CORPUS PUBLISHERS

Corpus Online Journal of Civil Engineering (COJCE)

Volume 1, Issue 2, 2023

Article Information

Received date : 17 April, 2023

Published date: 11 October, 2023

*Corresponding author

Richard Thomas Lermen, Post Graduation Program of Architecture and Urbanism, ATITUS Educação, Passo Fundo, RS, Brazil

DOI: 10.54026/COJCE/1006

Key Words

Foamed concrete; Foundry waste; Green sand fines; Properties

Research Article

Waste Reduction in Industry: A Study on Using Fine Green Foundry Sand Waste in Foamed Concrete Production

Richard Thomas Lermen*, Elen Cristina Faustino Boff Fernandes and Rodrigo de Almeida Silva

Post Graduation Program of Architecture and Urbanism, ATITUS Educação, Passo Fundo, RS, Brazil

Abstract

The reuse of waste in construction has been an alternative to minimize the environmental impact and transform waste into raw material. The present study evaluated the replacement of natural sand by fine green foundry sand waste in the manufacture of foam concrete. Different levels of substitution were tested, as well as the amount of foam and the type of curing. The results indicated that the compressive strength ranged from 4.0 to 12.6 MPa, with mixtures with 20% foam and 50% fine green foundry sand waste (FGFSW) presenting results close to 6 MPa. The cementitious matrices presented uniform and distributed pores for mixtures with 20% foam in all levels of FGFSW substitution. The dry and saturated densities varied from 946 to 1743 kg/m³ and from 1244 to 1881 kg/m³, respectively. Thermal conductivity results ranged from 0.28 to 0.53 W/m.K and water absorption ranged from 4.5% to 38.2%. In summary, the study showed that it is possible to use the FGFSW for the manufacture of foamed cellular concrete with technical effectiveness.

Introduction

The conservation of the environment has been a topic of great relevance in various branches of industry. Several researches seek ways to reduce the problems and environmental impacts caused by the generation of industrial waste. Among these wastes is the green foundry sand, which is the subject of studies in the development of materials for civil construction [1].

The main function of green foundry sand is to make molds for the production of castings. Green foundry sand has a huge potential for application in civil construction [2]. The molding sands in the casting process are classified into two groups, namely: the green sand, so called because it has a dark black color, having in its mixture about 80% to 95% of silica sand, 5% to 10% of bentonite as binder, also having about 2% to 10% of coal powder, used as an additive to improve the finishing of the pieces, And the phenolic sand, which is sand based on chemical binders, which has in its composition about 93% to 99% of silica sand and as binders, phenolic resins, about 1% to 3% [3]. These sands have their own characteristic, which is the ability to resist high temperatures [1]. According to a study conducted, this waste can be used in mortars and in the making of concretes, which reduces its volume of deposit in landfills [4]. The use of green foundry sand as aggregate for the development of concrete has been an alternative to reduce environmental and economic impacts through the preservation of natural resources [5].

Increasing the content of foundry sand to replace the natural aggregate in mortars leads to an increase in the compressive strength of the mixtures, according to Siddique et al. [6]. The authors concluded that the increase in compressive strength was due to the fact that the residue is finer than the natural aggregate, resulting in a denser concrete and may also be due to the silica content present in the foundry sand. Studies of the influence of the use of foundry sand waste in concrete were also conducted with the objective of replacing the natural sand in different proportions of foundry sand for the molding of the specimens, being 0%, 10% and 20% the replacement and using cement CP V - ARI, verifying that in its fresh and hardened state, this replacement as fine aggregate is technically feasible [7].

The use of foamed light concrete for non-structural purposes is a viable and efficient alternative for acoustic and thermal insulation purposes, due to the fact that in this type of concrete the compressive strength required is low. The lightweight concretes can also be generated from the use of introducing air bubbles distributed in its mixture, through the addition of preformed foam or chemical additives [8]. The foamed light concrete is considered a type of mortar, produced from the mixture of cement, sand, water and foam, forming a network of pores in the cement mass from the air bubbles formed by the foam added to the mixture, the density of foamed concrete can range from 300 kg/m³ to 1800 kg/m³, thus being classified as lightweight concrete [9].

Raj et al. [10] proposed some future studies on foamed cellular concrete, among which the verification of the factors that influence the stability of the foam in the mixture, the evaluation of the physical and mechanical properties of concrete, and the development of a low density and high mechanical strength foamed concrete. They also considered the study of the effect of replacing conventional components of the mixture with additions and wastes. However, among the researches conducted with respect to studies on the use of green foundry sand waste (GFSW) to replace natural sand in the development of foamed lightweight concrete, few studies were found in the literature. One study that can be cited is that of [11], which presented the use of GFSW as a viable alternative in the manufacture of foamed concrete to replace natural sand, obtaining significant results regarding compressive strength, above 2.5 MPa and decrease in the percentage of dry and saturated densities by 21% and 14%, respectively. Regarding the use of fines from this waste (GFSW) for the production of foaming cellular concrete, no work was found.

Thus, the present study had as aim the production of foamed cellular concrete with replacement of natural sand by the fine green foundry sand waste (FGFSW). The evaluation of the mechanical and physical properties of foam concretes developed with different percentages of substitution was performed.

Materials and Methods

Aggregates

The natural sand used was river sand, whose particle size curve can be observed in figure 1(a). The natural sand has a fineness modulus and density of 3.10 and 1530 kg/m^3, respectively. The discarded green foundry sand waste was supplied by a foundry company in the region of Passo Fundo/RS/Brazil. The fines of this waste were obtained using the material passing the sieve of number 70 and opening 0.212 mm. Figure 1(b) shows the laser granulometry for the FGFSW, which was characterized in detail in the work of [12].

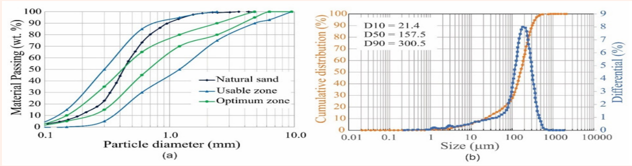

Figure 1: (a) Particle size curve for natural sand and (b) particle size curve for green foundry sand fines.

Binder

As a binder of the mixture, Portland cement composed with filler (CP II-F-32) was used, indicated for use in light non-structural concretes. The properties of cement CP II-F-32 can be seen in table 1.

Table 1: CP II-F 32 Portland cement characteristics.

Physical Properties										
Cement type	Setting time		Blaine cm/g^2	#200 %	#325 %	HE[1] Mm	D[2] g/cm^3	Compressive strength (average)		
	Initial Min	Last min						3 days Mpa	7 days Mpa	28 days Mpa
CP II-F 32	187	245	3.34	1.43	11.31	0.27	3.06	27.1± 0.8	32.4 ± 1.3	32 ± 0.7
Chemical Properties										
Cement type	Al O$_{23}$ %	SiO$_2$ %	Fe O$_{23}$ %	CaO %	MgO %	SO$_3$ %	LOI$_3$.%	Free CaO %	I.R.[4] %	A.E.[5] %
CP II-F 32	4.13	18.24	2.82	61.27	2.76	2.56	6.72	1.56	1.03	0.71

[1]HE - Hot expansion; [2]D - Density; [3]LOI - Loss on ignition; [4]I.R. -Insoluble Residue; [5]A.E. - Alkaline Equivalent.

Foaming additive

The foaming additive used in the production of the specimens was Amide 90, at a ratio of 1:10 (Amide/water), thus producing the foam with the aid of a mechanical mixer. The established proportion was obtained in studies done by Favaretto et al. [13]. According to the authors, amide 90, known as condensed coconut oil diethanolamine, is a mixture of the diethanolamines of the fatty acids that constitute coconut oil. The foam formed showed a density of approximately 80 kg/m3

Experimental program and procedures

The production, molding and curing of the specimens followed the criteria established in NBR 5738 [14], adopting cylindrical specimens with dimensions of 50x100 mm. For the thermal conductivity tests, prismatic specimens of 300 × 100 × 30 mm were used. Initially, cement, aggregate and water were mechanically mixed in a mortar mixer at a speed of 140 rpm. Sequentially, the foam was added and mixed manually until homogeneity was reached. The foam was previously prepared with water and the foaming additive, being mixed mechanically for 10 minutes at a speed of 240 rpm. The cylindrical molds were coated with a thin layer of release agent inside and positioned on a flat surface. The demolding took place 24 hours after molding and the specimens subjected to dry curing were wrapped in plastic film for 28 days at room temperature. The specimens subjected to wet curing were immersed in a tank saturated with lime for the same period of 28 days.

After curing for 28 days, the specimens were submitted to the following tests: compressive strength, densities (saturated and dry), water absorption, air void and thermal conductivity. Also, an image evaluation (macrography) was performed to evaluate the distribution and shape of the pores. The compressive strength test was performed at an age of 28 days after curing, using an EMIC hydraulic press, model PC200, with a capacity of 2000 kN, a breaking speed of 0.7 mm/min, and an accuracy of approximately 1% of the applied load, thus following the specifications established by NBR 5739 [15].

The densities (dry and saturated), air void, and water absorption were determined according to C948-81 [16] and NBR 9778 [17]. The thermal conductivity test was performed using the surface hot wire test. This technique has been used and described in detail in previous works, such as Lermen, et al. [18], Sacht et al. [19], Santos [20], and others.

The macrography test was used to evaluate the distribution and shape of the pores. To perform this test, cylindrical specimens were cross-sectioned, sanded and polished. Sequentially, images were obtained for the specimens with and without surface treatment. The surface treatment consisted in painting the specimens with black paint and then covering them with white powder (sodium bicarbonate) to better identify the pores (technique used by different authors [13,21,22]). Images were obtained using a digital magnifying glass and processed with imageJ software (National Institutes of Health, Bethesda, MD, USA).

The study was developed with three factors, being the percentage of replacement of natural sand by FGFSW with six levels (0% - reference concrete, 10%, 20%, 30%, 40% and 50%), the amount of foam with four levels (5%, 10%, 15%, 20% in relation to the total mass) and the type of curing with two levels (wet curing and dry curing). The water/cement ratio (W/C) was kept constant at 0.5. The response variables analyzed in the study were compressive strength, densities (dry and saturated), air void (porosity), water absorption, and thermal conductivity. The experimental matrix used in the study can be seen in table 2. Results were obtained through variance analysis, where the variances between the medians were compared. The graphs show the points of the mean values of the analyzed groups, complemented by the boxes (box) that represent the standard deviations and the whiskers (vertical lines) that are the confidence intervals at 95% level.

Table 2: Experimental matrix.

Order	Cement (g)	Sand (g)	FGFSW (g)	Water (g)	Foam (g)	W/C
1	2000	1000	0	800	200	0,5
2	2000	900	100	800	200	0,5
3	2000	800	200	800	200	0,5
4	2000	700	300	800	200	0,5
5	2000	600	400	800	200	0,5
6	2000	500	500	800	200	0,5
7	2000	1000	0	600	400	0,5
8	2000	900	100	600	400	0,5
9	2000	800	200	600	400	0,5
10	2000	700	300	600	400	0,5
11	2000	600	400	600	400	0,5
12	2000	500	500	600	400	0,5
13	2000	1000	0	400	600	0,5
14	2000	900	100	400	600	0,5
15	2000	800	200	400	600	0,5
16	2000	700	300	400	600	0,5
17	2000	600	400	400	600	0,5
18	2000	500	500	400	600	0,5
19	2000	1000	0	200	800	0,5
20	2000	900	100	200	800	0,5
21	2000	800	200	200	800	0,5
22	2000	700	300	200	800	0,5
23	2000	600	400	200	800	0,5
24	2000	500	500	200	800	0,5

Results and Discussions

Characterization by image and air void (porosity)

The macrographs of the samples are presented in figures 2 & 3, for dry cure and wet cure, respectively. It can be seen that the higher the percentage of foam in the mixture, the more porosity the sample has [9]. For values of 5% foam present in the mixture, there are denser specimens, with micropores and greater visualization of FGFSW grains. The samples containing 20% foam present a uniformity of the pores in all levels of replacement of FGFSW, visualizing the grains of FGFSW in the mixture.

Figure 4 shows the percentage of the void ratio as a function of the percentage of substitution of FGFSW, for the different types of curing (dry and wet curing). It can be observed that the specimens subjected to dry curing showed a lower percentage of voids when compared to the specimens subjected to wet curing. The fact may be due to the need for hydration of the concrete. It was also found that their values are approximate for substitutions of FGFSW in the mixture at 20% and 30%, regardless of the curing method adopted, when there is presence of 20% of foam incorporated into the mixture. It can also be seen that the higher the replacement of FGFSW in the mixture, the samples tend to have an increase in the percentage of the air voids, contrary to studies by [3], which reports that the voids index is reduced as the natural sand is replaced by the residue of green foundry sand, due to the amount of fines present in its composition, filling a larger amount of voids in the cement matrix.

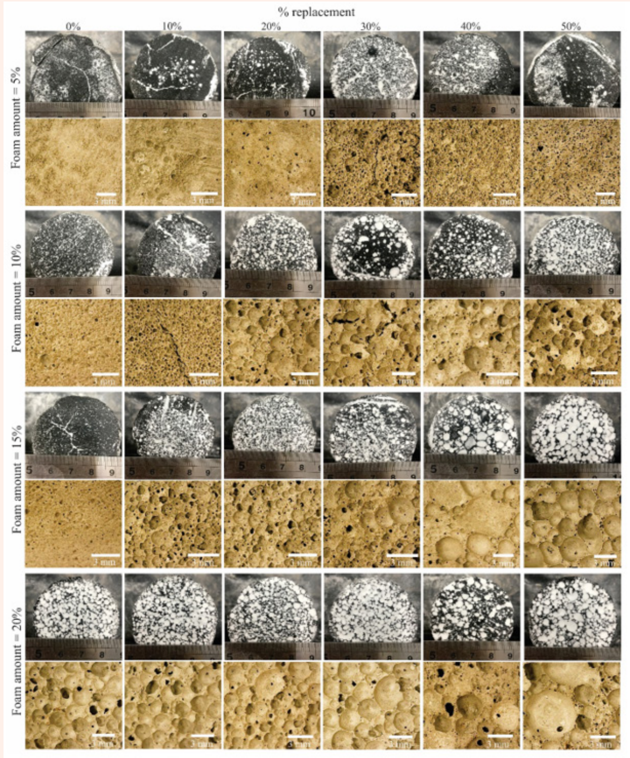

Figure 2: Macrograph of the specimens subjected to dry curing.

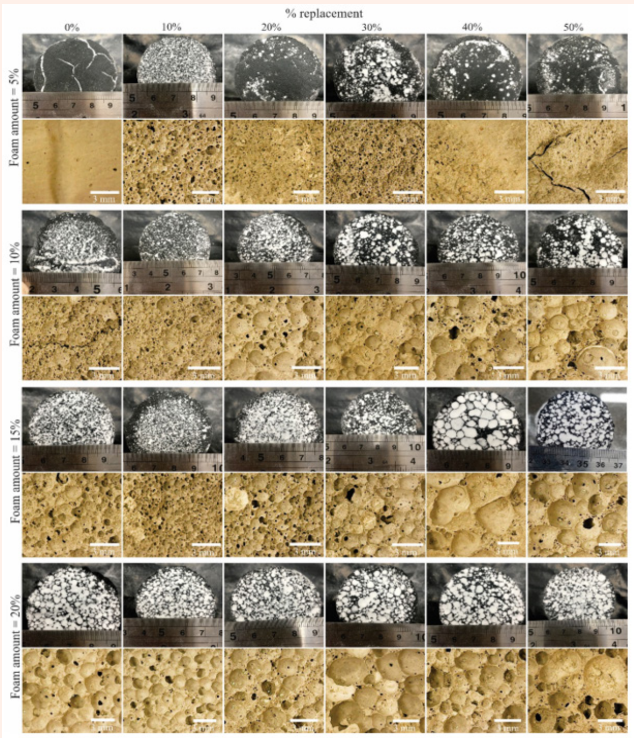

Figure 3: Macrograph of the specimens submitted to wet curing.

For wet curing, the values of the voids index were between 20% and 42% approximately. For dry curing, the values were between 5% and 35% approximately, with the lowest percentages observed for the mixtures with lower foam contents.

The analysis of variance for the air voids can be seen in table 3, with 95% reliability, in which the factors related to the type of curing, amount of foam and percentage of substitution had significant contribution on the air voids, because the P-Value was less than 0.05. However, the most representative factor was the type of cure, followed by the amount of foam, and the percentage and substitution had the lowest contribution, which can be verified by the F-Value, where higher values express greater influence.

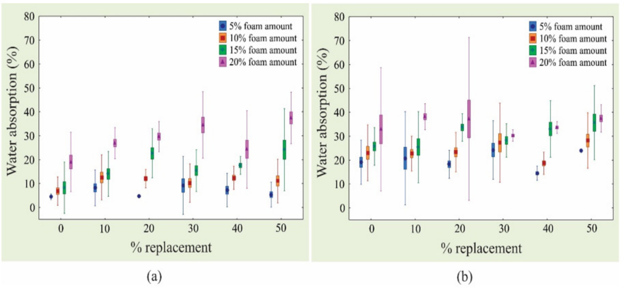

Figure 4: Air voids as a function of percentage of FGFSW replacement. (a) Dry curing and (b) wet curing.

Table 3: ANOVA for the air voids.

Factor	Sum of Squares	Degree of freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	7731.25	1	7731.25	277.183	0	Yes
Amount of foam	3462.95	3	1154.32	41.385	0	Yes
% replacement	363.41	5	72.68	2.606	0.0277	Yes
Error	3737.56	134	27.89			

Water absorption

Regarding the water absorption of the specimens, it can be seen in figure 5 that the lowest percentage of absorption was verified in the specimens submitted to dry curing, with water absorption approximately between the range of 0% to 40%, and for wet curing the water absorption showed initial values above 10% up to 50%, approximately.

The specimens that presented higher water absorption (between 15% and 45%) and lower water absorption (between 5% and 25%) in all levels of sand replacements and in both curing routes were, respectively, the PSCs with an increment of 20% and 5% of foam in the mixture. For the 5% and 10% foam levels present in the samples, there was less water absorption, justified by the fact that the lower the percentage of foam present, the lower the generation of voids (air bubbles present), occurring the reduction of connectivity between the pores [23,24]. For both dry and wet curing, the specimens with 15% and 20% foam in their mixture, were the ones that showed higher water absorption values when compared to the other percentages, noting only approximate values of the samples subjected to wet curing at all levels of foam replacement for the replacement of 30% of FGFSW.

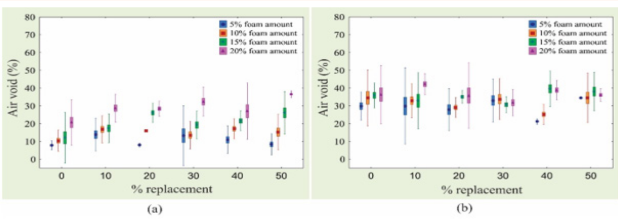

Figure 5: Water absorption as a function of the percentage of FGFSW replacement. (a) Dry curing and (b) wet curing.

Table 4 contains the analysis of variance for water absorption, with 95% reliability, it can be stated that the type of curing and the amount of foam significantly influence this observed factor.

Table 4: ANOVA for water absorption.

Factor	Sum of Squares	Degree of freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	4800.65	1	4800.65	179.259	0	Yes
Amount of foam	7005.6	3	2335.2	87.197	0	Yes
% replacement	869.87	5	173.97	6.496	0	Yes
Error	3588.6	134	26.78			

Dry and saturated densities

For the results of dry and saturated densities shown in figures 6 & 7, it can be observed that the higher the foam increment in the sample, the less dense they are, this for the different percentages of substitution of natural sand by the residue of green foundry sand, noting a difference in densities in each mix of approximately 300 kg/m³, presenting this pattern regardless of the curing method adopted, thus being an influential factor in the densities of the samples the percentage of foam adopted in the mixture [11].

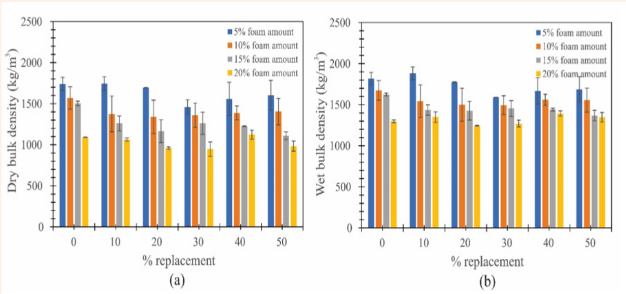

Figure 6: Density (a) dry and (b) saturated as a function of FGFSW replacement percentage for the dry cure type.

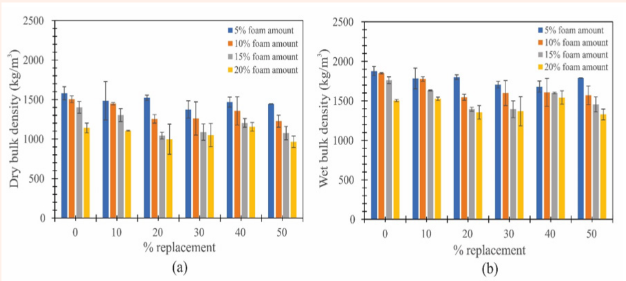

Figure 7: Density (a) dry and (b) saturated as a function of FGFSW replacement percentage for the wet curing type.

Regarding the replacement of natural sand by FGFSW, the density values were constant, regardless of the percentage of replacement present in the mixture. It can be seen that the sample with 20% of foam and 50% of FGFSW has a difference of about 25 kg/m³ in relation to the reference mix present in the study. The sand itself provides a higher density to the concrete due to the high density of the material explains that to obtain lower density, lower than 800 kg/m³, a higher content of fineness should be applied, not exceeding 20% of fines lower than 250 μm [25].

Another factor observed in the results obtained can be seen in figure 7, where the samples submitted to wet curing presented similar values in their densities when compared to the samples that were dry-cured.

For the ANOVA analyses presented in tables 5 & 6, dry and saturated density respectively, it was evident that the amount of foam factor, as well as the percentage of FGFSW substitution and the type of curing in which the CPs were submitted were influential in the results, with 95% reliability.

Table 5: ANOVA for dry density.

Factor	Sum of Squares	Degree of freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	134828	1	134828	10.12	0.0018	Yes
Amount of foam	5063477	3	1687826	126.69	0.0000	Yes
% replacement	868067	5	173613	13.03	0.0000	Yes
Error	1785146	134	13322			

Table 6: ANOVA for saturated density.

Factor	Sum of Squares	Degree of Freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	262231	1	262231	25.57	0.0000	Yes
Amount of foam	2777051	3	925684	90.28	0.0000	Yes
% replacement	658620	5	131724	12.85	0.0000	Yes
Error	1374007	134	10254			

Compressive strength

Figure 8 shows the results for compressive strength in relation to the percentage of replacement of FGFSW of the samples subjected to the two curing routes, wet and dry, at the age of 28 days. In a general analysis, the samples show a drop in their mechanical performance when compared to the reference mixture, which has no replacement of material, this can be verified both for dry and wet curing. As the mixtures of specimens have greater substitutions of natural sand for FGFSW and greater increments of foam in the mixture, their compressive strength decreases [26]. The decrease in compressive strength relative to the increased amount of foam occurs due to the incorporation of air inside the specimens, causing more pores in the structure, thus decreasing the density and, consequently, the compressive strength. In relation to the percentage of substitution of natural sand by FGFSW, the compressive strength in most of the analyzed specimens tends to decrease as the substitution values increase and densities decrease. Punctually, we can observe that the specimens that have 10% of FGFSW substitution, present a gain in their compressive strength of approximately 2 MPa. After this replacement, the others, which have in their mixture 20%, 30%, 40% and 50%, tend to decrease or maintain constant their values, this can be observed for all levels of foam present in the samples, such behavior can also be observed in studies of [27].

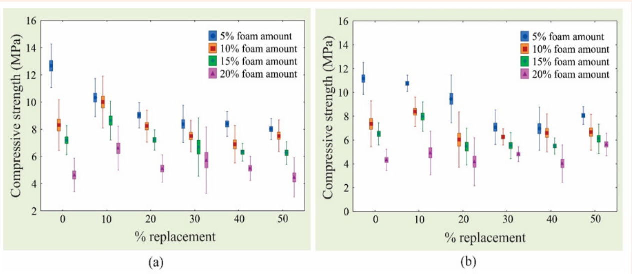

Figure 8: Compressive strength in relation to the percentage of FGFSW replacement. (a) Dry curing and (b) wet curing.

Another factor that can be observed is related to the curing route adopted, in which the samples did not present significant differences in their compressive strength values.

The obtained values of compressive strength are higher than the values required for foam cellular concrete walls, according to NBR 12646 [28], which determines a minimum strength of 2.5 MPa at 28 days. All specimens in this study had compressive strengths higher than 4 MPa, as shown in the graphs with a 95% reliability interval.

By ANOVA, presented in table 7, the analysis of variance for the compressive strength can be observed. It can be observed that both the type of curing, the amount of foam and the percentage of substitution of FGFSW, influenced the compressive strength, as can be seen by the P-Value being less than 0.05 with 95% reliability or higher.

Table 7: ANOVA for compressive strength.

Factor	Sum of Squares	Degree of freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	24.075	1	24.075	29.536	0	Yes
Amount of foam	335.086	3	111.695	137.027	0	Yes
% replacement	89.361	5	17.872	21.926	0	Yes
Error	109.228	134	0.815			

Thermal conductivity

In the graph shown in figure 9, one can observe the thermal conductivity in relation to the percentage of substitution of FGFSW for dry curing and wet curing. It is noted that as the specimens have greater replacement of FGFSW in its mixture, the thermal conductivity of the material decreases, the same occurred in studies of [26]. It can also be seen that the thermal conductivity of specimens with lower percentages of foam showed higher values when compared to samples with higher levels of foam in their mixture. The decrease in the thermal conductivity of the material occurs due to the increase of voids in its interior, taking into account the low thermal conductivity of air when incorporated into the mixture, causes it to present significant results regarding its thermal performance, obtaining values lower than 0.3 W/mK [29].

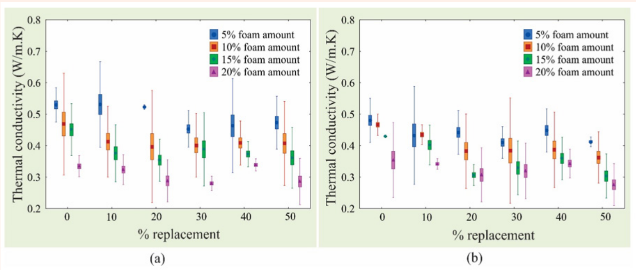

Figure 9: Thermal conductivity versus percentage of FGFSW replacement. (a) Dry cure and (b) wet cure.

Table 8 also shows the analysis of variance for the thermal conductivity of the material developed for the study. With 95% reliability, it was found that the percentage of substitution of FGFSW and the amount of foam in the samples had an influence on the thermal conductivity of the material.

Table 8: ANOVA for thermal conductivity.

Factor	Sum of Squares	Degree of freedom	Mean Squares	F-Value	P-Value	Significant
Type of cure	0.01616	1	0.01443	11.22	0.001	Yes
Amount of foam	0.436	3	0.14656	100.88	0	Yes
Replacement %	0.1005	5	0.02117	13.95	0	Yes
Error	0.19305	134	0.00144			

Conclusion

The main objective of the present study was to evaluate the mechanical and physical properties of foam concretes developed with different percentages of substitution of natural aggregate by fine green foundry sand waste. Thus, within the specific conditions and limits of this study, the following conclusions were obtained:

a) The FGFSW can technically be used as a potential alternative aggregate substitute for the manufacture of foamed cellular concrete. Presenting characteristics compatible with conventional materials used as aggregates in the concrete mixture. Highlighting the fact of disposing of an industrial waste, reducing the environmental impacts caused by the incorrect disposal of FGFSW.

b) The wet curing process was one of the factors that most influenced the results obtained regarding the voids content and water absorption of the foamed cellular concrete, showing improvement in the analyzed characteristics.

c) The increase in the percentage of foam in the mixture resulted in a decrease in the compressive strength of foam-filled aerated concrete due to the generation of voids in the cement matrix. However, even with the increase of foam in the mixture, the value of compressive strength of the foam concrete obtained in this study meets the minimum value required by NBR 12646 [28], which is 2.5 MPa. The decrease in the compressive strength of the foam concrete also occurred by the percentage of replacement of FGFSW in the mixture, where the highest values were obtained in the mixtures with up to 30% of FGFSW, in all percentages of foam.

References

1. Casali JM, Miguel TF, Felizardo CC, Meira N, Dos S, et al. (2018) Characterization and influence of the content of phenolic foundry sand residue in coating mortars. Ambient. build 18(1): 261-279.
2. Armange LC, Neppel LF, Gemelli E, Camargo NHA (2005) Use of Residual Foundry Sand for use in Mortar. Matter Magazine 10(1): 51-62.
3. Siddique R, Singh G (2011) Utilization of waste foundry sand (WFS) in concrete manufacturing. Resources. Conservation and Recycling 55(11): 885-892.
4. Wanatabe FA (2004) Study on the use of residual foundry sand as an aggregate in the manufacture of concrete pavements. Masters dissertation. Graduate Program in Materials Science and Engineering, State University of Santa Catarina-UDESC.
5. Manoharan T, Laksmanan D, Mylsamy K, Sivakumar P, Sircar A (2018) Engineering properties of concrete with partial utilization of used foundry sand. Waste management 71: 454-460.
6. Siddique R, De Schutter G, Noumowe A (2009) Effect of used-foundry sand on the mechanical properties of concrete. Construction and Building Materials 23(2): 976-980.
7. Pinto FB (2013) The use of discarded foundry sand (ADF) in the production of concrete. Masters dissertation. Postgraduate Program in Materials Engineering, Federal University of Itajubá.
8. Ramamurthy K, Nambiar EKK, Ranjani GIS (2009) A classification of studies on properties of foam concrete. Cement and Concrete Composites 31(6): 388-396.
9. Amran YHM, Farzadnia N, Ali AAA (2015) Properties and applications of foamed concrete; a review. Construction and Building Materials 101: 990-1005.
10. Raj A, Sathyan D, Mini KM (2019) Physical and functional characteristics of foam concrete: A review. Construction and Building Materials 221: 787-799.
11. Lermen RT, Bonatto G, Silva RA (2020) Use of Foundry Green Sand Waste in the Development of Foam Concrete. Architecture Magazine IMED 9(1): 153-170.
12. Comparsi TD, Lermen RT, Silva RdeA, Farias SM, Bonsembiante FT, et al. (2020) Preliminary Study on The Use of Green Foundry Sand Waste Fines in the Development of Geopoliméric Paste. National Meeting of Built Environment Technology 18(1): 1-9.
13. Favaretto P, Hidalgo GEN, Sampaio CH, Silva RdeA, Lermen RT (2017) Characterization and use of construction and demolition waste from south of Brazil in the production of foamed concrete blocks. Applied Sciences 7: 1090.
14. ABNT (2015) NBR 5738 - Concrete - procedure for molding and curing specimens. Brazilian Association of Technical Standards, Rio de Janeiro.
15. ABNT (2018) NBR 5739 - Concrete - Compression test of cylindrical specimens, Brazilian Association of Technical Standards, Rio de Janeiro.
16. ASTM (2016) C948-81 - Standard Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass-Fiber Reinforced Concrete. American Society for Testing and Materials.
17. ABNT (2009) NBR 9778 - Hardened Mortar and Concrete - Determination of Water Absorption by Immersion - Void Index and Specific Mass. Brazilian Association of Technical Standards, Rio de Janeiro.
18. Lermen RT, Favaretto P, Silva RdeA, Hidalgo GEN, Tubino RMC, et al. (2019) Effect of additives, cement type, and foam amount on the properties of foamed concrete developed with civil construction waste. Applied Sciences 9: 2998
19. Sacht HM, Rossignolo Ja, Santos Wn (2010) Evaluation of thermal conductivity of lightweight concrete with expanded clay. Matter Magazine 15: 31-39.
20. Santos WN dos (2002) The hot wire method: parallel technique and surface technique. Ceramics 48(306): 86-91.
21. Hilal AA, Thom NH, Dawson AR (2015) On void structure and strength of foamed concrete made without/with additives. Construction and Building Materials 85: 157-164.
22. Nambiar EKK, Ramamurthy K (2007) Air-void characterisation of foam concrete. Cement and concrete research 37(2): 221-230.
23. Gomes PCC, Alencar TFF, Silva NV, Moraes KAM, Angulo SC (2015) Obtaining lightweight concrete using recycled aggregates. Built Environment 15(3): 31-46.
24. Dang J, Zhao S, Chen G, Cao X, Yang J (2022) Effect of polyethylene powder and heating treatment on the microstructure and hardened properties of foam concrete. Journal of Building Engineering 50: 104143.
25. Khalaf MA, Ban CC, Ramli M (2019) The constituents, properties and application of heavyweight concrete: A review. Construction and Building Materials 215: 73-89.
26. Xiao J, Hao L, Cao W, Ye T (2022) Influence of recycled powder derived from waste concrete on mechanical and thermal properties of foam concrete. Journal of Building Engineering 61: 105203.
27. Matos PRde, Marcon MF, Schankoski RA, Prudêncio LR (2019) Novel applications of waste foundry sand in conventional and dry-mix concretes. Journal of environmental management 244: 294-303.
28. ABNT (2022) NBR 12646 - Cast-in-place foamed cellular concrete walls – Specification. Brazilian Association of Technical Standards, Rio de Janeiro.
29. Wagh CD, Indu SRG, Kamisetty A (2021) Thermal properties of foamed concrete: a review. In: 3rd International Conference on Innovative Technologies for Clean and Sustainable Development: ITCSD 2020 3. Springer, pp. 113-137.