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PARTICULARITIES OF SYNTHETIC WOOD - A BIOMATERIAL WITH RECYCLED WASTE

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Abstract

Depletion of world resources, increasing pollution and climate change effects, make it necessary a shift from linear economy to systemic economy – an economy of technologies integrated to reach a non-polluting, zero emissions production system. Transition to renewable resources requires replacing the existing crude oil refinery with biomass refinery. Along with conventional biomass refinery technologies, bioengineering and nano-technologies are becoming significant players of systems in the design of clusters of integrated biorefinery technologies.

This study presents a set of samples obtained by combining biomass waste such as wood waste with other types of recyclable construction waste compatible with the new material. In the context of the growing economy of raw materials, it is considered necessary to develop a material capable of absorbing as much waste as possible from nearby areas. Thus, the investigated samples are presented and analyzed to highlight their physicochemical properties and compatibility with integrated waste and, last but not least, to significantly improve these characteristics by introducing nanoparticles obtained by plasma conversion of municipal waste.

Key words: artificial biomaterial, recyclable waste, synthetic wood

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1. Introduction

Wood is a natural material of organic nature, with a pleasant appearance, easy to process, and has been used since ancient times in the construction of buildings and engineering works, shipbuilding etc. Being a material with a relatively low durability due to the presence in its structure of compounds that allow the development of microorganisms, fungi, insects etc., but also of the physical instability in water action, changes in its structure are generally favored by temperature and humidity.

Although over time many flame-retardant or anti-cavity treatments for wood protection have been developed (oil types), as well as modern processing technologies that considerably increase its physical and mechanical properties, it remains a material with limited durability. Therefore, researchers have imagined, developed and made, this time in the laboratory, alternatives through interesting combinations that have removed some of these inconveniences but created others (Chanhoun et al., 2018; Keskisaari and Kärki, 2018; Spirchez and Lunguleasa, 2016; Suzuki et al., 2008).

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There are researchers (Kinoshita et al., 2018; Kodama et al., 2012; Łukawski et al., 2018, Sevilla et al., 2007; Song et al., 2020; Suzuki et al., 2017) who have also studied the introduction of nanocarbons into the wood component. Thus, wood-derived nanocarbons (Kinoshita et al., 2018) can be easily synthesized from wood powders by metal-catalyzed carbonization, which gives superior properties to the new material. The composite biomaterial known as liquid wood is biodegradable and reusable in 5 cycles without affecting its basic properties. In literature, there are several types of artificial wood called liquid or synthetic wood with three variants: arbofill, arboblend and arboform (Nägele et al., 2002; Perkins 2018; Puiu, 2018; Tecnaro, 2018). Another research team has developed a revolutionary biomaterial called Zeiform (www.zeoform.com). Also called "The Holy Grail of eco-materials", zeiform is a new green material derived from raw cellulose with the following characteristics: it preserves the natural beauty of the wood, it has plasticity and it is completely nontoxic and is environmentally stable.

There are several artificial or synthetic woods in the literature called Wood Plastic Composites - WPC, whose composition differs depending on the recipe and the use or not of recyclable waste (Keskisaari and Kärki, 2018; Najafi, 2013; Saeed et al., 2009). Thus, natural fibers vary between 24-64%, the plastic is generally 30% but it is also found with other percentages (40%), the rest being provided by lubricants or coupling agents in most cases (Puiu 2018). Also called liquid wood due to the thermal treatment of the component elements, synthetic wood is already the product of several development research teams (Petrescu et al. 2021), (Henke et al. 2021).

Numerous researches (Avram et al., 2014; Lupescu et al., 2017; Pintilei et al., 2015) have been carried out on different materials with modern and efficient means such as Scanning Electron Microscopy (SEM) or spectral analysis - X-ray spectrum in dispersed energy (EDAX) permits the observation and characterization of heterogeneous organic and inorganic materials on a nanometer (nm) to micrometer (μm) scale and provides information's about the samples including texture, chemical composition, crystalline structure and orientation of material particles.

The area to be examined or the microvolume to be analyzed is irradiated with a finely focused electron beam and a 2-dimensional image is generated that displays spatial variations in these properties. A very interesting observation is that the SEM is also capable of performing analyses of selected point locations on the sample; this feature is very useful in qualitatively or semi-quantitatively determinations of chemical compositions (using EDAX), crystalline structure (Goldstein et al. 2003).

At the same time, the recovery of waste has become more and more appealing because the cost of natural raw materials is gradually increasing due to the decrease in the volumes of natural resources. The experimental planning of the tests in order to obtain the perfect compositions will be done using design of experiment and response surface methodology. The optimization of the composition and the properties of the new synthetic wood obtained in this way will be carried out by using these advanced optimization methods (Bliuc et al., 2017; Dean and Draguljić 2017; Montgomery, 2017; Lepadatu et al., 2018) for achieving the desired characteristics alongside with the maximization of waste (Ashori 2008; Goodship 2007) content.

This paper investigates the possibility of introducing in the composition of a future new material called synthetic wood recyclable waste as varied as possible based on the strength of the bonds induced by this variety.

2. Material and methods

The present study proposes the conception of a biomaterial that responds to the recycling philosophy including the circular economy by maximizing the content of recyclable waste that can be integrated into its recipe. In this context, it is proposed and analyzed several variations of recipes that primarily use woody-recyclable wood materials such as sawdust, wood biomass etc., as well as other waste compatible with this recipe and which improve the physical-mechanical characteristics of the new biomaterial with a huge absorption potential for recyclable waste.

The wood biomass waste of different types and dimensions resulting from the constructions that were used in the experimental tests are shown in Fig. 1.

(a) (b) (c) (d)

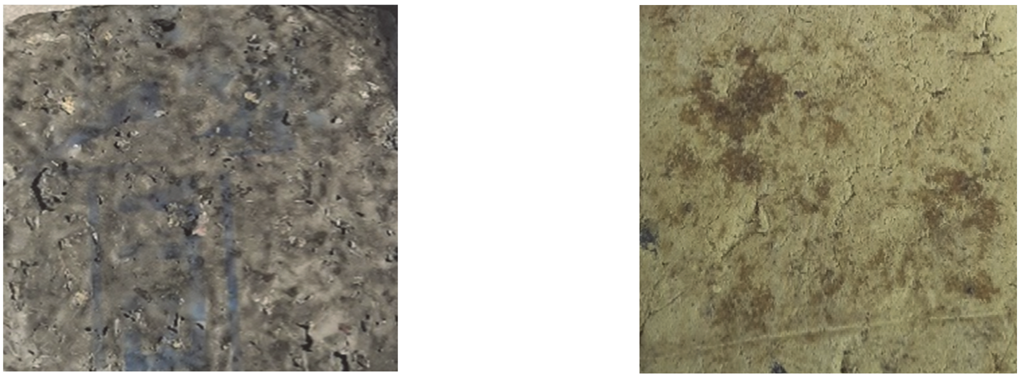
Fig. 1. Biomass waste used for experimental research to produce synthetic wood: (a) wet linden 35%; (b) dried beech; (c) beech powder; (d) oak chips

The experimental tests were made as a series of combinations between different types of waste (sawdust of different sizes as well) with different additives and binder. The dosing was established both in volumetric (Fig. 2a) and mass measures (Fig. 2b). All the samples (Fig. 3) were obtained as a cold mechanical mixture in a blender at first, so as not to generate additional energy consumption necessary to increase working temperatures up to 200 degrees.

The hardening of the samples (Figs. 2-4) was slow for a relatively long period, but their quality is quite promising in the first place in terms of mechanical strength. What we have not been able to do yet is to give it properties that facilitate its modeling and processing. The material is still quite brittle and does not allow a thread to be made in its mass. The advantages induced by the production and use of this synthetic biomaterial wood are: ensuring physical-mechanical performance superior to classic wood; full use of wood waste; various molding, extrusion and preservation of natural wood beauty; it can be used in multiple fields with low production / operating costs; much less production time than the natural one.

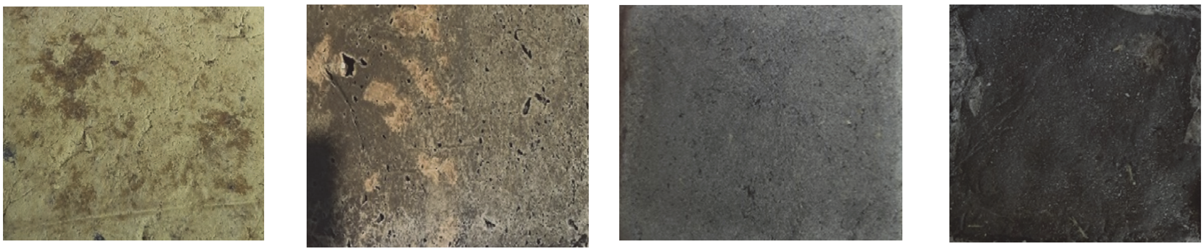
3. Results and discussion

In this study is presented the characteristics of synthetic wood, a biomaterial with a huge potential in the absorption of biomass waste and not only. Thus, the combination of different biomass wastes with binders and other recyclable materials can generate a product with net characteristics superior to natural wood linked primarily to its average production duration but also to properties such as superior mechanical strength or resistance to water absorption.



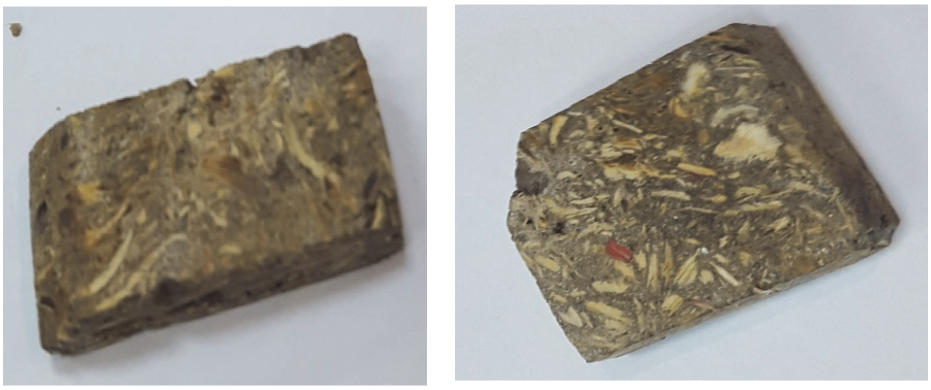
(a) (b)

Fig. 2. Samples obtained through volumetric/mass dosing: (a) volumetric dosing; (b)mass dosing



(a) (b) (c) (d)

Fig. 3. Samples obtained by adhesive composition based on cold mass mixture: (a, b) represent the simple mixture with white cement and/or lime (c, d) represent the simple with different percentages of grin cement and/or silica powder



(a) (b)

Fig. 4. Hardened samples: (a) represent the simple mixture of different percent of waste recycled wood, (b) represent the simple with mixture of different percentages of waste recycled fine wood

The compatible recyclable resources for the production of synthetic wood used in the various mixtures from the experimental presented researches were mainly: biomass waste: forestry; wood waste production; waste from the wood construction sector or packaging cartons; polymer waste, plastic bags, packaging; other industrial recyclable waste compatible. The binder used to obtain the samples was an ureilite type resin combined in different configurations with sodium silicate - solution. The ureilite adhesive composition based on urea-formaldehyde resin is a classic composition with room temperature hardening and with the characteristics presented in Table 1.

Table 1. Binder Characteristics

Characteristics Name	*UM*	*Conditions of admissibility*
Appearance	-	viscous liquid, weak opalescent
Density at 20°C	g/cm^3	1.33 ± 0.03
Dynamic viscosity at 20°C	mPa/s	1000 - 3000
Solid substance, 2 h at 120°C	%	70 ± 2
pH, at 20°C	-	7.5 ± 0.5
Free formaldehyde, max.	%	3.50
Shear Bonding Strength in dry state, min.	N/mm^2	8
Gelling time at 20°C, max.	minutes	45

The urea-formaldehyde resins, mixed with fillers (cellulose fibbers and dyes), can be pressed into heated forms, where condensation between macromolecules takes place, through the participation of CH_2OH groups, which they contain. The final resin is composed of three-dimensional macromolecules (Fig. 5) and is insoluble and infusible.

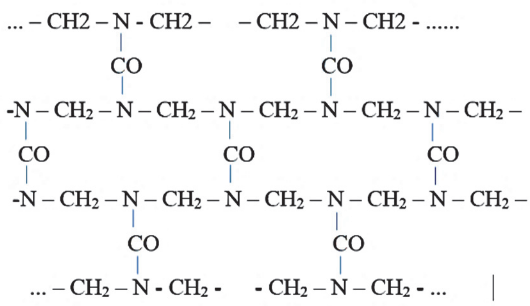


Fig. 5. Urea-formaldehyde resin composed of three-dimensional macromolecules

By this study it is proposed and analyzed several variations of recipes that primarily use woody-recyclable wood materials such as sawdust, wood biomass, etc., as well as other waste compatible with this recipe and which improve the physical-mechanical characteristics of the new biomaterial with a huge absorption potential for recyclable waste. From the beginning the research was founded on the accepted and necessary idea to use as efficiently as possible the resources coming from recyclable waste to obtain a new material that includes as much of this chosen waste so that their compatibility facilitates the achievement of this goal. Thus, different specimens with mechanical mixing and slow cold or accelerated hot drying were designed. The analyzed samples were made from cold mixtures of quantities of wood biomass with a polymeric matrix.

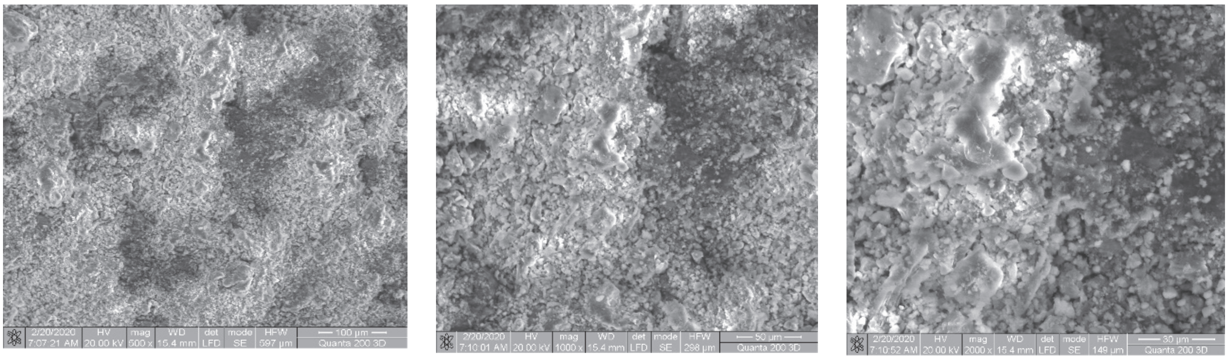
Two samples were prepared to microstructural investigation (Fig. 6 – Simple P_1 and Fig. 9 – Sample P_2) and analyzed to identify and determine the bonds of the microstructures of the different constituents as well as their influence on the physicochemical and mechanical properties of the newly obtained material.

(a) (b)

Fig. 6. Prepared sample P_1 to microstructural investigation: (a) represent the whole P_1 sample (b) represent a part of the resized P_1 sample for microstructural investigation

Samples made by the research team long ago (Sample P_2) and which have kept their physicochemical characteristics until today were also analyzed. Thus, using the electron microscope (SEM Quanta 200 3D microscope) it was possible to capture at different scales the microstructure made from the combinations in the polymer matrix of the different constituents. Scanning electron microscopy was obtained on the same samples used for energy dispersive X-ray spectroscopy, chemical analysis and optical microscopy, performing SEM images at high magnification powers (500X/2000X – Fig. 7).

Also, with the help of the electron microscope was determined the elementary chemical content structure of the new material. The figure above shows a spectral analysis - X-ray spectrum in dispersed energy (EDAX) which indicates the percentage of the elementary structure of the new material. The crystalline formations are clearly differentiated from the organic binder (formed from urea-formaldehyde resin). The crystals have sizes ranging from 20-70 μm with a slight appearance of segregation. The shape and size of the SiO_2 crystals (from the silica powder added as the initial ingredient), the $CaSO_4$ crystals and the calcium silicates and the silico-ferro-aluminates that are part of the cement added to the mixture are clearly highlighted.



(a) (b) (b)

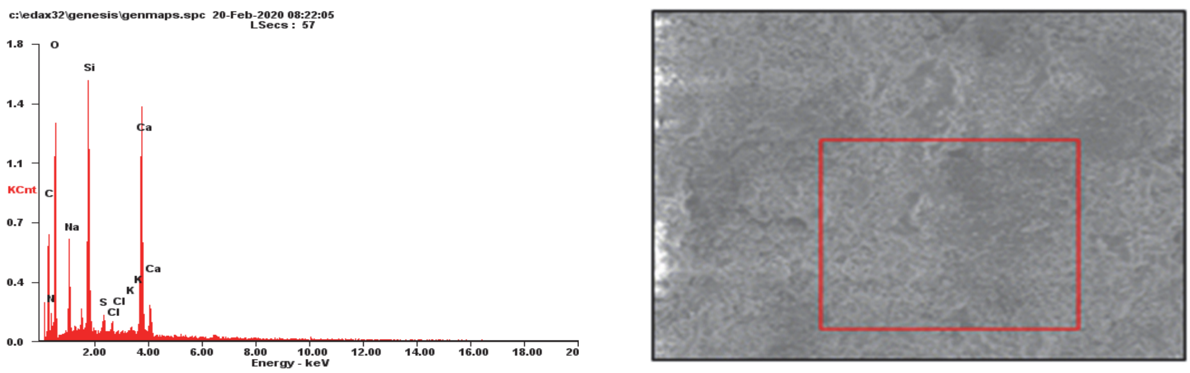
Fig. 7. Scanning electron microscopy images of synthetic wood sample at different scales – sample P_1: (a) 500; (b) 1000; (c) 2000

However, Fig. 8 shows that the appearance of the sample is quite homogeneous, showing that in the end our mixture was well done. The elemental chemical composition, observable in Fig. 8 and Table 2, indicates an increased percentage of C and O, which is absolutely normal since both the organic binder and the crystalline formations contain these elements. And the fairly high calcium content is explainable because most crystalline formations contain this element in the structure. In the Table 2, a spectral analysis is presented - X-ray spectrum in dispersed energy (EDAX), which also indicates the percentage of the elementary structure of the new material for the two analyzed sample. For the simple no 2 (Fig. 9) we did the same investigation to compare and analyze. Thus, the electron microscope managed to capture at different scales the microstructure made from the combinations in the polymer matrix of the different constituents.

The considerations related to this Fig. 10 are similar to those related to Fig. 7. The differences consist in the fact that an increase of the degree of homogeneity is observed (the influence of temperature is felt as the dispersion of the crystals in the binder is uniform). Also, with the help of the electron microscope was obtained the elementary chemical analysis of the new material. Comparing the chemical composition presented in Table 2 – sample 1, with the chemical composition in Table 2 - sample 2, a significant increase of the percentage of C is observed, but also the decrease of the percentages of Si and Ca. This is due to the fact that for sample P_2 the amount of binder was increased and the additions decreased (SiO_2 no longer appears in the composition of sample P_2). The comparative analysis of the results of the two samples indicates the highlighting of the shape and size of SiO_2 crystals (from silica powder added as initial ingredient), $CaSO_4$ and calcium silicates and silico-ferro-aluminates that are part of the cement added to the mixture. It should also be noted that the appearance of the sample is quite homogeneous, showing that in the end our mixture was well done. Fig. 11 (investigated surface) shows lance-shaped crystals, this form being specific to calcium sulphate, so the percentage of gypsum is significantly higher for sample P_2 (so the percentage of Ca of 6.95% of sample P_2 is due, mostly calcium from the addition of gypsum).

The new material obtained by incorporating as much recyclable waste of the compatible types (seed shells, ash, glass powder) as possible into the initial matrix while optimizing its dosage by employing advanced methods of experimental planning can lead to significant improvements of the physical-mechanical characteristics, such as:

- Higher mechanical resistance through physicochemical combinations and reactions between binders and recycling additions, some of them brought to nanometric powder sizes;

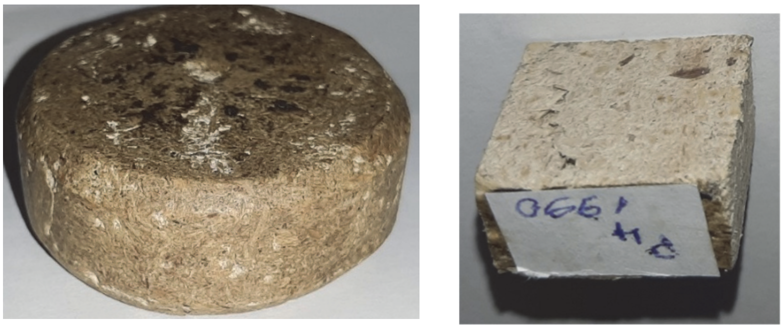


(a) (b)

Fig. 8. X-ray diffractograms of synthetic wood – sample P_1: (a) Chemical element identification; (b) Investigated surface

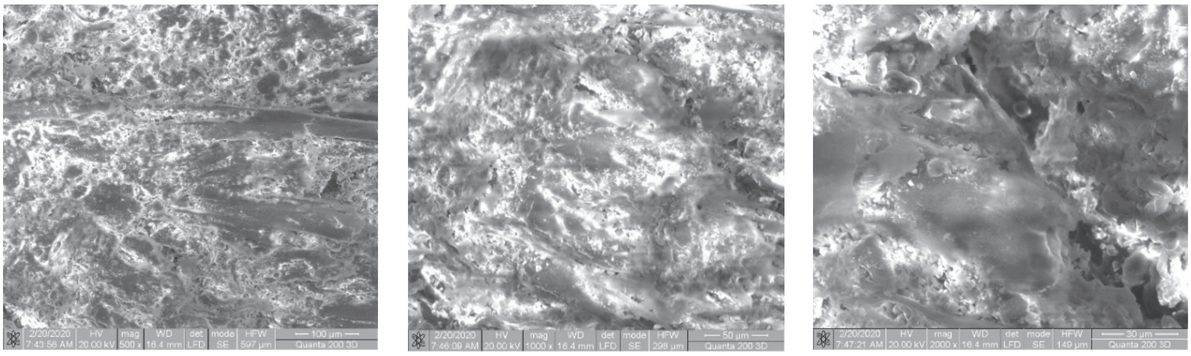
Table 2. Chemical composition of synthetic wood

Sample P_1			***Sample P_2***		
Element	***Wt%***	***At%***	***Element***	***Wt%***	***At%***
CK	13.08	20.71	***CK***	31.23	42.73
NK	03.17	04.31	***OK***	45.90	47.14
OK	41.83	49.74	***NaK***	00.60	00.43
NaK	06.91	05.72	***SiK***	01.71	01.00
SiK	13.44	09.10	***SK***	01.82	00.93
SK	01.04	00.61	***ClK***	01.78	00.83
ClK	00.70	00.37	***CaK***	16.95	06.95
KK	00.72	00.35	***Matrix***	Correction	ZAF
CaK	19.11	09.07			
Matrix	Correction	ZAF			



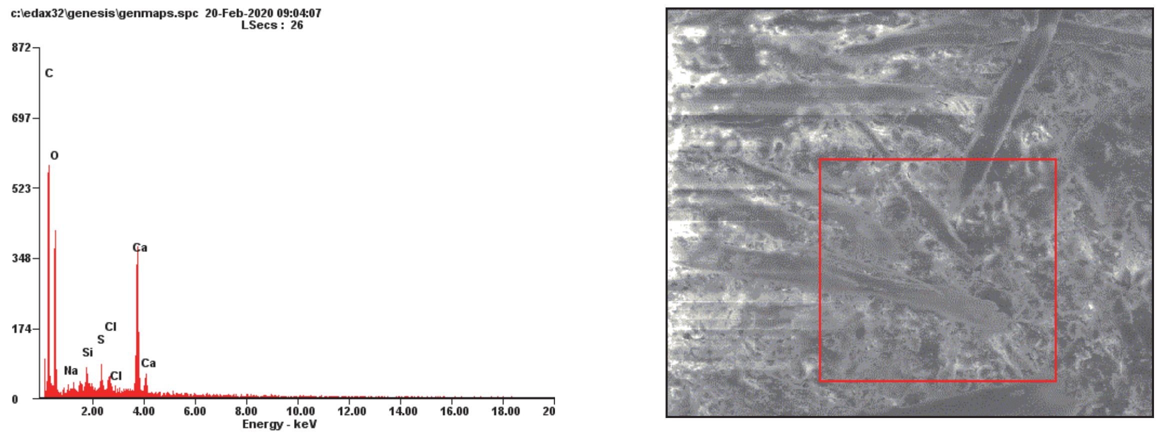
(a) (b)

Fig. 9. Prepared sample P_2 to microstructural investigation: a) represent the whole P_2 sample; (b) represent a part of the resized P_2 sample for microstructural investigation



(a) (b) (c)

Fig. 10 Scanning electron microscopy images of synthetic wood sample at different scales – sample P_2: (a) 500; (b) 1000; (c) 2000



(a) (b)

Fig. 11. X-ray diffractograms of synthetic wood – sample P_2: (a) Chemical element identification; (b) Investigated surface

- Better soundproofing (phonic and sonic insulation);
- Improved fire resistance by adding cement powder;
- Thermal insulation by adding polystyrene waste;
- Many ways of processing it: casting, extrusion, cutting

The presented investigations wanted to highlight the ability of such a material to incorporate varied recyclable waste in its structure, waste that can bring significant improvements to its physical and mechanical properties. To reuse wastes is imperative in the context of the increasingly acute shortage of raw materials and the potential of such a material can make it very attractive. Our interest in obtaining synthetic wood is also based on the heat treatment behavior of lignin, when it acts as a thermoplastic adhesive, melting and forming a strong binder for all its components, thus achieving a very good internal cohesion and implicitly superior physical-mechanical properties.

4. Conclusions

This paper presents the characteristics of synthetic wood, a biomaterial with a huge potential in the absorption of biomass waste and not only. Thus, the combination of different biomass waste with binders and other recyclable materials can generate a product with net characteristics superior to natural wood linked primarily to its average production duration but also to properties such as superior mechanical strength or resistance to water absorption. Also called liquid wood due to the thermal treatment of the component elements, synthetic wood is already the product of several development research teams that we have presented in this research.

Although the images obtained by electron microscopy clearly distinguish the crystalline formations and the binder (urea-formaldehyde resin), as well as their degree of homogeneity, it should be noted that the larger formations (such as those obtained from residual wood) cannot be observed. These formations are too large to be captured by electron microscopy. To see if their distribution is uniform in relation to the rest of the components, we must use other methods (optical microscopy).

Crystalline formations are responsible for the increase of mechanical strengths and therefore their weight in the matrix of the new material, the chemical composition and last but not least a uniform distribution and a high degree of homogeneity are important.

The synthetic wood presented in this paper can be obtained much faster than natural wood and has the advantage that it includes in its structure a wide range of recyclable waste. Thus, this recyclable waste can increase its reuse by incorporating them in a new material with properties at least similar to the natural one or even much improved.

Acknowledgements

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