Materials Research. 2023; 26(suppl. 1):e20230073
DOI: https://doi.org/10.1590/1980-5373-MR-2023-0073

Analysis of Substitution of Coarse Aggregate by Eps and Its Application in the Production of Hollow Blocks

Mariana N.F. Fabiche[a]*, ***Larissa Q. Minillo[a]***

[a]*Universidade Estadual de Londrina (UEL), Departamento de Engenharia Civil, Londrina, PR, Brasil.*

Received: January 15, 2023; Revised: June 23, 2023; Accepted: August 08, 2023

The work aims to analyze the effect of partial replacement of coarse aggregate by expanded polystyrene (EPS) in the production of hollow blocks, a type of concrete block. Substitution levels, by volume, of 0% (reference), 5%, 10%, 15%, 20%, and 25% were tested. The following tests were performed: granulometric composition, specific mass, unit mass, surface analysis tests, absorption, mass determination, dimensional analysis and compressive strength. Regarding surface analysis, the hollow blocks showed satisfactory results. As for water absorption, the blocks performed similarly to the reference blocks with small variations in the results. As for its mass and dimensional variability, the insertion of EPS did not promote significant changes. All specimens with substituted EPS contents met the requirements regarding the blocks' compressive strength. From an environmental point of view, the replacement of EPS meets the requirements of the block standard, contributing to its removal from the environment.

Keywords: *Expanded Polystyrene, Performance, compressive strength, Environmental Aggregates.*

1. Introduction

One of the biggest obstacles faced by society is the increasingly significant increase in the amount of waste. In this context, several studies have addressed the use of waste as viable alternatives to reduce the environmental impact and improve the properties of materials used in civil construction. One such waste is Expanded Polystyrene (EPS), the production of EPS has increased sharply in the last 20 years due to its versatile applications such as for making disposable trays, cups, packaging materials, containers, insulation boards for floors, walls, and roofs in buildings etc. Accordingly, the accumulation of waste thermocol in the environment has also increased alarmingly[1]. This significant increase in waste makes professionals from different areas seek increasingly cleaner and more efficient technologies, with the aim of reducing the disposal of this waste as much as possible.

EPS is a low-density, lightweight material with excellent insulating characteristics. However, its improper disposal represents an environmental challenge, since it is a synthetic polymer that is difficult to degrade. Given this scenario, several studies[2-5] have been dedicated to exploring possible applications for this residue, aiming at its incorporation as an addition to concrete. Reducing the final weight of concrete without compromising its mechanical strength is also the subject of current research, several authors[6-8] have defended this approach as a promising alternative, as in addition to contributing to sustainability, it can provide benefits such as reduction of structural loads, better thermal and acoustic insulation, in addition to reducing costs and consumption of traditional materials.

In an attempt to contribute to sustainable development, and increase knowledge regarding the use of construction waste in new products, the present work aims to use EPS waste, in partial replacement of coarse aggregate for the production of blocks of concrete.

According to Chandru et al.[9] expanded polystyrene spheres can be easily cast into mortar or concrete to produce lightweight. The lightweight concrete can be obtained by totally or partially replacing the standard aggregate with low-weight components[10].

The main objective of this research is to produce concrete blocks with partial replacement of coarse aggregate by EPS and to analyze the influence of this replacement under similar conditions following the criteria determined in Brazilian standards.

2. Materials and Methods

When dosing lightweight concrete, the particle size distribution of the lightweight aggregates, as well as other components such as cement and water, are taken into consideration. It is important to find the correct proportion among different sizes of lightweight aggregates to ensure a homogeneous mixture and avoid segregation issues.

For this study, a combination of fine natural and artificial aggregates (stone dust), coarse aggregate (gravel), EPS (Expanded Polystyrene) beads, and Portland V-ARI Cement were utilized. In the present research, EPS was classified as a coarse aggregate. For the fine natural aggregate, natural sand from the region of Guaíra/PR was used, the fine artificial aggregate (stone dust) and the coarse aggregate (gravel) were purchased from the region of Santa Izabel do Ivaí/PR. The crushed EPS was collected from a company in the region of Umuarama/PR, which uses this type of waste in the manufacture of concrete slabs.

*e-mail: mnffabiche2@uem.br

The granulometry of the materials was analyzed according to ABNT NBR NM 248:2003[11]. The materials was divided into groups at the grain sizes of 25.4, 19, 12.7, 9.51, 6.3, 4.76, 2.38, 1.19, 0.595, 0.297, 0.149 and 0.075 mm by means of a set of square wire mesh test sifters, sieve analysis and sifter shaking machine.

The determination of the unit weight and air-void contents for the aggregates was carried out according to ABNT NBR NM 45:2006[12]. The bulk specific gravity and apparent specific gravity test for fine aggregates (natural and artificial) was carried out according to ABNT NBR NM 52:2009[13], for coarse aggregate and also for EPS, ABNT NBR NM 53:2009[14] was used.

The mixes used for the manufacture of hollow concrete blocks were in the order of 1:5 and the replacement quantities of each material are shown in Table 1 below.

The volumes of cement, stone powder and sand were kept constant, while the volumes of EPS varied in pre-set percentages, while the volume of water and glue varied according to the amount of EPS introduced into the mix. As the spheres are substitutes for the gravel, the latter is reduced in the mix after each mix.

The production process of the blocks is displayed in Figure 1, first the materials needed to produce the blocks were separated in the boxes of granular materials. Then the dosage for each material was carried through the conveyor (step 2) to the mixer (step 3). The mixed materials (step 4) were vibro/pressed (step 5) and the fresh state blocks were obtained (step 6).

With the increase in the content of EPS in substitution, a better workability of this mass was noticed, as a result, the mixtures M15, M20 and M25 have a lower water/cement ratio.

Fifteen specimens (empty blocks) were made for each mix, 12 of which were used for the simple compressive strength test and the other three were used for the water absorption test.

The molding of the hollow blocks was carried out in a concrete artifacts factory located in the city of Iporã/PR, using a pneumatic vibro-press. The dimensions of the hollow blocks were 390x140x190mm (LxWxH). After the production process of the blocks, they were subjected to tests to verify physical and mechanical properties, as presented in the scheme of Figure 2.

Table 1. Consumption of materials.

Group	Material by volume (liters)						
	Cement	Gravel	Stone dust	Sand	EPS (% volume)	Water	PVA Glue
M00	1	1.500	1.5	2.0	0.000 (0%)	0.533	0.000
M05	1	1.425	1.5	2.0	0.075 (5%)	0.533	0.042
M10	1	1.350	1.5	2.0	0.150 (10%)	0.533	0.084
M15	1	1.275	1.5	2.0	0.225 (15%)	0.516	0.126
M20	1	1.200	1.5	2.0	0.300 (20%)	0.505	0.168
M25	1	1.125	1.5	2.0	0.375 (25%)	0.498	0.210

Figure 1. Scheme for preparing blocks with EPS residues.

Figure 2. Result of the tests with the samples.

For the superficial analysis test, 6 hollow blocks of each mix were selected in order to verify aspects related to cracks; parallelism between faces; sharp edges and presence of organic materials.

For the water absorption test, three hollow blocks of each mix (M00, M05, M10, M15, M20, M25) were separated, which followed the specification of ABNT NBR 12118:2013. The blocks were placed inside a drying oven at 110 ºC for 24 hours. After that, they were weighed at each 2 hours until the mass between subsequent weight measurements had not varied more than 0,5%. In sequence, after the blocks were let to be naturally cooled, they were submerged in water at 23ºC for 24 hours and weighed again.

The dimensional analysis tests followed the methodology provided by ABNT NBR 12118:2013[15] and NBR 6136:2014[16]. The following dimensions were analyzed: width, height, length and thickness of the walls.

The compressive strength tests followed the methodology provided by the ABNT NBR 12118:2013[15] standard. The blocks were tested at the ages of 7 and 28 days of curing, with six blocks per age. The Universal Testing Machine (EMIC) was used in the test, with a load capacity of 200 Ton and a constant loading speed.

For a correct performance of the compressive strength tests, the hollow blocks were capped in accordance with ABNT NBR 5738: 2016[17], with a mixture of sulfur and kaolin, two days before the test.

3. Results and Discussion

The materials were characterized by means of the previously defined methods, presenting a maximum characteristic diameter of the coarse aggregate of 4.75 mm and of the EPS of 9.50 mm and a Sand Fineness Modulus of 2.40 mm. The values of granulometry of the materials are presented in Figure 3.

Table 2 below presents the results obtained for the physical characterization of the materials. The fine natural aggregate has the lowest density among the compared aggregates. As regards the Specific mass of the grains in the loose state, the coarse aggregate had the lowest value.

The determination of water absorption was performed in triplicate according to ABNT NBR 6136: 2014[16], and the average values obtained are shown in Table 3.

Blocks from group M15 showed a higher rate of absorption compared to the others, however, using the Analysis of Variance test, it was found that the difference between the means of water absorption as a function of EPS content is not statistically significant at the alpha level of 0.05, commonly used for this type of material.

One of the biggest difficulties in using hollow concrete blocks in relation to their constructive method is their weight, making their handling difficult. For the analysis of the mass of the blocks, the same blocks were weighed both at 7 days and at 28 days. As a result, the blocks that presented the most significant change in mass compared to the reference blocks were the blocks of the M10 group, with 10.995 kg at 7 days and 10.861 kg at 28 days

The geometry of a constructive component has important characteristics for its use, and also for compliance with the standard. For the dimensional analysis test, the hollow blocks followed the requirements of ABNT NBR 12118: 2013[15], the results were tabulated and their averages are shown in Table 4, while the dimension captions are presented in Figure 4.

It was found that there was no variability in the dimensional analysis because the standard deviation is very small in all traces of the hollow blocks, so they are in accordance with the ABNT NBR 6136:2014[16] standard. Figure 5 presents the results referring to the compressive strength test of the concrete blocks poured at 7 and 28 days.

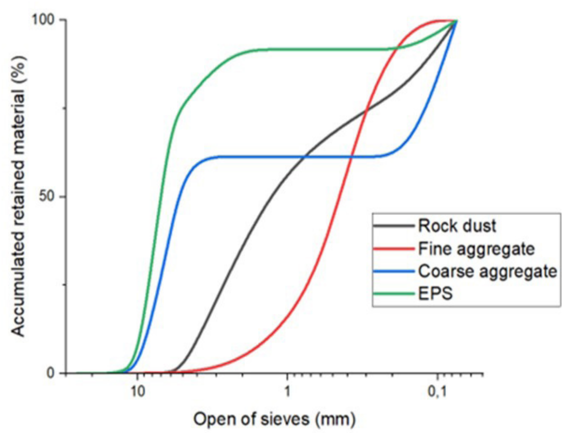

Figure 3. Granulometric analysis of rock dust, fine aggregate, coarse aggregate and EPS waste.

Table 2. Analysis of tested materials.

Aggregates (kg/m³)	Natural fine	Artificial fine	Coarse
Density	2.652	2.850	3.300
Specific mass of the grains	1.602	1.555	1.525

Table 3. Water absorption index according to EPS contents.

Material	M00	M05	M10	M15	M20	M25
Dry Weight (kg)	10.03	10.20	10.50	10.16	10.03	10.52
Saturated Weight (kg)	10.65	10.83	11.15	10.81	10.66	11.09
Absorption (%)	6.19	6.10	6.12	6.39	6.27	5.42

Table 4. Dimensional analysis.

Group	Dimension (in mm)				
	Length (L)	Width (W)	Height (H)	Wall Thickness (WT)	
				Longitudinal (WTL)	Transversal (WTT)
M00	390.00	139.98	189.98	25.17	25.22
M05	390.01	139.98	189.93	25.05	25.10
M10	390.02	140.01	190.11	25.05	25.20
M15	390.04	140.01	190.01	25.10	25.09
M20	390.03	140.04	190.02	25.02	25.13
M25	390.03	140.00	190.00	25.08	25.04
Mean	390.02	140.000	189.99	25.08	25.13
Standard deviation	0.015	0.023	0.036	0.057	0.069

Table 5. Comparison between the compressive strength of hollow blocks as a function of EPS replacement content.

	p-value Density	p-value Compressive Strength	p-value Specific strength
M00/M05/M10/M15/M20/M25 7 of curing	0.090	0.226	0.254
M00/M05/M10/M15/M20/M25 28 of curing	0.018	0.066	0.064

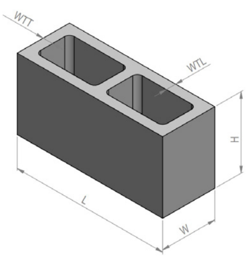

Figure 4. Dimensions of the concrete block.

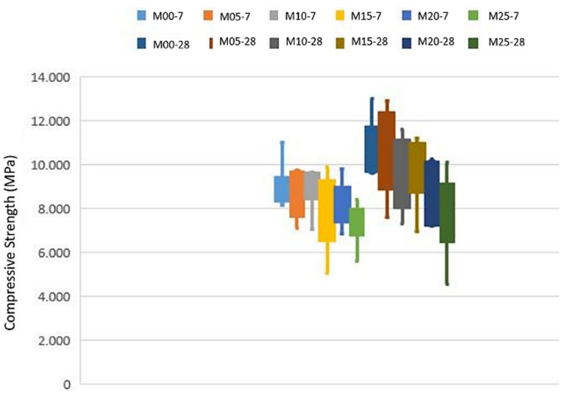

Figure 5. Statistical analysis of blocks regarding compressive strength.

There was a decrease in the compressive strength of the hollow blocks as EPS was added to the mass, both for 7 and 28 days of curing. To confirm the significance of the influence of the variables considered in compressive strength, an ANOVA was conducted and the results are presented in Table 5. The p–value less than 0.05 indicates that the relationship between the variables and their interactions are statistically significant with a confidence level of 95% in concrete the density, compressive strength and specific compressive strength after the curing time of 28 days.

Concrete strength at 7 days increased up to 10% of replacement of coarse aggregate by EPS, larger replacements caused a drop in strength. At 28 days with material variations, the blocks did not show a standard behavior, that is, oscillations according to the addition of material. All tested hollow blocks exceeded the minimum limit of the ABNT NBR 6136:2014[16] standard for blocks without a structural function, that is, the values were above the established limit of ≥3 MPa for hollow blocks for sealing.

4. Conclusions

This work presents a study of the partial replacement of coarse aggregate by EPS residues in the manufacture of hollow concrete blocks, with the objective of evaluating the potential of its use in commercial purposes in civil construction, considering the aspects of surface analysis, water absorption, weight variability, dimensional control, as well as compressive strength tests to confirm compliance with Brazilian standards.

With regard to the finishing of the hollow blocks, a visual evaluation of the finishing was carried out in order to adjust the amount of water in the molding process. In the dosage process it was found that the higher the rate of incorporated EPS, the lower the amount of water added, this is due to the fact that EPS does not absorb water from the concrete mix.

The experimental results referring to the water absorption test by the hollow blocks showed little significant variations in all cases, the fact indicates that the use of EPS in the hollow blocks did not affect this property. However, the results were below the limit established in the norm.

As for the dimensional analysis, the hollow blocks did not show significant changes in relation to the replacement of coarse aggregate by EPS, thus meeting the values established in the standard. This fact indicates that the addition of EPS does not cause dimensional variability in dry concrete for hollow masonry blocks.

With regard to compressive strength tests, all hollow blocks tested after 7 days have already presented results in compliance with the minimum limit of the Brazilian standard for hollow blocks for sealing (Strength > 3 MPa). At 28 days, all tested blocks showed results above the minimum limit required by the Brazilian standard for hollow blocks that perform a structural function.

It can be concluded that the partial replacement of coarse aggregate by EPS waste is technically feasible for all replacement percentages used in the research. However, for the use of EPS residues to reduce the impacts related to the inadequate disposal of these residues, the use of 25% of EPS in partial replacement of the coarse aggregate represents a greater advantage in terms of environmental issues, since the incorporation of EPS residue was greater without loss of resistance.

5. References

1. Uttavalli A, Dinda S, Gilda BR. Scientific and engineering aspects of potential applications of post-consumer (waste) expanded polystyrene : a review. Process Saf Environ Prot. 2020;137:10-148. http://dx.doi.org/10.1016/j.psep.2020.02.023.
2. Awoyera PO, Adesina A. Plastic wastes to construction products: Status, limitations and future perspective. Case Studies in Construction Materials. 2020;12:e00330. http://dx.doi.org/10.1016/j.cscm.2020.e00330.
3. Maghfouri M, Alimohammadi V, Gupta R, Saberian M, Azarsa P, Hashemi M, et al. Drying shrinkage properties of expanded polystyrene (EPS) lightweight aggregate concrete: a review. Case Stud Constr Mater. 2022;16:e00919. http://dx.doi.org/10.1016/j.cscm.2022.e00919.
4. Prasittisopin L, Termkhajornkit P, Kim YH. Review of concrete with expanded polystyrene (EPS): performance and environmental aspects. J Clean Prod. 2022;366:132919. http://dx.doi.org/10.1016/j.jclepro.2022.132919.
5. Hilal N, Hamah Sor N, Faraj RH. Development of eco-efficient lightweight self-compacting concrete with high volume of recycled EPS waste materials. Environ Sci Pollut Res Int. 2021;28(36):50028-51. http://dx.doi.org/10.1007/s11356-021-14213-w.
6. Karaki A, Mohammad M, Masad E, Khraisheh M. Theoretical and computational modeling of thermal properties of lightweight concrete. Case Stud Therm Eng. 2021;28:101683. http://dx.doi.org/10.1016/j.csite.2021.101683.
7. Araujo GS, Iwamoto LC, Lintz RC, Gachet LA. Influence of incorporation and dimension of expanded polystyrene on lightweight concrete. ACI Mater J. 2021;118(1):79-90. http://dx.doi.org/10.14359/51728280.
8. Chen B, Liu N. A novel lightweight concrete-fabrication and its thermal and mechanical properties. Constr Build Mater. 2013;44:691-8. http://dx.doi.org/10.1016/j.conbuildmat.2013.03.091.
9. Chandru G, Vijay N, Vignesh V, Sachin KV. Study on behavior of concrete blocks with EPS and partial replacement of fly ash and quarry dust. International Journal of Advanced Engineering Research and Science. 2017;4(1):236-9. http://dx.doi.org/10.22161/ijaers.4.1.38.
10. Kaya A, Kar F. Properties of concrete containing waste expanded polystyrene and natural resin. Constr Build Mater. 2016;105:572-8. http://dx.doi.org/10.1016/j.conbuildmat.2015.12.177.
11. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR NM 248: Aggregates - Sieve analysis of fine and coarse aggregates. Rio de Janeiro: ABNT; 2003.
12. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR NM 45: Aggregates - Determination of the unit weight and air-void contents. Rio de Janeiro: ABNT; 2006.
13. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR NM 52: Fine aggregate - Determination of the bulk specific gravity and apparent specific gravity. Rio de Janeiro: ABNT; 2009.
14. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR NM 53: Coarse aggregate - Determination of the bulk specific gravity, apparent specific gravity and water absorption. Rio de Janeiro: ABNT; 2009.
15. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 12.118: Hollow concrete blocks for concrete masonry — Test methods. Rio de Janeiro: ABNT; 2013
16. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 6.136: Hollow concrete blocks for concrete masonry — Requirements. Rio de Janeiro: ABNT; 2014.
17. ABNT: Associação Brasileira de Normas Técnicas. ABNT NBR 5.738: Concrete — Procedure for molding and curing specimens. Rio de Janeiro: ABNT; 2016.