MATERIALE PLASTICE
https://revmaterialeplastice.ro
https://doi.org/10.37358/Mat.Plast.1964

Use of Panels Made from Plastic Waste in Thermal Insulation

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Abstract: *The materials of the given article are devoted to the problem solution associated with one of the processing plastic waste methods by adding various fillers in order to obtain the final product for the thermal insulation materials manufacture. The researches were conducted using the UPR (unsaturated polyester resin) samples made of EPS (expanded polystyrene) plastic waste and crushed recycled polyethylene from greenhouse film waste with various types of wood waste from carpentry workshops. The tests have revealed that when EPS is added to the unsaturated polyester mixtures, the EPS thermal conductivity coefficient decreases with a slight decrease in density, which gives the wide opportunities to use EPS waste as an additive for UPR and expands the ways of its potential industrial application, and the addition of styrene to the compositions containing 10% of styropor causes a clear decrease in thermal conductivity characteristics and a slight decrease in the density of these mixtures. The values of the thermal conductivity coefficient and the density of the low-density polyethylene material increase with the wood powder percentage raising used as an organic filler.*

Keywords: *RLDPE, styropor, thermal conductivity coefficient*

1. Introduction

Plastic waste currently poses a serious threat to the environment. In this regard, scientists around the world are looking for a solution of this problem by processing it with the use of certain safe additives to enable further use as thermal insulation materials. Modern scientific developments, with the increasing danger of an environmental catastrophe, are aimed at analyzing the experience of previous research in this area and finding the optimal way to use recycled plastic mass for the production of thermal insulation materials with the greatest efficiency [1-7].

To find out the possibility of replacing traditional insulation materials with solid waste as a filler made of synthetic polyethylene, researcher Ahmad Cherif [8] and his colleagues conducted an experimental and theoretical study, which consisted of two parts: the first of which included measuring the thermal properties of plastic waste using the method of temperature instability depending on the trans-temperature state, and the second was a comparative study conducted for various building structures using traditional insulation, or insulation using solid waste in the form of polyethylene filler. As a result, it has been concluded that the thermal conductivity coefficient in the case of using polyethylene waste is on average 0.195 W / (m · K), which is five times better than in the case of using conventional insulation.

The several fillers types influence on the thermal conductivity of polystyrene and polyethylene was researched by John Wiley [9]. In these studies glass granules and MgO were added to two materials, and it was found that with an increase in the volume ratios of the filler the thermal conductivity increased.

Low profileadditives influence on shrinkage of unsaturated polyester at low temperatures from 25 to 70^{o}C was studied by Mohamad Hosain [10], meanwhile, the following compounds acted as these additives:

1 - Polyvinylacetate (PVAC).
2 - Polymethyl methacrylate (PMMA).
3 - Polystyrene (PS).
4 - High density polyethylene (HDPE).

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During this study it has been found that with the solidification temperature increase shrinkage increases, and anti-shrinkage additives reduce volumetric shrinkage at the value that varies depending on the type of additive.

Researcher Uang Y. J. [11] used thermoplastic polymers such as PVAC, PS, PE and others, he revealed that when they were added to unsaturated polyester in the presence of styrene monomer during the solidification process the volume shrinkage decreases.

Researcher Yayi Arsandrie [12] with his colleagues found that the composition of plastic waste, mixed with sawdust and rice husk became an alternative brick material for thermal insulation of buildings. Moreover, the whole process consisted of two stages: the first consisted in the manufacture of several samples from plastic waste with sawdust or rice husk, and the second consisted in measuring the thermal properties of samples from the obtained materials. The samples were made using various compositions of the mixture, which were then tested for their ability to absorb heat both during the day and at night. The measurement results showed that 70% of plastic waste increased the thermal conductivity of materials equally throughout the day.

The research relevance is to obtain new thermal insulation materials from the ingredients available on the market for their use in the formation of polymer mixtures based on some plastic waste, while solving the problem of its effective disposal.

The study objective is to obtain samples made of low-density polyethylene, remaining from the disposal of plastic greenhouses produced in large quantities, as well as from used boxes of expanded polystyrene, known as styropor, used for the vegetables and fruits transportation. They are a major waste source and for this reason used in research as additives to unsaturated polyester for reducing the economic cost of the base material and studying its effect on thermal properties.

2. Methods and materials

Styrene is a monomer used in the production of a wide variety of materials for the manufacture of many plastic products. Styrene-based materials have unique properties of hardness, versatility, high productivity and ease of production. These products also have excellent insulation properties for use in construction and lightweight components. It is considered one of the solvent materials for unsaturated polyester (UPR) [13].

The materials used in the research are cheap because they represent waste that was used for the purpose of manufacturing test samples. The following types of waste were used in the conducted studies:

1 - Crushed flakes of low-density polyethylene used in greenhouses as shown in the Figure 1a.

2 - EPS waste shown in Figure 1b.

Figure 1. a. RLDPE shredded waste, b. expanded polystyrene waste

3 - Organic waste, represented by carpentry workshop waste, which was used in powder form with an approximate diameter D = 0.3 mm, medium particles with a diameter within 1.18 - 2.3 mm and random, representing a random mixture of the two previous types, as in the Figure 2.

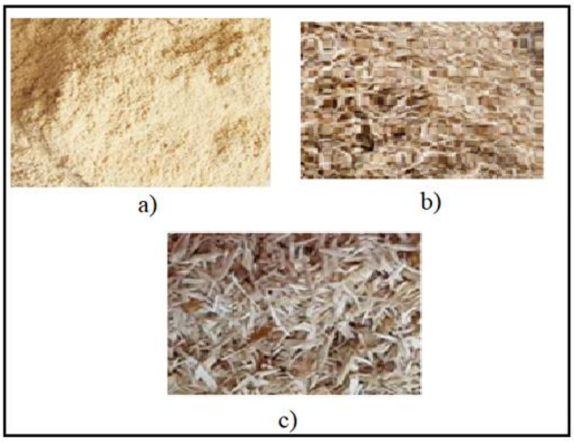


Figure 2. Wood waste: a. powder, b. medium particles, c.random particles

4 - The binding matrix is an unsaturated polyester.
5 - The basic material is methyl ethyl ketone peroxide (MEKP).
6 - Booster compound substance, which is cobalt naphthenate containing 6% cobalt.

Test samples preparation
Two sets of samples were prepared:

The first group: these are UPR samples with plastic waste, which is waste from ESP.

The following tools were also used to conduct research:
- precision scales with measurement accuracy up to 0.001 g;
- mercury thermometer that can measure temperature up to 200^{o}C;
- timer for measuring time.

To manufacture each of the samples the following components were put into a glass beaker: an appropriate amount of UPR (20 g), 1% peroxide soil of MEKP and cobalt naphthenate containing 0.5% of UPR as a booster compound, and then the mixture was mixed well. As for the samples to which EPS was added, it was first dissolved using UPR, and then the basic material and a booster were added to it. Next, the tip of the mercury thermometer was put in the mixed mixture and the mixture temperature was observed over time. Figure 3 shows some samples obtained at this stage, which were used to measure the thermal conductivity coefficient.

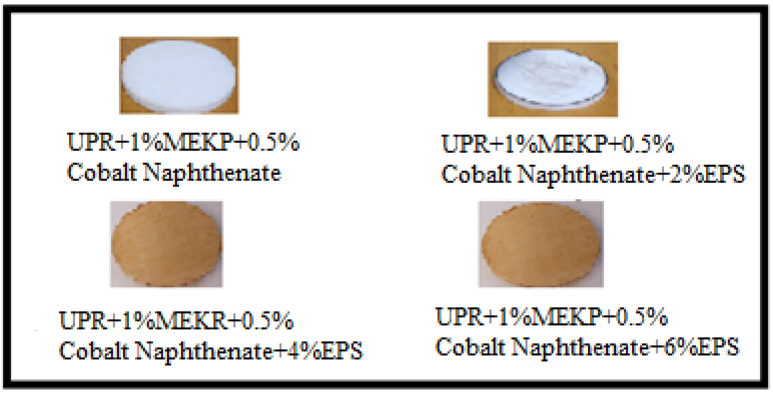


Figure 3. Test samples UPR with waste of EPS and styrene (S)

The second samples group was made from crushed recycled polyethylene of greenhouse waste with the addition of various types of wood waste from carpentry workshops.

These samples were molded on the floor of a hydraulic molding press according to the following system: the temperature of the mold halves was T = 16^{o}C, initial molding pressure was P = 0.294 MPa, initial pressure application time was t = 5 min, final molding pressure was P = 6.37 MPa, application time of the final pressure was t = 10 min. At the end of the molding cycle the mold was cooled at a speed of V=10^{o}C/min, at the same time the final pressure was maintained until the temperature was reached at which the final product could be removed without deformation [14]. Figure 4 shows some samples made of wood and low-density polyethylene (LLDPE).

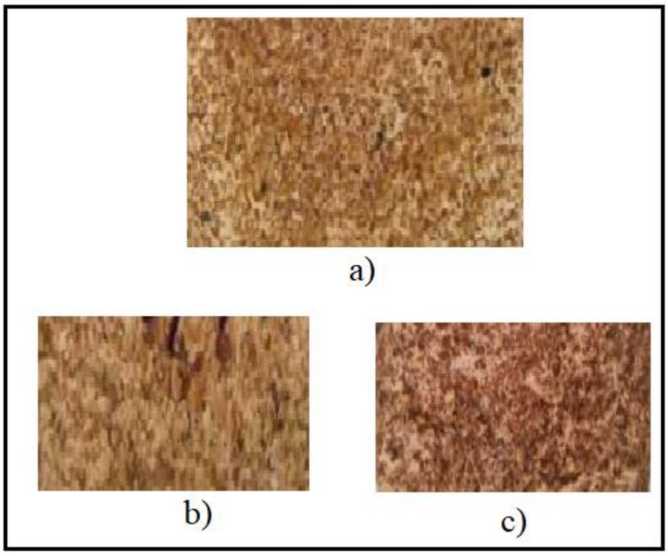


Figure 4. A sample of artificial wood made from
a) - 60% of wood powder + 40% of RLDPE,
b) - 50% of medium particles + 50% of RLDPE,
c) - 20% of random particles + 80% of RLDPE

Experimental procedure

1- The measurement of the samples thermal conductivity coefficient:

The measuring method of the thermal conductivity coefficient is to determine the heat flow through the sample, which is placed in the installation and heats up at a certain speed from one side. The temperature of the sample on its various sides is recorded by thermocouples, which ensure the accuracy of the measurements. The amount of heat given to the sample is determined by the following mathematical relationship:

$$\lambda = \frac{Q . \Delta X}{A . \Delta T}, \quad (1)$$

$$Q = V . I, \quad (2)$$

$$A = \frac{\pi . D^2}{4}, \quad (3)$$

$$\Delta T = T_2 - T_1, \quad (4)$$

where: I - current strength in amp
V - potential difference in volts;
D - sample diameter in meters;
ΔX - sample thickness in meters;
Q - the amount of heat transferred in W;
λ - the coefficient of thermal conductivity in W/m·K;
ΔT- temperature difference in degrees.

Figure 5. Thermal conductivity measuring device

2- Sample density measurement:

The two most important characteristics that thermal insulation materials should have are: low density and low coefficient of thermal conductivity.

The density was measured by the ratio of the mass of the samples to their volume, considering the samples as round disks with a diameter of 2.5 cm and a thickness of 1 mm:

$$\rho = \frac{m}{\nu}$$

where: m - sample mass (g);
ν - sample volume (cm^3);
ρ - density (g/cm^3).

3. Results and discussions

Materials differ in their ability to transfer heat, that is, to have the property of thermal conductivity. Metals are the best heat conductors, and there are materials that conduct heat poorly, such as wood and styropor, so they are used as insulators.

The values of the thermal conductivity coefficient for all thermal insulation materials vary from 0.3 (W/m·K) up to higher values.

Such values gradation of the thermal conductivity coefficient allows to have a large number of materials with physical and mechanical properties that are really suitable for their use cases, therefore, the search for materials with specific values of the thermal conductivity coefficient λ and having properties suitable for the cases of their application, is the goal of many studies nowadays (7).

Scientific studies show that additive materials of any kind have different effects on the values of the thermal conductivity coefficient, and polymer materials in general are characterized by low values of the thermal conductivity coefficient compared to many materials.

Figure 6a shows the curve of change in the values of the thermal conductivity coefficient of unsaturated polyester compounds depending on the percentage of styropor waste of EPS.

As can be seen from the figure the thermal conductivity coefficient of these compounds decreases with increasing of EPS from 0.16 (W/m·K) at 0% of EPS to 0.144 (W/m·K) at 12% of EPS.

The change in the values of the thermal conductivity coefficient is relatively small, but positive, especially if it is known that the addition of styropor waste reduces the economic costs of unsaturated polyester when using waste as the main part of the mixture of UPR.

The reason for the decrease in the thermal conductivity coefficient is the difference in density of UPR, the value of which is 1.225 g /cm^3 and the addition of EPS material, the density of which is 1.1 g/cm^3.

This result confirms the curve shown in Figure 6b, which shows the change in the density of UPR compounds in terms of added EPS waste styropor, where there is a slight decrease in density with an increase in the percentage of added EPS styropor.

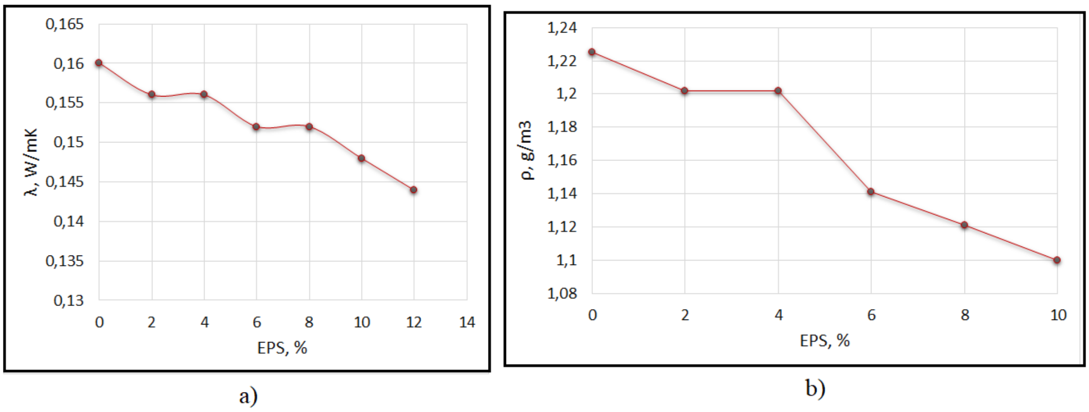


Figure 6. Change in: a. values of the thermal conductivity coefficient, b. UPR compositions density, containing 1 % of MEKP and 0.5 % of cobalt naphthenate, in terms of EPS

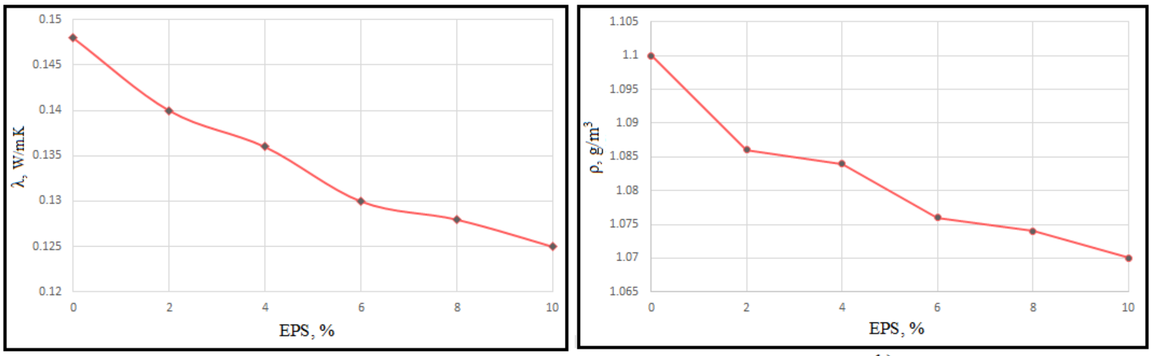
This important result opens up a wide field for the possibility of using EPS waste as an additive to UPR, which makes it possible to study new types of compounds and actually expands the horizons of potential industrial applications of UPR.

Figure 7a shows the effect of styrene added to compositions, containing a fixed percentage of styropor (10%) and a different percentage of styrene, on the values of the thermal conductivity coefficient.

As it can be seen from Figure 7a the addition of styrene to unsaturated polyester mixtures, containing fixed proportions of 10% of styropor, causes a clear decrease in the values of the thermal conductivity coefficient from 0.148 (W/m·K) up to 0.127 (W/m·K). The reason for this is due to the structure uniformity of the mixture as a result of the addition of styrene, which plays the role of a solvent, on the one hand, and the role of an uniformity element of the resulting mesh structure in the final compound, on the other hand.

Figure 7b shows the curve of change in the density of the mixture (UPR+10% of EPS) in terms of added styrene, since it is clear that there was a slight decrease in the density of these mixtures with an increase in the proportion of styrene, which confirms the role of styrene in reducing the density of the spatial network between UPR molecules.

In fact, in order to know accurately the effect of EPS and styrene added to UPR it is necessary to conduct extensive experimental studies of physical and mechanical properties. However, the preliminary results obtained by us confirm the possibility of using these compounds in thermal insulation.



a) b)

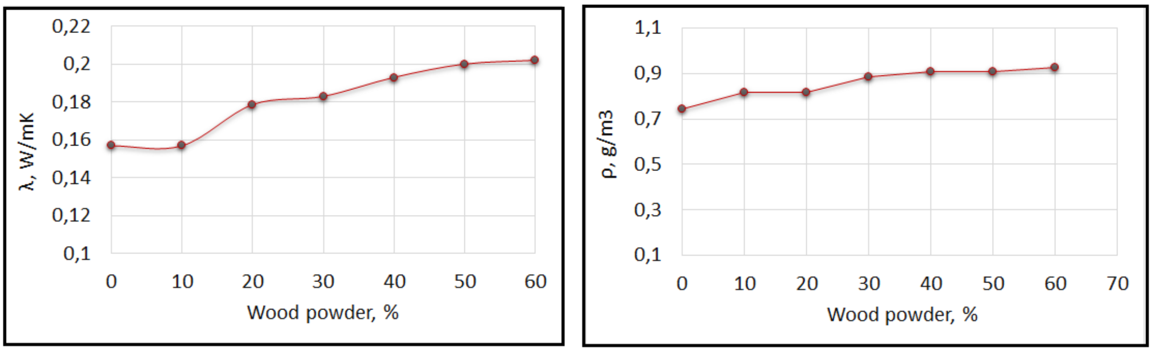
Figure 7. Change in: a. values of the thermal conductivity coefficient,
b. density of UPR compositions, containing 1 % of MEKP, 0.5 % of cobalt naphthenate and 10 % of styropor, depending on the added styrene EPS, %

Figure 8a shows the measurements results of the thermal conductivity coefficient λ for test samples made of crushed polyethylene mixture with different percentages of wood powder.

As it can be seen from Figure 8a, an increase in the values of the thermal conductivity coefficient from 0.157 (W/m·K) in a mixture of crushed low-density polyethylene up to 0.202 (W/m·K) in a mixture with 60% of wood powder, where there is a steady increase in the values of the thermal conductivity coefficient with an increase in the proportion of wood powder.

The measuring results of the samples density prepared from RLDPE show a value of 0.74 g/cm^3. It is actually lower than the density of the new LDPE, in which this value is 0.910 g/cm^3. The reason for this may be the aging to which polyethylene flakes are subjected, which actually leads to a decrease in physical and mechanical properties as well as density.

Figure 8b shows an increase in density to a value of 0.925 g/cm^3 with an increase in the proportion of wood powder 60%, which explains the increase in the values of the thermal conductivity coefficient λ.



a) b)

Figure 8. Change in: a. values of the thermal conductivity coefficient,
b. density for mixtures obtained from RLDPE and having different percentages of wood powder

This increase in the values of λ, which occurs due to the addition of wood powder, cannot be neglected, especially if it is known that all the materials used in the manufacture of these samples are waste that has not been subjected to any chemical or physical treatment before use, except for cleaning and the grinding process.

Also, all the values shown in the Figure 8 indicate that the values of the thermal conductivity coefficient for all vehicles do not lose their possibilities of use in thermal insulation materials.

Figure 9a shows the measurements results of the thermal conductivity coefficient λ for test samples made of crushed polyethylene mixture containing different percentages of medium wood particles. As can be seen from the Figure 9a, a slight and gradual decrease in the values of λ from 0.157 (W/m·K) to

0.135 (W/m·K) occurred with an increase in the proportion of medium-sized wood particles. The size and quality heterogeneity of medium-sized wood particles used in the research makes it difficult to explain many of the properties possessed by the final products.

The density change curve in relation to the average wood particles shown in Figure 9b confirms the results presented in Figure 9b, which shows that the density first decreased from 0.74 g/cm^3 to 0.653 g/cm^3 with 20% of content of medium-sized wood particles, and then increased again up to a value of 0.793 g/cm^3 with a 30% of content of medium-sized wood particles.

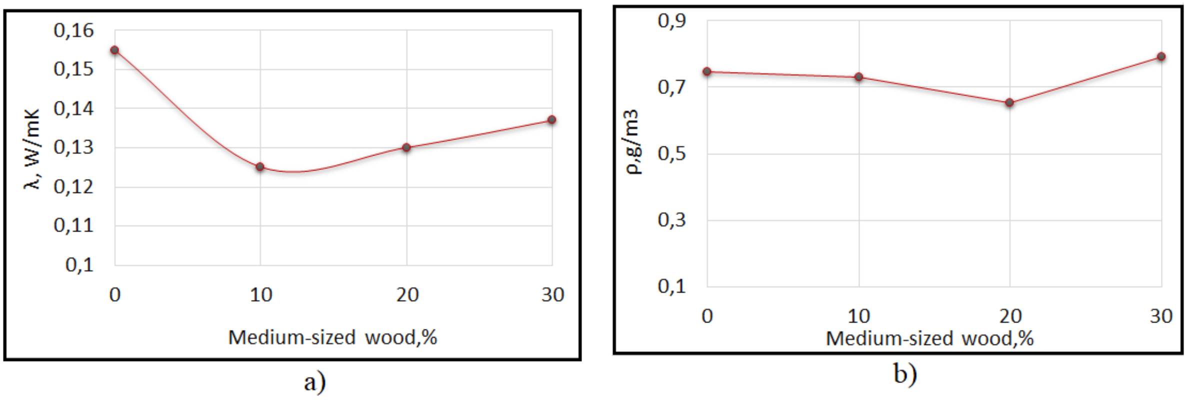


Figure 9. Change in: a. values of the thermal conductivity coefficient, b. density for mixtures obtained from RLDPE and having different proportions of medium wood particles

Figure 10a shows the results of measurements of the thermal conductivity coefficient λ for test samples made of crushed polyethylene mixture RLDPE, depending on the percentage of organic filler, represented by particles of random size.

As it can be seen from the Figure, there is a clear increase in the thermal conductivity coefficient of compounds from a value of 0.157 (W/m·K) at 0% of random wood particles to a value of 0.165 (W/m·K) at 30% of their content.

The results of the thermal conductivity coefficient curve correspond to the curve of Figure 10b, which shows a density change in terms of the percentage of organic filler, where there is a slight change in density values from 0.747 g/cm^3 at 0%, to a value of 0.815 g/cm^3 at 30% of organic filler content of random wood particles.

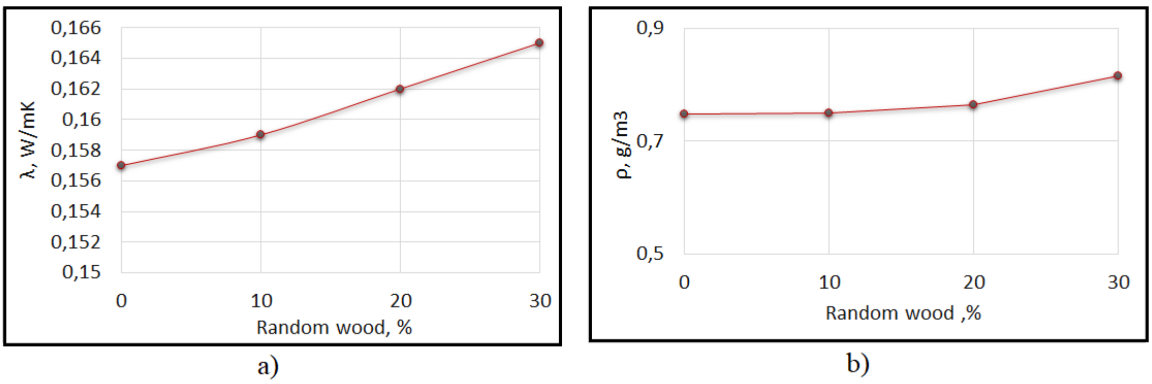


Figure 10. Change in: a. values of the thermal conductivity coefficient, b. density for mixtures obtained from RLDPE, having different proportions of random wood particles

4. Conclusions

The addition of EPS to the unsaturated polyester mixtures causes a decrease in the EPS thermal conductivity coefficient with a positive and slight decrease in density, which gives wide opportunities for the use of expandable polystyrene waste as an additive for UPR and expands the horizons of its potential industrial application, especially since this waste reduces the economic cost of UPR material when used as the main part of the mixture.

The styrene addition to the compositions, containing 10% of styropor, causes a clear decrease in thermal conductivity and a slight decrease in the density of these mixtures, which confirms the possibility of using these compositions in thermal insulation.

The values of the thermal conductivity coefficient and the density of the low-density polyethylene material increase with an increase in the percentage of wood powder used as an organic filler, and the analysis of the results obtained by these indicators indicates the possibility of using the obtained compounds as thermal insulation materials.

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Manuscript received: 15.12.2022