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Experimental analysis of the resistance of lightweight concrete produced with basalt stone residues

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ABSTRACT

The utilization of residues as aggregates for concrete is relevant, as it reduces the extraction of natural resources, for example, natural sand. The study of basalt stone residues for the production of light concretes is embryonic, however, it is an alternative, because the sand is produced from the crushed basalt rock residue, called crushed sand. Expanded clay is traditionally used by several researchers for the production of lightweight concrete. The present research studied the mechanical resistance of lightweight concrete produced with expanded clay with partial replacement of 20% of natural sand by crushed sand, with plasticizer additive. Two traces were prepared, the first Trace 1 of reference (NS100%) and the second Trace 2 with the replacement of 20% of natural sand by crushed sand (CS20%). Compressive strength and tensile strength by diametrical compression were analyzed. The results show that the concrete produced in the research is promising, as it fulfilled the specifications of NBR NM 35, 1995, and the results of compressive strength, at 7 days, were approximately 23.1MPa (T1) and 22.5MPa (T2), values greater than 17MPa, at 28 days, minimum established for structural lightweight concrete in NBR NM 35, 1995. The replacement of 20% of natural sand by crushed sand caused a 9% reduction in tensile strength by diametrical compression and a 10% reduction in compressive strength in relation to the trace (T1) that does not contain crushed sand.

KEYWORDS: Light concrete. Expanded clay. Crushed sand.

1. INTRODUCTION

The discovery of concrete began in the late 19th century, but its constant use was only in the early 20th century, when it became the most used material by man after water. Concrete revolutionized the way of building and has always been present in the development of civilizations until the current days (HELENE; ANDRADE, 2007, p. 905).

From 1824 to 1970, concrete was basically the mixture of cement, water and simple aggregates, with few changes in their properties. In the last 40 years, with the great technological advances and the need to improve the way of preparing and applying concrete, new materials have appeared as aggregates for concrete (ROSSIGNOLO, 2009).

The construction sector is one of the main agents that degrade the environment, which is why it has been innovating and searching for new materials and construction techniques to then end this negative impact on nature. The emergence of new aggregates for concrete has provided the reuse of materials left by construction and the use of artificial aggregates that do not negatively affect the environment. It is worth mentioning that for the production of 1 ton of cement clinker, 0.5 tonnes of carbon dioxide are required, due to the calcination of limestone and 0.45 tonnes of fuel, thus transforming the common cement industry (Portland Cement) into one of the polluting ones (HELMY, 2016; WANDERLEY, 2018).

According to Viero (2010) despite the great advances in construction, the consumption of raw materials from nature used to elaborate the main construction elements, such as concrete, causes great problems in nature. Problems such as extracting sand from river beds, which is why the construction sector has been looking for alternatives to the use of natural sand in the preparation of structural concretes. One of these alternatives that has been studied is the use of sand produced from crushed basalt rocks called crushing sand.

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According to Aquino (2013), the replacement of natural sand by crushing sand in concrete provides great benefits to the environment by reducing the extraction of natural sand in rivers. It is worth mentioning that the waste from the crushing process of basaltic rocks is used for the production of crushing sand, therefore, an ecological benefit for this by-product.

According to Angelin (2014), the technological evolution in the world has provided new construction methods in the construction sector, thus originating the use of special concretes, especially those made with light aggregates, as they have lower specific mass than conventional concretes, consequently, superior thermal performance.

Structural lightweight concrete elaborated with expanded clay has great advantages regarding to thermal comfort over conventional concretes, and it should be noted that its constant use in seals and covers is due to reduced absorption and heat transfer transmitted by solar radiation (ANGELIN, 2014).

The dry density below 2000 kg / m^3 is one of the characteristics of lightweight concretes compared to conventional concretes and shows significant changes in some properties, such as workability, mechanical strength, deformation and shrinkage module. The thermal properties of lightweight concretes are significantly different from those analyzed in traditional concretes, mainly due to the amount of voids in the cellular structure of lightweight aggregates, such as expanded clay, which reduces heat transfer and absorption compared to traditional aggregates (ROSSIGNOLO, 2009).

Based on the above, the present research evaluated the mechanical properties of lightweight concrete produced with expanded clay as coarse aggregate and the replacement of 20% of natural sand by crushed sand. Tensile strength tests by diametrical compression and compressive strength were performed in order to qualify the laboratory-produced structural lightweight concrete.

2. OBJECTIVES

This research aimed to evaluate the mechanical resistance properties of lightweight concrete made with expanded clay (coarse aggregate) with replacement of 20% of natural sand by crushing sand, with the addition of superplasticizer.

3. METHODOLOGY

The experimental and exploratory research planned the preliminary tests for the production of structural lightweight concrete, with expanded clay, with definition of the quantitative of the inputs required for experimental dosing. In Trace 1 (T1), of reference, it was produced with natural sand (100%), while in Trace 2 (T2), with the replacement of 20% of natural sand by crushing sand.

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The lightweight aggregate of expanded clay is used by several researchers in the production of lightweight concrete with suitable results for mechanical strength, for this reason, it was chosen as a standard feature (reference).

Dosing and tests were performed at the Civil Construction Laboratory at UNESP / FEB / DEC and preliminary tests were performed with 6 repetitions of specimens for each evaluation at 7 days of age, totaling 24 cylindrical specimens.

The tests were performed on concrete in the fresh state (slump test) and in the hardened state (resistance to diametrical traction and resistance to compression) based on the technical standards of ANBT.

3.1 MATERIALS

3.1.1. Cement

Portland cement CPII-E-32 Votoran was used to produce the concrete, with characteristics in accordance with ABNT NBR 11578: 1991.

3.1.2. Aggregates

Natural Sand: Natural Sand: Medium grade quartz sand, free of organic materials, from the Tietê river, in the municipality of Pederneiras, State of São Paulo, was used. Table 1 shows the characteristics of the sand according to the requirements of ABNT NBR 7211/2009.

Table 1: Granulometry of Natural Sand

Granulometric composition - ABNT NBR 7211/2009		
Sieve	% Withheld	% Accumulated
4,8	0,65	0,65
2,4	6,83	7,48
1,2	21,93	29,41
0,6	24,08	53,48
0,3	23,32	77,30
0,15	14,24	91,54
Fundo	8,26	100
Maximum Dimension characteristic	4,8 mm	
Fineness module	2,6	

Source: THE AUTHORS, 2020.

Crushed sand: the material used was the residue from basalt stone, whose extraction site was in Pedreira Nova Fortaleza, located in Pederneiras, state of São Paulo. Table 2 shows the granulometric characteristics of the crushing sand.

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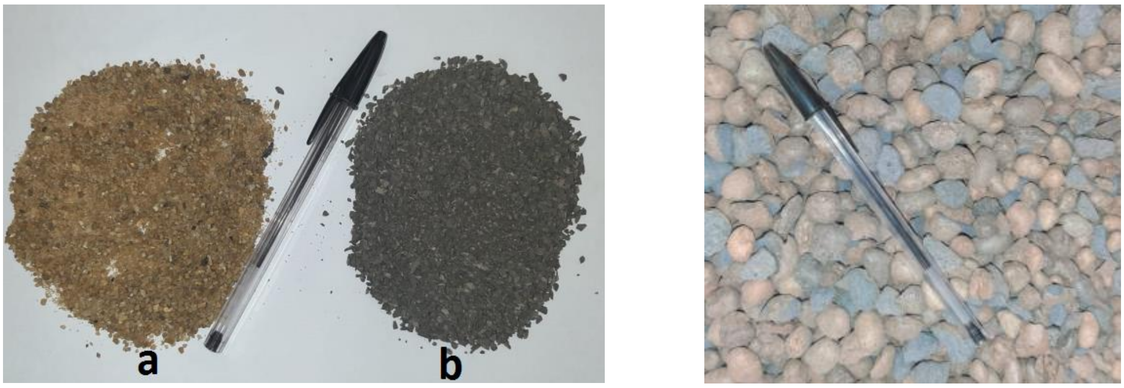
Table 2: Crushed Sand Granulometry

Composição granulométrica- ABNT NBR 7211/2009		
Sieve	% Withheld	% Accumulated
4,8	5,09	5,09
2,4	47,81	52,90
1,2	27,31	80,21
0,6	9,07	89,28
0,3	3,71	92,99
0,15	2,16	95,15
Fundo	4,85	100
Maximum Dimension characteristic	4,8 mm	
Fineness module	4,2	

Source: THE AUTHORS, 2020.

Figure 1 shows the fine aggregates used in the research and figure 2 shows the granulometric curves of the fine aggregates.

Figure 1: Fine aggregates (natural sand and crushed sand) and coarse aggregate



a) Natural Sand b) Crushed Sand Cinexpan expanded clay 1506

Source: THE AUTHORS, 2020.

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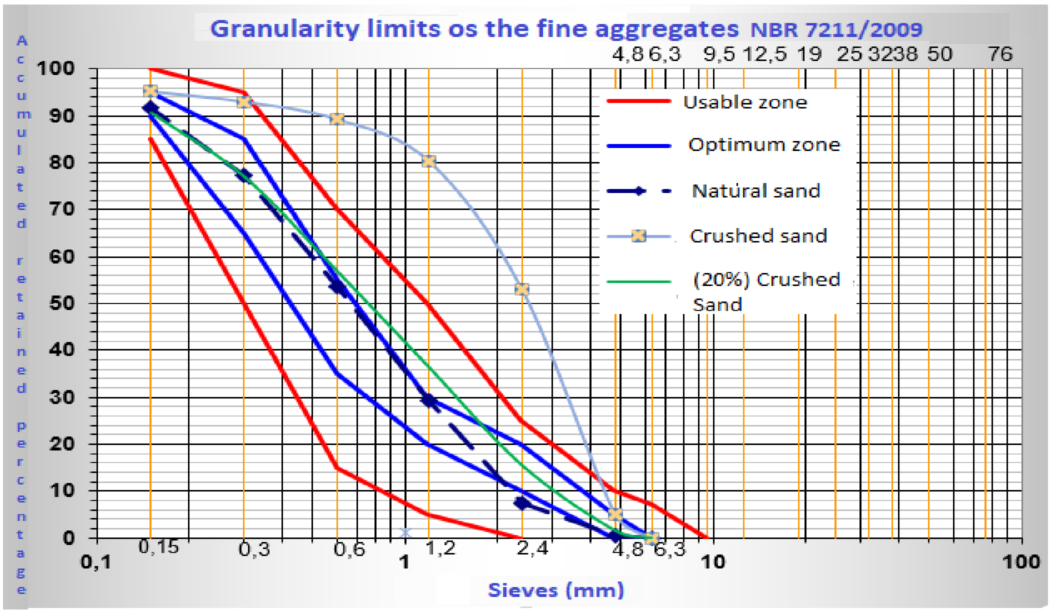
Figure 2: Granulometry of fine aggregates



Source: THE AUTHORS, 2020.

Expanded Clay: the coarse aggregate used was expanded clay 1506 produced by the brazilian company Cinexpan. Table 3 shows the properties of the coarse aggregate.

Table 3: Coarse aggregate properties

Property of Cinexpan 1506 Expanded Clay	
Apparent Density (Kg/m³)	600±10%
Specific Mass (Kg/m³)	1,11
Granulometric variation (mm)	6-15
Mechanical Resistance (MPa)	2,3
Thermal Conductivity (W/m. k)	0,10 a 0,16
Water absorption in 24 hours (%)	7
Acoustic Insulation (dB)	44

Source: CINEXPAN CATALOG, 2020.

Water: in the production of concrete, drinking water from the local supply system - Bauru / SP was used.

Plasticizer Additive: the lignosulfonates plasticizer was used, whose characteristics are shown in table 4.

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Table 4: Characteristics of the Additive

Additive: CEMIX 2000	
Apparent Density (g/cm³)	1,22
Appearance	Dark brown liquid, chlorides free
Basic Composition Variation	Lignosulfonates
pH	9
Odor	Characteristic
Boiling point	100ºC
Flash point	100ºC

Fonte: VEDACIT, 2020.

3.3. CONCRETE DOSING

Table 5 shows the traces of the lightweight concrete produced in the experimental dosage.

Table 5: Lightweight concrete dosages

Traces	Cement (kg/m³)	Natural Sand (Kg/m³)	Crushed Sand (kg/m³)	Expanded Clay (Kg/m³)	Water (Kg/m³)	Additive (%)
1-AN100%	400	840	-	320	155,73	1,50
2-AB20%	400	672	168	320	183,80	1,50

Source: THE AUTHORS, 2020

3.4. CONCRETE PRODUCTION

The process of mixing the materials occurred in the concrete mixer, with a capacity of 350 liters, sequentially, before priming was done. First the expanded clay was placed, then water and the superplasticizer additive, with the concrete mixer in motion, and finally the cement and sand. Then the materials were mixed in the concrete mixer for approximately 5 minutes. After the concrete mixing process in the mixer, the mixture was homogeneous. The slump test was performed according to ABNT NBR 67: 1998, in which the consistency and plasticity of the concrete was verified. The molding of the concrete was carried out in cylindrical specimens of 100 mm in diameter and 200 mm in height and the thickening process was carried out using a vibrating table. After 24 hours of concrete curing, the specimens were demoulded and then to the wet chamber for the wet curing process. The specimens remained in the humid chamber for 7 days, after which they were tested.

4. RESULTS AND DISCUSSIONS

4.1. Tensile strength diametrical compression

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The results of tensile strength by diametrical compression were determined at the age of 7 days, using 6 cylindrical specimens of 100 mm in diameter and 200 mm in height for each trace, as required in ABNT NBR 7222: 2001. Figure 2 illustrates the tensile strength test performed by diametrical compression. Figure 3 illustrates the specimens after rupture by diametrical traction, there was no segregation of the light aggregate. Table 6 shows the results of trace 1 (NS100%) and table 7 presents the results of trace 2 (20%).

Figure 3: Tensile strength test by diametrical compression

Source: THE AUTHORS, 2020.

Figure 4: Specimens after rupture

Source: THE AUTHORS, 2020.

Table 6: Results for Trace 1 (NS100%)

	Breaking force (KN)	Breaking stress (MPa)
Minimum value	4265	13,58
Maximum value	7865	25,03
Average	5850	18,62
Standard Deviation (S)	1480	4,712
Coefficient (%)	25,31	25,31

Source: THE AUTHORS, 2020

Table 7: Results for Trace 2 (CS20%)

	Breaking force (KN	Breaking stress (MPa)
Minimum value	4589	14,61
Maximum value	6057	19,28
Average	5377	17,11
Standard Deviation (S)	503,04	1,602
Coefficient (%)	9,362	9,362

Source: THE AUTHORS, 2020

Figure 5 shows the values of tensile strength by diametrical compression of the two traces at the age of 7 days.

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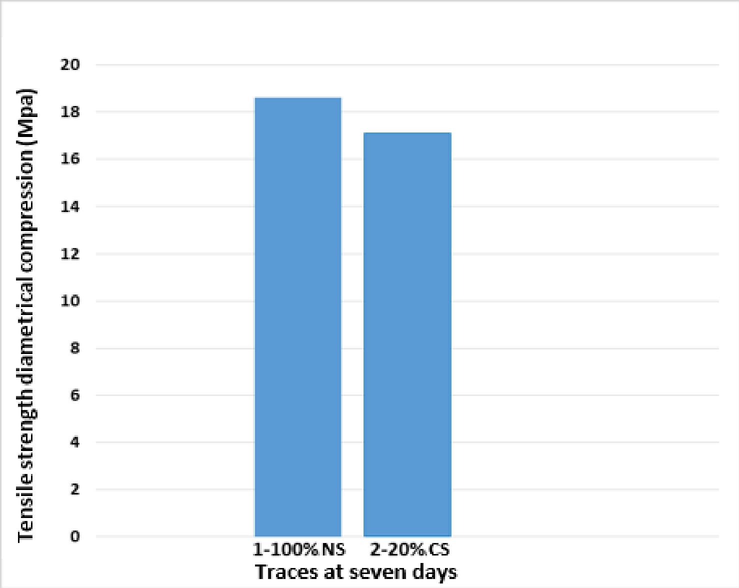
Figure 5: Result of tensile strength by diametrical compression



Source: THE AUTHORS, 2020

As the figure illustrates, there was a decrease of 9% of the mix with 20% replacement of natural sand by crushed sand in relation to the reference mix (AN100%).

4.2. Compressive strength

The results of compressive strength were determined at the age of 7 days, using 6 cylindrical specimens of 100 mm in diameter and 200 mm in height for each line, according to ABNT NBR 5739: 2007. Figure 6 illustrates the compressive strength test and figure 7 illustrates the specimens after compression rupture, in which it is possible to observe the types of rupture. Tables 8 and 9 show the results of compressive strength for the studied traces. Figure 8 shows the results of compressive strength of the traces.

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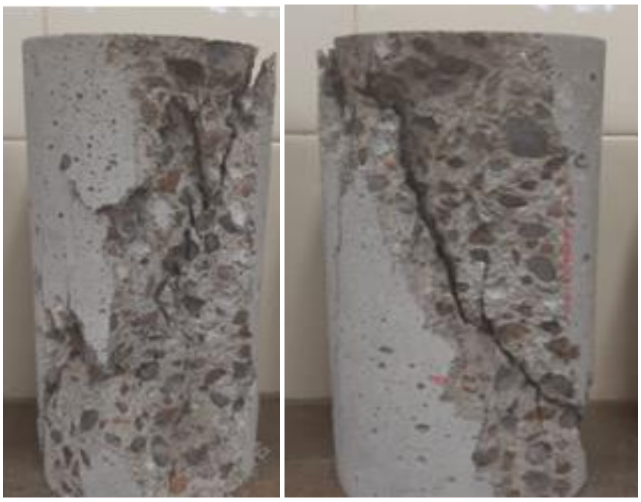
Figure 6: Compressive strength test

Source: THE AUTHORS, 2020.

Figure 7: a) Type D - Conical and Sheared and b) Type E - Sheared



(a) (b)

Source: THE AUTHORS, 2020.

Table 8: Results for trace 1 (NS100%)

	Breaking force (KN)	Breaking stress (MPa)
Minimum value	15550	19,41
Maximum value	21360	26,57
Average	18620	23,08
Standard Deviation (S)	2554	3,258
Coeficiente (%)	13,72	14,12

Source: THE AUTHORS, 2020.

Table 9: Results for trace 2 (CS20%)

	Força de ruptura (KN)	Tensão de ruptura (MPa)
Minimum value	16760	20,83
Maximum value	21730	25,27
Average	18580	22,53
Standard Deviation (S)	1842	1,787
Coefficient (%)	9,913	7,933

Source: THE AUTHORS, 2020.

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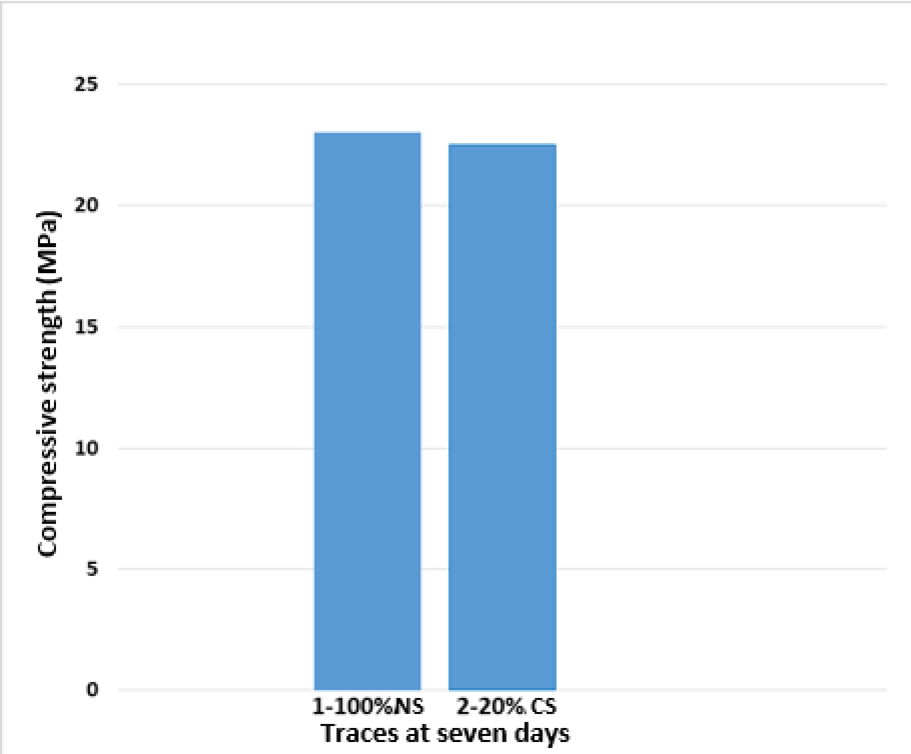
Figure 8: Results of compressive strength



Source: THE AUTHORS, 2020.

It can be noted that the replacement of 20% of natural sand by crushed sand resulted in a 10% reduction in compressive strength in relation to the trace that does not contain crushed sand. Although there is a reduction in the compressive strength, the crushed sand showed adequate results for the production of lightweight concrete, as the compressive strength values for all mixes at 7 days exceed the minimum value of 17 MPa at 28 days, established by NBR NM 35, 1995 in item 4.3.1.1.

6. CONCLUSION

The research showed acceptable results for the parameters evaluated of resistance to diametrical compression and resistance to compression, at 7 days of age, for the exploratory study of experimental dosage of lightweight concrete produced with expanded clay with replacement of fine aggregate of natural sand by 20% of crushed sand. The sequence of studies will evaluate the parameters at 28 days, to affirm the potential for structural use of the lightweight concrete produced. It is important to observe that the strokes produced, at 7 days of age, have already reached the minimum resistance suggested in Brazilian technical standards.

6. ACKNOWLEDGMENTS

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7. REFERENCES

ABREU, F. de S. **Análise da Durabilidade de Concreto Leve de Argila Expandida com Camada Protetora Submetida a Meio Agressivo Ácido**. Dissertação (Mestrado) - Escola de Engenharia, Universidade Federal de Minas Gerais, 2014.

ANGELIN, A. F. **Concreto leve estrutural: Desempenhos físicos, térmicos, mecânicos e microestruturas**. Dissertação (Mestrado) - Faculdade de Tecnologia, Universidade Estadual de Campinas, 2014.

ÂNGULO, S. C.; FIGUEIREDO, A. D. Concreto com agregados reciclados. *In*: ISAIA, G. C. (Org.). **Concreto**: ciência e tecnologia. São Paulo: IBRACON, 2011. v. 2, p. 1731-1767.

AQUINO, J. L. S. **Desenvolvimento de Compósitos de Matriz Cimentícia Utilizando Resíduos de Politereftalato de Etileno (Pet) e de Areia de Britagem na Produção de Concretos**. Tese (Doutorado)- Universidade Federal de Campina Grande, 2013.

ARAUJO, E. C., DIAS, F. M. Massa Específica e Absorção de Água de Concretos Manufaturados com Agregados Alternativos. **Revista IBRACON de Estruturas e Materiais**, *[S. l.]*, v. 4, p.764-783, 2011.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, **NBR 5739**, Concreto – Ensaio de Compressão de Corpos de Provas Cilíndricos, Rio de Janeiro, 2018.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, **NBR 9778**, Argamassa e concreto endurecidos - Determinação da absorção de água, índice de vazios e massa específica, Rio de Janeiro, 1987.

ASSUNÇÃO, J. W. **Concreto Leve Auto adensável**: Avaliação da Influência da Argila Expandida do Processo de Dosagem e nas Propriedades do Concreto. Dissertação (Mestrado) – Instituto de Arquitetura e Urbanismo, Universidade de São Paulo, 2016.

BASTOS, S. R. B. **Uso da Areia Artificial Basáltica em Substituição Parcial à Areia Fina Para a Produção de Concretos Convencionais.** Dissertação (Mestrado)- Universidade Federal de Santa Catarina, 2002.

BORJA, E. V. de. **Efeito da Adição de Argila Expandida e Adições de Minerais na Formulação de Concretos Estruturais Leves Auto adensáveis**. Tese (Doutorado)- Centro de Tecnologia. Universidade Federal do Rio Grande do Norte, 2011.

CABRAL, K. O. **Influência da Areia Artificial Oriunda da Britagem de Rocha Granito-Gnaisse nas Propriedades do Concreto Convencional no Estado Fresco e Endurecido**. Dissertação (Mestrado) - Escola de Engenharia Civil, Universidade Federal de Goiás, 2007.

CARNEIRO, S. S.; RIBEIRO, J. M. S.; MOREIRA, K. M. V. Areia de Britagem como Agregado Miúdo em Concretos. Encontro Nacional Sobre Aproveitamento de Resíduos na Construção, 5., 2017, Fortaleza CE. **Anais** […]. Ceará: UniChristus, 2017, p. 168-182.

CHUNG, S.-Y. *et a*l. Evaluation of the effects of crushed and expanded waste glass aggregates on the material properties of lightweight concrete using image-based approaches. **Materials**, *[S. l.]*, v.10, 2017

DRAGO, C.; VERNEY, J. C. K. de; PEREIRA, F. M. Efeito da Utilização de Areia de Britagem em Concretos de Cimento Portland. **Revista Escola de Minas**, *[S. l.]*, v. 62, n. 3, p. 399-408, 2009.

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Gerenciamento de Cidades
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ANAP

FABRO, F. *et al*. Influência da Forma dos Agregados Miúdos nas Propriedades do Concreto. **Revista IBRACON de Estruturas e Materiais**, *[S. l.]*, v. 4, p.191-212, 2011.
GOMES, P. C. C. *et al*. Obtenção de Concreto Leve Utilizando Agregados Reciclados. **Ambiente Construído**, Porto Alegre, v. 15, n. 3, p. 31-46, 2015.

HELENE, P.; ANDRADE, T. Concreto de Cimento Portland. *In*: ISAIA, G. C. (Org.). **Materiais de construção civil e princípios de ciência e engenharia de materiais**. São Paulo: IBRACON, 2007. v. 2, p. 905-944.

HELMY, A. I. I. Intermittent curing of fly ash geopolymer mortar. **Construction and Building Material**, *[S. l.]*, v. 110, p. 54-64, 2016

LANG, C. L. **Avaliação do uso de Areia Britada de Origem Basáltica Lavada e não Lavada para Utilização em Concreto à Base de Cimento portland**. Dissertação (Mestrado) - Universidade Federal de Santa Catarina, 2007.

LYRA, G. P. **Agregados Leves de Cerâmica Vermelha com Incorporação de Cinza do Bagaço de Cana-De-Açúcar Sinterizados em Fornos de Micro-ondas**. Dissertação (Mestrado) - Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo, 2019.

MORAVIA, W. G. *et al*. Caracterização Microestrutural da Argila Expandida para Aplicação como Agregado em Concreto Estrutural Leve. **Cerâmica**, *[S. l.]*, v. 52, p. 193-199, 2006.

MORAVIA, W. G.; GUMIERI, A. G.; VASCONCELOS, W. L. Fator de Eficiência e Módulo de Elasticidade do Concreto Leve com Argila Expandida. **Revista IBRACON de Estruturas e Materiais**, *[S. l.]*, v. 3, p. 195-204, 2010.

OLIVEIRA, A. de.; GARCIA, S. L. G.; CORDEIRO, G. C. Avaliação do Desempenho Estrutural em Serviço de Lajes Treliçadas Pré-moldadas de Concretos com Agregados Leves. **Ambiente Construído**, Porto Alegre, v. 11, n. 4, p. 37-45, 2011.

ROSSIGNOLO, J.A. **Concreto leve estrutural: Produção, propriedades, microestrutura e aplicações**. São Paulo: Editora PINI, 2009.

SACHT, H.M.; ROSSIGNOLO, J.A.; SANTOS, W.N. Avaliação da condutividade térmica de concretos leves com argila expandida. **Revista Matéria**, *[S. l.]*, v. 15, n. 1, p. 31-39, 2010.

SARTORI, A. L. *et al*. Aderência entre barras de aço e concreto leve com pérolas de EPS. **Revista Ibracon de Estruturas e Materiais**, *[S. l.]*, v. 10, n. 1, 2017.

VIERO, E. H. **Aplicação de Areia de Britagem de Rochas Basálticas na Fabricação de Concreto de Cimento Portland**. Dissertação (Mestrado) –Universidade de Caxias do Sul, 2010.

WANDERLEY, G. V. **Produção de Material para Enchimento Leve de Elementos das Edificações a partir da Mistura de Geopolímero com Argila Expandida**. Dissertação (Mestrado) –Centro Acadêmico do Agreste, Universidade Federal de Pernambuco, 2018.