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The influence of perlite on concrete properties. Case study

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Abstract **– There is a global concern for reducing energy consumption and protecting the environment. The use of products with high thermal resistance, to make the envelope of a building, favours the reduction of energy consumption for heating/cooling of building and, implicitly, the reduction of CO_2 emissions. The replacement, total or partial, of the basic components of the concrete compositions, can lead to the obtaining of innovative products with modified physical-mechanical properties, which meet the energy efficiency requirements of buildings. The study examines the effect of replacing the volume of sand in percentages of 10%, 20%, 30% and 100% with an equivalent volume of perlite, and the results have underlined that these compositions reduced density and thermal conductivity, compared to the reference concrete. The research carried out has emphasized that perlite can be successfully introduced in the production of concrete blocks used for non-load-bearing external wall panels, the outstanding feature being the reduced their thermal conductivity and weight. The paper identifies solutions for the use of perlite in the prefabricated construction industry.**

Keywords – concrete blocks, perlite, prefabricated construction industry, sustainability.

1. INTRODUCTION

The prefab industry has many opportunities to develop products that can help achieve zero energy goals in buildings, while reducing carbon dioxide emissions. These two targets are today much desired worldwide, in order to minimize, in the current climatic conditions, the influences of the global warming phenomenon and to ensure the environmental

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protection requirements. The construction industry is known to be a major environmental polluter, not only through the industrial processes that support the creation of the built environment, but also through the large amount of waste produced during building construction or demolition. Most of the objectives of sustainability and circular economy concepts are directed to the construction industry. Therefore, research in the field is currently mainly focused on the development of local green energy production, to improve the buildings' energy efficiency, and on the processing of waste into secondary products, which can re-enter production cycles. As mentioned in the study [1], where crushed rubber waste was analysed as a replacement material for concrete aggregates, it is necessary to implement new technologies and use secondary products as raw material, in the conditions that the quality requirements are not affected, and some parameters even improved.

Concrete is a material widely used in the construction industry, the raw materials in its compositions being natural aggregates, cement, water and additives. Aggregates represent approximately 60-75% by volume of the concrete mix, the rest being cement and water. Therefore, various raw materials, processed or not from waste, have been explored as alternatives, following the trend of global initiatives, [2, 3]. The concept of circular economy, which has as its central objective the efficient and economical use of resources, has gained importance nowadays, [4].

Perlite, an amorphous alumino-siliceous volcanic material, derived from raw perlite rock, is commonly used in construction, [5-7], being a material that brings a positive and significant contribution to the thermal performance of the construction element in which is used. Global production of perlite is increasing, driven by growing demand. As such, manufacturers of materials in the perlite industry must find solutions to collect perlite waste and create an economically viable system that encourages the use of this waste. Expanded perlite stands out as a favourable option, due to its low-density characteristic, to produce lightweight concrete, [8]. Numerous research papers have consistently shown that the incorporation of expanded perlite, as an aggregate in concrete, leads to significant reduction in some concrete characteristics, such as density and thermal conductivity, [9-12].

These findings underline the justification for the use of expanded perlite in lightweight concrete precast element applications, [13-16]. The replacement of natural aggregate with expanded perlite in concrete compositions reduces their thermal conductivity due to the porous structure of perlite, [17-31]. According to Oktay et al., [32], incorporating 10%, 20%, 30%, 40% and 50% by volumes, of 0.15–11 mm perlite particles, as a replacement for natural sand, led to reductions of thermal conductivity of 22.96%, 38.01%, 64.23%, 74.36%, and respectively 81.48%, for the elements made from the modified concrete compositions.

Research on concrete with perlite has shown that replacing natural sand with expanded perlite significantly reduces the density of the mixture, with some studies reporting reductions of up to 65.46%, [21]. According to the research carried out by Türkmen and Kantarcı, [33, 34], the partial replacement of natural sand with perlite (size 0-4 mm) in equivalent volumes up to 15%, reduces the weight of the concrete mix by 11.36%. The low density of concrete with perlite can bring advantages for buildings' design and execution, resulting from the reduction of the dead load given by the overall weight of the building on the supporting ground. At the same time, it can also lead to disadvantages regarding some mechanical strength properties, [17-31], such as compressive resistance.

Compressive strength is an essential characteristic of concrete when used as construction material. Studies, identified in the specialized literature, mention that the partial replacement of natural sand with perlite can lead to a significant decrease in the compressive strength of the resulting concrete mixture, [35, 36]. For example, the study [32], highlights that the replacement of natural aggregate with perlite (size 0.15-11 mm) in percentages of 10%, 20%, 30%, 40% and 50%, by volumes, caused a reduction in compressive strength of 39.8%, 63.33%, 80.69%, 84.29%, and 90.58%, respectively.

In the light of the above information, the objective of this paper is to examine the behaviour of concrete with perlite, highlighting the impact of the use of perlite on the properties, in order to identify construction products with characteristics that innovatively combine the results obtained in the research carried out. The research presented in the paper aims to identify the reference parameters of these concrete compositions for use as prefabricated blocks in the execution of masonry walls.

For the detailed analysis of concrete with perlite, an experimental program was implemented to study its general behaviour, including density, compressive strength and thermal conductivity.

2. EXPERIMENT DESCRIPTION

In this study, the perlite granules, (Fig. 1), used in the concrete mixture, had sizes of 0.5-4 mm and were not subjected to any form of treatment. Considering the perlite granules sizes, the sand was replaced with perlite in the modified concrete compositions. The amount of perlite that has replaced the sand, partially or totally, can be a newly manufactured product, or it can be the result of processing waste from the construction site, which can be reused.

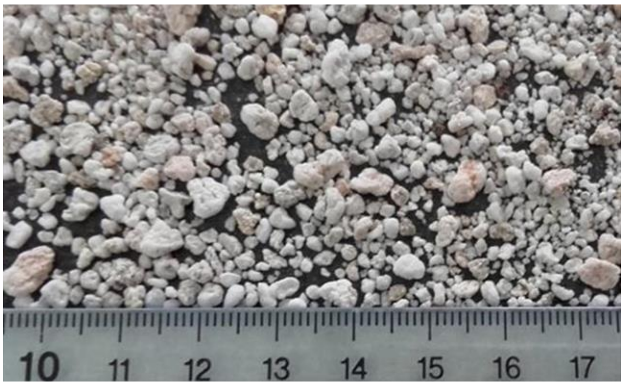

Fig. 1 Perlite granules

The composition of the control concrete was designed to meet the characteristics determined for strength class C 20/25, exposure class XC3-XA1 and consistency class S3. The water/cement ratio (W/C) was 0.545 for control concrete composition, and it was the same for all compositions of concrete with perlite, with an exception, for case S4—0S_100P, when the concrete workability requested to increasing it.

Four distinct compositions of concrete with perlite were made, in which parts, in percentages of 10%, 20%, 30% and 100% of the sand volume, were replaced with equivalent volumes of perlite granules. The volumes of cement and of the aggregates were kept to the same proportions.

The constituent materials used in the compositions of control concrete and concrete with perlite, in volumetric parts are shown in Table 1.

Table 1 Component materials in volumes for 1 m^3 of control concrete and of concrete with perlite

Case study	Water	Cement (CEM I 42.5R)	Sand 0-4 mm	Aggregate 4-16 mm	Perlite	Total volume
	Volume (m^3)					
C- control concrete, [1]	0.1244	0.1735	0.3219	0.3802	-	1
S1—90S_10P	0.1244	0.1735	0.2897	0.3802	0.0322	1
S2—80S_20P	0.1244	0.1735	0.2575	0.3802	0.0644	1
S3—70S_30P	0.1244	0.1735	0.2253	0.3802	0.0966	1
S4—0S_100P	0.1244	0.1735	-	0.3802	0.3219	1

Cubic samples were prepared for each composition to evaluate the compressive strength and thermal conductivity properties of the concrete compositions. According to standardized methodologies, these samples, measured 150 mm on each edge.

After 28 days, the densities were determined and the samples were subjected to laboratory tests. The cubic specimens were tested for compressive strength using ZwickRoell SP1000 hydraulic equipment, according to the requirements of the SR EN 12390:2019 standard, [38]. The compressive force was applied to the samples with a loading rate of 0.2 MPa/s, [1].

For measuring thermal conductivity, the device ISOMET 2114 was used, based on the regulation stipulated by standard ASTM – 5334-08. According to [37], ISOMET 2114 is a portable instrument for direct measurement of heat transfer properties of various materials, including insulating materials, plastics, glass and minerals. This device has a surface sensor designed for hard materials and uses a dynamic investigation method to rapidly measure the thermo-mechanical characteristics of samples, [1]. The dynamic method involves measuring the heat flow resulting when temperature changes occur in the sample.

3. RESULTS AND DISCUSSION

3.1. Density

After the samples were fully cured, their weight and volume were measured to calculate their density. The results were calculated for the five mixture compositions and are presented in Table 2.

Analysing the results, the perlite concrete samples have a lower density than the control samples (C-control concrete) and emphasizing a reduction of 4.46% in the case of S1—90S_10P, 5.89% in the case of S2—80S_20P, 7.83% in the case of S3—70S_30P and 15.56% in the case of S4—0S_100P.

Table 2 shows that the majority of measured densities are lower than designed values. An exception is the composition S4—0S_100P where the measured value has increased by 17.93% compared to designed value. This is due to the fact that the perlite granules were broken during mixing, so that, the composition became denser, with fewer closed air pores in perlite, and, implicitly, having a higher density. Also, during the execution of the S4—0S_100P, the perlite absorbed the mixture water, so that, in order to ensure a minimum mixture workability, it was necessary to add additional water. These observations are confirmed by the decreasing in density, of only 15.56% for samples S4—0S_100P, compared to measured control concrete density, while the expected reduction was designed to be of 30.75%.

Table 2 The density of the case study compositions

Nr. crt.	Case study	Density Designed values ρ_d (kg/m^3)	Density Measured average values ρ_m (kg/m^3)	Ratios ρ_m / ρ_d (%)	Decreasing $(\rho_{mC} - \rho_{mSi}) / \rho_{mC}$ (%)
1	**C- control concrete [1]**	2374	2295.92	96.67	-
2	**S1—90S_10P**	2301	2193.53	95.33	4.46
3	**S2—80S_20P**	2228	2160.57	96.97	5.89
4	**S3—70S_30P**	2155	2116.05	98.19	7.83
5	**S4—0S_100P**	1644	1938.78	117.93	15.56

3.2. Compressive strengths

The samples underwent uniaxial compression using a hydraulic testing machine to evaluate the compressive strength of the five different concrete mixture compositions (see Fig. 2). The compressive strengths of the samples were then calculated based on the testing results.

Fig. 2 The tests of compressive strength

Table 3 The compressive strength of case study compositions

Nr. crt.	Case study	Compressive strength, (R_c) (MPa)	Decreasing of R_c (%)
1	**C- control concrete [1]**	25.98	-
2	**S1—10% perlite**	24.23	6.74
3	**S2—20% perlite**	23.80	8.40
4	**S3—30% perlite**	22.44	13.63
5	**S4—100 % perlite**	18.55	28.60

The results are presented in Table 3. The outcomes of the compressive strength tests for the concrete mixture with perlite replacements were consistent with previous research on the topic. As the proportion of perlite increases, there is a decline in the compressive strength of the concrete mixture. This reduction in compressive strength was expected, as previous studies have also reported a similar trend.

3.3. Thermal conductivity

The samples were subjected to thermal conductivity testing, using the ISOMET 2114, (Fig. 3). Results are shown in Table 4.

a) **b)**

Fig. 3 Measure the thermal conductivity: (a) the display of ISOMET 2114; (b) the measuring device for hard surface

Table 4 The thermal conductivity of the perlite concrete mixtures

	Thermal conductivity, (λ) (W/mK)		
Nr. crt.	**Case study**	**Heat flow direction versus casting direction**	
		Parallel	**Perpendicular**
1	**C- control concrete, [1]**	2.55	2.16
2	**S1—90S_10P**	2.52	2.20
3	**S2—80S_20P**	2.44	2.14
4	**S3—70S_30P**	2.41	2.12
5	**S4—0S_100P**	1.36	1.42

The results from Table 4 highlight that the thermal conductivity values for the heat flows parallel to the casting direction have magnitudes almost equal to the values of the thermal conductivity for the heat flows perpendicular to the casting direction, with a difference of about 1-4%. In cases where the sand was replaced with perlite in volumetric ratios of 10-30%, the differences for the thermal conductivity compared to the control sample are insignificant. Thermal conductivity decreases of almost 40-45% are observed only when the total replacement of sand with perlite is done (samples S4—0S_100P).

4. CONCLUSIONS

The present study is part of a larger experimental investigation of incorporating two environmentally friendly materials, perlite and crumb rubber, into cement-based products to enhance their thermal insulation properties and reduce concrete environmental impact.

Based on the results presented in this study, the following conclusion can be drawn:

• Incorporating perlite into cement-based products shows potential for enhancing thermal insulation properties;

• The results obtained from the research show that replacing sand with perlite in proportions of 10, 20, and 30 volume ratios, lead to the improvement of thermal insulation properties, simultaneously with the reduction of mechanical resistance. The advantage obtained for the thermal performance is diminished in importance, being out-ranked by decreased mechanical resistance;

• The total replacement of sand with perlite (100%) determines an obvious improvement of the thermal insulation properties, with the undoubted disadvantage of weakening the concrete, slightly under the limit of the C16/C20 concrete resistance class, more precisely, class C12/15;

• Based on the substantial decrease in thermal conductivity and density, as well as a decrease but within adequate limits of compressive strength, it can be concluded that for prefabricated concrete blocks used in non-load-bearing walls, concrete with perlite as a 100% substitute for sand, is a solution that can be used successfully, to highly increase the insulated thermal performance of exterior walls.

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