable natural feedstock, i.e., Jatropha curcas oil (JCO) for the synthesis of non-isocyanate polyurethane (NIPU) resin for wood composite applications. Commercial polyurethane (PU) is synthesized through a polycondensation reaction between isocyanate and polyol. However, utilizing toxic and unsustainable isocyanates for obtaining PU could contribute to negative impacts on the environment and human health. Therefore, the development of PU from eco-friendly and sustainable resources without the isocyanate route is required. In this work, tetra-n-butyl ammonium bromide was used as the activator to open the epoxy ring with 3-Aminopropyltriethoxisylane as a catalyst to yield urethane of JCO (UJCO). The UJCO were characterized by Fourier Transform Infra-Red spectroscopy (FTIR) and their oxirane, and hydroxyl values were measured. The result showed that a decrease in oxirane value was found while the hydroxyl value was increased during the time, confirming that the urethane group was formed. The presence of functional groups in FTIR spectra at wave numbers 1732.08, 1562.34, and 3348.42 cm^{-1} indicates the functional groups of C = O (urethane carbonyl), –NH, and –OH, respectively confirmed this finding. The potential applications of NIPU in the wood composite were also outlined.

10. Mihajlova, J., **Savov, V.** (2022). Effect of the content of Corn Stalk Fibres and Additional Heat Treatment on Properties of Eco-friendly Fibreboards Bonded with Lignosulphonate. Drewno 65 (209). ISSN 1644-3985. https://doi.org/10.12841/wood.1644-3985.395.06. IF. 1,00. Квартил Q3.

Abstract: This study aims to find the possibility of producing eco-friendly thin Medium Density Fibreboards (MDF) with the participation of corn stalk fibres and using lignosulfonate as a bio-based binder. The main novelty in the research is the establishment of the effect of additional heat treatment on the properties of MDF manufactured with the participation of non-wood lignocellulosic raw materials and bonded with bio-based adhesive – lignosulfonate. Panels with 15% lignosulfonate content and variation of the content of corn stalk fibres from 0% to 30% were manufactured. Previous experiments showed that when only lignosulfonate is used as a binder, the manufactured panels generally have low waterproofness. To reduce the effect of this main disadvantage, the panels were subjected additionally to heat treatment. The properties of the MDF with and without additional heat treatment were compared. The effect of both the content of corn stalk fibres and the additional heat treatment was found. The additional heat treatment improves the properties of MDF produced with lignosulfonate. Still, in case of increased content of corn stalk fibres, it is necessary to apply softened regimes than the ones selected for this study.

11. Taib., M. N. A. M., Antov, P., **Savov, V.**, Fatriasari, W., Madyaratri, E. W., Wirawan, R., Osvaldová, L. M., Hua, L. S., Ghani, M. A. A., Osman Al Edrus, S. S. A., Chen, L. W., Trache, D., Hussin, H. (2022). Current progress of biopolymer-based flame retardant, Polymer Degradation and Stability,205, 110153. ISSN 0141-3910. https://doi.org/10.1016/j.polymdegradstab.2022.110153. IF. 5,204. Квартил Q1.

Abstract: Due to thermal and flame/fire sensitivity of biopolymers especially in plant-based biopolymer fillers, it is extremely and necessary to improve the reaction to flame. The biopolymers currently are used in many applications and daily life products and due to the potential risks of its tendency to burn and widespread the flames. To overcome these risks, an introduction of flame retardant (FR) compounds, additives, or fillers based on organic and inorganic approaches such as nitrogen-based FRs, halogenated-based FRs, and nano fillers have becoming significant incorporated into biopolymers. Most traditional uses of FRs that involve halogenated and inorganic FRs are toxic and non-biodegradable during disposal. Thus, the need to look for more environmentally friendly FRs such as nanocellulose, lignin, and others have become crucial. Because of concern on environmental and human health issues the biopolymers becoming a popular subject nowadays among scientists and researchers. The aim of this review paper is to promote the use of biodegradable and bio-based compounds for flame retardants with reduction in carbon footprint and emission. Furthermore, the addition of biobased FRs are significant in preventing and reducing the spread of flames compared with conventional FRs. A detailed discussion on the flame retardants mechanism, characterization techniques, morphology correlation and various biopolymers with flame retardants are also discussed.

12. Hussin, M., H., Abd Latif, N. H., Hamidon, T. Sh., Idris, N. N., Hashim, R., Appaturi, J. N., Brosse, N., Ziegler-Devin, I., Chrusiel, L., Fatriasari, W., Syamani, F. A., Iswanto, A. H., Hua, L. S., Al Edrus, S. S. A. O., Lum, W. Ch., Antov, P., **Savov, V.**, Lubis, M. A. R., Kristak, L., Reh, R., Sedliavcik, J. (2022). Latest advancements in high-performance bio-based wood adhesives: A critical review. Journal of Material Research and Technology, 21, pp. 3909-3946. Elsevier, ISSN 2238-7854. https://doi.org/10.1016/j.jmrt.2022.10.156. IF: 6.267; CiteScore 5.9. Квартил Q1.

Abstract: Over the last 50 years, the use of wood adhesives in the manufacturing of wood-based panel goods has increased the efficiency of wood resources. Wood adhesives are becoming more popular as the need for wood-based panels grows. By 2028, the global market for wood adhesives is expected to reach 21.8 billion dollars. Even though urea- formaldehyde (UF), phenol-formaldehyde (PF), melamine-formaldehyde (MF), phenol- resorcinol-formaldehyde (PRF), and resorcinol-formaldehyde (RF) resins are excellent in terms of bonding performance, workability, quality, and economy, they consist of harmful or toxic chemical agents derived from fossil resources, which make their application severely limited. This review aims to go through the most significant 'green' wood adhesives for manufacturing high-performance wood-based panels, such as lignin, tannin, protein, natural rubber, emulsion polymer isocyanate (EPI), 1C PUR polyurethane (for glue- laminated wood and cross-laminated timber), PMDI (for particleboards, medium-density and low-density fiberboards), carboxylic acid, and vegetable oil. The physical and mechanical characteristics of bio-based wood adhesives, as well as the development of sustainable, greener, and high-performance bio-based wood adhesives, are discussed in this work. Original research papers and review articles are among the most important sources since they provide complete information on the most recent developments in sustainable, eco-friendly, and high-performance bio-based wood adhesives.

13. Antov, P., **Savov, V.**, Mantanis, G.I., Neykov, N. (2021). Medium-density Fibreboards Bonded with Phenolformaldehyde Resin and Calcium Lignosulfonate as an Eco-friendly Additive. Wood Material Science and Engineering, 16(1), pp.42-48. Taylor & Francis publishing house. ISSN 1748-0280. https://doi.org/10.1080/17480272.2020.1751279. IF 1,265.

Abstract: Medium-density fibreboards with acceptable physical and mechanical properties can be produced with conventional PF resin, at low addition levels, if combined with calcium lignosulfonate, specifically at 5% to 10% addition (on the dry fibres). Results from laboratory tests, with low PF resin contents (3%, 4%, 5%) and different calcium lignosulfonate additions (5% to 15%), showed that lignosulfonate-PF resin bonded MDF panels complying with the EN standard requirements can be fabricated with at least 3.5% PF resin content.
Furthermore, at the low PF resin level (3%), addition of calcium lignosulfonate should not exceed 10% to avoid unacceptable deterioration in the mechanical properties of the panels.
The use of lignin-based compounds like lignosulfonates along with PF resins is a promising approach for producing 'eco-friendly' MDF panels with acceptable properties. As a result, it can be concluded that PF resin content can be reduced to 3%, with the addition of calcium lignosulfonate in the glue, even without further cross-linking.
Future studies in this topic should be aimed at lowering the PF resin content by modifying the formula of lignosulfonate additive, optimising the pressing parameters and investigating the chemical interaction between phenolic resins, lignosulfonate and wood fibres, in order to achieve an optimal performance.

14. Antov, P. **Savov, V.**, Krišťák, Ľ., Réh, R., Mantanis, G. I. (2021). Eco-Friendly, High-Density Fiberboards Bonded with Urea-Formaldehyde and Ammonium Lignosulfonate. Polymers 13 (2):220. ISSN 2073-4360. https://doi.org/10.3390/polym13020220. IF 4.329. 5-Year IF: 4,493. Квартил Q1.

Abstract: The potential of producing eco-friendly, formaldehyde-free, high-density fiberboard (HDF) panels from hardwood fibers bonded with urea-formaldehyde (UF) resin and a novel ammonium lignosulfonate (ALS) is investigated in this paper. HDF panels were fabricated in the laboratory by applying a very low UF gluing factor (3%) and ALS content varying from 6% to 10% (based on the dry fibers). The physical and mechanical properties of the fiberboards, such as water absorption (WA), thickness swelling (TS), modulus of elasticity (MOE), bending strength (MOR), internal bond strength (IB), as well as formaldehyde content, were determined in accordance with the corresponding European standards. Overall, the HDF panels exhibited very satisfactory physical and mechanical properties, fully complying with the standard requirements of HDF for use in load- bearing applications in humid conditions. Markedly, the formaldehyde content of the laboratory fabricated panels was extremely low, ranging between 0.7–1.0 mg/100 g, which is, in fact, equivalent to the formaldehyde release of natural wood.

15. Antov, P., **Savov, V.**, Trichkov, N., Krišťák, Ľ., Réh, R., Papadopulus, A. N., Taghiyari, H. R., Pizzi, A., Kunecová, D., Pachikova, M. (2021). Properties of High-Density Fiberboard Bonded with Urea–Formaldehyde Resin and Ammonium Lignosulfonate as a Bio-Based Additive. Polymers 13 (6), 2775. ISSN 2073-4360. https://doi.org/10.3390/polym13162775. IF 4,329. 5-Year IF: 4,493. Квартил Q1.

Abstract: The potential of ammonium lignosulfonate (ALS) as an eco-friendly additive to urea–formaldehyde (UF) resin for manufacturing high-density fiberboard (HDF) panels with acceptable properties and low free formaldehyde emission was investigated in this work. The HDF panels were manufactured in the laboratory with very low UF resin content (4%) and ALS addition levels varying from 4% to 8% based on the mass of the dry wood fibers. The press factor applied was 15 $s \cdot mm^{-1}$. The physical properties (water absorption and thickness

swelling), mechanical properties (bending strength, modulus of elasticity, and internal bond strength), and free formaldehyde emission were evaluated in accordance with the European standards. In general, the developed HDF panels exhibited acceptable physical and mechanical properties, fulfilling the standard requirements for HDF panels for use in load-bearing applications. Markedly, the laboratory-produced panels had low free formaldehyde emission ranging from 2.0 to 1.4 mg/100 g, thus fulfilling the requirements of the E0 and super E0 emission grades and confirming the positive effect of ALS as a formaldehyde scavenger. The thermal analyses performed, i.e., differential scanning calorimetry (DSC), thermal gravimetric analysis (TGA), and derivative thermogravimetry (DTG), also confirmed the main findings of the research. It was concluded that ALS as a bio-based, formaldehyde-free adhesive can be efficiently utilized as an eco-friendly additive to UF adhesive formulations for manufacturing wood-based panels under industrial conditions.

16. Antov, P. **Savov, V.**, Krišťák, Ľ., Neykov, N. (2021). Effect of Hot Pressing Parameters on the Properties of Hardboards Produced from Mixed Hardwood Tree Species. Wood Research 66(3), pp. 437-438. e-ISSN 2729-8906. https://doi.org/10.37763/wr.1336-4561/66.3.437448. IF: 0.688; 5-Year IF: 0,785. Квартил Q2.

Abstract: In this work, wet-process fibreboards (hardboards) were produced in the laboratory using industrial wood fibres of the species European beech (*Fagus sylvatica* L.) and Turkey oak (*Quercus cerris* L.) at the total volume of 40%, and white poplar (*Populus alba* L.) at60% volume. The effects of hot pressing pressure (varied from 3.3 MPa to 5.3 MPa) and pressing time (from 255 s to 355 s) on the physical and mechanical properties of hardboards were investigated and optimal values of the parameters for fulfilling the European standard requirements were determined. It was concluded that hardboards with acceptable physical and mechanical properties may be produced from 60% poplar wood waste and residues, combined with 40% hardwood raw materials (beech and oak) by regulating the hot pressing regime only, i.e. pressure and pressing time. The following minimum parameters for producing hardboards from mix hardwood tree species were determined: a pressure of 4.6 MPa and a pressing time of 280 s.

17. Réh, R., Krišťák, Ľ., Sedliačik, J., Bekhta, P., Božiková, M., Kunecová, D., Vozárová, V., Tudor, E.M., Antov, P, Savov, V. (2021). Utilization of Birch Bark as an Eco-Friendly Filler in Urea-Formaldehyde Adhesives for Plywood Manufacturing. Polymers 13 (4):511. ISSN 2073-4360. https://doi.org/10.3390/polym13040511. IF 4.329. 5-Year IF: 4,493. Квартил Q1.

Abstract: The potential of using ground birch (*Betula verrucosa* Ehrh.) bark as an eco-friendly additive in urea-formaldehyde (UF) adhesives for plywood manufacturing was investigated in this work. Five-ply plywood panels were fabricated in the laboratory from beech (*Fagus sylvatica* L.) veneers bonded with UF adhesive formulations comprising three addition levels of birch bark (BB) as a filler (10%, 15%, and 20%). Two UF resin formulations filled with 10% and 20% wheat flour (WF) were used as reference samples. The mechanical properties (bending strength, modulus of elasticity and shear strength) of the laboratory-fabricated plywood panels, bonded with the addition of BB in the adhesive mixture, were evaluated and compared with the European standard requirements (EN 310 and EN 314-2). The mechanical strength of the plywood with the addition of BB in the adhesive mixture is acceptable and met the European standard requirements. Markedly, the positive effect of BB in the UF adhesive mixture on the reduction of formaldehyde emission from plywood panels was also confirmed. Initially, the most significant decrease in formaldehyde release (up to 14%) was measured for the plywood sample, produced with 15% BB. After four weeks, the decrease in formaldehyde was estimated up to 51% for the sample

manufactured with 20% BB. The performed differential scanning calorimetry (DSC), thermal gravimetric analysis (TGA), and derivative thermogravimetry (DTG), also confirmed the findings of the study. As this research demonstrated, BB as a waste or by-product of wood processing industry, can be efficiently utilized as an environmentally friendly, inexpensive alternative to WF as a filler in UF adhesive formulations for plywood manufacturing.

18. Antov, P., Krišťák, Ľ., Réh, R., **Savov, V.** Papadopulus, A. N. (2021). Eco-Friendly Fiberboard Panels from Recycled Fibers Bonded with Calcium Lignosulfonate. Polymers 13 (4), 639. ISSN 2073-4360. https://doi.org/10.3390/polym13040639. IF 4,329. 5-Year IF: 4,493. Квартил Q1.

Abstract: The potential of using residual softwood fibers from the pulp and paper industry for producing eco-friendly, zero-formaldehyde fiberboard panels, bonded with calcium lignosulfonate (CLS) as a lignin-based, formaldehyde free adhesive, was investigated in this work. Fiberboard panels were manufactured in the laboratory by applying CLS addition content ranging from 8% to 14% (on the dry fibers). The physical and mechanical properties of the developed composites, i.e., water absorption (WA), thickness swelling (TS), modulus of elasticity (MOE), bending strength (MOR), as well as the free formaldehyde emission, were evaluated according to the European norms. In general, only the composites, developed with 14% CLS content, exhibited MOE and MOR values, comparable with the standard requirements for medium-density fiberboards (MDF) for use in dry conditions. All laboratory-produced composites demonstrated significantly deteriorated moisture-related properties, i.e., WA (24 h) and TS (24 h), which is a major drawback. Noticeably, the fiberboards produced had a close-to-zero formaldehyde content, reaching the super E0 class (≤1.5 mg/100 g), with values, ranging from 0.8 mg/100 g to 1.1 mg/100 g, i.e., equivalent to formaldehyde emission of natural wood. The amount of CLS adhesive had no significant effect on formaldehyde content.

19. Bekhta P., Noshchenko G., Réh R., Kristak L., Sedliačik J., Antov P., Mirski R., **Savov V.** (2021). Properties of Eco-Friendly Particleboards Bonded with Lignosulfonate-Urea-Formaldehyde Adhesives and pMDI as a Crosslinker. Materials. 14(17), 4875. ISSN 1996-1944. https://doi.org/10.3390/ma14174875. IF 3,623, 5 Year IF: 3,920. Квартил Q1.

Abstract: The purpose of this study was to evaluate the feasibility of using magnesium and sodium lignosulfonates (LS) in the production of particleboards, used pure and in mixtures with urea-formaldehyde (UF) resin. Polymeric 4,4′-diphenylmethane diisocyanate (pMDI) was used as a cross- linker. In order to evaluate the effect of gradual replacement of UF by magnesium lignosulfonate (MgLS) or sodium lignosulfonate (NaLS) on the physical and mechanical properties, boards were manufactured in the laboratory with LS content varying from 0% to 100%. The effect of LS on the pH of lignosulfonate-urea-formaldehyde (LS-UF) adhesive compositions was also investigated. It was found that LS can be effectively used to adjust the pH of uncured and cured LS-UF formulations. Particleboards bonded with LS-UF adhesive formulations, comprising up to 30% LS, exhibited similar properties when compared to boards bonded with UF adhesive. The replacement of UF by both LS types substantially deteriorated the water absorption and thickness swelling of boards. In general, NaLS-UF-bonded boards had a lower formaldehyde content (FC) than MgLS-UF and UF-bonded boards as control. It was observed that in the process of manufacturing boards using LS adhesives, increasing the proportion of pMDI in the adhesive composition can significantly improve the mechanical properties of the boards. Overall, the boards fabricated using pure UF adhesives exhibited much better mechanical properties than boards bonded with LS adhesives. Markedly, the boards based on LS adhesives were characterised by a much lower FC than the

UF-bonded boards. In the LS-bonded boards, the FC is lower by 91.1% and 56.9%, respectively, compared to the UF- bonded boards. The boards bonded with LS and pMDI had a close-to-zero FC and reached the super E0 emission class (≤1.5 mg/100 g) that allows for defining the laboratory-manufactured particleboards as eco-friendly composites.

20. Handika, S.O., Lubis, M.A.R., Sari, R.K., Laksana, R.P.B., Antov, P., **Savov, V.**, Gajtanska, M., Iswanto, A. H. (2021). Enhancing Thermal and Mechanical Properties of Ramie Fiber via Impregnation by Lignin-Based Polyurethane Resin. Materials 14 (7), 6858. ISSN 1996-1944. https://doi.org/10.3390/ma14226850. IF: 3.623, 5 Year IF: 3.920. Квартил Q1.

Abstract: In this study, lignin isolated and fractionated from black liquor was used as a pre-polymer to prepare bio-polyurethane (Bio-PU) resin, and the resin was impregnated into ramie fiber (*Boehmeria nivea* (L.) Gaudich) to improve its thermal and mechanical properties. The isolated lignin was fractionated by one-step fractionation using two different solvents, i.e., methanol (MeOH) and acetone (Ac). Each fractionated lignin was dissolved in NaOH and then reacted with a polymeric 4,4-methane diphenyl diisocyanate (pMDI) polymer at an NCO/OH mole ratio of 0.3. The resulting Bio-PU was then used in the impregnation of ramie fiber. The characterization of lignin, Bio-PU, and ramie fiber was carried out using several techniques, i.e., Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), pyrolysis-gas-chromatography-mass-spectroscopy (Py-GCMS), Micro Confocal Raman spectroscopy, and an evaluation of fiber mechanical properties (modulus of elasticity and tensile strength). Impregnation of Bio-PU into ramie fiber resulted in weight gain ranging from 6% to 15%, and the values increased when extending the impregnation time. The reaction between the NCO group on Bio-PU and the OH group on ramie fiber forms a C=O group of urethane as confirmed by FTIR and Micro Confocal Raman spectroscopies at a wavenumber of 1600 cm−1. Based on the TGA analysis, ramie fiber with lignin-based Bio-PU had better thermal properties than ramie fiber before impregnation with a greater weight residue of 21.7%. The mechanical properties of ramie fiber also increased after impregnation with lignin-based Bio-PU, resulting in a modulus of elasticity of 31 GPa for ramie-L- isolated and a tensile strength of 577 MPa for ramie-L-Ac. The enhanced thermal and mechanical properties of impregnated ramie fiber with lignin-based Bio-PU resins could increase the added value of ramie fiber and enhance its more comprehensive industrial application as a functional material.

21. Savov, V., Antov, P. (2020). Engineering the Properties of Eco-Friendly Medium Density Fibreboards Bonded with Lignosulfonate Adhesive. Drvna Industrija 71 (2), pp. 157-162. ISSN 0012-6772. https://doi.org/10.55 52/drvind.2020.1968. IF 0,830. SJR 0,284. Квартил Q3.

Abstract: Free formaldehyde emissions from wood-based panels, especially in indoor applications, pose serious risks to human health at certain concentrations. Prolonged exposure to formaldehyde can cause adverse health effects including eye, nose and throat irritation, other respiratory symptoms and cancer. As a consequence, new formaldehyde emission limits for composite wood products were established in Europe, USA and Japan. This, together with the stricter environmental legislation are the main driving factors for shifting the scientific and industrial interest from the traditional formaldehyde-based synthetic resins to the new bio-based adhesives for production of eco-friendly wood-based panels. The lignin-based products are one of the most prospective ecological alternatives to the traditional formaldehyde resins. The main interest in lignin is due to its phenolic structure with several favourable properties for the formulation of wood adhesives such as high hydrophobicity and low polydispersity.
The present article is aimed at studying the possibilities for using lignosulfonate as an adhesive for the production of eco-friendly MDF. Regression models describing the impact of

lignosulfonate concentration and hot pressing temperature on the exploitation properties of MDF panels were developed. The individual and combined impact of both factors was analysed in order to determine the optimal exploitation properties of the panels.

22. Antov, P., **Savov, V.**, Neykov, N. (2020). Sustainable Bio-Based Adhesives for Eco-Friendly Wood Composites – A review. Wood Research 65 (1), pp. 51-62. ISSN 1336-4561. https://doi.org/10.37763/wr.1336-4561/65.1.051062. IF 0,740. Квартил Q2.

Abstract: The aim of the present review is to summarize the current state of research in the field of sustainable bio-based adhesives used for production of eco-friendly wood composite materials. The article is focused mainly on the use of lignin, starch and tannins as raw materials and alternatives to the existing conventional adhesives. It is expected that increased amounts of bio-based adhesives will be used in the production of wood composites in order to meet the current needs for development of sustainable and innovative materials which will make the wood-based panel industry more sustainable and lower its dependence on fossil fuels. However, there are still substantial challenges for the complete replacement of petroleum-based wood adhesives with bio-based adhesives, mainly because of their relatively poor water resistance, low bonding strength and large natural variations due to different growing conditions. In this respect, fundamental research is still need in order to determine the factors for formulating bio-based adhesives with optimal properties and broaden their application in wood-based panel industry.

23. Antov, P., Mantanis, G.I., **Savov, V.** (2020). Development of Wood Composites from Recycled Fibres Bonded with Magnesium Lignosulfonate. Forests 11(6), 613. MDPI, ISSN 1999-4907. https://doi.org/10.3390/f11060613. IF 2.221, 5 Year IF 2,804. Квартил Q1.

Abstract: The potential of producing ecofriendly composites from industrial waste fibres, bonded with magnesium lignosulfonate, a lignin-based formaldehyde-free adhesive, was investigated in this work. Composites were produced in the laboratory using the following parameters: a hot press temperature of 210 °C, a pressing time of 16 min, and a 15% gluing content of magnesium lignosulfonate (on the dry fibres). The physical and mechanical properties of the produced composites were evaluated and compared with the European Standard (EN) required properties (EN 312, EN 622-5) of common wood-based panels, such as particleboards for internal use in dry conditions (type P2), load-bearing particleboards for use in humid conditions (type P5), heavy-duty load-bearing particleboards for use in humid conditions (type P7), and medium-density fibreboards (MDF) for use in dry conditions. In general, the new produced composites exhibited satisfactory mechanical properties: a bending strength (MOR) (18.5 $N.mm^{-2}$) that was 42% higher than that required for type P2 particleboards (13 $N.mm^{-2}$) and 16% higher than that required for type P5 particleboards (16 $N.mm^{-2}$). Additionally, the modulus of elasticity (MOE) of composites (2225 $N.mm^{-2}$) was 24% higher than that required for type P2 particleboards (1800 $N.mm^{-2}$) and equivalent to the required MOE of MDF panels for use in dry conditions (2200 $N.mm^{-2}$). However, these ecofriendly composites showed deteriorated moisture properties, i.e., 24 h swelling and 24 h water absorption, which were a distinct disadvantage. This should be further investigated, as modifications in the lignosulfonate formula used and/or production parameters are necessary.

24. Antov, P., Jivkov, V., **Savov, V.**, Simeonova, R., Yavorov, N. (2020). Structural Application of Eco-Friendly Composites from Recycled Wood Fibres Bonded with Magnesium Lignosulfonate. Applied Science, 10(21), 7526. MDPI, ISSN 2076-3417. https://doi.org/10.3390/app10217526. IF 2.474, 5 Year IF 2,736. Квартил Q1.

Abstract: The pulp and paper industry generates substantial amounts of solid waste and wastewater, which contain waste fibres. The potential of using these recycled wood fibres for producing eco-friendly composites that were bonded with a formaldehyde-free adhesive (magnesium lignosulfonate) and their use in structural applications was evaluated in this study. Fibreboards were produced in the laboratory with a density of 720 $kg \cdot m^{-3}$ and 15%

magnesium lignosulfonate gluing content, based on the dry fibres. The mechanical properties (bending strength, modulus of elasticity and internal bond strength), physical properties (thickness swelling and water absorption) and formaldehyde content were determined and compared with the European Standards requirements for wood-based panels. In general, the laboratory-produced panels demonstrated acceptable mechanical properties, such as bending strength (18.5 $N \cdot mm^{-2}$) and modulus of elasticity (2225 $N \cdot mm^{-2}$), which were higher than the minimum requirements for type P2 particleboards and equal to the requirements for MDF panels. The moisture properties, i.e., thickness swelling (24 h) and water absorption (24 h) significantly deteriorated. The free formaldehyde content of the laboratory-produced composites (1.1 mg/100 g) reached the super E0 grade (≤1.5 mg/100 g), which allowed for their classification as eco-friendly, low-emission wood-based composites. The L-type corner joints, made from the developed composites, demonstrated significantly lower bending capacity (from 2.5 to 6.5 times) compared to the same joints made from MDF panels. Nevertheless, the new eco-friendly composites can be efficiently utilised as a structural material in non-load-bearing applications.

25. Savov, V., Angelski, D. (2022). Effect of Lignosulfonate Content on the Adhesive Strength at Veneering of Medium Density Fibreboards. Innovations in Woodworking Industry and Engineering Design 11(2), pp. 45-50. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: The transition to a circular bio-oriented industry requires the search for alternative raw materials, sources and binders in producing materials for the furniture industry. Lignosulfonates (sulphite lignins) are by-products, residues, of cellulose production, and they are bio-based materials with adhesive properties. This work presents a study evaluating lignosulfonates as binders in the veneering of Medium Density Fibreboards (MDF). An adhesive composition of urea-formaldehyde (UF) resin and ammonium lignosulfonate was used in the veneering. Preliminary experiments have been carried out that show a significant reduction in the adhesion strength when the lignosulfonate content in the adhesive system passes 60%. Therefore, the study used the substitution of UF resin with lignosulfonate from 0 to 60%, with a step of variation from 10%. It is carried out at the gelling time of the various adhesive systems. An analysis of the adhesive strength in veneering at adhesive systems with different lignosulfonate content was performed. Based on this, conclusions and recommendations were derived.

26. Savov, V., Grigorov, R., Alexandrov, S. (2022). Properties of Particleboards with the Participation of Hemp and Vine Particles in the Core Layer – Part II: Optimisation of the Composition. Innovations in Woodworking Industry and Engineering Design 11 (2), pp. 51-60. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: Volarization of agro-industrial residues into value-added materials such as particleboards will increase the utilisation of natural bio-resources and support the transition to a circular economy.

In the first part of the publication, research was presented regarding the effect of the con- tent of vine, hemp and wood particles in the core layer of three-layered particleboards on the properties of these panels. It was established that the variation in the content of vine and hemp particles does not affect the waterproof properties.

The present part represents the results of the optimisation of the core layer of the panels, given their mechanical properties. Data are delivered with accompanying analysis regarding the screw withdrawal resistance of particleboards. This property is of primary importance in using particleboards as a structural element in furniture production.

As a result of the conducted research, it was established that the panels fabricated with a core layer entirely of hemp particles have the best exploitation properties. It was also found that when using vine particles for the core layer of particleboards, their content is not recommended to be over 30%.

27. Panchev, Ch., **Savov, V. (2022).** Recycling of Medium Density Fibreboards – A Review. Innovations in Woodworking Industry and Engineering Design 1 (21), pp. 39-46. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: Production of Medium Density Fibreboards (MDF) is one of the growing woodworking industries. It has been found that a quarter of the produced MDFs have a life cycle of up to five years, and by ten years, this amount has increased to fifty percent. There is no established industrial practice for recycling that type of waste. That, together with the fact that some countries have banned the dumping of these panels in landfills, poses significant challenges.

There are currently two main research directions on MDF recycling, namely with and without pre-treatment. In both cases, with an increase in the content of recycled fibres, a deterioration in the properties of the panels is observed. Still, the share of cut fibres and formaldehyde emissions from the boards are reduced during the preliminary treatment, mainly by hydrolysis.

In the present manuscript, a review and analysis of MDF recycling methods are performed. On that base, conclusions and recommendations are derived.

28. Grigorov, R., **Savov, V.**, Alexandrov, S. (2022). Properties of Particleboards with the Participation of Hemp and Vine particles in the Core Layer – Part I: Effect of the Composition. Innovations in Woodworking Industry and Engineering Design 1 (21), pp. 47-56. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: Increasing deforestation worldwide, on the one hand, and the increased production of wood-based panels, on the other hand, lead to the need for alternative lignocellulosic raw materials. In this context, it should be said that significant amounts of lignocellulosic biomass remain annually from agricultural production, and unfortunately, that biomass is generally burned. However, individual types of lignocellulosic non-wood raw materials can hardly cover the needs of wood-based panel manufacturers, which necessitates their combination.

For the aim of the study, particleboards with a core layer of vine and hemp particles were produced. The contents of vine and hemp particles varied from 0 to 100% in steps 20%. A control panel composed only of wooden raw material was also fabricated, and the face layers of the panels were from hardwood particles.

As a result of the study, it was found that the variation in the composition of the core layer does not affect the waterproof properties of the panels. In contrast, with the increased content of hemp particles, the mechanical properties of particleboards improved significantly.

29. Savov, V., Antov, P., Trichkov, N. (2021). Properties of Hight-Density Fibreboards Bonded with Urea-Formaldehyde and Phenol-Formaldehyde Resins. Innovations in Woodworking Industry and Engineering Design 2 (20), pp. 17-26. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: Urea-formaldehyde (UF) resins are the most common type of resins used in the production of wood-based panels. Despite their numerous advantages, the main drawbacks of these thermosetting amino-plastic resins are the deteriorated water resistance, emission of hazardous volatile organic compounds, and to a lesser extent, the reduced strength. Hence, for producing wood-based panels with increased quality, a modification or partial replacement of UF resins should be performed. There are many previous studies on the improvement of UF resins with melamine-formaldehyde (MF) resins. The partial replacement of UF resins with phenol-formaldehyde (PF) resins has been studied to a lesser extent.

The aim of this research work was to investigate the effects of replacing the UF resin with PF resins on the properties of high-density fibreboards (HDF). The panels were produced at a press factor of 15 $s.mm^{-1}$ and a pressing temperature of 220° C. The resin content in

fibreboards was 6%, based on the dry weight of fibres. A complete replacement of UF with PF resin was performed with an increment of 1%. It was found that at 50% content of PF resin in the adhesive system, the panels meet the strictest requirements for load-bearing applications and use in hu- mid conditions. For achieving further improvement of fibreboard properties, the PF resin content should be increased to 83.3%.

30. Savov, V., Mihajlova, J., Yotov, N., Madjarov, B. (2021). Influence of Hot-Pressing Temperature on Properties of Eco-Friendly Dry-Process Fibreboards with Lignosulfonate Adhesive. Innovations in Woodworking Industry and Engineering Design 1 (19), pp. 29-36. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: A major challenge for the producers of wood-based panels is to achieve formaldehyde emissions at wood levels. For that purpose, various types of lignin have emerged as particularly promising substitutes for the traditionally used urea-formaldehyde resins.

Lignosulfonates are a by-product of the production of cellulose by the sulphite method. They are practically harmless to human health. The main functional groups of lignosulfonates are the hydroxyl groups and the connection with fibres is mainly through hydrogen bonds. To form these bonds, in addition to the surface with active hydroxyl groups, the temperature of hot-pressing is also essential.

This paper presents a study on the effect of hot-pressing temperature on the properties of eco-friendly dry process fibreboards. As an adhesive was used calcium lignosulfonate in a content of 10% to dry fibres. In the experiment, the hot-pressing temperature varied from 150 to 200° C, with increments of 10° C. The main physical and mechanical properties of the panels were determined. On this basis, an analysis was made. It was found that the properties of dry process fibreboards with only lignosulfonate as a binder are significantly affected by the temperature of hot-pressing, because of which the hot-pressing temperature should be at least 190°C.

31. Savov, V. (2020). Engineering of Selected Properties of Light Medium Density Fibreboards Produced from Hardwood Tree Species (2020). Innovation in Woodworking Industry and Engineering Design, 1/2020 (17), pp. 53-59. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: In this paper are presented results from study for the influence of hot-pressing temperature and press factor on some properties of light Medium Density Fibreboards (MDF) from hard- wood tree species. MDF were produced from under laboratory conditions with phenol-formaldehyde resin as binder. The press factor varied from 45 to 90 $s.mm^{-1}$ and the hot-pressing temperature was from 150° to 190 °C.

For the engineering of selected properties of the boards were applied the methods of regression analyze. Experimentally statistical models that describe the studied relations and the optimal values of the factors were deduced. It has been established that by adjustment of the studied factors the properties of MDF from hardwood tree species can be significantly improved. It was also found that in the studied range, the temperature of hot pressing has a significantly greater influence on properties of MDF than the press factor.

32. Savov, V., Valchev, I. Yavorov, N., Sabev, K. (2020). Influence of press factor and additional thermal treatment on technology for production of eco-friendly MDF based on lignosulfonate adhesives. Bulgarian Chemical Communications, Volume 52, Special Issue B, pp.48-52. https://doi.org/10.34049/bcc.52.B0015. ISSN 0324-1130. SJR 0,140. Квартил Q4. Indexed in Web of Science; Scopus.

Abstract: A major shortcoming of medium density fibreboards (MDF) as a material for furniture production is the emission of formaldehyde from the boards. To solve the problem of formaldehyde emissions, an especially perspective direction is the use of lignosulfonates as natural adhesives. A major disadvantage of the lignosulfonates compared to the presently used synthetic binders is their lower reactivity. This leads to the need for an extended duration of the hot-pressing and to the worse water-resistance of the panels. This report presents a study on the influence of the duration of hot-pressing and the additional thermal treatment on the properties of eco-friendly MDF. Panels are produced in laboratory conditions with lignosulfonate as adhesive without any formaldehyde-based synthetic binders. Six types of panels were produced with variation of the press factor from 30 to 60 $s.mm^{-2}$ with and without additional thermal treatment. The properties of the obtained boards were compared with values in EN standards and with a control board obtained with 10% urea formaldehyde resin. The obtained panel properties fully satisfy the relevant EN standards on mechanical properties of boards. A comparative analysis was carried out, with corresponding conclusions and recommendations, on the influence of the press factor and the additional thermal treatment on the efficiency of the eco-friendly technology for MDF production based on lignosulfonate adhesives.

33. Savov, V., Mihajlova, J., Grigorov, R. (2019). Selected physical and mechanical properties of combined wood based from wood fibres and sawdust. Innovation of woodworking industry and engineering design. Vol. 8(2), pp. 42-48. ISSN 1314-6249. Indexed in Web of Science; CABI.

Abstract: The production of wood fiber mass is a very energy-intensive process This is also one of the reasons for the higher cost of this material in comparison of that at particleboards. One possibility to partially solving this problem is the inclusion of industrial wastes, which has not undergone a refining process, in MDF composition.

There is a significant amount of industrial wastes resulting from logging – these are mainly the sawdust resulting from the processing of solid wood with a band saw. It should be pointed out that this method of obtaining solid wood materials is widespread, both globally and in Bulgaria.

The manuscript presents a study on the influence of the content of coniferous sawdust on the properties of combined panels from wood fiber and sawdust. Produced panels were with variation of sawdust content from 0 to 50% and respectively the fiber content was from 100 to 50%. The increase in sawdust content was with a step of 10%. The main physical and mechanical properties of panels were determined and experimentally-statistical equations for the influence of coniferous sawdust content on the properties of the panels were derived. It was determined at what percentage of sawdust the panels have properties that meet the requirements of the relevant standards for MDF.

34. Savov, V. Mihajlova, J. Grigorov, R. Molev, E. (2018). Effect of Participation of Vine Fibers on Some Physical and Mechanical Properties of Fibreboards. Innovation in Woodworking Industry and Engineering Design, Vol. VII. pp. 44-52. ISSN 1314-6149. Indexed in Web of Science; CABI.

Abstract: Wood is a raw material in short supply both in Bulgaria and worldwide. In Bulgaria, vine twigs are widespread lignocellulosic waste from agricultural production.
In this study, the effect of inclusion of vine fibres in the composition of fibreboards on their properties is presented. Vine fibres were obtained by means of defibration with a defibrator laboratory mill. For the purpose of the study, fibreboards were produced under laboratory conditions with inclusion of vine fibres at a content from zero to twenty percent in increments of five percent. The main physical and mechanical properties of the boards were determined. On this basis, analysis was made, and respective conclusions were drawn.

35. Mihailova, J., **Savov, V.**, Grigorov, R. (2019). Utilization of Mass of Industrial Hemp in the production of Medium-density Fibreboards. Journal of Anatolian Environmental and Animal Sciences. Year: 4, No: 4, pp. 679-683., e-ISSN 2548-0006 https://doi.org/10.35229/jaes.637270.

Abstract: In the near past, industrial hemp (*Cannabis sativa* L. subsp. sativa) found main application in the production of ropes and fabrics. At the present moment, this crop finds increasingly big application for pharmaceutical purposes and in the cosmetics industry. As a result of which not only hurds, but whole stalks remain as waste from this production. On the other hand, MDF, which on a world scale are the second production of wood-based boards in terms of volume after that of veneer plywood, allow at least partial inclusion of non-woody lignocellulosic raw materials in their composition. That is why, in this paper, an investigation about the possibility for inclusion of mass of hemp stalks in the MDF composition is presented.
Under laboratory conditions, previously washed hemp stalks were defibred. The defibration was performed in a laboratory crusher defibrator for 2 min. Under laboratory conditions, MDF with participation of mass of hemp stalks from 0% to 100% in the MDF composition were produced. The content of mass of hemp stalks was increased by a step of 10%. The boards were produced at a temperature of hot pressing of 185 °C, with 10% participation of urea-formaldehyde resin (UFR) and have a density of 850 kg/m3.
The effect of the content of mass of hemp stalks on the properties of MDF was established. Regression equations for this effect on the individual properties were also derived. It has been established in case of increase of what share in the composition of boards, most significant deterioration of the MDF indicators is observed. On this basis, a recommendation for the maximum justified content of mass of hemp stalks in the MDF composition was derived.

36. Antov, P., **Savov, V.,** Neykov, N. (2019). Possibilities for Manufacturing Insulation Boards with Participation of Recycled Lignocellulosic Fibres. Management and Sustainable Development, vol. 75, pp. 72–76. ISSN 1311-4506.

Abstract: The pulp and paper industry is characterized by a significant negative environmental impact. Even at the first recycling of group II and III paper (medium and high quality), about 20% lignocellulosic material, unsuitable for paper production, is eliminated. These materials represent a compostable waste product that requires additional financial resources.
The present research is aimed at studying the possibilities for utilization of low quality lignocellulosic material, which has undergone only mechanical recycling, in the composition of insulation boards using a technology, similar to the production of dry- process fibreboards. Several design variants of insulation boards with recycled lignocellulosic fibres were

developed and manufactured in laboratory conditions. The main mechanical properties were determined in order to analyze the possibilities of application of the boards. The main water-repellent and sound insulation properties of the boards - water absorption, swelling in thickness, sound reduction index and sound transmission coefficient, were also deter-mined. Analysis with conclusions and recommendations was made on the basis of the obtained results.

37. Antov, P., **Savov, V.**, Neykov, N. (2018). Influence of the Composition on the Exploitation Properties of Combined Medium Density Fibreboards Manufactured with Coniferous Wood Residues. European Mechanical Science Journal, Vol. 2(4), pp.140-145, e-ISSN 2587-1110. https://doi.org/10.26701/ems.443891.

Abstract: One of the main disadvantages of medium density fibreboards (MDF) in comparison with particleboards is the higher price of the panels, due to the energy-intensive defibration process.
Studies on the possibilities for replacing a part of the wood fibre mass in the composition of MDF with coniferous sawmill residues (shavings) obtained from bandsaw, are presented in this article. The experimental plan is designed using the McLean and Anderson method for studying the properties of multi-component systems in the presence of constraints on the components. The content of coniferous wood shavings varies up to 40%. The panels are manufactured with a density of 720 kg.m-3. The content of urea-formaldehyde resin varies from 8 to 14% in order to compensate the negative effect of the inclusion of coniferous wood shavings in the composition of the manufactured MDF panels. The main exploitation properties of the panels are determined. Experimental and statistical models on the influence of the studied factors are obtained by applying stepwise regression and optimization is performed in order to acquire the best exploitation properties of MDF panels.
As a result of the study it was determined that in order to achieve the values of MDF properties, required by the respective standards, the maximum permissible content of coniferous wood shavings should be up to 10.6%, in which case the content of urea-formaldehyde resin should be above 10%. If the content of urea-formaldehyde resin is below 10%, the maximum permissible content of coniferous wood shavings should be up to 5%.

38. Yotov, N., **Savov, V**, Valchev, I, Petrin, St., Karatotev, V. (2017). Study on possibility for utilization of technical, hydrolysis, lignin, in composition of medium density fiberboard. Innovation in woodworking industry and engineering design. Vol VI 2/2017. pp. 69-74. ISSN 1314-6149.

Abstract: In the present report is presented a study on the possibility for utilization of hydrolysis lignin in the composition of Medium Density Fiberboard. For the purpose of the study in laboratory conditions were produced boards with five percentage technical lignin in their composition and different quantity of phenol-formaldehyde resin. The main physical and mechanical properties of boards were determined, and they have been compared with those of boards without technical lignin. It is compared the visual appearance of MDF with and without technical lignin. On that base was accomplished an analysis of the results with proper conclusions.

39. Savov, V., Mihajlova, J. (2017). Influence of the Content of Lignosulfonate on Physical Properties of Medium Density Fiberboard. PRO LIGNO. Vol. 13 № 4/2017. pp. 247-251. ISSN 2069-7430.

Abstract: One of the essential shortcomings in the production of MDF is the existence of formaldehyde emissions from boards. This could be overcome by replacement of the currently used synthetic binders. Lignin is a natural binder in wood. Globally, at laboratory level, there are numerous studies on the use of enzyme lignin as a binder for MDF. In these studies, were observed some significant shortcomings that could be overcome with the use of lignosulfonates.
In this article is presented a study on the influence of the content of lignosulfonate in the composition of MDF made from hardwood tree species on their physical properties. The boards were produced with only 5% content of urea-formaldehyde resin and alteration in the content of calcium lignosulfonate from 0 to 20%.
The approximating functions for the influence of the content of lignosulfonate on physical properties of MDF were derived. On that base is made analysis with proper conclusions and recommendation for optimal content of calcium lignosulfonate in the composition of fiberboard.

40. Savov, V., Mihajlova, J. (2017). Influence of the Content of Lignosulfonate on Mechanical Properties of Medium Density Fiberboard. PRO LIGNO. Vol. 13 № 4/2017. pp. 2252-256. ISSN 2069-7430.

Abstract: One of the essential shortcomings in the production of MDF is the existence of formaldehyde emissions from boards. This could be overcome by replacement of the currently used synthetic binders. Lignin is a natural binder in wood. MDF find mainly used in the production of furniture and furnishings. For that their application essential in view of the suitability of the boards are their mechanical properties.
In this article is presented a study on the influence of the content of lignosulfonate in the composition of MDF made from hardwood tree species on their mechanical properties. The boards were produced with only 5% content of urea-formaldehyde resin and alteration in the content of calcium lignosulfonate from 0 to 20%.
The approximating functions for the influence of the content of lignosulfonate on mechanical properties of MDF were derived. On that base is made analysis with proper conclusions and recommendation for optimal content of calcium lignosulfonate in the composition of fiberboard.

41. Antov, P., **Savov, V.**, Neykov, N. (2017). Utilization of Agricultural Waste and Wood Industry Residues in the Production of Natural Fiber – Reinforced Composite Materials. International Journal – Wood, Design & Technology, Vol. 6, No. 1, pp 64-71. ISSN 1857 – 9140.

Abstract: Composite materials, based on renewable and biodegradable natural fibers, derived from agricultural waste and wood industry residues, are increasingly utilized in a wide variety of applications. These products represent an ecological and inexpensive alternative to the traditional petroleum-based materials, as they significantly decrease the use of fossil fuels and reduce the greenhouse gas emissions. In addition, these materials have good mechanical properties and require lower consumption of energy for their production. On the other hand, wood-based industries and agriculture produce significant amounts of organic waste and residues which are still underutilized, as low value energy resources and organic waste is commonly disposed of by some of the traditional waste management techniques, such as landfilling, anaerobic digestion or composting. The use of organic agricultural and wood industry waste and residues in production of natural fiber-reinforced polymer composites (NFPCs) is an environmentally friendly, sustainable and economical alternative. This paper

represents a review of the possibilities for application of organic waste and residues as reinforcements or additives in NFPCs on the basis of the existing scientific information in the respective field.

42. Mihajlova, J. **Savov, V.** (2017). Analysis of Possibilities for Utilization of Agricultural Lignocellulosic Residuals as Alternative Raw Material for Production of Medium-Density Fibreboards (MDF). International Journal – Wood, Design & Technology, Vol. 6, No. 1, pp. 38-48. ISSN 1857 – 9140.

Abstract: As a result of performance of tasks from the first year of the project "Effect of content of non-wood lignocellulosic raw material and lignosulphonate in the composition of medium-density fibreboards (FB) (MDF) on their performance", analysis of the possibilities for utilization of agricultural lignocellulosic residues as alternative raw material for production of MDF has been made. The world experience in this respect has been examined and the amount of this type of raw materials in Bulgaria has been determined. It has been established that there is huge amount of publications which report on the satisfactory use of agricultural lignocellulosic residues as alternative raw material for fibreboards, including such ones intended for construction. In Bulgaria, there exist more than sufficient quantities of residual lignocellulosic fibres for meeting the needs of manufacturers of wood-based boards. Nevertheless, this type of raw material is not utilized.

43. Neykov, N., Antov, P. **Savov, V.** (2020). Circular Economy Opportunities for Economic Efficiency Implement in Wood-Based Panel Industry. Proseedings of the 11th International Scientific Conference "Business and Management 2020" May 7–8, 2020, Vilnius, Lithuania, pp. 8-17. https://doi.org/10.3846/bm.2020.493. ISBN 978-609-476-231-4.

Abstract: The enhanced technological possibilities to utilise wood waste and residues in the production of wood-based panels can help towards the transition to a circular, low-carbon bioeconomy. The cascading use of wood resources, defined as "the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system" is one of the leading principles for achieving this goal. The wood-based panel industry is characterised by significant amounts of waste and residues that present a great volume potential for cascading. The aim of the present study is to define the basic guidelines for cascading use of wood waste from the production of wood-based panels and analyse the economic impact in terms of economic efficiency in line with the circular and bioeconomy principles. Time series analysis of wood waste and raw material flows in the Republic of Bulgaria, eco-nomic assessment of the current utilisation of wood waste in the wood-based panel industry along with comparative analysis of the potential utilization methods have been presented. The existing technical and market barriers to the cascading use of wood have also been discussed.

44. Antov, P., **Savov, V.,** Neykov, N. (2020). Reduction of Formaldehyde Emission from Engineered Wood Panels by Formaldehyde Scavengers – a Review. Proseedings of the 13th International Scientific Conference WoodEMA2020 and 31st International Scientfic Conference ICWST 2020 "Sustainability of Forest-Based Industries in the Global Economy", pp.289-294. ISBN 978-953-57822-8-5.

Abstract: The increased environmental consciousness related to the sustainability of raw materials and final products, as well as the stricter legislative requirements to formaldehyde emission from wood-based panels are the main driving factors for shifting the industrial interest to production of eco-friendly wood composites. The common methods to reduce the formaldehyde emission from engineered wood panels have been to decrease the free formaldehyde in the adhesive by using low-emission or bio-based adhesives, and by applying suitable additives, called formaldehyde scavengers. This article presents a review and analysis

of the current state of research in the field of formaldehyde scavengers for achieving lower formaldehyde emission from wood-based panels, such as urea, ammonia, ammonium salts, and some natural compounds, such as tannin and wood bark. Factors, affecting the amount of formaldehyde emissions from wood-based panels, have also been presented and discussed.

45. Valchev, I., **Savov, V.,** Yordanov, I. (2020). Reduction of Phenol Formaldehyde Resin Content in Dry-Processed Fibreboards by Adding Hydrolysis Lignin. Proceedings of the 2020 Society of Wood Science and Technology International Convention "Renewable Resources for Sustainable and Healthy Future". July 12-15 Portoroz, Slovenia, pp. 592-602. ISBN 978-1-73404-850-6 .

Abstract: Production of dry-processed fibreboards is dominant and account more than 80% of the total production of this type of wood-based panels. A major challenge for the development of the technology to produce dry-processed fibreboards is the reduction of formaldehyde emissions from the panels. This can be achieved by the reduction of the content of synthetic binders based on formaldehyde.
This report presents a study on the possibility of partial substitution of phenol-formaldehyde resin by technical, hydrolysis, lignin in the adhesive system for dry-processed fibreboards. Technical lignin is a residual product after diluted acid hydrolysis of wood to sugars and as such its cost is low. The investigations were carried out in laboratory conditions as total content of adhesives was 10% to absolutely dry fibers. The content of phenol-formaldehyde resin varied from 10 to 2% and respectively the content of hydrolysis lignin was from 0 to 8%. The substitution of phenol formaldehyde resin with hydrolysis lignin was by step of 2%.
It is obtained that the addition of hydrolysis lignin more than 6%, leads to considerable difficulties in its homogeneous distribution in the fibreboards. This necessitates a decrease in the concentration of the lignin-phenol formaldehyde suspension. On the basis of the experimental studies, an analysis was made on the variation of the physical and mechanical properties of the fibreboards and on the minimum possible content of phenol-formaldehyde resin in adhesive system. The all produced dry-processed fibreboards meet the requirements of the relevant EN standards.

46. Antov, P., **Savov, V.** (2019). Possibilities for Manufacturing Eco-friendly Medium Density Fibreboards from Recycled Fibres – a Review. Proceedings of 30th International Conference on Wood Science and Technology - ICWST 2019 "IMPLEMENTATION OF WOOD SCIENCE IN WOODWORKING SECTOR" & 70th Anniversary of Drvna industrija Journal, 12th – 13th December, Zagreb, Croatia, pp. 18-24. ISBN 978-953-292-062-8.

Abstract: The production of medium density fibreboards (MDF) is the second largest worldwide, preceded only by the production of plywood. A major advantage of this technology is the possibility for utilization of small-sized and low quality wooden raw material. However, the increased production and the expected average life cycle of panels of about 15-20 years result in significant amounts of post-consumer wood waste. Due to the content of synthetic adhesives the panels are not suitable for energy applications. On the other hand, their recycling and re-use will reduce the consumption of wood raw material. Significant amounts of lignocellulosic waste and residues also remain in the production and recycling of paper and cardboard. This article presents a review and analysis of the current state of research in the field of recycling lignocellulosic fibres and possibilities for their use in the production of MDF panels. Different methods for recycling with and without the use of chemical reagents in terms of quantitative yield, quality of panels and production costs, are presented.

47. Mihajlova, J. **Savov, V.,** Grigorov, R. (2018). Effect of Participation of Mass of Maize Stalks on Some Physicomechanical Indicators of Medium-density Fibreboards (MDF). Proceedings of the International Forest Products Congress Trabzon, Turkey, 26-29 September 2018. ORENKO 2018 Paper ID. 85. pp. 425-433. ISBN: 978-605-2271-32-2.

Abstract: Main advantage of the technology for production of fibreboards (FB) are the reduced requirements to the wood and the possibility for inclusion of other non-woody lignocellulosic raw materials in the composition of boards. This is of main significance in view of the world shortage of wood raw material. Such lignocellulosic raw materials are residues (waste) from the agriculture, e.g. maize stalks.
In this paper, an investigation about the effect of participation of mass of maize stalks on some physical and mechanical properties of MDF is presented.
Under laboratory conditions, test boards with participation of mass of maize stalks to the amount of 0% to 100% were produced. The defibration was performed in a laboratory disk crusher defibrator. The main fraction of maize fibres has a length of 1 to 2 mm. The boards were produced with 10% participation of urea-formaldehyde resin (UFR), at a temperature of hot pressing of 185 °C. The set density of the boards is 850 kg/m3.
The qualitative yield during defibration of maize stalks was determined. Regression models for the effect of content of mass of maize stalks on some physical and mechanical properties of MDF were derived. The permissible share of mass of maize stalks in the MDF composition and at what share of mass of maize stalks most significant deterioration of these indicators is observed were analyzed. On the basis of the results, a recommendation with respect to the maximum content of mass of maize stalks in the MDF composition was derived.

48. Savov, V., Ivanova, J. (2016). Influence of the content of corn stalks and phenol-formaldehyde resin on some physical and mechanical properties of very hard fibreboards. Proceedings of 10th international science conference "Chip and chipless woodworking processes", pp 171-179. 08-10 September 2016, Zvolen, Slovakia. ISBN 978-80-228-2143-8 .

Abstract: The main advantages of production of fiberboard are lowered requirements to wood raw material and possibility for utilization of lignocelluloses agricultural wastes in their composition. The negative impact of the higher content of hemicelluloses, minerals and wax in the non-wood lignocelluloses raw materials can be reduced by increase the contents of the binders.
In the report is presented study about complex influence of the content of corn stalks and phenol-formaldehyde resin on some physical and mechanical properties of very hard fiberboard.
For the purpose of the study are produced fiberboards in laboratory conditions in alternation of the content of corn stalks from ten to thirty percent and alternation of phenol-formaldehyde resin from eight to sixteen percent. Regression models for the influence of both factors are drawn and it is conducted an optimization of the results by the method of random search. On that base is done analysis and proper conclusions are made.

49. Savov, V. (2023). Nanomaterials to Improve Properties in Wood-Based Composite Panels. In: Taghiyari, H.R., Morrell, J.J., Husen, A. (eds) Emerging Nanomaterials. Springer, Cham. pp. 135-155. ISBN 978-3-031-17377-6. https://doi.org/10.1007/978-3-031-17378-3_5.

Abstract: The production of wood-based composite panels is one of the developing industries with increasing production quantity. Nanomaterials are emerging as the foremost opportunity for that industry to move to the next level of development. By applying nanomaterials, the properties of nearly all composite panels can be significantly improved. The use of

nanomaterials can also lead to the acquisition of specific properties in the materials. That is why there has been a significant amount of studies in recent decades on incorporating nanomaterials in the composition of wood-based composite panels. This work presented an overview, without claims for exhaustiveness, of studies related to improving waterproofness, electrical and magnetic resistance, thermal conductivity, antibacterial, antimould and other specific properties of wood-based composite panels using nanomaterials. As the chapter explains, much work has been carried out so far. However, many areas still need to be elaborated on in future studies.

50. Савов, В. (2021). Учебник по Технология на материалите от дървесни влакна. Интел Ентранс, стр. 290. ISBN 978-619-7554-86-1. Рецензенти – проф. д-р Иво Владимиров Вълчев; доц. д-р Петър Йорданов Антов.

Abstract: The textbook is intended for the students of the "Wood and Furniture Technology" speciality of the University of Forestry. It was developed following the curriculum of the discipline "Technology of Materials from Wood Fibres", studied in the third year of regular education and the fourth year of part-time education.
In the textbook, questions about the technologies and properties of materials from wood fibres are advocated. The focus of the lecture course is on technologies for the production of fibreboards, including the production of gypsum fibreboards. The technologies to produce wood fibres-polymer materials, cellulose, paper and cardboard are also examined in a significantly reduced volume.
The textbook can also be used in developing graduate works in the discipline and by specialists from practice.

51. Савов, В. (2020). Ръководство за упражнения по Технология на материалите от дървесни влакна. Интел Ентранс, стр. 102. ISBN 978-619-7554-05-2. Рецензенти – проф. дтн. Николай Асенов Йосифов; доц. д-р Иво Владимиров Вълчев.

Abstract: The handbook is intended for the students of the "Wood and Furniture Technology" speciality of the University of Forestry. It was developed according to the curriculum of Technology of Materials from Wood Fibres, studied in the third year of full-time study and the fourth year of part-time study. Eleven topics cover the methods for determining fibreboard's physical and mechanical properties; the balance of raw materials and adhesives in this production; technological control of the raw material and the pulp; the output of pulp and panels in laboratory conditions; as well as designing the properties of the panels.
The guide can also be used in developing graduate works in the discipline.

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