Performance assessment of mortars produced with sand from fluidized bed of biomass burning plants

CRISTIANA GONILHO-PEREIRA[1]

JÚLIA DELOROSO[2]

ANDREA BETIOLI[2]

[1] ESTB e INCITE, Instituto Politécnico de Setúbal | Barreiro | Portugal

[2] Departamento Acadêmico de Construção Civil, Instituto Federal de Santa Catarina| Florianópolis| Brasil

Building Materials

1. Introduction

The impacts associated with the supply of natural resources for industrial activity are increasing, both at an environmental and economic level. The use and transformation of these resources generates impacts on the environment, namely through the production of waste. It is essential to promote the use of waste as alternative raw materials, implementing studies that provide concrete recovery solutions [1].

The Civil Construction sector is no exception. With the increase in the cost of raw materials and the reduction of natural resources and, in some cases, the benefits they present, the use of waste materials is a viable alternative. There are several studies on the potential of the use of waste materials, in fact, the environmental impact related to the use of various materials is imperious and has been the subject of study in recent decades [3]-[6].

In 2015, the European Commission identified the Construction and Demolition domain as a priority in this matter, as well as the Biomass and Biologically Based Products domain [1]. Hereafter, Portugal imposed the deactivation of coal-burning thermoelectric plants by the year 2030. With the deactivation of these plants, the fly ash used today in the production of cement and concrete also will disappear.

An important aspect of the thermochemical conversion of biomass into energy is the production of ash, which, depending on its properties, could have different applications [7]-[10]. Hence, the ash from biomass burning boilers has been the subject of studies, similarly to what happened with the homologous materials from coal burning plants. In cement, mortar and concrete applications, the objective has been to evaluate the potential of partial cement replacement, use as addition and replacement of fine aggregates. Bearing in mind the objectives of CE, the number of studies and publications on this subject has grown [2], [4], [5], [10]-[13].

Fluidized bed sands are normally non-hazardous waste materials composed mainly of silica sand particles (quartz), with a granulometry ranging from a few micrometers to a few millimeters, usually containing a coating layer with a relatively thin thickness of vitreous material, by products of combustion of higher dimensions and by ash [9], [10].

There are several studies on the total/partial replacement of fine natural aggregates by fluidized bed sands (FBS) from biomass burning plants [10]-[12], [14]. The purpose of this work is to evaluate the total/partial replacement of fine natural aggregates in the production of mortars.

2. Methodology

This work intends to contribute to the state of the art on the potential of using FBS in total/partial replacement of natural aggregates in the production of mortars. With this purpose, 3 types of mortar were produced and characterized (Table 1), at a ratio of 1:3.5 (cement:aggregate, in mass). A reference mortar was produced and characterized - cement mortar (CEM I 42.5N), fine sand 0/2 and coarse sand 0/4, in the proportion 1:2, and water/cement ratio (W/C) of 0.60. In parallel, a mortar with fluidized bed sand (FBS) was produced, without having been subjected to any type of processing, i.e., in as supplied (FBSwm). With this, it is intended to assess the feasibility of using the FBS as it is generated. A mortar with FBS with manipulated granulometry (FBSm) was also produced, keeping it equal to that of fine natural sand 0/2. The A/C ratio in mass remained constant.

Tabela 1 – Produced mortars

Designation	CEM 42,5N	Natural Aggregates		Fluidized Bed Sand (FBS)	
		0/2	0/4	as supplied (wm)	manipulated granulometry (m)
Ref	✓	✓	✓	-	-
FBSwm	✓	-	✓	✓	-
FBSm	✓	-	✓	-	✓

The work was carried out in 5 phases: (i) characterization of the natural aggregate 0/2, 0/4 and FBS; (ii) composition and production of Ref, FBSwm and FBSm mortars; (iii) characterization of the mortars in the fresh state; (iv) molding, demolding and curing specimens; and, finally, (v) characterization of the mortars in the hardened state, at 7 and 28 days of age.

3. Mortars production and characterization

3.1 Aggregates characterization

In the production of mortars, two natural sands with different granulometries were used. A fine sand, 0/2, from Herdade da Mesquita, Sesimbra, Portugal, and a coarse sand, 0/4, from Pinhal Conde Cunha 4, Seixal, Portugal. According to the suppliers, the first consists of quartz, feldspar, quartzite (sub-angled to sub-rounded particles) and the second, in addition to these three components, also incorporates muscovite. The use of these two sands in a 1:2 ratio (fine sand: coarse sand in mass) aimed to reduce the volume of voids in the solid skeleton of the mortar.

The characterization of the three aggregates under study was carried out: natural fine sand 0/2; natural coarse sand 0/4 and fluidized bed sand (FBS).

The granulometry and loose bulk density were determined according to the procedures described in NP EN 933-1:2014 [15] and in NP EN 1097-3: 2002 [16], respectively. With regard to loose bulk density, Table 2 presents the values obtained for each of the sands studied.

Table 2. Loose bulk density of natural aggregates and fluidized bed sands (FBS)

	Natural Aggregates	Fluidized Bed Sand (FBS) (supply

	0/2	0/4	conditions)
Loose bulk density [kg/m³]	1495,83 ± 5,50	1554,05 ± 2,86	1390,20 ± 3,50

Regarding the granulometry (Figure 1), it appears that the FBS granulometry is close to the granulometry of natural sand 0/2 and, therefore, it was decided to study the partial replacement of the natural aggregate in the mortars, replacing 100% of the fine natural sand – sand 0/2 –and maintaining the usage of the natural coarse sand – sand 0/4.

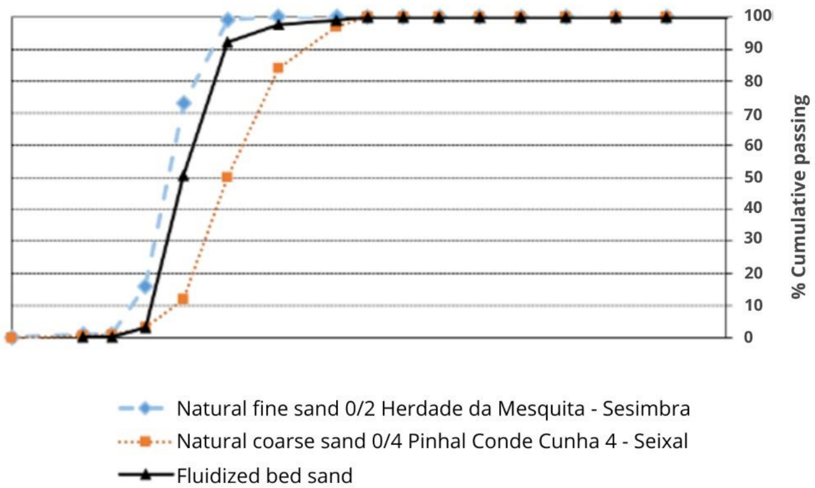


Figure 1. Granulometric curves of natural aggregates – 0/2 and 0/4 – and fluidized bed sand (FBS)

3.2 Mortars composition and production

As already mentioned, 3 types of mortar were produced: reference mortar (Ref); mortar with partial replacement of natural aggregate by FBS under supply conditions (FBSwm); and mortar with partial replacement of the natural aggregate by FBS with modified granulometry (FBSwm). The manipulation of the FBS aimed to ensure that it had a granulometry equal to that of fine natural sand – 0/2 sand. Table 3 presents the compositions of the mortars produced.

Table 3. Quantity of material used in mortars production.

Material	Quantity	
	[kg]	[l]
Cement	100,00	-
Natural aggregate 0/4	239,04	-
Natural aggregate 0/2 | FBSwm | FBSm	115,10	-
Water	-	60,00

The mortar preparation sought to follow the methodology described in the NP EN 196-1 [17] and EN 1015-2/A1 [18] standards, using a mechanical mixer. The solid constituents were dry mixed manually, prior to mechanical mixing. In the mechanical mixer, water was introduced at the predetermined dosage.

3.3 Mortars characterization in the fresh state

Mortars were characterized in terms of consistence and apparent density. The consistence analysis was performed according to the EN 1015-3/A1/A2 standard [19]. The determination of the apparent density of the mortars in the fresh state was based on the standard EN 1015-6:1998 [20]. The results obtained are shown in Table 4.

Table 4. Consistence and bulk density of mortars Ref, FBSwm e FBSm

Mortar	Consistence - Flow (mm)	Bulk Density (kg/m^3)
Ref	166,6	2120,3
FBSwm	158,0	2010,8
FBSm	152,1	1934,1

Mortars with replacement of natural sand 0/2 by FBS show a flow decrease, when compared to the mortar Ref. FBSwm mortar shows a flow decrease of 5.1%. When the replacement occurs by FBS with manipulated granulometry, the decrease is of the order of 8.7%. The same trend is observed in the apparent density. Mortar FBSwm has an apparent density lower than that of mortar Ref, by 5.2%, and mortar FBSm has a decrease of 8.2%. The density decrease in mortars with replacement is probably due to the lower loose bulk density and lower density of FBS, when compared to natural sand. With regard to flow, the Ref and FBSm mortars were produced with aggregates of equal granulometry, however, it appears that the FBSm mortar has greater consistency. This may indicate that the particles shape also influences the consistency and density [21], but this hypothesis should be investigated.

3.4 Mortars specimens moulding, demoulding and setting

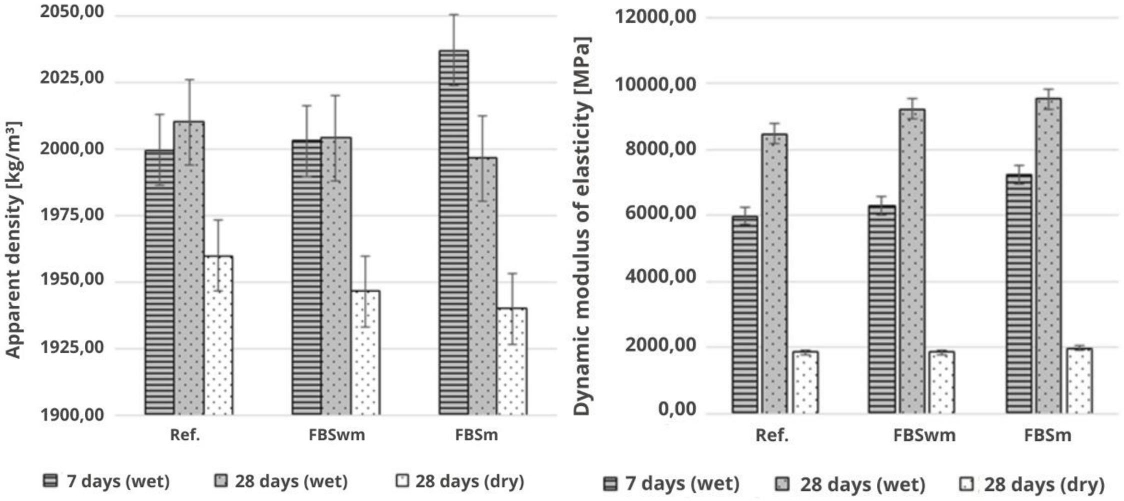
For each mortar, 9 prismatic specimens were molded (40x40x160 mm) and a mechanical compactor was used for compaction, in accordance with NP EN 196-1 [17]. After compaction, the molds were placed on a horizontal surface, protected from direct sunlight and covered by a polyethylene film. The specimens were demolded at 2 days of age, identified and placed in a wet cure with a relative humidity of 95% and a temperature of 20ºC. The specimens were removed at 7 and 28 days of age for characterization in the hardened state, apparent density, ultrasound propagation speed and mechanical strengths.

3.5 Mortars characterization in the hardened state

3.5.1 Apparent bulk density

The determination of the apparent density of the mortars was determined by weighing the specimens and determining the apparent volume based on the dimensions of the specimens (40 x 40 x 160 mm). The apparent density was determined at 7 and 28 days, with the specimens in the wet conditions, and at 28 days with the specimens in the dry condition (Figure 2 (a)).

The trend verified in the apparent density, measured in the fresh state, is verified again in the hardened state, for the dry specimens, at 28 days of age. Even so, the apparent density decreases are in the order of 1%, which can be considered that there are no differences between the 3 mortars. With regard to specimens in the wet state, the differences in density do not reach 2%, so, once again, they can be considered similar.



(a) (b)

Figure 2. Apparent density (a) and dynamic modulus of elasticity (b) of mortars Ref, FBSwm e FBSm, at 7 and 28 days, in wet and dry conditions.

3.5.2 Ultrasound propagation speed and dynamic modulus of elasticity

The determination of the ultrasound propagation speed was carried out according to EN 14146:2004 [22], through the direct method, at 7 and 28 days, with the specimens in wet conditions, and at 28 days with the specimens in the dry condition using the Pundit Lab equipment. To estimate Poisson's ratio according to Carneiro (1999), cited by Silva and Campiteli (2008) [23], the value must vary between 0,10 and 0,20 for mortars. In the present work, the value of 0,20 was adopted.

With the exception of the FBSwm mortar (Figure 2 (b)), at 28 days of age and in the dry condition, the mortars with replacement of natural sand by FBS have a higher modulus of elasticity than the reference mortar, at all ages and for the two specimen conditions – wet and dry. When the results obtained in the wet state are analyzed, FBSm mortar presents the highest modulus of elasticity. In the dry state, it can be considered that the modulus of elasticity of the FBSwm mortar is similar to that of the Ref mortar, with the FBSm mortar showing a slight increase (6%).

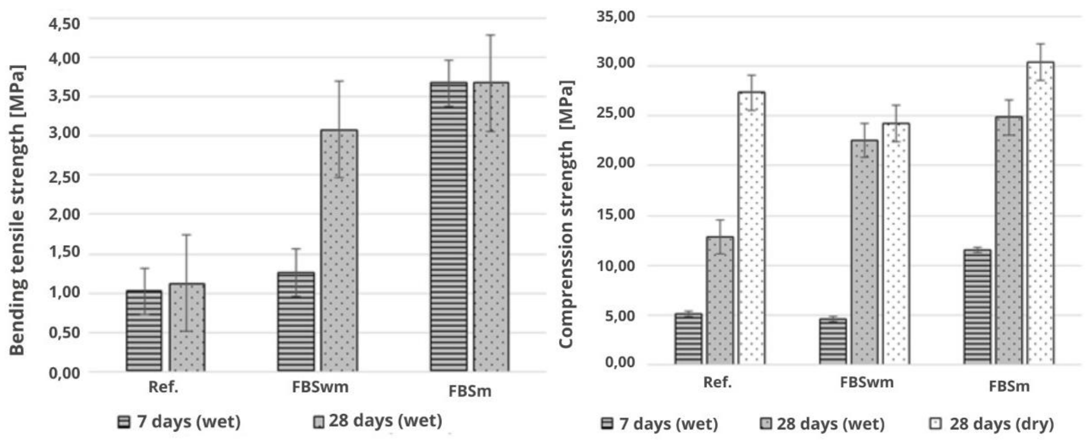
This similarity occurs because the wave propagation time is directly proportional to the sand/binder ratio [23] and all mortars have the same ratio. Likewise, as the dynamic modulus of elasticity (Ed) depends only on propagation speed and Poisson's ratio, the three mortars have similar values.

3.5.3 Mechanical Strengths

The mechanical characterization of the mortars was carried out in accordance with EN 1015-11/A1 [24] and the tests were carried out at 7 and 28 days, with the specimens in wet conditions, and at 28 days with the specimens in the dry condition. The flexural tensile strength test was carried out on the specimens used to determine the dynamic modulus of elasticity. The equipment used was a bending/compression press (flexion module) with a load cell of 15 Kn. The results of specimens at 28 days of age, under dry conditions, are not considered in this work because an error was detected in the test procedure. The compressive strength test was performed on one of the halves of the specimens that resulted from the tensile strength test. In this test, the equipment used was a bending/compression press (compression module) with a load cell for compression of 250 kN.

Figure 3 (a) allows us to conclude that the flexural tensile strength increases with the replacement of natural aggregate by FBS. If the FBS presents manipulated granulometry, the mechanical gains are increased by about 258% and 227%, for the ages of 7 and 28 days, respectively, when compared with the mortar Ref.

Regarding the compressive strength (Figure 3 (b)), at 28 days of age and in the wet condition, a similar trend can be observed. Regarding the results obtained at 7 days (wet condition) and at 28 days (dry condition), it appears that the replacement of the natural aggregate by FBS only leads to an increase in mechanical strength if the FBS has modified granulometry. Otherwise, there is a decrease in mechanical strength of 10 and 11%, respectively, when compared to the mortar Ref. The results obtained here are corroborated by Ed. Moreover, the Ref mortar and the FBSm mortar present aggregates with the same granulometry. The difference recorded here is attributed to the nature of the aggregate.



(a) (b)

Figure 3. Bending tensile strength (a) and comprenssion strength (b) of mortars Ref, FBSwm e FBSm, at 7 and 28 days, in wet and dry conditions

4. Results analyses and discussion

Table 5 presents a summary of the benchmarked performance in the 3 mortars. The symbol "↑/↓" indicates the mortar that presents better/worse performance than the mortar Ref. and the symbol "=" indicates similar performance to the mortar Ref.

Table 5. Summary of the results obtained

Properties/Characteristics analyzed	Mortar	
	FBSwm	FBSm
Consistence (Flow)	↓	↓↓
Bulk density (fresh state)	↓	↓↓
Apparent bulk density (28 days - dry)	=	=
Dynamic modulus of elasticity	=	↑
Mechanical strength (compreession, 28 days - dry)	↓	↑↑

As can be seen, the FBSwm mortar generally presented results closer to those of the Ref mortar. The FBSm mortar presented, in the hardened state, and at 28 days of age, dynamic modulus of elasticity and mechanical resistance higher than Ref. and that FBSwm. The results obtained are corroborated by the results obtained by other authors. Mortars with replacement of natural aggregate by FBS tend to have a lower flow rate than mortars with natural aggregates. Modolo, R.C.E. et al [10], studied cement mortars with FBS incorporation in partial (50%) and total (100%) replacement of the natural aggregate and found that, with the increase in the percentage of replacement of natural sand by FBS, the setting and flow decrease.

With regard to mechanical strength, namely compression, it appears that the partial replacement of natural aggregate by FBS can lead to a decrease or increase in this parameter. Modolo, R.C.E. et al [10] verified that the mechanical compressive strengths tend to increase with the use of FBS but that this increase is of the order of 0,1 to 0,3 MPa when compared with the reference mortar (100% natural sand). Dias [14] also concluded that the replacement of 40% of natural aggregate by FBS contributes to the increase of compression strength, verifying an increase in the order of 18%. Kayali [13] found an increase in compressive strength, of about 16%, with the total replacement of fine and coarse natural aggregates by FBS in the production of concrete. Yüksel et al. [25] found that the mechanical strength, evaluated at 28 days of age, decreases with the partial replacement of natural fine aggregate by FBS (50%). Kurama and Kaya [6] obtained similar results. Also, Waldemar Kępys [12], in his study, replaced 25, 50, 75 and 100% of the natural sand with FBS and found a decrease in mechanical strength with the presence of FBS.

5. Conclusions

After analyzing the characteristics of the waste material and verifying the main characteristics of the mortars produced, it is concluded that the incorporation of fluidized bed sands (FBS) from biomass burning plants seems to be a viable alternative to the use of natural sand. Mortars with partial replacement of natural aggregates by of FBS produced showed satisfactory results and close to those obtained with Ref mortar which shows that it is technically feasible to produce this type of mortar without major handling of the residue and without significant repercussions on the properties and characteristics required in mortars.

The study corroborates both Modolo, R.C.E. et al [10], and Waldemar Kępys [12], also concluding that the physical and economic properties of FBS give the material the potential to replace natural sand in mortars, without significant negative repercussions.

This work also demonstrates that, in general, FBSwm and FBSm mortars present satisfactory performances and are capable of representing a sustainable alternative to conventional solutions. However, FBSwm mortar seems to be a more interesting option once it has properties and characteristics closer to the Ref mortar. Added to this is the fact that it makes it possible to use the waste under the conditions of supply.

6. Acknowledgments

The authors thank The Navigator Company for providing the fluidized bed sands.

7. References

[1] Comissão Europeia, “Fechar o ciclo – plano de ação da UE para a economia circular,” Off. J. Eur. Union, pp. 1–24, 2015.

[2] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, “The Circular Economy – A new sustainability paradigm?,” J. Clean. Prod., vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.

[3] H. R. Gavali, A. Bras, P. Faria, and R. V. Ralegaonkar, “Development of sustainable alkali-activated bricks using industrial wastes,” Constr. Build. Mater., vol. 215, pp. 180–191, Aug. 2019, doi: 10.1016/j.conbuildmat.2019.04.152.

[4] F. L. Oliveira and E. F. Mello, “A mineração de areia e os impactos ambientais na bacia do rio São João, RJ,” Rev. Bras. Geociências, vol. 37, no. 2, pp. 374–389, 2007, doi: 10.25249/0375-7536.2007373374389.

[5] F. Pacheco-Torgal, A. Shasavandi, and S. Jalali, “Eco-efficient concrete using industrial wastes: A review,” Mater. Sci. Forum, vol. 730–732, pp. 581–586, 2013, doi: 10.4028/www.scientific.net/MSF.730-732.581.

[6] H. Kurama and M. Kaya, “Usage of coal combustion bottom ash in concrete mixture,” Constr. Build. Mater., vol. 22, no. 9, pp. 1922–1928, Sep. 2008, doi: 10.1016/j.conbuildmat.2007.07.008.

[7] A. Demeyer, J. Voundi Nkana, and M. Verloo, “Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview,” Bioresour. Technol., vol. 77, no. 3, pp. 287–295, May 2001, doi: 10.1016/S0960-8524(00)00043-2.

[8] N. C. Cruz et al., “Ashes from fluidized bed combustion of residual forest biomass: recycling to soil as a viable management option,” Environ. Sci. Pollut. Res., vol. 24, no. 17, pp. 14770–14781, Jun. 2017, doi: 10.1007/s11356-017-9013-6.

[9] S. V. Vassilev, D. Baxter, L. K. Andersen, and C. G. Vassileva, “An overview of the chemical composition of biomass,” Fuel, vol. 89, no. 5, pp. 913–933, May 2010, doi: 10.1016/j.fuel.2009.10.022.

[10] R. C. E. Modolo, V. M. Ferreira, L. A. Tarelho, J. A. Labrincha, L. Senff, and L. Silva, “Mortar formulations with bottom ash from biomass combustion,” Constr. Build. Mater., 2013, doi: 10.1016/j.conbuildmat.2013.03.093.

[11] H. K. Kim and H. K. Lee, “Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete,” Constr. Build. Mater., vol. 25, no. 2, pp. 1115–1122, Feb. 2011, doi: 10.1016/j.conbuildmat.2010.06.065.

[12] W. Kępys, “Bottom ash obtained from biomass burning in fluidised-bed boilers as a mortar component,” E3S Web Conf., vol. 46, pp. 1–7, 2018, doi: 10.1051/e3sconf/20184600009.

[13] O. Kayali, “Fly ash lightweight aggregates in high performance concrete,” Constr. Build. Mater., vol. 22, no. 12, pp. 2393–2399, Dec. 2008, doi: 10.1016/j.conbuildmat.2007.09.001.

[14] D. M. Dias, “Estudo da Valorização de Cinzas de Biomassa na produção de materiais para a construção de recifes artificiais,” Universidade Nova de Lisboa, 2011.

[15] NP EN 933-1:2014, “Ensaios das propriedades geométricas dos agregados; Parte 1: Análise granulométrica; Método da peneiração.” 2014.

[16] NP EN 1097-3:2002, “Ensaios das propriedades mecânicas e físicas dos agregados; Parte 3: Determinação da baridade e do volume de vazio.” 2002.

[17] NP EN 196-1:2017, “Métodos de ensaio de cimentos; Parte 1: Determinação das resistências mecânicas.” .

[18] EN 1015-2/A1:1998/2006, “Methods of test for mortar for masonry - Part 2: Bulk sampling of mortars and preparation of test mortars.” 2006.

[19] EN 1015-3/A1/A2:1999/2004/2006, “Methods of test for mortar for masonry - Part 3: Determination of consistence of fresh mortar (by flow table).”.

[20] EN 1015-6:1998, “Methods of test for mortar for masonry - Part 6: Determination of bulk density of fresh mortar.”.

[21] H. Carasek, R. C. Araújo, O. Cascudo, and R. Angelim, “Parâmetros da areia que influenciam a consistência e a densidade de massa das argamassas de revestimento,” Rev. Mater., vol. 21, no. 3, pp. 714–732, 2016, doi: 10.1590/S1517-707620160003.0068.

[22] EN 14146:2004, “Natural stone test methods - D etermination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency).” .

[23] N. G. da Silva and V. C. Campiteli, “Correlação entre módulo de elasticidade dinâmico e resistências mecânicas de argamassas de cimento, cal e areia,” Ambient. Construído, vol. 8, no. 42, pp. 21–35, 2008.

[24] EN 1015-11:1999, “Methods of test for mortar for masonary - Part 11: Determination of flexural and compressive strength of hardened mortar.” .

[25] İ. Yüksel, T. Bilir, and Ö. Özkan, “Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate,” Build. Environ., vol. 42, no. 7, pp. 2651–2659, Jul. 2007, doi: 10.1016/j.buildenv.2006.07.003.