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Physical and Mechanical Properties Analysis of Wood-waste Composite Panels

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Abstract: *The timber industry takes an important place in our modern life, and there has been an increased interest in it for a long time, especially in industrially developed countries. The concerns of the environmental organization regarding the plant wealth preservation have caused scientific trends to search for sources or industries that can achieve acceptable alternatives to natural wood. The materials in this article are related to industrial timber manufacturing of greenhouse wood waste, low density polyethylene and non-standard joinery waste. Moreover, panel samples made from the above materials were briefly subjected to tests as well as tested by fresh and salt water absorption.The density calculation results for all samples have shown the possibility of obtaining a wide range of wooden planks from the lightest to the heaviest ones, depending on the type of filler used. Additionally, the conducted research has shown the possibility of producing artificial wood panels made from the studied materials with good quality and fully satisfactory physical and mechanical properties.*

Keywords: *timber industry, industrial wood, wood waste, fillers, physical and mechanical properties*

1.Introduction

The timber industry takes an important place in modern life, and there has been an increased interest in it for a long time, especially in developed industrialized countries.

Timber consumption volume in the world is constantly increasing; therefore, resource-efficient technologies developing is important for ensuring the forest resources protection by exploiting the recycling of raw materials left over from timber processing [1-4].

Scientific studies [5-7] show the use of thermoplastic waste or mixtures of recycled plastics with new plastics in the timber processing industry.

The study [8] demonstrates the possibility of using RLDPE waste in the industrial timber panel production; moreover, these panels were pressure formed, with an increase in the percentage of low density polyethylene waste (30-50%) at temperatures of 140°C and 180°C, forming pressure of 30-40 kg/cm^2 with a pressure time of 3-7 min. This article also investigates the mechanical properties and stability of these wood-plastic materials panels affected by various conditions, in addition to determining their microstructure.

Chow Poo and his colleagues [9] developed thermoplastic composite panels using corn fiber mesh as the main material. Corn stalk fibers were cropped from the western part of the United States of America and the panels were formed in various ways.

Fatih Mengel and his colleague [10] studied the thermal behavior of recycled high-density polyethylene (RHDPE) composites as base material, to which eucalyptus timber waste was added.

Nwigho Solomon and his colleague [11] studied the evaluation of industrial wood panels mechanical properties made from recycled LDPE as base material stuffed with ‘Iroko’ sawdust as a filler. The RLDPE was accordingly mixed with sawdust by applying molding at a pressure of 150 MPa and a temperature of 160°C. The tests have shown a tensile strength decrease and impact resistance as well as an increase in hardness with a sawdust increased amount; the researchers concluded that it was possible to use sawdust to increase the RLDPE/timber composites hardness and impact resistance.

Idris and his colleagues [12] investigated the possibility of watermelon skin waste to produce timber-plastic mixtures.

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Panels were manufactured by adding watermelon skin waste after drying, mixing and precision separation into recycled low density polyethylene, after which its microstructure, absorption, moisture, tensile modulus, elastic modulus, strength modulus, internal adhesion and impact strength were determined.

Research objective: industrial timber manufacturing of greenhouse wood waste, low density polyethylene and non-standard joinery waste.

2. Methods and materials

2.1. Plastic matrix

Chopped plastic greenhouse crumbles, made from low density polyethylene (RLDPE) and shown in Figure 1, were used as the base matrix material:

Figure 1. Low Density Polyethylene (RLDPE)

2.2. Joinery waste, resulted from the processes of creating wood products in the form of organic material having different particle sizes (powder, medium particles, large particles, long particles), is shown in Figure 2:

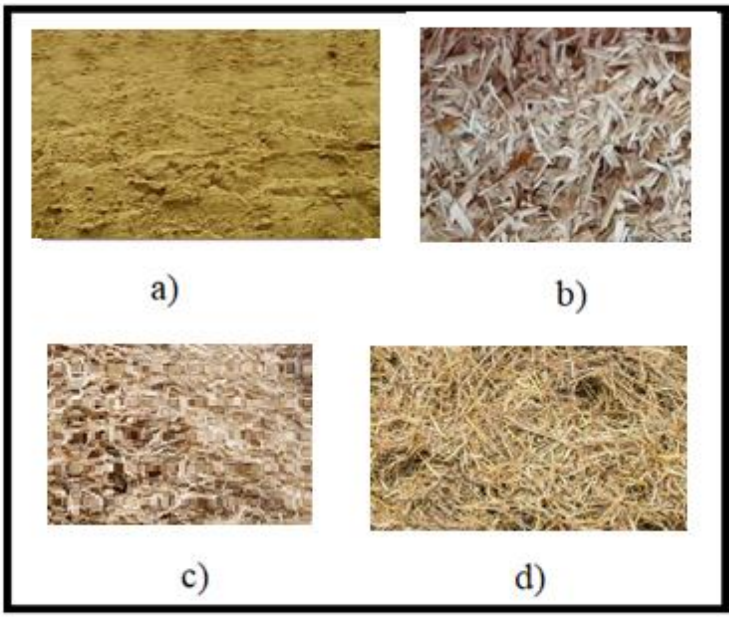

Figure 2. Wood waste: a) powder, b) large particles, c) medium particles, d) long particles

Four sample groups were formed, in which sawdust of various sizes and particle sizes of organic substance were used as a matrix:

- a wood powder set;

- a group of medium particle sizes;
- a group of long particle sizes;
- a random set of particles group.

Each of these groups contained five samples with the following proportions by weight:
- 20% organic filler + 80% RLDPE;
- 30% organic filler + 70% RLDPE;
- 40% organic filler + 60% RLDPE;
- 50% organic filler + 50% RLDPE;
- 60% organic filler + 40% RLDPE.

These samples were manufactured using a semi-hydraulic molding press according to the following system:
- mold temperature T = 160°C;
- initial molding pressure P = 4 kg/cm^2;
- initial pressure time t = 5 min;
- final molding pressure P = 70 kg/cm^2;
- final pressure time t = 10 min.

At the end of the molding cycle, the mold was cooled at a cooling rate of V = 10°C / min, while the final pressure remained unchanged until the temperature, at which the final product could be removed without deformation, was reached.

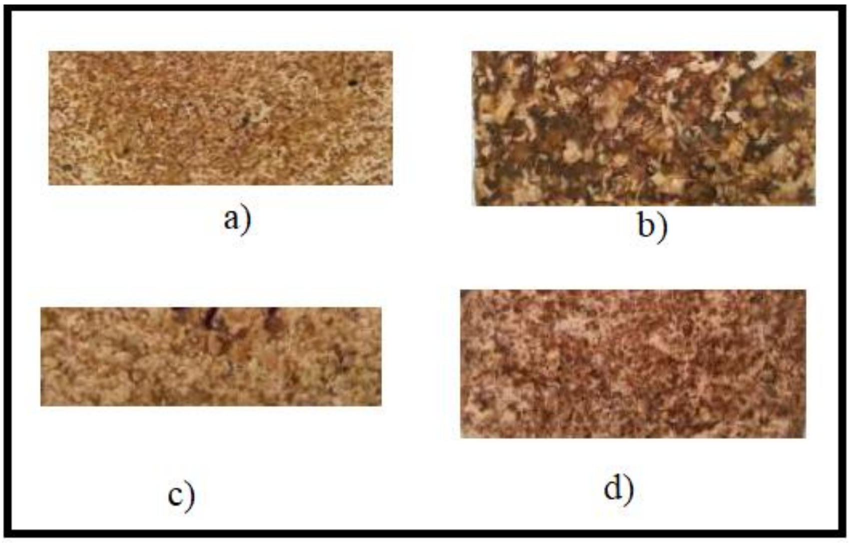

Figure 3. an artificial wood sample made from: a) 60% wood powder + 40% RLDPE, b) 20% large particles + 80% RLDPE, c) 50% medium particles + 50% RLDPE, d) 30% long particles + 70% RLDPE

2.3. Experimental procedure

2.3.1. The density was calculated by subtracting samples from the prepared panels to determine whether the formed panels are light or heavy and whether their density is close to that of natural wood or not. Density was calculated using the following formula:

$$P = m / v, \quad \text{gr/cm}^3$$

where:
- m - sample mass, gr;
- v - sample size, cm^3.

Charpy Test: the samples for tests were prepared in accordance with the standard specifications (ASTM D256-93) and were 10 mm in length and 10.5 mm^2 in cross section.

2.3.2. Short-time absorption

The test was made with samples prepared within a short period of time (2 h, 24 h and 48 h). The test samples were cut from 2.2 cm plates. The test samples weight was measured before the immersion into water to find the percentage absorption that occurred after the immersion for the specified time. The absorption percentage was calculated by the ratio:

$$W = \frac{W_2 - W_1}{W_1} \, .100$$

where:

W_1 - sample weight before immersion (g);
W_2 - sample weight after immersion (g);
W - absorption percentage (%).

3. Results and discussions

The samples density measurement results in this study have shown the different values, that can be explained by a clear difference in the density of the fillers used.

As it is known (3), the timber density is about 1.5 g / cm^3, while the density of other different sizes types fillers (large, medium and long) is the same as density of wood obtained therefrom, which is generally in 0.4-0.8 g/cm^3 range. If it is known that only RLDPE samples density was 0.898 g/cm^3, the obvious difference in the density of the matrix and fillers used showed a different behavior of the density curves compared to the samples with an organic filler.

Figure 4 shows the density curve of chopped LDPE samples with different percentages of wood powder waste. Figure 4-1 shows that the density increases with an increase in the percentage of an organic filler from 0.898 g/cm^3 at 0% to 1.066 g/cm^3 at 60%.

This result can be divided due to the difference in density values between an organic filler and RLDPE, showing that the compounds density enlarges with an increasing proportion of a filler. The obtained results have revealed that all compounds in Figure 4-1 belong to high density hardwoods according to the classification in [13].

The density measurement results, made on the samples consisting of chopped LDPE and medium-sized wood particles, have shown that the differences in density values relative to the matrix density are small, as shown in Figure 4-2, where a slight increase in the sample density of 0.898 g/cm^3 can be observed at a zero level particle, then the density with a composition of 40% medium wood particles becomes 0.908 g/cm^3, further it decreases and at 60% it becomes equal to 0.811 g/cm^3.

The results presented in Figure 4-2 show that these compounds are very close in density to industrial hardwoods according to [13], and the addition of medium wood waste up to 60% leads to a slight decrease in density values and it is possible to produce a wide range of mixtures approximately equal to the density of the base material.

Figure 4-3 shows the density development curve of chopped RLDPE matrix composites with various percentages of fillers, consisting of long wood particles and at 60% filler the density value is 0.42 g/cm^3.

The results shown in Figure 4-3 show a wide range of variable density panels production: from high density panels up to 30% to low density panels, comparable to that of insulation panels [14]. Alternatively, this result presents the compositions, which are similar to those of certain light woods, such as spruce, that is the main purpose of our study - developing of industrial mixtures with properties as close as possible to those of wood.

The search for specific particle sizes of an organic filler increases the cost of the production process due to the production stages lack, and since the main purpose was to develop waste wood and plastic products as an organic filler, subsequent research entailed the use of various random shapes and sizes waste without sorting or categorizing.

The experimental work has shown that it is advisable to use such random organic waste and to produce products whose properties can be considered good to obtain the required consistency of the studied samples after immersion them into water for more than 40 days.

This percentage amounted to 60% for all types and shapes of organic fillers, because using higher ratios, which is the main purpose of our study, it was impossible to obtain cohesive samples with acceptable properties under the same conditions. Since experimental objective of this study was to develop products at the lowest cost, an increase in the proportion of an organic filler to a value greater than the declared value requires preliminary procedures to develop compounds before they are formed, increasing the economic cost.

Figure 4-4 shows the density evolution curve of the low density polyethylene chopped with a random set of wood particles samples. In addition, the density values are almost constant up to 30% of the composition, and a gradual decrease in the density values is due to an increase in the filling percentage from 30 to 60%.

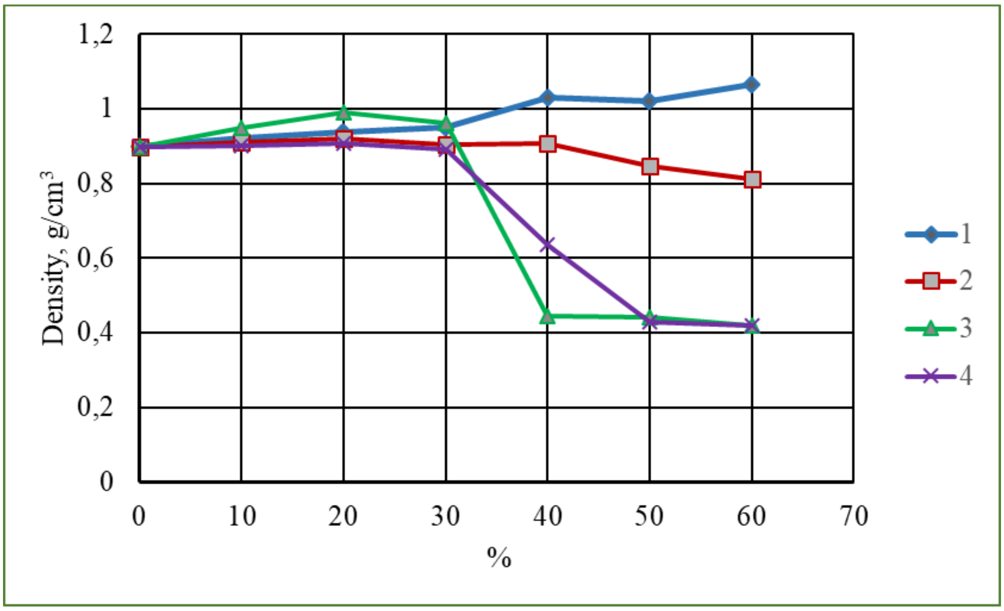

Figure 4. The RLDPE composites density development curve containing different proportions of a 1) wood powder, 2) medium-sized wood, 3) long wood, 4) random set of wood particles as an organic filler

The results given in Figure 3-4 show that the use of random waste gave approximately the same results for a long particle filler, and the density measurements of all previous samples mentioned in Figures 3 have demonstrated the possibility of a wide range of industrial wood panels producing comparable to light wood of (0.40 - 0.45) g/cm^3, used as insulation panels, as well as high-density heavy wood of 0.9 g/cm^3, close in density to polymer - based materials.

3.1. Impact tests

The impact strength values of plastic products give an adequate representation of the final product resistance to dynamic loads, since it is known [15] that most objects are destroyed under the influence of dynamic loads, such as hit or regular loads, while the effect of static loads, such as creep, remains very insignificant and lasts for a long time compared to the product life expectancy under the influence of dynamic loads.

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Determining the RLDPE impact resistance in terms of organic loads percentage is an important point for the future study of the resistance of products made from these materials to the dynamic loads to which they may be subjected during the tests.

Figure 5-1 shows that the impact strength values of chopped RLDPE compositions with wood powder as a filler decrease with increasing percentage of an organic filler. This result complies with many reference studies [15] and is predictable since, as it is known, additives generally cause a decrease in the impact strength values, regardless of their percentage value.

According to Griffith's theory [14], fillers, regardless of their composition in general, are as stress concentrators in the final product, that in its turn causes different types of loads (static - dynamic) concentration in certain parts of the structure.

Figure 5-1 shows the development curve of the impact RLDPE resistance as a function of the percentage of an organic filler (wood powder). A high percentage of wood powder results in a decrease in wetting and penetration of the base material, that, in addition to an increase in agglomeration, makes it difficult to develop the batch-to-batch uniformity final structure.

It should be noted that in order to reduce the size difference between the chopped RLDPE and the wood powder a separation process was performed using a set of sieves, with the approximately equal particle sizes of wood powder to achieve uniformity of the components of the mixture.

The curve in Figure 5-1 shows a decrease in impact resistance from 20 kJ/m^2 at 20% wood powder to 7.91 kJ/m^2 at 60%, i.e., about threefold.

Figure 5-2 shows that as the particle size of an organic filler increases, the impact resistance of the tested compositions improves. It can be noted that when using a medium size organic filler, the impact resistance of the studied compositions improves and it is clear that the impact stress values have decreased from 20 kJ / m^2 to 20% to 11.2 kJ / m^2 at 60%, that is 2 times less.

This result confirms a marked improvement in impact resistance over the impact strength values of compositions containing wood powder, and is due to an improvement in the distribution of the base material due to a reduction in the surface area of an organic filler. Figure 5-2 also shows that when using medium size fillers, the impact strength values remain almost constant until the percentage of organic fillers reaches 30%, followed by a slight decrease in impact resistance at a value of 18.2 kJ/m^2. This result is explained by the ability of the base material for better wetting and encapsulation until this percentage is reached, then there is a significant decrease in impact strength values to 11.21 kJ/m^2 at 60%.

These results are considered important from the point of view of application, as they show that the optimal percentage of the filling process for this type of filler is up to 40% with keeping the good values of impact resistance, and that an increase in an organic filler volume improves the impact resistance up to 40%: when using wood powder of 10.12 kJ/m^2 and when using medium-sized particles, it reaches up to 18.2 kJ/m^2, hence, there is a result importance, that showed an improvement in impact resistance using medium-sized particles, therefore, the effect of larger particles on impact resistance has been investigated.

Figure 5-3 gives the impact resistance evolution curve of mixtures containing long wood particles, and it is clear that the general behavior of the impact resistance curve is identical to the previous curves, where it decreases with an increase in the percentage of organic filler, and the value of this stress at 20% is 31.26 kJ/m^2, and at 40% it becomes 18.24 kJ/m^2, i.e., it is more than the impact resistance at the same ratio in the case of using wood powder, or when using medium-sized particles, and this result confirms the improvement of the penetrating power of the base material used due to the reduction of the surface area of the organic filler particles.

The replacement of the polymeric material with low cost and high performance polymeric materials aims at reducing the economic cost of the final product with obtaining satisfactory physical and mechanical properties. A simple comparison of the impact strength values at 60% shows that the values are generally close to each other and that the best of them are associated with the use of compounds containing organic fillers with large or medium particles, compared to a wood powder filler.

The effect of randomly mixed (short - medium - long) particle sizes material on the impact resistance was studied to demonstrate the clear effect of the filler particle size and its uniformity. Figure 5-4 shows the development curve of impact resistance due to the percentage of organic fillers with any particles set. The results have shown that at 40% composition of this type of fillers the stress value was 24.75 kJ/m^2, while at 60% it was 14.54 kJ/m^2 and compared to previous results these values were higher than when using fillers with long and medium particles.

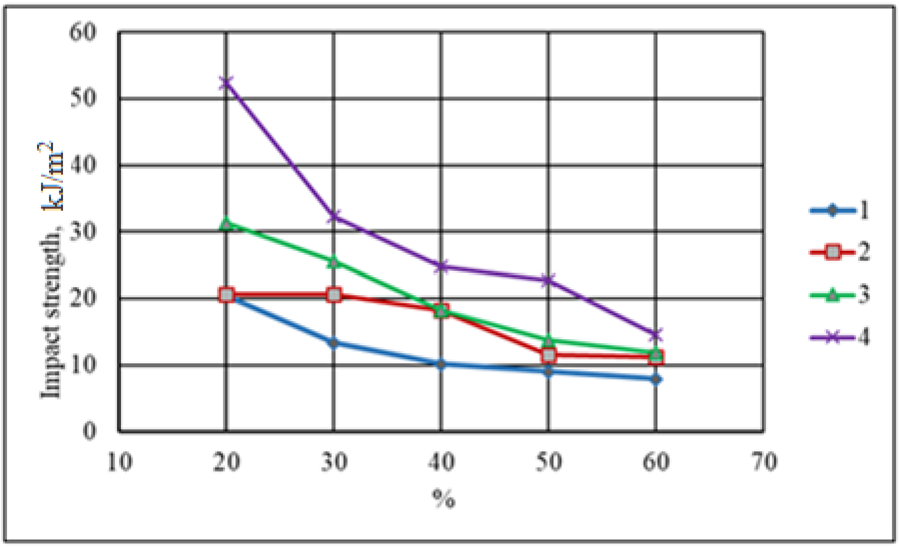

Figure 5. The LDPE impact resistance development curve depending on the percentage of organic fillers 1) wood powder, 2) medium-sized wood, 3) long wood, 4) random particles

According to Charpy, the results of impact tests show that if there is a need for impact-resistant products, the effective range to be investigated is in the range of 20% organic fillers, regardless of the difference in shape of these particles, and that the intensification of the research should not depend on the particle size of this filler and should be aimed to improve the adhesion conditions by preliminary treating of the wood particles with matrix, they provide the group "polymer - filler" with the functional basis, which is necessary to ensure the adhesion of the elements of this group together.

Short Term absorption study

The water absorption study over a short period of time focuses on the rapid assessment of the water resistance of the samples produced. This test is considered to be one of the rapid tests performed on industrial timber and it has been approved by the international standards as a resistance test as one of the physical tests for this type of material [13]. These tests usually involve measurements of swelling or thickening of the materials to determine any irreversible changes that may occur due to the size of the wood particles.

By analyzing the results obtained, presented in the Figures 6-13, the following can be noted:

1. The high resistance of cellulose compounds to water is explained by an increase of the absorption percentage with an increase in the percentage of a filler and a time increase in water.

2. A decrease in the coating and wetting capacity of the base material with an increase in the filler percentage is explained by an increase in the absorbency with an increase in the organic filler percentage.

3. There a low absorption capacity of salt water compared to fresh water due to the existence of high molecular weight compounds such as sodium chloride in salt water.

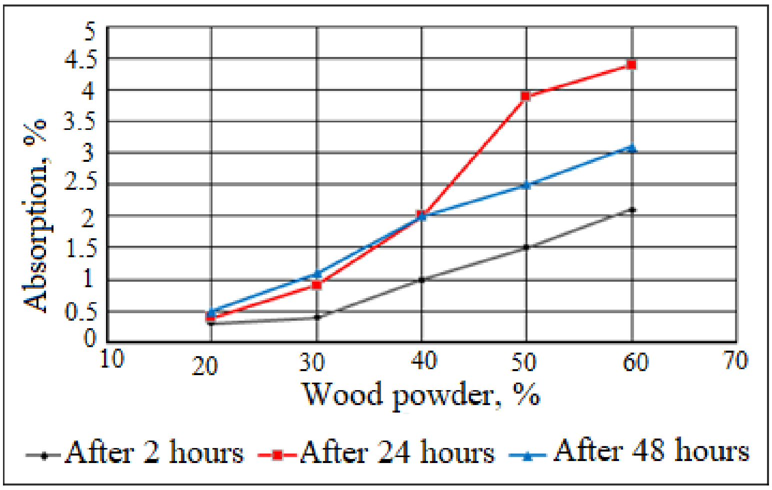

Figure 6. The fresh water absorption by RLDPE samples depending on the percentage of wood powder

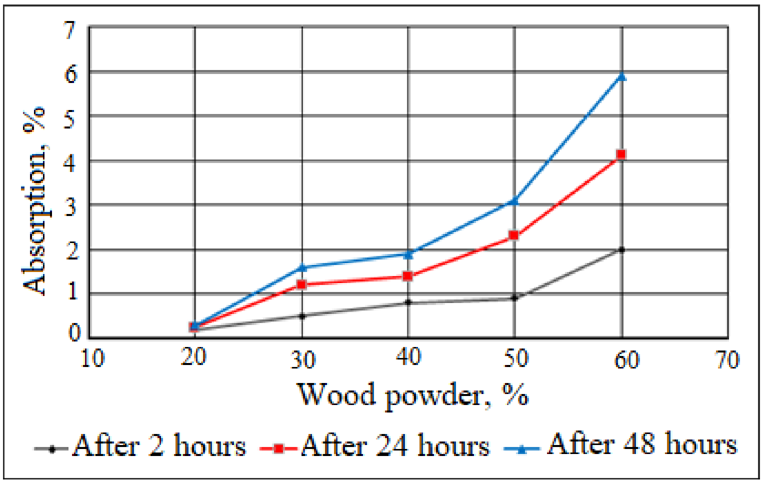

Figure 7. The salt water absorption by RLDPE samples depending on the percentage of wood powder

The density measurements results have shown a clear discrepancy of the density values of compounds with different particle sizes of an organic filler, as shown in Figures 8, 9. The results of measuring the absorption rate of fresh and salt water by medium particle compounds showed that the values reach high levels at a filler composition of 60%, with the absorption exceeding approximately at 40% after immersion in water for 24 h and 48 h. This result shows that the RLDPE base coating capacity is low and does not guarantee the necessary of an organic filler all particles cohesion.

This result conforms with the impact tests, which have shown that the lowest impact resistance values were for mixtures with a high composition of an organic filler.

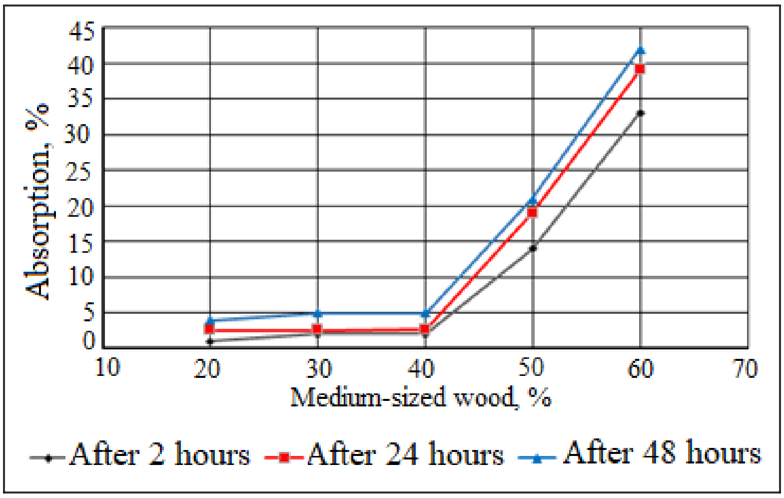

Figure 8. The fresh water absorption by RLDPE samples
due to the percentage of organic fillers - medium-sized particles

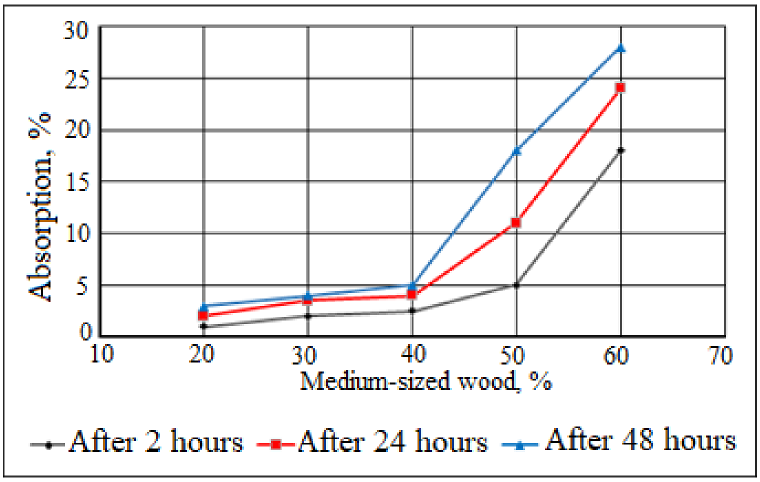

Figure 9. The salt water absorption by RLDPE samples
depending on the percentage of an organic filler – medium-sized particles

The rapid density measurements were made on the samples containing large wood particles precisely the same way. As can be seen from two Figures 10,11, the average absorption in fresh and salt water after 48 h is approximately 16% for a 60% filler, and Figures 12, 13 show a change in the density value as a percentage of an organic filler represented by wood large-sized particles, differing in a random way.

As can be seen from Figures 12, 13 the highest absorption values are achieved when the percentage of a filler is 60%, with the average absorption value to be 31% in fresh and 28% in salt water after 24 h of immersion.

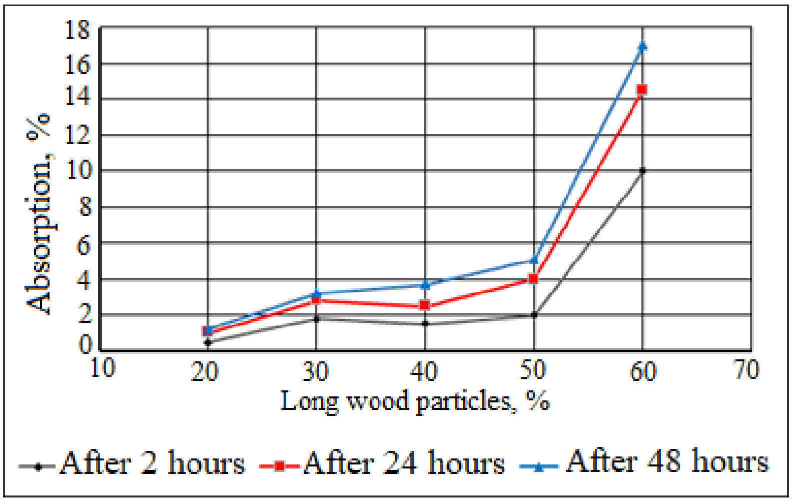

Figure 10. The fresh water absorption by RLDPE samples as the percentage of an organic filler - long particles

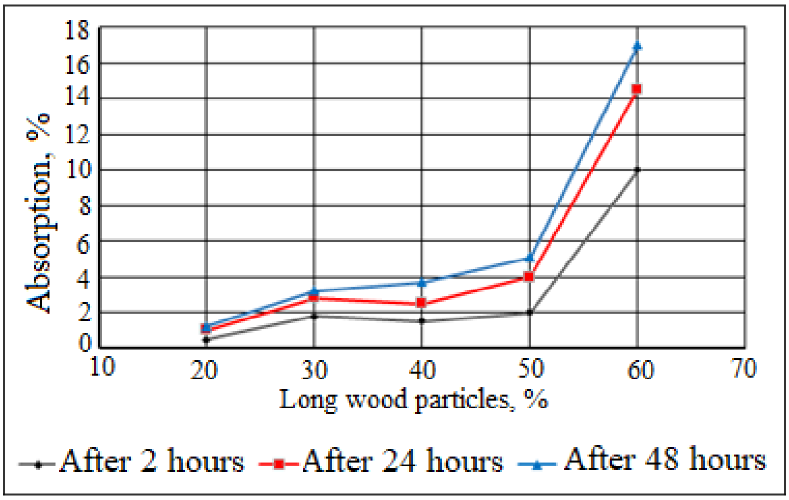

Figure 11. The salt water absorption by RLDPE samples as the percentage of an organic filler - long particles

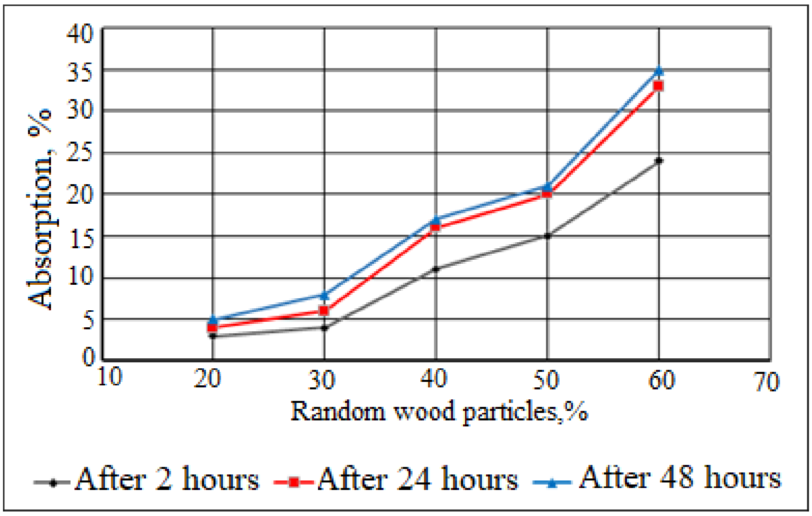

Figure 12. Fresh water absorption by RLDPE samples as the percentage of organic fillers – random particles

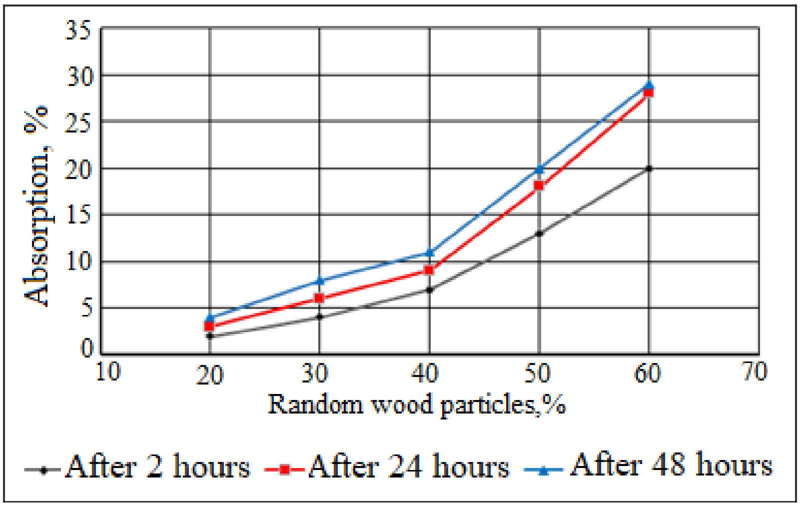

Figure 13. The salt water absorption by RLDPE samples as the percentage of organic fillers - random particles

4. Conclusions

The density calculation results for all samples show a wide spectral range of panels that can be made from these compounds, from the lightest with the density of 0.40-0.45 g/cm^3 to the heaviest with the density of 1.066-0.89 g/cm^3.

The impact energy decreases with an organic filler percentage increase and declines with a particles size and volume increase up to a certain percentage due to the distribution improvement of the material base according to a filler area decrease.

The fresh and salt water absorption coefficient increases with increasing immersion in water time, an organic filler percentage and its size. This means that these panels can be used in a wet environment. That it depends on the nature of the wood and on the initial moisture.

The test results have shown that it is possible to produce good quality artificial wood panels without preliminary procedures for the materials used in the study.

The given studies have shown that it is possible to use wood waste of different sizes and that any filler size allows developing a product with its own final properties.

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