FEASIBILITY OF USING INDUSTRIAL BOILER ASH IN THE DOSING OF STRUCTURAL CONCRETE

ORIGINAL ARTICLE

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ABSTRACT

Industrialization and accelerated population growth generate side effects on various social aspects, and the environmental issue is worrisome due to the impacts caused by social evolution. The management of industrial waste is a great challenge that involves both control of its generation and the proper disposal, ensuring environmental sustainability. Boiler ash residue is found in abundance in factories that use this equipment for steam generation. This abundance occurs due to the lack of a place for proper disposal or reuse of the residue. In view of this scenario, this article had as a guide question: Would it be possible to use this residue in the production of structural concrete? The aim of this study was to classify the residue by defining its possible form of use in concrete dosage and to perform experimental dosages with the use of industrial boiler ash to evaluate its possible technical contributions to basic properties of concrete. For this, samples were collected by an industry installed in the city of Uberlândia, State of Minas Gerais, active in several sectors such as agriculture, animal nutrition, pharmaceutical and others. The

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classification of boiler ash was performed by applying the Brazilian normative procedures and parameters used for classification of binders and aggregates for concrete. Considering its granulometric curve and density, the residue was classified as light and very thin aggregate, thus adopting the methodology of partial replacement of the thin aggregate by boiler ash. It was verified that there was a reduction in the workability of concrete in the fresh state proportionally to the residue content used. Therefore, it is necessary to use superplasticizer additives in these cases to maintain the expected workability. A reduction in the density of concrete was noticed when the residue was used, considering as necessary the attention to this property of the concrete in relation to the content used of the residue in the dosage. It was also observed when comparing the dosages with the use of the residue at the standard dosage, that there was a reduction in compressive strength. However, there was no great variation in compressive strength between the dosages with different substitution levels used. It was concluded, therefore, considering the levels used in this study, as feasible the use of this residue in the production of structural concrete.

Keywords: Concrete, Biomass, Industrial Boiler Ash.

1. INTRODUCTION

The Industrial Revolution begun in England in the 18th century from the creation of the steam engine by Scottish engineer James Watt, boosted British industrialisation in order to transform the production system. This period according to Cavalcante (2011) "was the precursor of capitalism, that is, the transition from commercial capitalism to industrial capitalism". This means that, in this context, the manufacturing regime, previously used, is replaced by the maquinio regime, resulting in much more agile production processes capable of putting mass production into practice, ensuring greater product supply and low production costs, comparing to the previous scenario.

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The transformations that occurred during the Industrial Revolution expanded globally and accompanied the evolution of society over time, modernizing and improving production practices over the years. However, with the progress of the industrialization process, the world population growth and consequently the high demand for products, the consumption of natural resources grows proportionally to this demand, since these resources serve as raw material for manufacturing processes.

The accelerated growth process generates, therefore, as side effects, the environmental impacts caused by the exploitation of natural resources, without proper management focused on the maintenance and conservation of the environment. "The exploitation of natural resources has become predatory in favor of obtaining capital" (GANZALA, 2018).

The negative effects of industrialization throughout the 20th and 21st centuries related to the environment are not only linked to the unsustainable consumption of natural resources involved in production processes, but also to water, soil and air pollution caused by waste or waste generated by industrial processes. This reality is observed both in developed and developing countries.

Several industrial processes use equipment called steam generation boilers in the production process of various sugar and alcohol industries, drying and parboiling factories of grains, refrigerators, metallurgical industry, textile and in the energy generation sector. The most common type of boiler currently used is the so-called biomass boiler. These boilers use as combustion material the different forms of biomass such as: pine, eucalyptus, rice husk and sugarcane bagasse. After burning the biomass, boiler ash is generated as waste, so the boiler ash consists of the burn-resistant part, present in the composition of the biomass used as fuel in industrial boilers.

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The industries that use the boilers, aiming at energy efficiency and the economic factor, apply controls of biomass burning processes, which reduce the generation of this type of waste as much as possible. However, the generation of waste is inevitable in this process. Therefore, the availability of this residue becomes abundant. In these industries, large deposits of this material are accumulated due to the lack of alternatives for the destination or reuse of it. These deposits occupy large physical spaces in the production plants, which could be better used, considering the end activity of the industry in question.

In the scenario found of high availability of the gray boiler residue and the lack of a suitable disposal site or activity for reuse of the residue, the fundamental question arises for the development of this study: would it be possible to use this residue in the production of structural concrete? Considering the accelerated pace of the construction sector and its search for innovations, the waste generated could be reused in this segment as a sustainable alternative, with the possibility of promoting technical and economic benefits for both the waste generating industry and concrete producing companies.

The environmental contribution is the main and most significant achievement with the use of ash residue from industrial boilers in the production of structural concrete, because there would be a double environmental contribution to avoid the disposal of waste in the environment, and, if verified the possibility of its application as a partial replacement of natural aggregates, it would avoid the extraction of part of these natural resources, that are becoming scarcer.

Concrete producing companies have as a characteristic use of raw materials, that is, without the need for large processing processes, such as natural sands, which are extracted from rivers or deposits, and require simple processing such as sieving for removal of impurities and particle size classification. Therefore, the use of waste in concrete production has an economic contribution both to the waste generating industry, which provides the waste without the need for large processing processes,

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and for concrete producing companies, which would benefit from the high availability of waste and its low cost, being used as raw material in its production.

The general objective of this study is to perform the preliminary classification of the ash residue of industrial boiler, define its possible way of use in the dosage of concrete, perform experimental dosages to verify the performance of basic properties of the dosed concrete with the use of chair ash, evaluating possible technical contributions and, finally, to conclude the feasibility of the use of this residue for dosage of structural concrete.

2. METHODOLOGY

The initial conception of the possibility of making it feasible to use boiler ash for concrete production arises from the idea that, originally, only three basic materials were used in concrete production: cement, aggregate and water. However, for better performance both in the fresh and hardened state, the use of chemical additives was initiated. After some time, the use of cementitious materials of an organic nature was introduced in this context as additions to the mixture of concrete as granulated blast slag, pozzolans, silica smoke and fly ash.

The initial reasons for using these materials were usually economical: they cost less than Portland cement, often because they existed in natural deposits, requiring little or no processing, other times because they were by-products or rejects of industrial processes (NEVILLE, 1997, p. 81).

"The fly ash is the result of boilers in the process of burning coal in which part of the mineral matter clusters forming grid ash, but most of it is dragged by the exhaust current of the gas, which is called fly ash" (MEHTA; MONTEIRO, 1994).

This study was carried out in April 2021, through research for innovations for the concrete production segment in the region of Uberlândia, state of Minas Gerais, where a large number of industries installed in this locality were observed, which

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used boilers as a means of generating steam in their production processes and, therefore, there was great availability of boiler ash, as well as the great need for adequate environmental disposal or reuse of the waste.

2.1 SAMPLE AND CHARACTERIZATION OF ASH

The sample of the material used in this study was provided by a large industry installed in the municipality of Uberlândia, State of Minas Gerais, operating in several sectors such as agriculture, animal nutrition, pharmaceutical and others. The ashes resulting from the burning process of eucalyptus biomass are mixed with water to avoid atmospheric dispersion, and conducted in the decanting process, where the sample was collected. Therefore, the collected material presents high moisture content, visually verified by the free water present superficially in the collected sample, in addition to the water absorbed by the material itself.

After the sample collection and its conduction to the materials laboratory, the drying process of the material was carried out to start its basic characterization. Due to the high moisture content observed in the sample, it was necessary to start the drying process by spreading the outdoor material over a plastic lining, avoiding contamination and dispersions of the same. After partial drying outdoors, the material was taken to the greenhouse to finish the drying process.

The fineness index was determined by sieve number 200, according to NBR 11579 ABNT (2012). During the performance of this test, it was observed that in the material retained in sieve number 200, most of them consisted of fine material, but the presence of particles with larger particle size dimensions was observed, but in a small proportion. The fineness index found for the material was 46%. This index was considered high, compared to Portland cement, which has this maximum index of 10%, established by NBR 16697 (ABNT, 2018).

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The apparent specific mass was determined according to NM 52 ABNT (2009). The ash presented apparent specific mass of 0.26 g/cm^3 . For Bauer (2008), aggregates can be classified according to their specific weight. Therefore, the ash was classified, in this aspect, as light aggregate, and the specific weight found was equivalent to the specific weight of light aggregates known, as an example of light aggregate to vermicusite, which has a specific weight of 0.3 g/cm^3 .

The granulometric characterization was performed according to NBR NM 248 ABNT (2003). The ash presented granulometric distribution according to Table 1, fineness module of 0.74 and maximum dimension of 1.2 mm.

Table 1 - Boiler Grey Granulometric Distribution

Sieve (mm)	#	Retained (%)	Accumulated (%)
2,4		0,80	0,80
1,2		2,47	3,27
0,6		5,74	9,01
0,3		12,23	21,24
0,15		18,43	39,67
Bottom		60,33	***

Source: Author (2021).

Based on the basic characteristics verified, we tried to assign initial classification of the ash to define its application form in concrete dosages. Two possibilities described below were initially considered.

The first possibility of using ash would be to incorporate it into the concrete dosage as addition, starting as reference the additions of materials as an example of active silica, widely used in the production of high performance concrete and to potentiate

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specific properties of concrete, such as mechanical resistances, mainly. However, due to the verified profile of the ash in the determination of its fineness index and granulometric distribution, this possibility was ruled out due to the incompatibility of its characteristics with this type of addition.

As a second possibility of using ash, its possible introduction as a replacement of aggregates in the concrete dosage was verified. The results obtained in relation to the specific weight were observed and, as already reported, it was framed as a light aggregate. Another characteristic analyzed, considering this possibility of use was the classification of the ash in relation to the granulometric range in which it was framed, based on Table 2.

Table 2 — Classification of Sands by Granulometric Ranges

Retained Percentages				
Sieves (mm)	Track 1 - Very Thin	Track 2 - Thin	Track 3 - Medium	Track 4 - Thick
6,3	0 to 3	0 to 7	0 to 7	0 to 7
4,8	0 to 5	0 to 10	0 to 11	0 to 12
2,4	0 to 5	0 to 15	0 to 25	5 to 40
1,2	0 to 10	0 to 25	10 to 45	30 to 70
0,6	0 to 20	21 to 40	41 to 65	66 to 85
0,3	50 to 85	60 to 88	70 to 92	80 to 95
0,15	85 to 100	90 to 100	90 a100	90 to 1

Source: Bauer (2008).

The granulometric distribution of the ash presented in Table 1 was not fully framed in any of the classification ranges described in Table 2. However, characteristics similar to the distribution classified as track 1 - Very Thin were noted, fitting in this range the

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percentages retained in the sieves with opening 2.4 mm, 1.2 mm and 0.6 mm. In the other sieves, the retained percentages remained below those specified in Table 2. A high concentration of material was observed at the bottom of the sieve series, i.e., passing material in the sieve with an opening of 0.15 mm.

It was verified, therefore, that the ash presented granulometric distribution very close to band 1 - Very Thin, but with a significant percentage of material thinner than predicted in this granulometric range, that is, tending to a previous range, if there were.

The fineness module of 0.74, obtained by the granulometric characterization of the ash, as already reported, reinforced the classification of ash in a range before band 1 - Very Thin, since the minimum fineness module for classification in this range would be 1.35 (BAUER, 2008).

Due to the incompatibility of the ash with the fineness index of traditionally used additions and their partial classification as a very thin aggregate, we chose, therefore, to study the possibility of replacing very thin aggregates with ash in the concrete dosage.

2.2 STANDARD STROKE AND REPLACEMENT LEVELS

The definition of the trait to be used as standard was based on the characteristics of the ash, previously determined. The default stroke should contain in its composition the aggregate classified as very thin, which would be replaced by gray.

The increase in water consumption in the dosage due to the addition of ash was a point of attention in the definition of the standard stroke, because taking into account Neville's warning (1997) "rice straw ash has complex shapes, according to the plant of origin and, therefore, require a lot of water.", it was observed the time required for drying the boiler ash sample and it was considered that due to its origin and specific

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surface, possibly the addition of ash would increase water consumption at dosage in relation to the standard dosage.

To combat the increase in water consumption in dosages with the addition of ash, it is recommended by Neville (1997) to use superplasticizer additives to achieve the expected workability. Therefore, we chose to define the standard trait with the use of this type of additive.

The standard stroke was adopted with compressive strength required of 25 MPa and scattering between 600 and 650mm, determined according to NBR 15823-2 ABNT (2017). The following proportions were found for the unit mass trait: 1 : 0.59 : 2.21 : 1.11 : 2.60 , with a/c ratio equal to 0.58, the quantitative for mixing according to Table 3 was obtained.

Table 3 — Standard Stroke 25.0 MPa Scattering 600 to 650 mm

Cement	10	Kg
Very Fine Sand	5,88	Kg
Middle Sand	22,10	Kg
Gravel 0	11,12	Kg
Gravel 1	25,96	Kg
Plasticizing Additive	0,035	L
Superplasticizer Additive	0,10	L
Water	5,8	L

Source: Author (2021).

The aggregate named as "very fine sand" in Table 3 was the aggregate adopted as replaceable by boiler ash. The aggregate presented in its granulometric distribution, fineness module of 1.42, classifying in the granulometric range 1, which comprises

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aggregates with fineness modulus between 1.35 and 2.25. Therefore it was classified as very thin aggregate (BAUER, 2008).

The replacement of the very fine aggregate by ash was partially performed, i.e., adopting random and progressive substitution levels, in order to provoke the observation of the possible influences caused by the replacement of the aggregate by boiler ash. As a starting point, substitution levels of 10%, 20% and 30% were adopted on the very fine aggregate mass present in the standard trait dosage already presented in Table 3.

Table 4 shows the mass unit traits adopted for each substitution content established.

Table 4 - Mass unit traces adopted according to the replacement content of the very fine aggregate by boiler ash

Aggregate replacement content for ash	Mass unit trait
10%	1 : 0.06 : 0.53 : 2.21 : 1.11 : 2.60 a/c = 0.58
20%	1 : 0.12 : 0.47 : 2.21 : 1.11 : 2.60 a/c = 0.58
30%	1 : 0.18 : 0.41 : 2.21 : 1.11 : 2.60 a/c = 0.58

Source: Author (2021).

2.3 EXPERIMENTAL DOSAGES AND EVALUATIONS CARRIED OUT

Experimental dosages were performed in the laboratory using stationary electric concrete mixer. First, the standard trait was dosed in Table 3, and then the other traits with the respective substitution levels adopted, presented in Table 4.

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As the main evaluation criterion, the possible influences of the introduction of boiler ash in the dosages in relation to the properties were adopted: workability of the concrete in the fresh state, density and compressive strength.

To evaluate the influence of ash introduction on the dosage in relation to the workability of concrete in the fresh state, the assay was performed in all dosages to determine the initial consistency by the abatement of the cone trunk, according to NBR 16889 ABNT (2020). The initial consistency adopted as standard was between 40mm and 60mm. After reaching the initial consistency, the superplasticizer additive was added to the dosages with the objective of increasing the workability and reaching the spread between 600 and 650mm, which was determined in all dosages according to NBR 15823-2 ABNT (2017).

Regarding density, it was determined according to NBR 9833 ABNT (2008).

The evaluation of compressive strength was performed through moldings of cylindrical specimens with dimensions of 10x20mm, according to NBR 5738 ABNT (2016). Two specimens of each series were submitted to the test to determine axial compressive strength at the ages of 7 days, 14 days and 28 days, according to NBR 5739 ABNT (2018).

2.4 RESULTS AND DISCUSSIONS

In the standard trait dosage, it was observed that the water predicted in the trait was sufficient to achieve the initial consistency, because the initial consistency index of 52mm was obtained. Thus, the superplasticizer additive was introduced to the mixture and the mixing time of 8 minutes after the dosage of the superplasticizer additive was established. This mixing time is the average time determined by the manufacturer to contemplate the full effect of the additive. After the mixing time, the spreading was determined and 620mm was obtained as a result, that is, within the previously established parameters.

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After the standard trace dosage, the trace was dosed with a replacement content of 10% of the very thin aggregate by boiler ash. In this dosage, using the same amount of water in relation to the standard trait, an initial consistency index of 49mm was obtained. It was noted, therefore, that the introduction of ash caused a slight fall in initial consistency of the concrete. However, being still within the parameters initially established, the superplasticizer additive was dosed and respecting the standard time of 8 minutes for mixing, the spreading was subsequently determined and 600 mm of opening was obtained.

In sequence, the trace was dosed with a replacement content of 20% of the very thin aggregate by boiler ash. With the same amount of water used in the previous dosages, the initial consistency index of 50mm was obtained. With the dosage of the superplasticizer additive and the end of the standard mixing time, the opening of 600mm was spread, i.e., a behavior very similar to the previous dosage, with a replacement content of 10 % of the very fine aggregate by boiler ash.

Finally, the trace was dosed with a replacement content of 30% of the very fine aggregate by boiler ash. Maintaining the amount of water of the previous dosages, the initial consistency index of 38mm was obtained, i.e., below the initial parameter established. In this case, it was observed that the introduction of ash in the mixture interfered in the initial consistency as warned by Neville (1997), but we opted for the dosage sequence because the initial consistency index obtained was very close to the established lower limit, which was 40mm. After the dosage of the superplasticizer additive and the end of the mixing time, 560mm was spread. Therefore below the parameter initially.

In the specific case of the dosage with a replacement content of 30% of the very fine aggregate by boiler ash, it was decided to increase the dosage of the superplasticizer additive in order to achieve the minimum predetermined mirroring. Therefore, the dosage of the superplasticizer additive was increased from 1% to 1.5% on the weight of cement. After this addition of additive the mixture and respected again the mixing

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time for total action of the additive, the spreading of 610mm was obtained, that is, fitting the pre-established parameters. Workability is very important property, because "a mixture of concrete that cannot be easily thrown or dense in its entirety will not provide the expected strength and durability characteristics" (MEHTA; MONTEIRO, 1994).

The densities found according to NBR 9833 ABNT (2018) are presented in Table 5.

Table 5 - Determined densities

Series identification	Density (kg/m ³)
Standard stroke	2335
Dash with 10% Gray	2078
Dash with 20% Gray	2070
Dash with 30% Gray	2066

Source: Author (2021).

It was observed that there was a drop of 11% density, comparing the standard trace to the trace with replacement content of 10% of the very fine aggregate by boiler ash. For the following traits, with substitution levels of 20% and 30%, the density decreases recorded were of the order of 0.4% and 0.2%, respectively, comparing the trait analyzed to the trait before it, considering the gradual and progressive order of the contents of replacement of the very thin aggregate by boiler ash.

The results found in the tests to determine axial compressive strength are presented in Table 6.

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Table 6 — Compression Strength (MPa) per series

Series/Age/Compression (MPa)	Resistance	7 days	14 days	28 days
Standard stroke		18,1	21,0	30,3
Dash with 10% Gray		14,6	18,0	19,6
Dash with 20% Gray		15,2	18,3	20,2
Dash with 30% Gray		14,6	18,5	19,8

Source: Author (2021).

It was verified by the results obtained that the dosages with the use of boiler ash showed lower compressive strengths than the standard trait adopted in all tested ages. The mean drop in compressive strength of the traces using boiler ash in relation to the standard stroke was presented as shown in Table 7.

Table 7 - Percentage of compression resistance drop in relation to the standard stroke

Trait/Age	7 days	14 days	28 days
Dash with 10% Gray	19%	14%	35%
Dash with 20% Gray	16%	13%	33%
Dash with 30% Gray	19%	12%	35%

Source: Author (2021).

It was observed that in all traits with the use of ash, the percentage of drop in compressive strength in relation to the standard stroke behaved similarly independently of the substitution content used.

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Regarding the color of the dosed concretes, it was found that both in the fresh and hardened state, the content of very fine aggregate replacement by boiler ash influenced evidently in this visual aspect, because due to the color of the boiler ash being similar to that of Portland cement, the concretes with higher levels of ash use were visually presented as concrete with higher cement consumption, that is, with darker color the higher the replacement content adopted.

3. FINAL CONSIDERATIONS

The industrial boiler ash was classified as light and with granulometric range slightly below the very thin range, both classifications are applied to aggregates, so its application was concluded as light aggregate and very thin.

With an increase in the content of the aggregate replacement by industrial boiler ash in the dosage, there was an influence on the workability of the concrete, observed by the reduction of the initial abatement and on the final scattering. Therefore, it was concluded the importance of adopting the method of partial replacement of the aggregate for the use of industrial boiler ash, since the total replacement of the aggregate was adopted, possibly there would be an even greater impact on this property of concrete in the fresh state.

The important contribution of the superplasticizer additive in the dosages with the use of industrial boiler ash was concluded, with the objective of compensating for the loss of workability caused by the use of boiler ash. It was understood that with plasticizing additives, it would not be possible to achieve satisfactory workability in the concretes dosed with the industrial boiler ash due to the nature of the ash and its large specific surface, which results in higher water consumption in the dosages.

Regarding density, it was concluded that with the substitution of the aggregate by industrial boiler ash, there was a decrease in density related to the increase in the replacement content, that is, the higher the content of replacement of the aggregate

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by the industrial boiler ash, the lower the density verified. It was considered very important in future dosages to observe the influence caused by the use of industrial boiler ash in the dosages in relation to this concrete property.

The performance of compressive strength of the concretes dosed with industrial boiler ash was similar regardless of the variations in the replacement content of the aggregate. However, there was a decrease in this property in relation to the standard trait, that is, without the use of the residue. Therefore, this reduction of resistance should be considered in future dosages when it comes to dosing-to-dosage compared without the use of residue.

It was concluded, therefore, that the use of industrial boiler ash in the measurement of structural concrete is feasible, because satisfactory characteristics were achieved in relation to workability and performance of compressive strength according to normative parameters. Therefore, through this study, it was possible to identify initial behaviors of the concrete dosed with boiler ash and to prove the feasibility of using this residue.

It is understood that it will be necessary to continue the research for improvements, ensuring the good performance of concrete in the fresh and hardened state, as well as during the useful life of the buildings.

REFERENCES

Associação brasileira de normas técnicas. **NBR 11579**: Cimento Portland - Determinação do índice de finura por meio da peneira 75 um (nº 200). Rio de Janeiro, 2012.

Associação brasileira de normas técnicas. **NBR 15823-2**: Concreto autoadensável: Parte 2 - Determinação do espalhamento, do tempo de escoamento e do índice de estabilidade visual - Método do cone de Abrams. Rio de Janeiro, 2017.

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Available in: <https://www.nucleodoconhecimento.com.br/civil-engineering/structural-concrete>

Associação brasileira de normas técnicas. **NBR 16889**: Concreto - determinação da consistência pelo abatimento do tronco de cone. Rio de Janeiro, 2020.

Associação brasileira de normas técnicas. **NBR 5738**: Concreto - procedimento para moldagem e cura de corpos de prova. Rio de Janeiro, 2016.

Associação brasileira de normas técnicas. **NBR 5739**: Concreto - ensaio de compressão em corpos de prova cilíndricos. Rio de Janeiro, 2018.

Associação brasileira de normas técnicas. **NBR NM 248**: Agregados - Determinação da composição granulométrica. Rio de Janeiro, 2003.

Associação brasileira de normas técnicas. **NM 52**: Agregados - Determinação da massa unitária e volume de vazios. Rio de Janeiro, 2009.

Associação brasileira de normas técnicas. **NBR 9833**: Concreto fresco — Determinação da massa específica, do rendimento e do teor de ar pelo método gravimétrico. Rio de Janeiro, 2008.

Bauer, Luiz Alfredo Falcao. **Materiais de construção**. Rio de Janeiro: LTC, 2008.

Cavalcante, Zedequias Vieira. **A Importância da Revolução Industrial no Mundo da tecnologia**. Unicesumar . Maringá, 2011. Encontro Internacional de Produção Científica. Disponível em: https://www.unicesumar.edu.br/epcc-2011/wp-content/uploads/sites/86/2016/07/zedequias_vieira_cavalcante2.pdf. Acesso em: 10 abr. 2021.

Ganzala, Gabryelly Godois. **A Industrialização, impactos ambientais e a necessidade de desenvolvimento de políticas ambientais sustentáveis no século XXI**. 2018. Centro Universitário Internacional – UNINTER. Disponível em: <https://repositorio.uninter.com/bitstream/handle/1/295/1355104%20->

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Available in: <https://www.nucleodoconhecimento.com.br/civil-engineering/structural-concrete>

%20GABRYELLY%20GODOIS%20GANZALA.pdf?sequence=1&isAllowed=y.

Acesso em: 4 abr. 2021.

MEHTA, P. K. e MONTEIRO, P. J. M. **Concreto: Estrutura, Propriedades e Materiais**. São Paulo: Editora Pini, 1994.

Neville, Adam Matthew. **Propriedades do concreto**. São Paulo: Editora Pini, 1997.

Submitted: August, 2021.

August: September, 2021.

RC: 97178

Available in: <https://www.nucleodoconhecimento.com.br/civil-engineering/structural-concrete>