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Concept of a technological system for manufacturing the composite products based on impregnated wood waste

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Abstract:

The article presents the results of the research work, which included a qualitative and quantitative analysis of the selected wooden wastes intended for manufacturing the composite materials. Additionally, the existing solutions related to the processing of wooden waste from power poles and railway sleepers were analysed. In the context of the analysis, the focus was on the methods for removing carcinogenic substances used for preserving the telecommunications poles, power poles and railway sleepers, with the aim of obtaining the safe end product. On this basis, the concept of a technological system for recycling the mentioned wastes has been developed. The recycling process involves reprocessing them and using as components of the composite materials.

Keywords: impregnated wood wastes, power poles, railway sleepers, composites

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1. Introduction

For over 60 years, the European industry has produced impregnated wooden poles in accordance with industry guidelines and national standards as well as specifications of the Wood European Institute (WEI). These standards are changing gradually, as knowledge about the harmfulness of the chemicals used for impregnation increases. These regulations in the past allowed the use of wood preservatives/impregnators containing hazardous chemicals. Three main chemical wood preservatives are as follows:

– creosote,
– pentachlorophenol,
– arsenate (copper-chromium-arsenic, i.e. CCA),
– copper naphthenate (alternative agent) [1, 2].

In 2001, the European Union severely restricted the sale and use of tar. In January 2003, the European Union announced a ban on all industrial uses of CCA, except for a limited number of special cases. Creosote was phased out in Poland temporarily in 2013, and finally from April 2018. Restrictions related to the use of chemical wood preservatives are the subject of ongoing discussion [2, 3].

FRP composite materials are materials made of a polymer matrix reinforced with fibres. The most commonly used fibres are glass, carbon, aramid, basalt and mixed fibres, e.g. basalt-carbon. Epoxy, polyester or vinyl ester resins are most often used as matrices [4, 5].

Due to a number of advantages, including: low density, high anti-corrosion and chemical resistance, as well as high strength, stiffness and durability, the above-mentioned. materials have found wide application. Unfortunately, the main advantages of composites such as durability are at the same time their disadvantages. Even though various methods of processing the composite materials are known (pyrolysis, solvolysis, mechanical methods). Although various methods of processing the composite materials are known, only a small amount of waste is recycled [6, 7].

1.1. Impregnated wood in railway sleepers

Impregnation is a technology used in manufacture of railway sleepers (Fig. 1) to increase the durability and resistance of wood to weather conditions, as well as to protect it against biological organisms. Creosote is one of the frequently used impregnating agents, but other chemicals are also used, such as petroleum oils and heavy metal salts [8, 9].

Fig. 1. Impregnated wood in railway sleepers [10]

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Based on data from 2018, the number of railway sleepers intended for recycling or neutralisation in Poland is over 20 million pieces. With an average weight of one sleeper of approximately 80 kg, it gives 1,600,000 Mg of impregnated wood waste [11].

1.2. Impregnated wood in poles

In Poland, impregnated poles (Fig. 2) are commonly used in various sectors of industry, such as power, telecommunication, in road infrastructure, etc. Impregnation of poles is intended to increase their durability and resistance to weather conditions and insects, fungi and other factors that may cause wood degradation [12].

Fig. 2. Impregnated telecommunication pole [13]

Orange Polska S.A. as well as Tauron Polska Energia S.A. have about 2 million pieces of wooden poles impregnated with carcinogenic substances. Due to their toxicity, they should be replaced as soon as possible. The technology suggested further will allow for elimination of the above-mentioned hazard [14].

Both wooden and composite components is the waste which, from the point of view of the circular economy model and should be used as a raw material in subsequent manufacturing stages.

Division of electric, telephone, street and parking (lighting) poles in the world, depending on the type of material used, is presented in Table 1 [15].

Table 1. Division of poles in the world, depending on the type of material used [15]

Place	Pole material				
	Wood	Concrete	Steel	Composite	Total
	Number of pieces [mil.]				
Europe	133	48	77	4	262
CIS	78	34	18	1	130
Near East	2	13	34	0	50
North Africa	22	9	10	1	42
Sub-Saharan Africa	43	6	8	0	58

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Place	Pole material				
	Wood	Concrete	Steel	Composite	Total
	Number of pieces [mil.]				
Asia-Pacific	157	421	125	8	710
Latin America	96	28	39	2	165
North America	202	20	51	4	277
Total	732	579	362	21	1,694

Based on the data presented above, it can be concluded that there are a very large number of wooden poles in the world that will be recycled in the future. Table 2 shows the total weight of wooden poles, assuming a pole weight of 160 kg [15].

Table 2. Division of wooden poles in the world, with estimation of their weight [15]

Place	Wooden poles	
	Number of pieces [mil.]	Weight [Mg]
Europe	133	21 280 000
CIS	78	12 480 000
Near East	2	320 000
North Africa	22	3 520 000
Sub-Saharan Africa	43	6 880 000
Asia-Pacific	157	25 120 000
Latin America	96	15 360 000
North America	202	32 320 000
Total	732	117 280 000

In Poland there is 2 mil. poles with weight of 320 000 Mg [14].

Therefore, the aim of the task is to develop a concept of technology for manufacturing the composite products from the waste wood, e.g. from the railway sleepers and the power poles. The developed concept will be used, in the next stages, to produce structural components for the power industry, e.g.: state-of-the-art composite poles.

2. Materials and Methods

The most popular method of "utilizing" impregnated wood from power poles or railway sleepers is to store and burn them.

The disposal of old wooden components of power and transport infrastructure, such as power poles and railway sleepers are important from an ecological, social and safety perspective. Old wooden components are aging, which may lead to weakening of the wood structure, to its damage caused by weather conditions as well as by insects and fungi. This may contribute to the loss of stability of the power pole and, consequently, breakage of electrical cables. Moreover, these components are covered with carcinogenic substances that are harmful to humans and the environment. To minimize the negative impact of old wooden poles on the environment and society, it is necessary to develop appropriate disposal processes.

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Disassembly is the first stage of disposal. Used wooden power poles are removed from their original installation place. This process requires special equipment and technical knowledge to avoid damage and hazards to workers and the environment. Disassembly can be manual or using the machines such as cranes or special vehicles. It is important that this process follows the safety regulations and industry standards.

Then, the next important step is transporting the wooden poles to the processing site. Timber can be transported by truck or other means of transport.

Wood that cannot be recycled or reused is burned to produce heat or electricity. The process is becoming increasingly popular in some regions as a way to extract energy from materials that would otherwise end up in a landfill.

Disposal in a controlled landfill is another option that requires monitoring and management to avoid environmental contamination. According to the currently applicable regulations, disabled power poles can be stored for up to 3 years. Then they must be processed or sold [16].

There are the following alternative approaches to removing the hazardous substances from wood:

– Mechanical removal: This is one of the basic methods. It involves manual grinding, planeing or scraping of the wood surface to remove the contaminated layer.
– Sandblasting: This is a more advanced method of mechanically removing substances from wood. It involves applying a stream of sand grains under pressure to the wood surface, which helps to remove contaminants more effectively.
– Chemical removal: Special chemicals are used that dissolve or soften chemicals present on the wood surface, such as sealers or paints. Then the impurities are removed mechanically.
– Thermal stripping: This involves heating the wood to a high temperature, which can help evaporate or break down chemicals. This is particularly effective in removing certain sealers.
– Ozonation: Ozone is a strong oxidant and can be used to remove chemicals from wood. This process involves the impact of ozone on saturated wood, which reacts with pollutants, leading to their decomposition.
– Microwave stripping: This method uses microwave waves to heat chemicals present in the wood, which can help break them down.
– Enzymatic method: Uses enzymes that have the ability to break down chemicals. This is a relatively new technology that is becoming more and more popular.
– Biodegradation: Uses microorganisms such as bacteria or fungi to naturally break down chemicals [17].

All stages of the disposal of wooden power poles must be in accordance with the applicable regulations and standards regarding environmental protection, health and safety.

To sum up, the disposal of old wooden power poles or railway sleepers is a complex process that aims to minimize the negative impact on the environment and society. Appropriate disassemble, transport, processing, recycling and energy recovery are crucial for the effective use of wood after its original function has ended. A deep knowledge of local regulations and the use of sustainable disposal methods are the foundations of this process, contributing to better protection of our environment.

Research work in Poland and abroad in the scope of a discussed problem

Recycling of the impregnated wood is a complex task due to the presence of chemicals used during the impregnation process.

Therefore, wood recyclers must use special methods to safely remove or neutralize these substances. In only a few regions and countries there are the companies specializing in recycling the impregnated wood. However, the activities of this type of companies are much less common than in the case of recycling the typical wood [18].

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Engineers from Belgium and Finland have introduced innovative solutions that are alternative to the traditional waste storage. The solution uses reactors enabling gasification and simultaneous neutralization of poisonous hydrocarbons. Moreover, one of the promising technologies for creosote neutralization is the biodegradation method, which is based on the biological decomposition of oily substances by the specially selected microorganisms. This innovative method is not only safe for the environment, but also eliminates waste, which makes it relatively economical [19].

In the biodegradation method, there are the following key elements of removing creosote from wood:

– Selected microorganisms: The creosote biodegradation process uses microorganisms capable of decomposing chemicals contained in creosote. These microorganisms are carefully selected and adapted to the conditions in which the process will be carried out.

– Biological degradation: Microorganisms used in biodegradation have the ability to metabolize poisonous chemicals contained in creosote. As a result of this process, creosote is transformed into more stable, less toxic compounds, what means its neutralization.

– Optimal conditions: For the biodegradation process to be effective, it is necessary to maintain optimal conditions such as temperature, pH, humidity and nutrient availability. Microorganisms function most effectively under specific conditions that must be controlled during the process.

– Monitoring and control: The biodegradation process requires monitoring and control to ensure effectiveness and environmental safety. Parameters such as chemical composition and amount of creosote before and after the process are monitored and process conditions are adjusted as necessary [20, 21].

Tests also included the use of lactic acid bacteria *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, allowing for the extraction of up to 93% of copper, 86.5% of chromium and 97.8% of arsenic after 8 days of fermentation (Fig. 3) [20].

Fig. 3. Use of lactic acid bacteria for the degradation of wood preservatives. Milled treated and untreated wood sample before or after bioprocessing treatment [20]

Fungi also have the ability to degrade molecules contained in preservatives such as creosote. The use of fungi has shown good results, especially when this method is combined with a citric acid. Nevertheless, positive results have been obtained on a laboratory scale, but the physiological mechanisms implemented by microorganisms are still poorly understood [20].

It is worth emphasizing that the effectiveness of the biodegradation method may depend on many factors, including the chemical composition of creosote, the type of microorganisms used in the process and the process conditions. Disadvantage of the method is the need to adapt it to a specific case and the proper biodegradation time [20, 21].

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3. Results

Based on the analysis of the literature and available information on the characteristics of impregnated wood, the initial concept of the system for its reuse was developed. The conceptual system for the production of new products from waste wood assumes using the processes from disassembly, through grinding, to obtain a new product (Fig. 4). The rest of the article describes in detail each stage of the conceptual technology for recycling the wood waste. The concept was developed on the example of recycling the power poles.

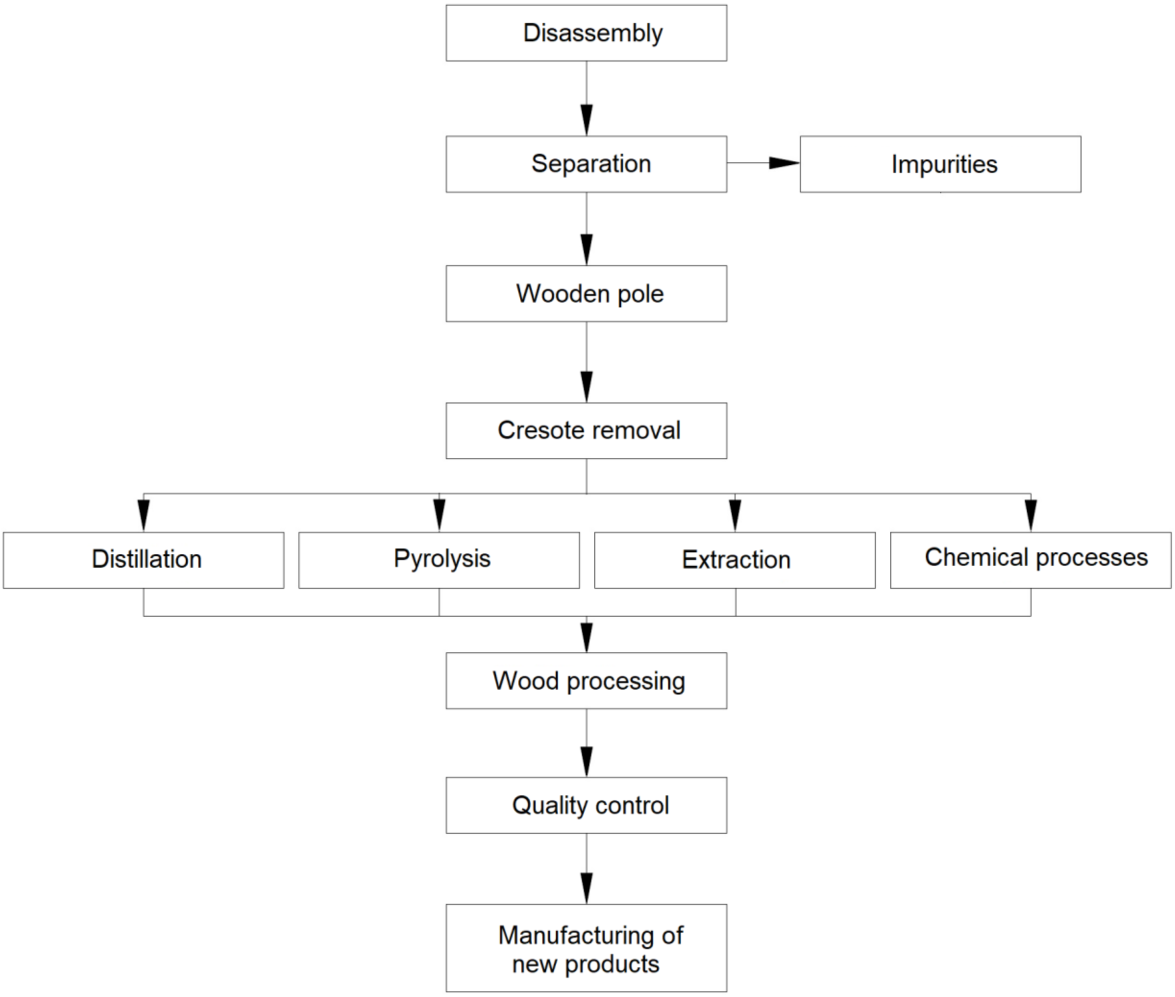

Fig. 4. Conceptual path for manufacturing new products from waste wood

Disassembly:

Power poles are first disassembled from their original location. This process requires special equipment and appropriate safety procedures because crested wood is treated as a hazardous material. Dismantling is carried out using simple construction equipment (saws, ropes, safety elements, etc.). The waste in question is then transported to a dismantling point, where it is subjected to the process of removing any insulating materials, such as wires or cables, that may be attached to them. Alternatively, the process can be expanded to include the use of vibrating screens to remove unwanted elements [22].

Removal of creosote:

Removing the creosote is one of the key steps in recycling impregnated wooden poles. There are various methods that can be used to remove creosote from wood. Future laboratory tests will analyse the most advantageous method for removing the creosote. The methods to analyse are as follows:

- Distillation: distillation process involves heating the wood in special furnaces to evaporate the creosote. The creosote vapor is then condensed and collected, then processed to obtain pure creosote. Distillation is a complicated and energy-intensive process that requires temperature and pressure control.
- Pyrolysis: Pyrolysis is a thermal process in which wood is subjected to high temperatures in limited air access. As a result, creosote and other chemicals break down into simpler compounds. Pyrolysis products, including gas and oil, can be collected and processed.
- Extraction: In this method, creosote is extracted from the wood using chemical solvents. The wood is soaked in an appropriate solvent that removes creosote. The extract is then processed to separate the creosote.
- Chemical processes: There are also chemical processes that can be used to neutralize the creosote contained in the treated wood. Using the proper chemical reagents, creosote can be converted into less toxic compounds.

Processing of wood:

After the creosote is removed, the wood is chipped into smaller pieces and transferred into various wooden products such as boards, beams and fuel. Cutting a pole into boards uses variety of tools, depending on available resources and preferences. Once you have finished cutting, clean the edges of the boards to obtain a clean and smooth finish. Boards prepared in this way are the ready-made commercial product.

The material resulting from cutting and processing, as well as scraps of the pole remaining after cutting the boards, are subjected to additional processes. The sections of the pole are crushed in a branch shredder. In the shredding process, it is important to obtain evenly shredded material with a granulation similar to the waste generated during cutting and processing the boards [23]. The obtained material can be used as fuel, construction material or as input for the production of composite materials.

Quality control:

Once processed, the wood can be subjected to testing and quality control to ensure it has no residual toxic substances and is safe for further use.

Manufacturing the new composite products:

One of the uses of fine wood chips is to make new composite products from them. Manufacturing the composite materials from harvested wood involves combining wood with resin or other polymeric materials to create a durable and versatile product. The manufacturing process assumes implementation of the stages shown in Fig. 5.

The following devices, which forms part of the system for the production of composites from waste wood, has been selected on the basis of our own experience of waste recycling and guidelines provided by the manufacturers of the devices. The estimated capacity of the system is in the range of 400-500 kg per day.

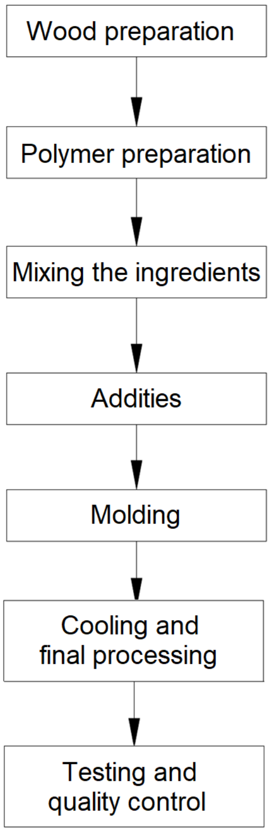

Fig. 5. Manufacturing the new composite products

– Wood preparation - wood crushed into fine fibres, chips or powder is dried in a condensing dryer for wood (Fig. 6) to reduce the water content, which improves the durability of the composite. We suggest the use of a condensation dryer with a capacity of $14m^3$, which will allow the drying of wood at a temperature of around 70° C.

Fig. 6. Condensing dryer for wood – Eberl TC6WP [24]

– Polymer preparation – the polymer is selected to create the composite matrix. Thermoplastic polymers such as polypropylene, polyethylene or PVC, or thermosetting resins are used for this purpose.

– Mixing the ingredients - wood and polymer are mixed in the required ratio. The process can take place in a wet or dry form (Fig. 7). We propose the use of a mixer with a capacity of 500 kg, equipped with a 3 kW motor.

Fig. 7. Mixer for dry process of multi-component feed mixture - Aluhaus MDS 500 [25]

– Additives - strengthening additives, dyes or antioxidants should be added to the mixture to improve the composite properties.

– Moulding process - the mixture of wood and polymer is formed using various technologies such as extrusion, injection (Fig. 8). In the case of extrusion, the mixture is passed through a forming die to create an extruded mould, which is then cooled and cut to appropriate lengths. The injection process involves injecting a mixture of wood and polymer into a mould, where it hardens under heat and pressure. Once the material has solidified, the mould opens and the finished product is removed. We recommend the use of a plastic injection molding machine with a power of 13 kW and an injection mold size of 480 x 280 mm.

Fig. 8. Plastic injection machine - CAN YANG MACHINERY CY-500C [26]

– Cooling and post-processing - composite products are cooled to obtain their final form. They can be subjected to additional processing, such as cutting, milling or grinding, to obtain the desired shape and surface finish.

- Testing and quality control – the products are tested to check their strength, durability and other important properties. Quality inspections help ensure compliance with industry standards.

The effectiveness of the suggested operations aimed at removing creosote and related to the production of composite products should be confirmed by the laboratory tests.

It should be noted that all stages of processing of creosoted wood must be in accordance with applicable safety and environmental regulations. Employees involved in this process must be properly trained and equipped with appropriate protective equipment. The recycling process can also generate waste such as creosote residue. This waste must be properly disposed in accordance with the regulations for hazardous waste.

4. Discussion

Recycling of impregnated wood has advantages and disadvantages. Below there is analysis of its advantages and disadvantages. A detailed analysis will be possible after testing the effectiveness of creosote removal and manufacture of the composite material.

Advantages:

- Reducing the waste material: Recycling the impregnated wood reduces waste, contributing to sustainable resource management.
- Conservation of resources: Recycling allows wood to be reused, which helps conserve natural resources and reduces deforestation.
- Cost reduction: In the long term, recycling can help reduce costs associated with purchasing new materials and production.
- Environmental protection: Effective recycling can reduce the environmental impact of impregnation chemicals through controlled removal of these substances and minimizing emissions.
- Regulatory compliance: Companies that recycle impregnated wood are typically required to comply with environmental regulations, which contributes to sustainability.

Disadvantages:

- Difficulty in removing chemicals: The recycling process may not be fully effective in removing or neutralizing the chemicals used in impregnation, which poses a potential risk to the environment.
- Technology costs: Advanced technologies necessary for effective recycling of impregnated wood is associated with high costs, which affects the project profitability.
- Lack of standardization of processes: Lack of standardization of recycling processes on a global scale may lead to a lack of uniform quality of recyclates and hinder their subsequent use.
- Potential for toxic emissions: Improper management of the recycling process may lead to accidental emissions of toxic substances into the environment.
- Limited markets: Lack of widespread understanding and acceptance of recycling the impregnated wood may limit markets for recyclates.

5. Conclusions

As part of the research work, wood impregnation and its use in railway and telecommunication infrastructure were analysed in literature. Wood impregnation in telecommunications poles and railway sleepers are mainly used to protect wood against weather conditions, insects, fungi and other pests. Chemical-based impregnations were widely used in Poland. Due to their toxicity, they are carcinogenic, so they should be removed as soon as possible.

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Moreover, a concept of a system for recycling the impregnated wood was suggested, including the development of an effective and sustainable process that allows the reuse of this material with minimal impact on the environment. As part of the concept, individual stages of the technology system were developed, allowing for the removal of toxic substances and the production of a new product. The scope of work also included the selection of devices and determining the scope of preliminary laboratory tests. These tests will aim to determine an effective method for removing creosote and verify the assumptions regarding the concept of the production system of composite materials containing impregnated wood waste.

When recycling the impregnated wood, it is crucial to strive for continuous process improvement to minimize disadvantages and maximize advantages. Moreover, development of innovative technologies and increasing public awareness of the benefits of impregnated wood recycling can contribute to improving the situation in this field.

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