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STUDY OF REPLACEMENT OF SAND BY EXPANDED POLYSTYRENE IN STRUCTURAL LIGHTWEIGHT CONCRETE

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The search for more efficient concrete structures requires use of new materials in the developed of new concretes. With this objective, it was proposed in this study the substitution of Part of the medium sand of the lightweight structural concrete for expanded polystyrene (PS). It was replaced 5%, 10% and 20% of the sand to observe the changes in compressive strength, flowability, absorption, density and modulus of elasticity of these concretes. The results of the study show that there was an increase in the absorption and loss in the compressive strength and modulus of elasticity. Also, there was a significant increase in the flowability and reduction in the density of these concretes. Even with the replacement of part of the medium sand by expanded polystyrene, the concretes developed were classified as lightweight structural concretes, showing the applicability of this substitution in concrete designs.

Keywords: Strength, Modulus of elasticity, Flowability, Absorption, Specific mass.

1 INTRODUCTION

According to ACI 213R-03 (ACI 2003) lightweight concrete is a cementitious material with density of less than 2,000 kg / m³. According to NBR NM 35 (ABNT 1995), to have structural use, lightweight concretes must have minimum values of compressive strength as a function of the apparent specific mass as indicated in Table 1.

Table 1. Reference values of density for lightweight structural concretes (ABNT NBR NM 35: 1995).

Strength at 28 days (MPa) – Minimum values	Density (kg/m³) – Maximum values
28	1,840
21	1,760
17	1,680

In order to reduce the density of the concrete, it is usual to use lightweight aggregates or reduce the amount of fine materials. It is also possible to use additives that allow the creation of bubbles to occupy spaces in the concrete with voids.

The present research aims to reduce the specific mass of concrete designs using the partial replacement of medium sand by expanded polystyrene (PS) and to evaluate the influences caused by this modification. The strength, modulus of elasticity, density and absorption were evaluated.

2 RESEARCH METHOD

In order to evaluate the influence of the substitution of the medium sand in the 5%, 10% and 20% portions (in volume) by expanded polystyrene, two designs of lightweight structural concretes were used as reference (T1 and T2). Then the concretes were submitted to slump, density, compressive strength, absorption and modulus of elasticity tests. The experimental procedure was carried out in the Civil Construction Materials Laboratory of Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) and in ETA - Materials Technology's Laboratory.

2.1 Materials Employed

The materials used for the concrete productions were the Portland cement CPV ARI (similar to ASTM C 150 Type I cement), crushed expanded polystyrene (PS), two types of expanded clay (2215 and 1506), two types of sand, commercially called fine sand and medium sand, available in the Porto Alegre/Brazil. Table 2 shows the values of the physical characteristics of those aggregates that were used.

Table 2. Physical characteristics of the aggregates used.

Size # (mm)	**Expand Clay 1506 Accumulated%**	**Expand Clay 2215 Accumulated%**	**Expanded Polystyrene Accumulated %**	**Medium Sand Accumulated%**	**Fine Sand Accumulated%**
25	0	0	0	0	0
19	0	39.6	0	0	0
12.5	6.5	97.5	0	0	0
9.5	76.2	99.2	0	0	0
6.3	99.3	99.2	0	0	0
4.75	99.6	99.2	0	0	0
2.36	99.6	99.2	27	0	0
1.18	99.6	99.2	88	0.05	0.1
0.6	99.6	99.2	96	62.3	0.2
0.3	99.6	99.2	98.7	92.8	2.6
0.15	99.6	99.3	99.8	99.2	89.9
Bottom	100	100	100	100	100
Dmax Charact (mm)	19	25	4.75	1.18	0.3
Fineness Module	6.73	7.34	4.09	2.55	0.928
Density (kg/dm^3)	0.83	0.88	0.0236	2.62	2.63
Weight Density (kg/dm^3)	0.47	0.46	0.0151	1.50	1.46

The concrete designs used are shown in Table 3. In total, ten specimens (cylinders, measuring 10 cm in diameter by 20 cm in height) were molded for each mixing proportion. Each design used three specimens for the 7 days compression test, thee for the 28 days compression test, three for modulus of elasticity (at 28 days) and one for absorption test (at 28 days).

Concrete was mixed in batches of 0.001 m^3, using a stationary open-top planetary revolving blade. The sequence consisted of homogenizing the course aggregate, the sand/expanded polystyrene, the cement and the water. After mixing, the concretes were tested for slump and after that the specimens were made.

Table 3. Concrete designs.

	T1	T1 5%	T1 10%	T1 20%	T2	T2 5%	T2 10%	T2 10%
Cement	1	1	1	1	1	1	1	1
Fine Sand	0.60	0.60	0.60	0.60	0.6	0.6	0.6	0.6
Medium Sand	2.40	2.28	2.16	1.92	2.4	2.28	2.16	1.92
Expand Clay 1506	0.56	0.56	0.56	0.56	1.12	1.12	1.12	1.12
Expand Clay 2215	0.24	0.24	0.24	0.24	0.48	0.45	0.48	0.48
Polystyrene	0	0.001079	0.002158	0.004316	0	0.001079	0.002158	0.004316
Water	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

3 RESULTS

3.1 Flowability

The results presented in Figure 1 show that the higher the medium sand content replaced by PS, higher the slump of the concretes, regardless of the reference concrete used. However, it should be noted that there was a greater difference in the slump of the substitutions made from the T1 concrete, this was due to the higher quantity of medium sand in the T1 concrete compared to the T2 concrete. These increases in slump occurred because the expanded polystyrene practically does not absorb water and the medium sand absorbs a good part of the free water in the concrete during the mixture due to its surface area and its absorption according to Neville (2011).

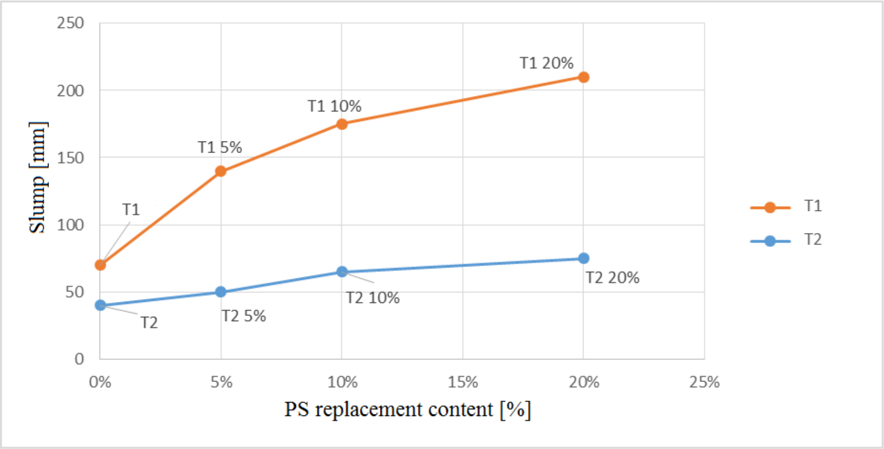

Figure 1. Slump test results.

The observed results indicate the possibility of a reduction in the water/cement ratio as the increase of the medium sand content replaced.

3.2 Density

To calculate the density of those concrete designs, the average weight was calculated using three test specimens, then those weights were divided by the specimen volume, resulting in the average density of each design, the results are presented in Table 4. According to NBR 8953 (ABNT 1992), it is possible to classify all concrete designs developed in the present study as light concretes because their densities are less than 2,000 kg / m³.

Table 4. Concrete density.

	T1	**T1 5%**	**T1 10%**	**T1 20%**	**T2**	**T2 5%**	**T2 10%**	**T2 10%**
Density (kg/m^3)	1,694.59	1,668.37	1,648.41	1,601.91	1,601.91	1,454.35	1,442.25	1,420.81

It should be noted that the reduction of density is not proportional to the substitution content of medium sand by polystyrene. In the T1 concrete, the incorporation of 5% of PS resulted in the reduction of the density in 1.54%, while substitution contents of 10% and 20% resulted in a mitigation of 2.72% and 5.47% in the density of the concretes T1 5% and T1 10%, respectively. For the concrete T2 5%, T2 10% and T2 20%, the reduction in density was 9.11%, 9.97% and 11.30%.

3.3 Strength

The results of the compressive strength test after 7 and 28 days from the mixing date of the test specimens of the concretes analyzed in this research were represented in Figure 2. The results showed that as the medium sand content replaced by expanded polystyrene increases, the strengths decrease.

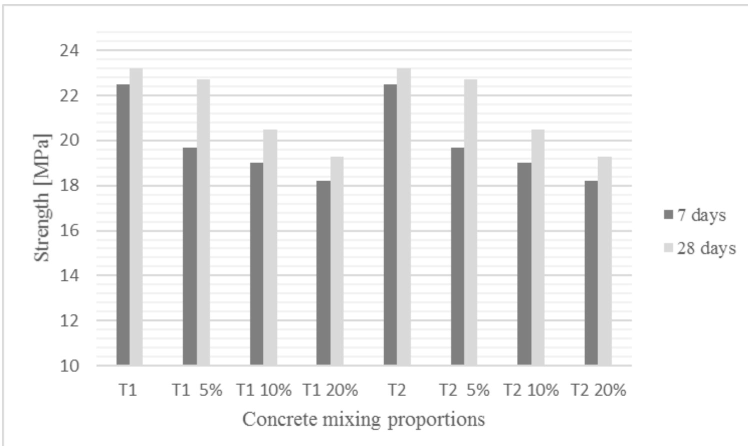

Figure 2. Strength test results.

Like the results of the slump test, there is a greater difference in the values of compressive strength in the substitutions made from the concrete T1. This happened because the increase in the amount of free water in the concrete can cause a significant loss in strength, as well as the substitution of a material with more strength (medium sand) by a lower one (expanded polystyrene) can cause a significant loss in the strength in a concrete (Neville 2011).

At 7 days, the 5%, 10% and 20% substitution content in the concrete T1 results in a reduction in strength of 12.44%, 15.56% and 19.11%, respectively, when compared to the reference concrete. At 28 days, this mitigation ranged from 2.16% to 16.81%, generating a less significant impact.

For concretes derived from mixing proportion T2 at 7 days, the incorporation of 5% decreases the compressive strength in 4.32%, while 10% and 15% decreases 4.32% and 8.11% respectively. At 28 days, concrete with the lowest substitution content presented a reduction of 1.64%, 7.69% in the intermediate and 10.77% in the greater amount of substitution when compared to the reference concrete T2.

According to NBR NM 35 (ABNT 1995), all tested concretes can be classified as structural lightweight concrete. It should be noted that the increase in the strength at 28 days compared to the strength at 7 days is small due to the use of the CP V ARI cement in the concrete mixing proportions, which is early age high strength cement.

3.4 Water Absorption

The water absorption tests of the concretes were made according to NBR 9778 (ABNT 1987), and the results are shown in Figure 3. The results show a tendency of increase in the water absorption as the expanded polystyrene replaces the medium sand. This is happening because the medium sand replacement causes an increase in the amount of free water in the concrete, which according to Neville (2011) leads to an increase in the absorption of the concrete.

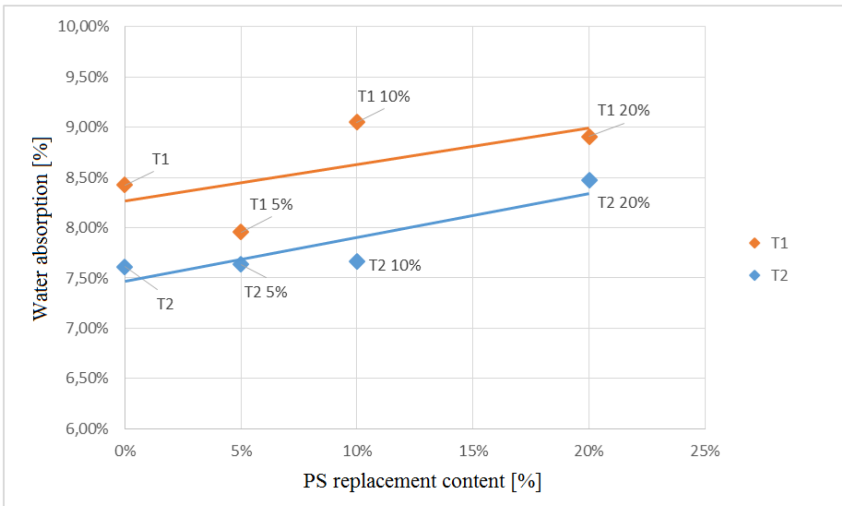

Figure 3. Water absorption test results.

3.5 Modulus of Elasticity

Modulus of elasticity tests were performed according to NBR 8522 (ABNT 2008) and the results are presented in Figure 4. The increase in the substitution of medium sand by expanded polystyrene caused a reduction of 3,8 GPa between T1 and T1 20%, while this reduction was of 2,4 GPa between the concrete T2 and the T2 20 %, those values are acceptable when compared with authors such as Angelin (2014). According to Rossignolo (2009), lightweight concrete presents lower modulus of elasticity than conventional concretes because the lightweight aggregates used in its concrete mixing proportions have relatively low deformation modulus, as more medium sand is replaced by expanded polystyrene the modulus of elasticity will be lower.

The concrete mixing proportions developed from T2, have a smaller modulus of elasticity because they have a larger amount of lightweight aggregates compared with T1, but obtained a smaller reduction in their modulus of elasticity when the medium sand was substituted because they have lower quantity of medium sand in the mixing proportion (compared with the total volume of the concrete design), ending with less expanded polystyrene in their compositions.

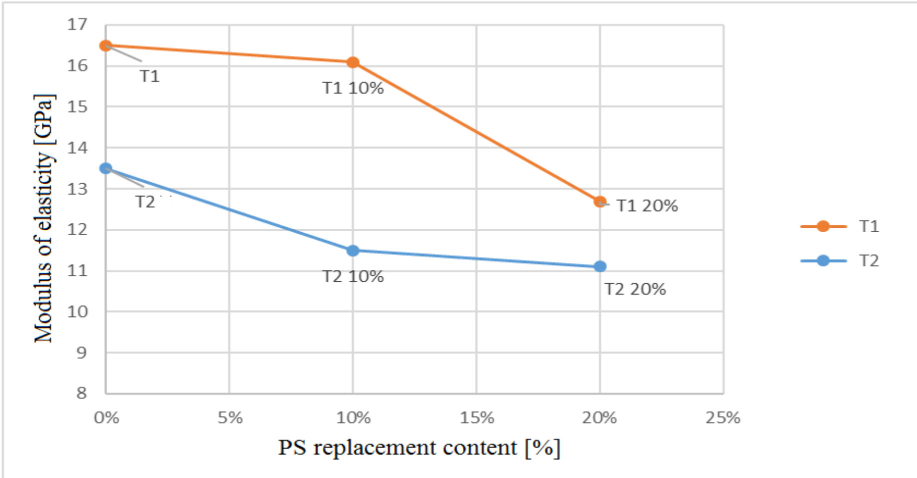

Figure 4. Modulus of elasticity test results.

4 FINAL CONSIDERATIONS

This study aimed to determine the influence of partial replacement of medium sand by expanded polystyrene on lightweight concrete. The results showed that there was a significant reduction in the density of the concretes studied, a small reduction in the resistances and an acceptable reduction in its modulus of elasticity. However, in the results of the slump and absorption test, it can be seen that the replacement of the medium sand by expanded polystyrene increased the amount of free water in the concrete, making possible a correction in the water / cement ratio of the present study. The results demonstrate the technical feasibility of replacing the medium sand with expanded polystyrene in lightweight structural concrete, and indicate the possibility of improving the cited properties of these concretes when correcting the mixing proportions studied.

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