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EXPERIMENTAL STUDY ON PERLITE MORTARS

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ABSTRACT:

The present paper presents some of the results of the experimental research carried out by the authors in order to obtain construction materials, mortars in particular, which are more environmentally friendly, less polluting, while aiming to obtain new materials that also help to increase the energy efficiency of buildings. The study includes the realization and testing of several mortar samples with different compositions in order to reduce the consumption of cement, a polluting material by its way of obtaining but a main component of mortars. The mortar samples had cement and perlite in different dosages and some of them also had lime in different quantities. They have been mechanically tested, determining bending tensile strengths and compressive strengths. At the same time, there are some physical characteristics for the mortars obtained, namely the density of the samples and their mass loss over time. The interpretation of the results obtained helps us to obtain useful information regarding the composition of mortars with the addition of perlite, an ecological material, difficult to degrade, with special physical properties and the possibilities of their use in constructions in order to increase the energy efficiency of buildings, reduce energy consumption and in identifying new efficient and sustainable solutions for constructions and for the built environment.

1. INTRODUCTION

1.1 Overview

Currently, in Romania, in Europe and around the world, the topic of sustainability in construction is a very important, challenging topic, leading to the need to use new, ecological materials and as many natural resources as possible. In the field of construction, a number of new innovative materials used in mortars and concrete have emerged, of which expanded and granular perlite are increasingly common due to their special properties. Perlite used in the production of heat-insulating, soundproofing and vapor-permeable mortars and concretes is a granular, natural and environmentally friendly, non-toxic, impurity-free product, which does not rot, does not pollute the soil and does not degrade over time by the action of atmospheric factors, being promoted for its qualities in increasing the thermal resistance of construction elements, fire resistance, in increasing the energy efficiency of buildings and in protecting the environment and ensuring human health (Fekete-Nagy, 2023). In recent years, worldwide, a series of researches have focused on finding new viable, economical, sustainable solutions for mortars, which has led to the use of new materials such as polystyrene balls, plastic fibbers and carbon fibbers, which, as shown in the study in paper (Dragoi-Anghel, 2024) have brought substantial improvements in some mechanical characteristics of mortars and provided various important information for improving mortar samples in future.

Some scientific papers show that light aggregates are frequently incorporated into mortars and plasters to control density and workability, thus, in their article (Lanzon, 2008), authors Marcos Lanzon and P.A. Garcıa-Ruiz showed that the expanded perlite used in the making of plaster mortars leads to higher than normal water/cement (w/c) ratios, analysing the effect that perlite has on state parameters considered of great importance, such as water mixing, density, consistency, workability and water retention, and on the values of mechanical strengths. The influence that the amount of perlite in cement and perlite mortars has on the density and certain mechanical characteristics of mortars is analysed by Ch. Panagiotopoulou together with a team of researchers from the National Technical University of Athens and presented in the paper (Panagiotopoulou, 2022). At the same time, perlite, being a porous material, makes perlite mortars have a lower specific gravity, which gives them the property of thermal and sound insulation (Sun, 2013). On the other hand, the authors Kandukuri Sai, Kunta Srikanth and K. Chaitra, in their paper (Kandukuri Sai, 2025) study the effects of natural perlite aggregate and perlite powder on the properties of lightweight concrete, including thermal conductivity, workability, compressive strength, density and durability, concluding that an optimal balance of perlite aggregate can make this type of concrete useful in non-load-bearing elements and thermal insulation layers. If the vast majority of researchers have focused in scientific articles on the qualities offered to mortars by the addition of perlite, the authors Al-Theiabat Abed and Lublóy Éva, in their paper (Al-Theiabat, 2025) present some possible shortcomings, examining the incorporation of expanded perlite in cementitious composites, focusing both on their impact on thermal insulation, fire resistance, durability and mechanical strengths as well as on the challenges related to increased porosity and strength. low mechanics in case of incorporating higher ratios of perlite in these composites, which should be taken into account in future research. Another important aspect of the recent research is focused on the possibilities of reducing the thermal conductivity of building materials by optimizing the use of various quantities of light aggregates, binders and additives and on the impact, this has on the environment, as presented in their work (Fenoglio, 2018) by the authors Elisa Fenoglio, Stefano Fantucci and others. Noting that in the studies of the last decade there has been an increase in the researchers' concern to use light, inorganic materials in the production of construction materials, respectively the use of perlite in the production of mortars and concrete, the authors, in the present paper, present the study carried out on new types of mortars designed with the idea of having materials that improve the energy efficiency of constructions and not have a negative effect on the their durability, through the corresponding mechanical resistances. For the analysis, a series of mortar samples based on cement, granular perlite and lime were made, having different compositions, which were experimentally tried to determine and analyse their physical and mechanical characteristics. Various compositions were used in the mortar samples, with different percentages of cement, granular perlite, water and lime, studying how they and the mixing time for homogenization of the mixtures of the compositions influence the density of the samples, the water absorption and some of their mechanical strengths. The concern for the use of perlite, along with other light materials such as rice straw and the partial replacement of cement with lime for the production of special mortars, with mechanical resistance that allows the production of special plaster panels, is present in the bibliographic works (Sun, 2013), (Palomar, 2018), (Rodrigues, 2023).

2. EXPERIMENTAL STUDY

2.1. Conducting experimental tests

In the experimental study, 16 types of mortars were made with different compositions, having different amounts of granulated perlite, cement and lime, the compositions being presented in table 1.

Proof/ Composition	Perlite (g/%)	Cement (g/%)	Var (g/%)	Solid mass (g)	Additive (g)
P1	90/31	200/69	-	290	2
P2	90/31	200/69	-	290	1
P3	90/31	200/69	-	290	1
P4	90/47	100/53	-	190	1
P5	90/21	300/68	50/11	440	1.5
P6	155/28	300/54	100/18	555	1.5
P7	155/34	250/55	50/11	455	1.25
P8	155/31	250/50	100/19	505	1.25
P9	155/31	172.5/34.5	172.5/34.5	500	1
P10	250/43	172.5/41	86.2/17	508.7	1
P11	155/47	172.5/53	172.5/34	505	1
P12	155/27	337.5/58	86.2/15	578.7	1
P13	155/27	337.5/58	86.2/15	578.7	2
P14	155/31	337.5/69	-	492.5	2
P15	155/47	172.5/53	-	327.5	2
P16	155/31	172.5/34.5	172.5/34.5	500	2

Table 1. Composition of the mortar samples made

In order to carry out the 16 analysed mortar samples in the laboratory, several stages were completed. For each of the samples performed, the quantities of each of the component materials were weighed, dry materials being mixed manually in a metal bowl (Figure 2).

Figure 2. Manual mixing of dry components

Then the amount of water and superplasticizer was added, then the components were mixed with the mechanical mixer (Figure 3) to ensure a uniform consistency.

Figure 3. The mechanical mixer used for mixing the mixture

From the homogeneous mixture obtained by mixing the components with the mechanical mixer, specimens were poured into the metal pattern of each composition, respectively each mortar sample, as in Figure 4.

Figure 4. Casting compositions in metal mold

From each type of composition, 2 or 3 sinks were obtained, depending on the amount of material resulting after mixing the components, and then they were noted so that some of the 16 types of samples can be identified later, as shown, in Figure 5.

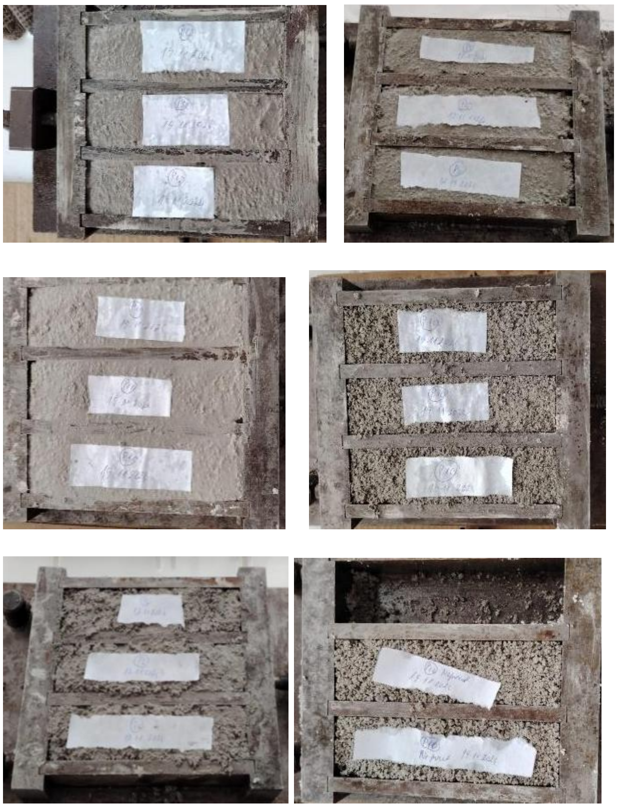

Figure 5. Specimens from P12, P5, P11, P10 and P6 lime samples in metal patterns

After casting the sample specimens into patterns, they were stored in the laboratory, then stripped and experimentally tested at different time intervals. Figure 6 shows two of the specimens from the P10 strip sample, which has in its solid composition a quantity of 47% pearlite and a quantity of 17% lime.

Figure 6. Stripping of specimens from sample P10

The 16 mortar samples made with different compositions were divided into two types of mortars, the first type having cement, perlite, water and additives and the second type of mortars having, in addition to cement, perlite, water and additives, different amounts of lime. From the first type of cement and perlite-based mortars, the samples P1, P2, P3, P4, P14 and P15 were made and from the second type of mortars, the cement-based, perlite and lime-based mortars, 10 samples were performed, respectively the samples marked with P5, P6, P7, P8, P9, P10, P11, P12, P13 and P16. Through their different compositions, presented in Table 1, we aimed to find new recipes for making mortars that have pearlite in their composition, this material and that are used in constructions, in order to increase their energy efficiency and durability. As can be seen from Table 1, the mortar recipes made for this study started from a percentage of perlite of 31% of the solid mass of the composition and increased to 47% of the total mass of the solid components of the compositions and as regards the mortar samples that have in their composition, in addition to perlite and lime, in variable quantities, like the dry component, the percentages of lime varied between 11% and 34.5%, the percentages of perlite for these mortars varying between 21% and 47%.

2.2. Experimental determinations

2.2.1 Apparent density: Each specimen of the mortar samples made was weighed on the date of formwork, then on each of the first days after stripping and on the day of the experimental research, in order to be able to analyse the mass loss of the samples and to study the influence that the percentage of perlite in the compositions has on the mass loss over time. Within the experimental determinations, the apparent densities for each sample P(i) were calculated, denoted, as the arithmetic average of the apparent densities of the (k) sinks made of the same composition (i), ρP_itwo or three, depending on the amount of composition made. The apparent density $\rho P_{i,k}$ of each test tube (k) was determined by the formula

$$\rho P_{i.k} = \frac{m_{Pi,k}}{V_{Pi,k}} = \frac{m_{Pi,k}}{0.000256}[\frac{kg}{m^3}]$$

where

$m_{Pi,k}$ – the weight of specimen k from sample Pi, in kg

$V_{Pi,k}$ – the apparent volume of the specimen k from the sample Pi, in m3

Since the dimensions of the specimens are the same, 40mmx40mmx160mm, the value of the volume of the specimens is (kg/m0.000256^3) for each of them. The determined values of the apparent densities for the 16 mortar samples are shown in Table 7.

Try	Bulk density (kg/m^3)	Try	Bulk density (kg/m^3)
P1	666	P9	696
P2	625	P10	449
P3	688	P11	641
P4	447	P12	752
P5	916	P13	890
P6	908	P14	770
P7	739	P15	474
P8	895	P16	715

Table 7. Values for apparent densities of mortar samples

With the values of the apparent densities of the mortar samples made (Table 7) the graph in Figure 8 was drawn up. Analysing the values obtained for the mortar samples that have only cement and perlite, respectively P1, P2, P3, P4, P14 and P15, it is observed that the densities of the first 3 mortar samples and of the P14 sample, which have the same percentage of perlite in the composition (31%) are substantially equal, varying around the values of 660 kg/m3 and even over 700 kg/m3. The differences were caused by the different amount of additive used and the different mixing time with the mechanical mixer, respectively by the degree of homogeneity obtained. On the other hand, the samples that have a higher percentage of perlite (47%), respectively the P4 and P15 samples, have much lower apparent densities, respectively 447 kg/m3 and 474 kg/m3. Analysing the value of the apparent densities of the mortar samples that also have lime in the component, respectively the samples P5, P6, P7, P8, P9, P10, P11, P12, P13 and P16, it can be seen that in the samples P5 and P7, which have the same percentage amount of lime in the component, of 11%, but the percentage of perlite increases from 21%, the sample P5, at 34%, sample P7, the apparent density of samples decreases slightly, from 913 kg/m3 to 739 kg/m3.

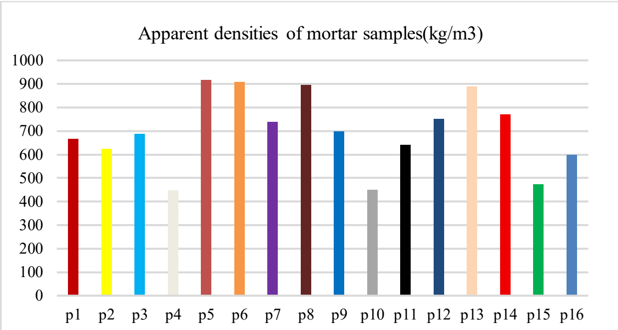

Figure 8. Apparent densities of mortar samples (kg/m3)

On the other hand, comparing the densities for the P6 and P10 samples, which have approximately the same percentage of lime (17%-18%) but the amount of perlite increases from 28% for the P6 sample, to 43% for the P10 sample, i.e. by ~ 16%, we notice that the density decreases drastically, from 908 kg/m3 to 449 kg/m3, i.e. it halves, the material becoming much lighter, possibly good thermal insulation. Analysing the values for the densities of the P11 and P16 samples, which have approximately the same amount of lime, but in double the percentage compared to the previous case (~34%), we notice that, in these cases, increasing the percentage of perlite from 31%, sample P16, to 47%, sample P11, i.e. also by ~ 16%, the density of the mortar samples obtained decreases only slightly, from 715 kg/m3 to 641 kg/m3. As the percentage of perlite in the composition does not produce a much lighter material, possibly a good thermal insulator, as a result, it can be concluded that in the case of mortars with perlite and lime in the component, the decrease in their densities by increasing the percentage of perlite is significant and effective only if the percentage of lime is lower, as close as possible to 18%.

2.2.2 Tensile strength from bending: the study includes the experimental testing of the samples of perlite mortars made to evaluate their mechanical strengths, respectively the tensile strength from bending and the resistance to pressure. For this, the mortar samples were mechanically tested in the research press (Figure 9) of the Materials Laboratory of the CCI Department, Faculty of Constructions of the Polytechnic University of Timisoara and the tests were carried out at 2 days, 7 days, 28 days and 90 days after casting, on prismatic specimens. following the evolution of the strengths over time for the mortar samples made and then analysing the effect that the modification of the quantities of the component materials, in differences of the percentage amount of perlite, has on the mechanical characteristics of the mortars thus obtained. The experimental test of the mortar samples at bending was carried out on prismatic specimens, samples from all 16 samples of perlite mortars made. They were subjected to bending between the arms of the test press, having two supports at the bottom and the concentrated force being applied centrally, at the top of the sample, as can be seen in Figure 10.

Figure 9. Press for mechanical research

Figure 10. Mortar Sample in Press - Bending Tension Testing

During the tests, the value of the concentrated force increased until, when the specimen failed, the value of the breaking force for each of the mortar samples was recorded. The tensile strength from bending was determined with the following formula:

$$f_t = \frac{3}{2}\frac{P \times l}{h^3} \left[\frac{N}{mm^2}\right]$$

where: P is the bending breaking force (N), l is the distance between the supports (mm) and h is the height of the specimen cross-section (mm).

The graph in Figure 11 shows the values obtained for the bending tensile strengths 7 days after casting, for all 16 samples of perlite mortars made. It can be seen that the highest values of these tensile strengths from bending were obtained for the P3 sample, among the samples containing no lime and the P12 sample, among those containing lime and that these two probes have very close densities, positioned around 650 kg/m3.

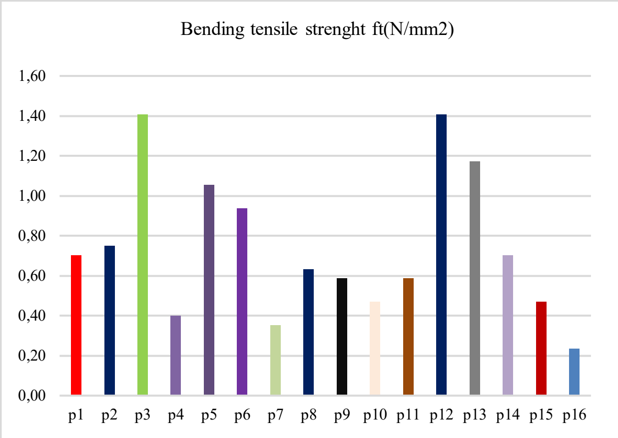

Figure 11. Bending tensile strengths ft (N/mm2)

As for the lowest values of tensile strengths from bending, they were obtained for the P4, P7 and P16 samples, samples that have an increased percentage of perlite.

2.2.3 Compressive strength: To determine the compressive strengths of the mortar samples, some of the prisms resulting from the bending testing of the samples were used. They were fixed between some support plates in the press arms (Figure 12) and were subjected to a compressive force that progressively increased, until they broke.

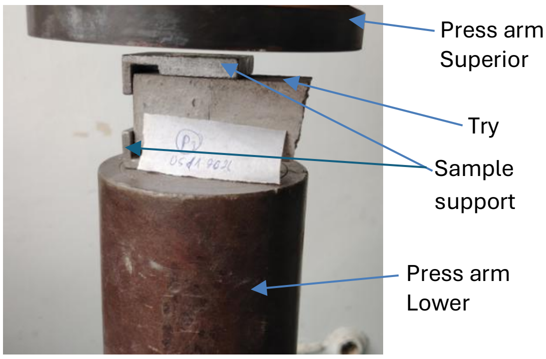

Figure 12. Mortar sample in the press – compression testing

The compressive strengths were determined with the formula:

$$f_c = \frac{F_{max}}{A} \left[\frac{N}{mm^2}\right]$$

where F max represents the maximum compressive force (N) and the breaking force, respectively, and A is the area of the loading surface (mm^2). The values obtained for the compressive strengths at 7 days of the studied mortar samples are represented in the graph in Figure 13.

Analysing the values contained in the graph in Figure 10, it can be seen that the compressive strengths at 7 days of the mortar samples with various percentages of perlite and lime vary greatly. The highest values, for the samples containing no lime, were obtained for the samples P3 (4.5 N/mm2) and P14 (3.3N/mm2) which have a maximum percentage of 31% pearlite and for those containing lime, were the samples P13 (5.0 N/mm2) and P12 (4.3 N/mm2), which had less than 30% perlite, respectively 27% and lime in a proportion of 15%. The lowest compressive strengths are found in the P10 lime sample (1.1 N/mm2), which has a high percentage of perlite (43%) and lime (17%) and in the non-lime sample, P15 (0.8 N/mm^2), which has a high percentage of perlite (47%).

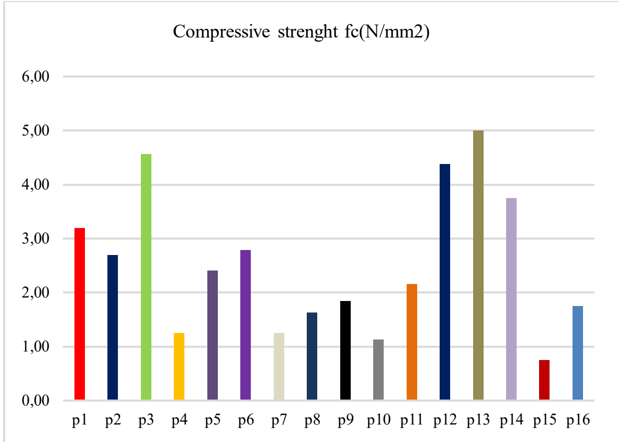

Figure 13. Compressive strengths fc (N/mm2)

The mortar samples were tested at 2 days, 28 days and 90 days, each time determining the tensile strengths from bending and compressive strengths in order to study the variation of the mechanical strengths during the 90-day interval after casting.

2.2.4 Loss of mass over time: Another physical characteristic that was taken into account in this study was the loss of mass over time of mortar samples with different compositions. For this, the mass of the samples was determined by weighing from the day after casting until the moment when the samples were tested in the press to determine the mechanical strengths. The variation of the masses of the samples without summer in the composition led to the graphs in Figure 14 for the samples P1, P2, P3 and P4, analysed over a period of 28 days.

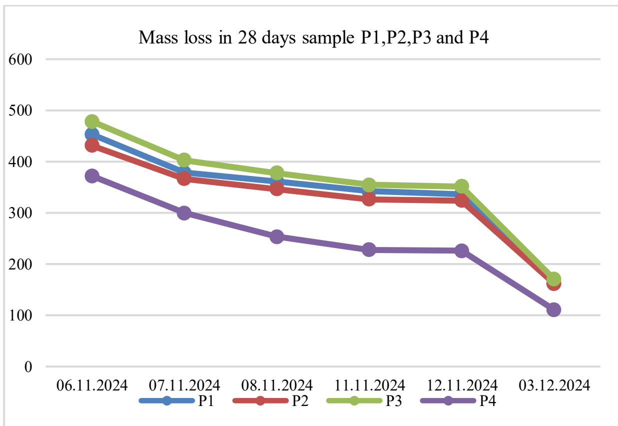

Figure 14. Mass loss in 28 days for samples P1, P2, P3 and P4

In Figure 15, the graphs represent the mass loss during 90 days after casting, of samples P14 and P15, samples that do not have a lime component. Sample P14 has 31% perlite composition and sample P15 has 47% perlite. From these graphs it can be seen that the mass loss in the first 7 days after casting is much more pronounced in the P15 sample, which has a higher perlite content, is more porous and has a lower density than the P14 sample. After 7 days after casting, the mass loss is slightly more pronounced for the P14 sample and after 28 days after casting, the decrease in weight of the samples is very small, remaining almost the same value until the end of the 90 days.

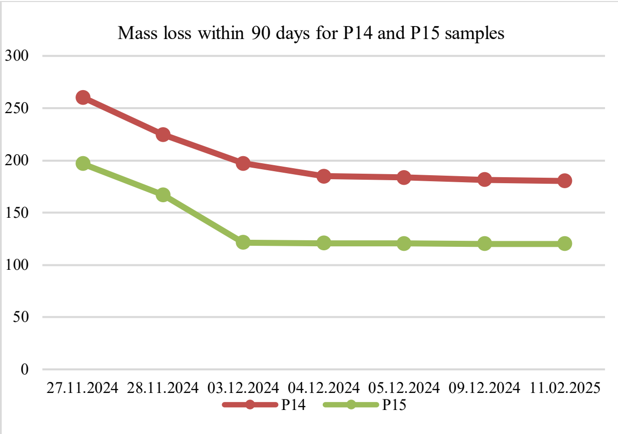

Figure 15. Mass loss within 90 days for P14 and P15 samples

Figure 16 shows the graphs for the mass loss during 90 days after pouring of the mortar samples containing lime in the composition, in addition to perlite and cement, in different quantities, respectively samples P9, P10, P11 and P12.

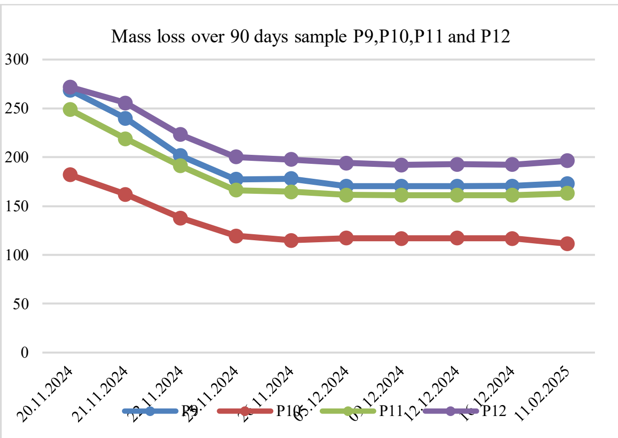

Figure 16. Mass loss over 90 days for samples P9, P10, P11 and P12

Figure 17 shows the graphs with mass loss over 90 days for samples containing both perlite and lime, in different quantities, respectively samples P13 and P16. An observation deduced from the study of the graphs presented above is that after 28 days after casting, the mass loss is greatly reduced, the weight of the samples reaching 90 days after casting at values very close to those at 28 days, it seems that the mass loss stabilizes after this period of 28 days after casting.

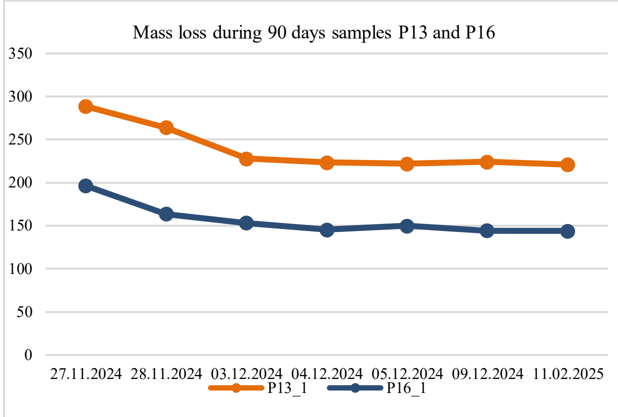

Figure 17. Mass loss during 90 days for samples P13 and P16

Observing the graphs in the figures above, it can be appreciated that the mass loss of the mortar samples over time is more drastic in the first 7 days after pouring for the samples that have an increased percentage of perlite, one of the causes being their higher porosity. Figure 18 shows the cross-sections of some of the samples with different percentages of perlite in the composition. These were obtained as a result of experimental bend stretching research when specimens were tested to break. For the samples that have a higher amount of perlite in the component, an increased porosity is observed, larger pores, while in the samples that have a lower percentage of perlite in the compositions, the number and volume of pores is decreased, as can be seen in the photos presented in Figure 18 and Figure 19.

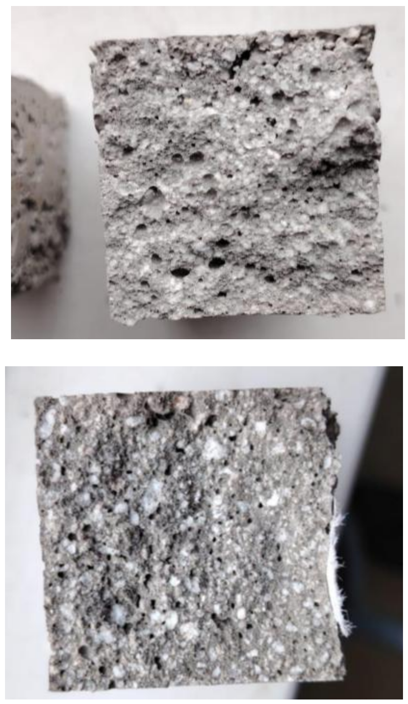

Figure 18. Porosity of different mortar samples

Figure 19. Porosity of different mortar samples

3. INTERPRETATION OF THE RESULTS

Following the results obtained after determining the physical and mechanical characteristics of the samples of mortars with variable perlite content tested, some observations were discovered regarding how the variation of the quantities of perlite and the amounts of lime in the compositions can influence the physical and mechanical characteristics of these mortars. Thus, analysing the graph in Figure 8 with the apparent densities determined for all the mortar samples made, it is observed that the densities of the samples that have only perlite and cement as solid components decrease with the increase of the percentage of perlite in the mixture. Thus, for samples P1, P2, P3 and P14, which have the same percentage of perlite in their composition (31%), the values of the apparent densities are substantially equal, varying around 700 kg/m3 while the densities of the samples that have a higher percentage of perlite (47%), respectively the P4 and P15 samples, have much reduced apparent densities, respectively 447 kg/m3 and 474 kg/m3, making the mortars obtained, possible materials that can be utilized when thermal insulation of constructions. Regarding the densities of the mortar samples that have lime in addition to perlite, it is observed that the samples with the highest densities, around 900 kg/m3 are those that have the percentage of perlite around 21%-28% and the percentage of lime of 11%-18%.

Regarding the mass loss of the samples over time, studying the values of the graphs in Figures 11, 12, 13 and 14, it can be concluded that the mass loss in the first 7 days after casting is higher for the P4 and P15 samples, samples with a higher percentage of perlite, compared to those with a lower percentage, the cause being the higher porosity of the samples that have a higher amount of perlite in their component.

As for the mechanical strengths obtained from the testing of the downspouts made from the 16 samples with different mortar compositions, it can be seen that both the tensile strengths from bending and the compressive strengths have the highest values for the P3 sample, among the samples without lime in the component, this having 31% perlite and from the samples of mortar with perlite and lime, the P12 and P13 samples have the highest tensile and compressive strengths, the composition of these samples being 27% perlite and 15% lime. As for the lowest mechanical resistances, they were recorded in the samples with a high percentage of perlite. The P4 and P15 samples, without lime in the component, which have the highest percentage of perlite (47%) also have the lowest mechanical strengths and for the samples that have lime in their composition, the samples that have the lowest mechanical strengths are the P7 and P10 samples, samples that also have the increased amount of perlite, respectively 34% and 43%, leading to the idea that the addition of perlite in these mortars should not exceed 31%, in order to have both satisfactory mechanical characteristics and physical properties, respectively the density, very close to that of thermal insulation materials.

4. CONCLUSION

The study included the realization and experimental testing of 16 samples of perlite mortars, having different compositions and analysis of the results obtained. The compositions made for the studied mortars had perlite and some of them also had lime in different proportions, in order to be able to analyse the effect that the percentage of perlite and its variation have on the specified mechanical characteristics and physical characteristics, such as density and mass loss over time of the mortar samples. The tensile strength of the bending and the compressive strengths for each of them resulted from testing at different time intervals after casting, respectively at 2 days, 7 days, 28 days and 90 days. From the results obtained from this study, the idea emerges that for the realization of new mortars that have perlite in their component, a percentage of 47% perlite from the solid components of mortars would lead to a decrease in their densities up to around 450-470 kg/m3, but at the same time it would also lead to a decrease in mechanical strengths. In conclusion, as a result of this study we can appreciate that in order to have perlite mortars that keep their physical characteristics within the limit of thermal insulating materials, light materials, with low densities but which also have satisfactory mechanical resistance, it is necessary to decrease the percentage of perlite to the area of no more than 31% and if we have lime in the mortars, its percentage should be somewhere around 15%. As proposals for future research, we started from the studies presented in the paper (A. Aprianti, 2017), where the successful usage as partial or whole replacement of Portland cement, with waste materials as supplementary cementitious material contributes to solve landfill problem, reduction in the cost of building materials, gives a satisfactory solution to the environmental issues and problems associated with waste management, save energy, and helps environmental protection from pollution. Therefore in our following studies, the authors want to improve the compositions of perlite mortars through various experimental tests, new determinations and at the same time the study of new types of mortars or other compositions that have, in addition to perlite, other light, ecological, environmentally friendly materials, aiming at the possibility of using them in the construction industry as materials for finishes, for increasing the thermal and energy efficiency of constructions and for the realization of sustainable and economically efficient constructions.

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