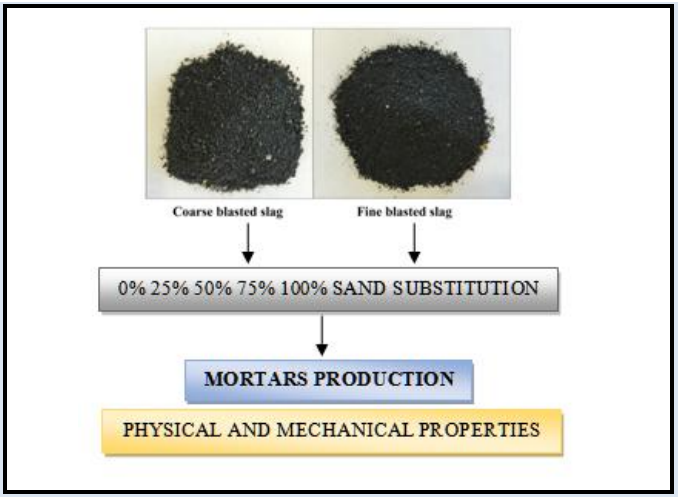
Rev. LatinAm. Metal. Mat.
Artículo Regular
www.rlmm.org

EFFECT OF REPLACEMENT OF NATURAL SAND WITH BLASTED COPPER SLAG ON MORTARS PHYSICAL AND MECHANICAL PROPERTIES

Rafaela Melo[1], Angela Teresa Sales[2], Daniel Sales[2], Rosane Maria Oliveira[1]*

1: Materials Science and Engineering Postgraduate Program, Federal University of Sergipe, 49100-000, São Cristóvão, Sergipe, Brazil
2: Civil Engineering Department, Federal University of Sergipe, 49100-000, São Cristóvão, Sergipe, Brazil*

e-mail: rafaela_l@live.com



ABSTRACT

Environmental preservation is a widely discussed topic throughout society, due to heavy reliance on natural resources for survival on the planet. Rational use of raw materials and their proper disposal are on the agenda of the productive sectors' major concerns. This work aimed to evaluate the feasibility of application of copper slag waste, after being used as an abrasive material, coming to be called blasted copper slag. It was intended to replace sand to blasted copper slag in mortars, into two fractions, named fine and coarse blasted slag sand, according to the number of times that were used in the abrasive process. Four mixtures were produced, for each type of blasted slag, with levels of 25%, 50%, 75% and 100% of replacement to natural sand, in addition to the reference mortar. The consistence of fresh mortars was measured by the flow table test and the spreading range was fixed for 270 ± 20 mm. Physical and mechanical tests were performed with produced mortars. Mortars with blasted copper slag, both fine and coarse slag, demanded lower water/binders ratio to achieve the desired spreading, compared to the reference mixture. Mechanical tests showed important performance reductions in compression strength of the mortars with fine blasted slag, both in relation to the reference mortar, and when compared to mortars with same replacement content of natural sand by coarse blasted slag. It could be concluded that, for levels between 25 and 50% of natural aggregate replacement by coarse blasted slag, there is feasibility of most mortar application, since there are not required high levels of strength and stiffness.

Keywords: *Mortar, Blasted copper slag, Waste.*

Recibido: 13-08-2020 ; **Revisado:** 14-12-2020
Aceptado: 15-12-2020 ; **Publicado:** 31-05-2021

DOI: 10.5281/zenodo.7397130

Rev. LatinAm. Metal. Mat.

Artículo Arbitrado
www.rlmm.org

EFEITOS DA SUBSTITUIÇÃO DE AREIA NATURAL POR GRANALHA DE COBRE BATIDA NAS PROPRIEDADES FÍSICAS E MECÂNICAS DE ARGAMASSAS

RESUMO

O presente artigo tem como objetivo avaliar a viabilidade de aplicação do resíduo de escória de cobre, após ser utilizado como material abrasivo, passando a ser denominado granalha de cobre batida. Buscou-se substituir o agregado fino natural pela escória de cobre batida em argamassas, em duas frações, denominadas escória batida fina e grossa, de acordo com o número de vezes que foram utilizadas no processo abrasivo. Foram produzidas quatro misturas, para cada tipo de escória batida, com teores de 25%, 50%, 75% e 100% de substituição para areia natural, além da argamassa de referência. A consistência das argamassas frescas foi medida pelo ensaio de espalhamento e a faixa foi fixada em 270 ± 20 mm. Ensaios físicos e mecânicos foram realizados com as argamassas produzidas. As argamassas com escória de cobre batida, tanto fina quanto grossa, demandaram menor relação água/aglomerantes para atingir o espalhamento desejado, em comparação com a mistura de referência. Os ensaios mecânicos mostraram reduções de desempenho importantes na resistência à compressão das argamassas com escória batida fina, tanto em relação à argamassa de referência, quanto quando comparadas às argamassas com mesmo teor de substituição de areia natural por escória batida grossa. Pode-se concluir que, para baixos níveis de substituição de agregados naturais por escória batida grossa, há viabilidade de aplicação da maioria das argamassas, uma vez que não são exigidos altos níveis de resistência e rigidez.

Palavras-chave: *Argamassa, Granalha de cobre batida, Resíduo.*

1. INTRODUCTION

Environmental preservation and sustainable development are widely discussed topics throughout society, due to the heavy reliance on natural resources for their survival. Rapid population growth, with concomitant consumption and waste, has widespread adverse effects on societies and ecosystems in the world [1]. Rational use of raw material, reuse of waste and adequate disposal of unworthy waste become imperative alternatives in the scope of sustainability. The use of finite raw materials and their impact lead to the search for alternatives, as the reused in the construction industry [2].

The Civil Construction industry is considered as one of the main promoters of environmental impacts, both due to the high consumption of natural and energy resources and the volume of waste generated. The construction and demolition waste generated in Brazilian vertical buildings construction is estimate about 0.05 and 0.15 t/m^2. This number is even bigger in building reforms, reaching 0.470 t/m^2 [3]. Despite actions to reduce the generation of waste in various production processes, it is impossible to eliminate them. Thus, it becomes a sustainable practice to recycle waste from other productive sectors, incorporating them into construction.

In comparison to concretes, mortars generally do not need to achieve high mechanical performance. Singh et al. [4] studied cement mortars and concluded that Abrams' Law is also applicable to cement mortars, showing that compressive strength and split tensile strength decrease as the water / cement ratio increases. Mortars have a large capacity to incorporate waste of diverse origins, with economic advantages. This incorporation capability may include toxic and hard to discard materials. As an example, the disposal of chromium in the hexavalent oxidation state is a major concern because of its toxicity and carcinogenicity. Husnain et al. [5] studied mortars with titanium oxide nanoparticles after being used to adsorb chromium from industrial effluents. This material was added to the mortar mixes, partially replacing the cement, from 0% to 20%. The mortars presented greater resistance than the mortar without this material. Thus, a safe method was obtained for the disposal of toxic metal waste such as chromium waste.

There were initiatives to incorporate various waste into mortars that achieve improvement of mechanical performance [5-7]. On the other hand, mortars with wastes may be suitable to avoid improper disposal in the environment, without contributing to the improvement of mechanical properties [3;8]. Therefore, both cost and environmental concerns motivated the search for alternative materials to incorporate industrial residues in mortars. Researchers achieved satisfactory results in their work such as incorporating granite residues to substitute sand in coating mortars, adding açaí fibre in mortars, replacement of hydrated lime by marble waste in block and wall laying mortars, substitution of hydrated lime with a combination of clay residue and marble waste, replacement of hydrated lime in mortars by a kaolinitic clay [9-13].

Waste of copper production, the copper slag, has been widely studied as a replacement of natural sand in mortars and concretes [6;14-17]. In the mining sector, for each ton of copper produced, about 2.2 tons of copper slag are generated [18]. In Brazil, gross copper production, in the year 2015, was 80,176,949 tons [19].

Copper slag is often used in abrasive blasting processes. The waste from this process is a material of small particle size, containing rust and wastes of old paintings. The presence of these impurities in the blasted copper slag may be the reason why there are not many studies and applications replacing natural aggregates by this waste in cementitious mixtures. In the present study, wastes of copper slag after abrasive blasting were inserted in mortars with different content of substitution in the natural sand. The performance of mortar with two types of blasted copper slag was investigated: one type with a thinner graduation and other with a thicker graduation, depending on the number of times the copper slag was used in the blasting process.

The physical appearance of blasted copper slag is similar to natural sand, with higher hardness and specific gravity, and it can be applied in civil construction industry as substitute of natural sand, although there is a decrease in strength, as the percentage of natural sand replacement is increased by the blasted copper slag [19].

Both the extraction of natural aggregates and the inadequate deposition of industrial waste cause environmental damage. By reusing a metallurgical industry waste, for example, applying it as replacement of natural aggregate, the amount of raw material that would be extracted is reduced and still provides an appropriate alternative of waste destination.

In Vietnam, with the development of the shipbuilding industry, an environmental concern emerged related to the use of copper slag as abrasive material to remove rust and marine deposits from ships. The copper slag contained a large amount of copper, which was released in significant quantities. Leaching tests showed arsenic and small levels of heavy metals, but the copper content exceeded the EU limit for non-hazardous waste [21].

The present work seeks to evaluate the effects of total and partial sand replacement by blasted copper slag on the physical and mechanical performance of mortars. The incorporation of the wastes from this abrasive process can contribute to avoid contamination of the soil and watercourses.

2. MATERIALS AND METHODS

2.1 Materials

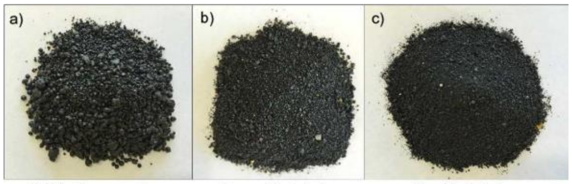
For mortar production, this study used High Early Strength Portland cement, with fineness modulus of 0.62%, when sifted through a 75 mm mesh sieve, according to the parameters from Brazilian Standard NBR 11579 [22]. The cement specific gravity was determined in 3.03, according to Brazilian Standard NBR 16605 [23].

The hydrated lime used in mortar production was CH-1 type (ABNT, 2003), with specific gravity of 2.25, according to Brazilian Standard NBR 16605 [23].

The natural aggregate used in this study was ravine sand, characterized by its specific gravity, resulting in 2.65, and by its unit weight, resulting in 1.73 g/cm³, according to Brazilian Standard NBR NM 52 [24]. The fine aggregate granulometric composition resulted in a maximum diameter of 4.8 mm and a fineness modulus of 2.24, according to Brazilian Standard NBR NM 248 [25].

The blasted copper slag, used in this study, was collected from a construction site, to be used at oil storage tanks in cleaning procedure. During sandblast, the slag was blasted in order to remove all the old painting and rust. This slag is used as abrasive material and, after a certain number of applications, loses its use, being discarded [26]. The adequate disposal of this waste is a serious environmental for its large quantity.

Figure 1 shows the original copper slag, prior to the blasting process (a), the coarse blasted slag (b) and the fine blasted slag (c).



Original copper glag
Coarse blasted slag
Fine blasted slag

Figure 1. Appearance of original copper slag and the two types of blasted copper slags.

For the two types of blasted copper slag, the specific gravity were determined, resulting in 3.60, for the coarse blasted slag, and 3.81, for the fine one.

The granulometric composition of the two types of blasted copper slag were determined according to Brazilian Standard NBR NM 248 [25], with the coarse blasted slag presenting a maximum diameter of 1.20 mm and a fineness modulus of 1.97, while the fine blasted slag obtained a maximum diameter of 1.20 mm and a fineness of 1.26. Further physical characteristics of blasted copper slag are seen in Table 1. The grain size distribution curves of the two types of waste and that of natural aggregate are shown in Figure 2.

Table 1. Physical parameters of blasted copper slag.

Blasted copper slag	*Specific gravity*	*Water absorption capacity (%)*	*Maximum diameter (mm)*	*Fineness modulus*
Coarse	3.60	0.16	1.20	1.97
Fine	3.81	0.21	1.20	1.26

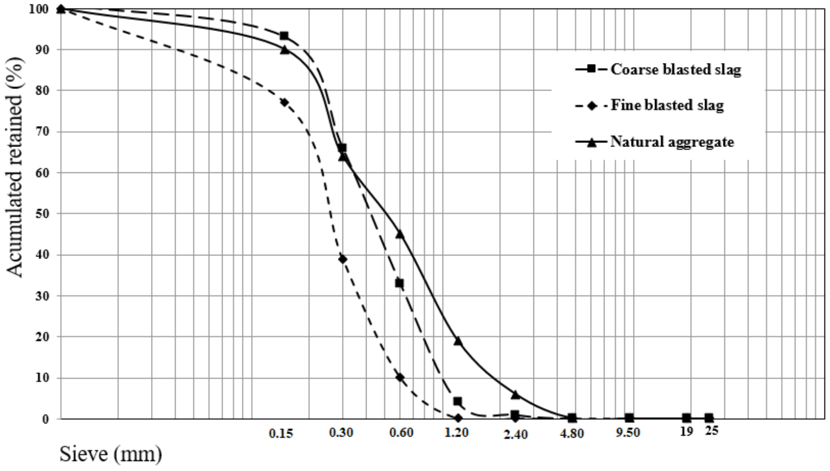


Figure 2. Grain size distribution curves of aggregates.

In order to chemically characterize the original copper slag and the two types of blasted copper slags, such materials were subjected to X-ray fluorescence (XRF) analysis, resulting in the oxide composition seen in Table 2.

Table 2. Composition of slags in terms of oxides.

Oxide	*Contents (%)*		
	Original copper slag	*Coarse blasted copper slag*	*Fine blasted copper slag*
Fe_2O_3	20.84	58.61	62.58
SiO_2	60.32	26.07	23.30
Al_2O_3	5.78	4.56	3.26
MgO	2.07	2,27	1.45
CaO	4.83	2.21	1.06
CuO	4.65	1.29	3.52
SO_3	-	1.22	1.05
ZnO	1.51	1.20	1.80
K_2O	-	0.83	0.61
MoO_3	-	0.57	0.22
TiO_2	-	0.47	0.36
PbO	-	0.10	0.09
Cr_2O_3	-	0.07	0.08

Typical copper ores contain from 0.5% Cu to 1 or 2% Cu. The concentration of these minerals in an ore body is low. Typical copper ores contain from 0.5% Cu to 1 or 2% Cu. Table 2 shows that the copper content in the slag is very small, both in the original slag and in the slag subjected to the abrasive blasting process [27].

The variation of wastes chemical composition indicates that the sandblasting process changes the slag's oxide contents, probably by the incorporation of corrosion products present on the blasted surfaces.

2.2 Mortar Production

In addition to the reference mixture, with 100% of natural aggregate, two series of mortar specimens were produced, varying the types of blasted copper slags and the percentages of natural aggregate replacement by the waste. The nomenclature of theses mortars are given in Table 3. The materials proportion, in volume, was set at 1: 1: 6 (cement: hydrated lime: fine aggregate). Figures 3 shows specimens of each mixture.

Table 3. Nomenclature and mortars composition.

Nomenclature	*Type of slag*	*Blasted copper slag content (%)*
Reference	-	0
CBSM025	Coarse	25
CBSM050	Coarse	50
CBSM075	Coarse	75
CBSM100	Coarse	100
FBSM025	Fine	25
FBSM050	Fine	50
FBSM075	Fine	75
FBSM100	Fine	100

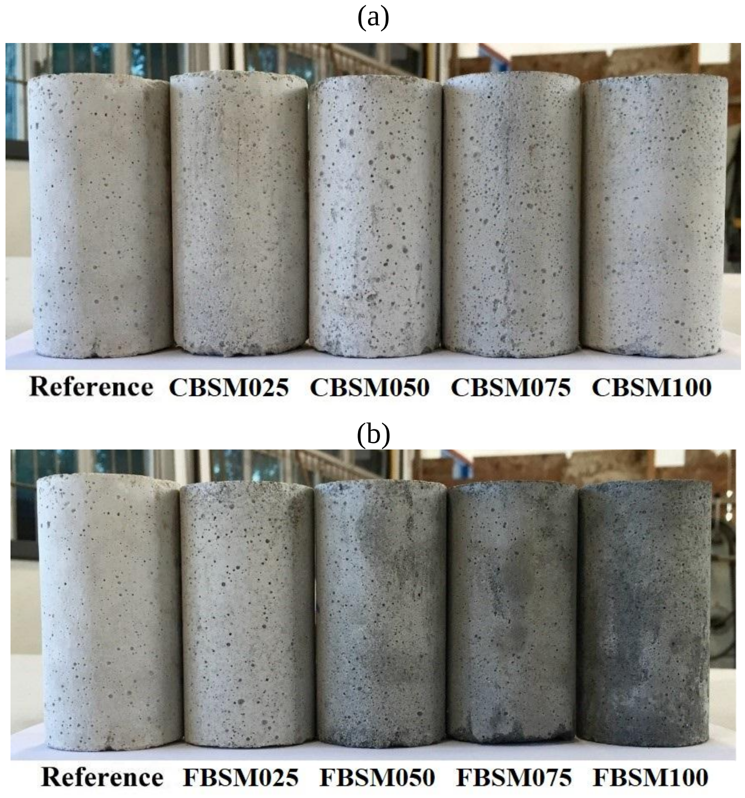


Figure 3. Aspect of reference mortar, coarse blasted slag mixtures (a) and fine blasted slag mixtures (b).

For each mixture, 19 cylindrical specimens were produced, presenting 100 mm of height and 50 mm of diameter, which tests sample plan is shown in Table 4.

Water/binders ratio was determined from each sample spreading, obtained by flow table test, according to Brazilian Standard NBR 13276 [28]. For this study, a spreading interval of 260 ± 20 mm was set for all mixtures.

Table 4. Sampling plan of dosed mortars.

Test	*Number of Samples*	*Brazilian Standard*
Axial compressive Strength	6	NBR 13279 [24]
Modulus of elasticity	2	NBR 8522 [25]
Diametrical compression tensile strength	6	NBR 7222 [26]
Water absorption Voids index Specific gravity	2	NBR 9778 [27]
Capillarity	3	NBR 9779 [28]

2.3 Testing Procedures

2.3.1 Physical Analysis

Tests were carried out to determine the physical properties related to porosity, such as water absorption, specific gravity and voids index, according to Brazilian Standard NBR 9778 [32].

The determination of water absorption by capillarity of the mortars was carried out following Brazilian Standard NBR 9779 [33]. After the measurements of masses at the times determined by the standard, the specimens were ruptured by diametrical compression, in order to determinate the water distribution in its interior.

2.3.2 Mechanical Analysis

For all mixtures, tests were performed on axial compressive strength, modulus of elasticity and tensile strength by diametrical compression, according to Brazilian Standards NBR 13279 [29], NBR 8522 [25] and NBR 7222 [21], respectively. The mechanical tests were performed on the universal testing machine, model DL 20000, brand EMIC, in the Laboratory of Building Materials and Structures of Civil Engineering Department of Federal University of Sergipe.

3. RESULTS AND DISCUSSION

3.1 Fresh Mortar

Values obtained for spreading of the fresh mortars studied are shown in Table 5.

Table 5. Spreading measures and mixtures water/binders ratio.

Mixture	*Spreading (mm)*	*Water/binders ratio*
Reference	260	1.09
CBSM025	280	1.03
CBSM050	280	0.96
CBSM075	280	0.55
CBSM100	270	0.83
FBSM025	270	1.06
FBSM050	270	1.06
FBSM075	280	1.03
FBSM100	280	0.99

For the same spreading range, it was observed that all mixtures, containing both coarse and fine blasted slag, required lower water contents, in relation to the mass of binders, than the reference mixture, especially CBSM075, with a reduction in water/binders ratio at about 71% compared to the reference mortar. This improved workability was attributed to the characteristics of blasted slag particles, which has preferably spherical shape, except for the impurities introduced in the abrasive sandblasting process, glassy texture and low water absorption capacity.

3.2 Physical Indexes of Hardened Mortars

Porosity parameters are shown in Table 6.

Table 6. Mortar physical index.

Mixture	*Absorption (%)*	*Voids (%)*	*Bulk specific gravity (g/cm³)*	*Bulk specific gravity SSD (g/cm³)*	*Apparent specific gravity (g/cm³)*
Reference	11.0	17.1	1.6	1.7	1.9
CBSM025	10.4	21.6	2.1	2.3	2.7
CBSM050	10.3	21.3	2.1	2.3	2.6
CBSM075	9.8	21.7	2.2	2.4	2.8
CBSM100	9.6	22.7	2.4	2.6	3.1
FBSM025	10.7	22.5	2.1	2.3	2.7
FBSM050	9.8	22.3	2.3	2.5	2.9
FBSM075	11.0	26.2	2.4	2.6	3.2
FBSM100	10.4	26.6	2.6	2.8	3.5

The results of the mortar porosity measurement, both with coarse and fine blasted slag, showed that water absorption, by the method of Brazilian Standard NBR 9778 [32], did not show significant differences in values, comparing them with each other and with the reference mixture. Contrary to the water absorption results, the void index of the mortars with waste showed values higher than the void index of reference mixture.

Bulk specific gravity of coarse blasted slag mortars had intensifying increments as the natural aggregate replacement levels increased. Regarding the mortars with fine blasted slag, the increments were quite superior to those of reference mortar and mortars with coarse blasted slag. The results obtained in water absorption by capillarity test are seen in Table 7.

Table 7. Evolution of water absorption by capillarity.

Mixture	*Capillarity (g/cm²)*				
	3 hours	*6 hours*	*24 hours*	*48 hours*	*72 hours*
Reference	1.00	1.39	1.89	1.91	1.92
CBSM025	1.01	1.34	1.85	1.89	1.91
CBSM050	0.64	0.88	1.61	1.89	1.90
CBSM075	0.62	0.82	1.40	1.79	1.88
CBSM100	0.76	1.01	1.68	1.96	2.00
FBSM025	1.13	1.57	2.01	2.04	2.06
FBSM050	1.60	1.90	1.97	2.02	2.04
FBSM075	2.03	2.06	2.12	2.16	2.18
FBSM100	2.00	2.13	2.20	2.24	2.27

The results of water absorption by capillarity test of mortars with coarse blasted slag showed that, after 72 hours, the absorbed water content of these mixtures presented values close to 2 g/cm². Concerning to mortars with fine blasted slag, after 72 hours, the maximum absorption slightly increased with the increase of the substitution levels of the natural aggregate.

The humidity stain pattern in the test specimens of all the studied mixtures remained constant, with very close heights and dry edges with practically the same thickness.

3.3 Mechanical Strength of Hardened Mortars

3.3.1 Axial Compressive Strength

Results from axial compression tests on mortar specimens with different contents of natural aggregate replacement by blasted slag are shown in Figures 4 and 5.

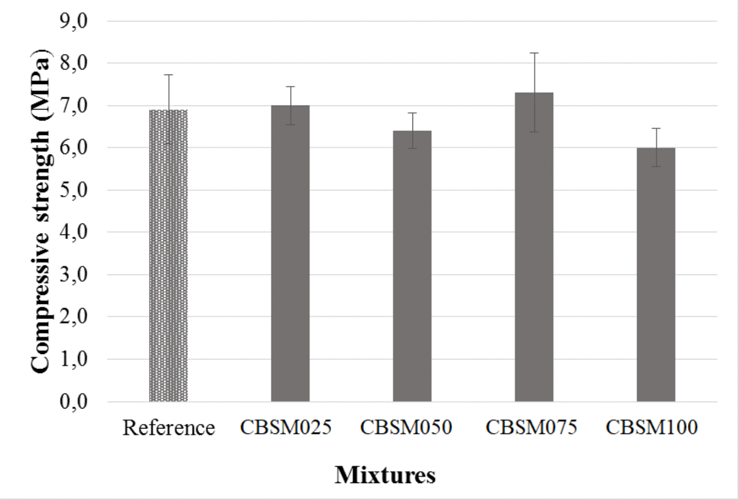


Figure 4. Average values of compressive strength for samples with coarse blasted slag.

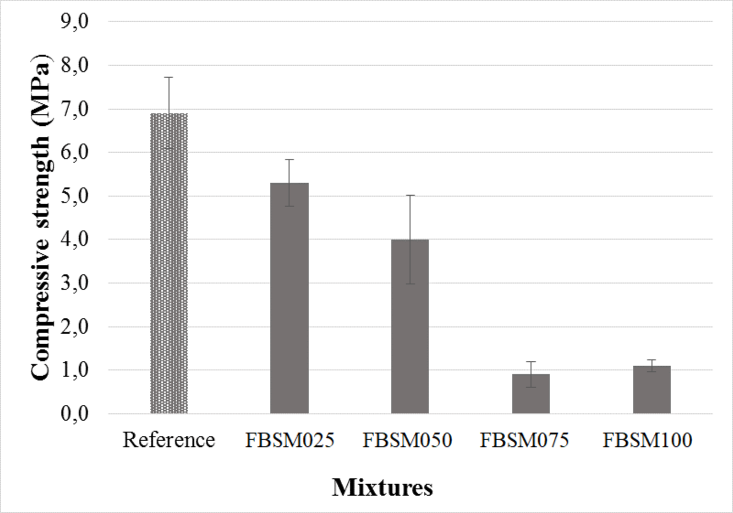


Figure 5. Average values of compressive strength for samples with fine blasted slag.

The axial compression strength tests showed that, for 75% natural aggregate replacement by coarse blasted slag, resistance increased by 5.5%, as compared with reference mixture. The CBSM075 mixture was the one that required a lower water/binders ratio, in order to be framed on the fixed spreading range, among all mixtures studied, which justifies this distinguished mechanical performance. However, according to the analysis of variation, there was a significant difference between the values obtained (ANOVA, F = 3.80, Fcrit = 2.76, p = 0.02).

Concerning the mortars with substitution of the natural aggregate for fine blasted slag, the results of axial compression strength tests showed that there was significant reduction for all the replacement contents, in relation to the reference mortar. Analysis of variance showed that there was a significant difference between the values obtained (ANOVA, F = 97.8, Fcri = 2.76, p = 6.9E-15).

This performance can be attributed to the fact that the fine blasted slag, since it has been used as abrasive material in a greater number of times, has brought with it higher levels of impurities, some of which are organic in nature, such as old paint particles from surface of blasted tank. It is well known that organic matter, in cementitious mixtures, tends to reduce mechanical strength.

Resende [20] evaluated the compression strength of mortars with blasted copper slag. For replacements of 25%, 50% and 75% of natural sand, there was a reduction of 11%, 17% and 21.4%, respectively. In the present work, for the same replacement contents, there was a reduction of 23%, 42% and 87%, respectively.

3.3.2 Static Elastic Modulus in Compression

The average values of elastic modulus under compression for the mortar samples studied are shown in Figures 6 and 7.

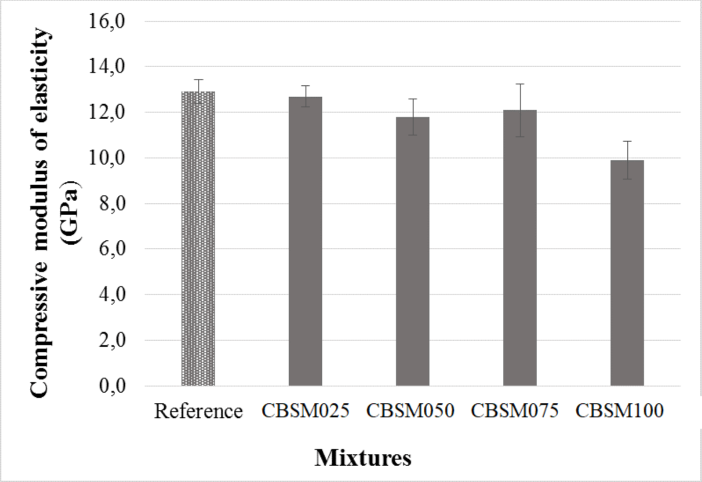


Figure 6. Average values of elastic modulus for samples with coarse blasted slag.

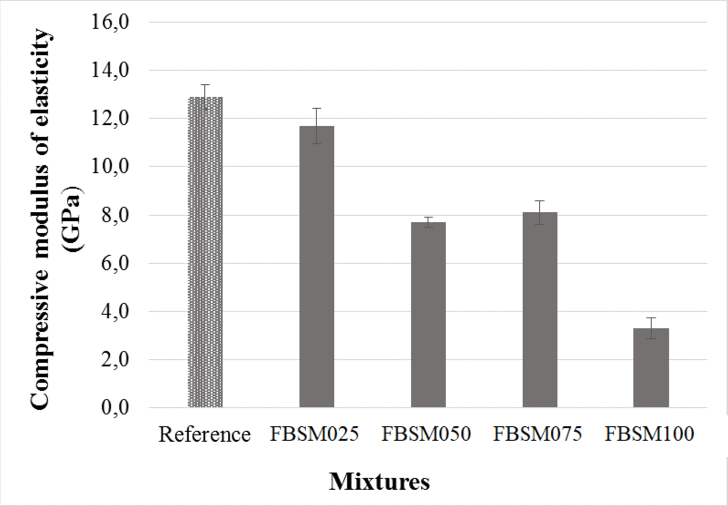


Figure 7. Average values of elastic modulus for samples with fine blasted slag.

The results of elastic modulus tests showed that, for natural aggregate replacement by coarse blasted slag at 25, 50 and 75%, the variations were not significant, as confirmed by the analysis of variance (ANOVA, F = 4.40, Fcrit = 5.20, p = 0.07). For the mixture with 100% replacement, the elastic modulus was reduced by 22.9%, compared to the reference mixture.

The fine blasted slag mixtures had very strong reductions in the elastic modulus, as ratified by the analysis of variance (ANOVA, F = 112.47, Fcrit = 5.19, p = 4,40E-5). As for the compressive performance, the presence of organic matter in the fine blasted slag may have caused a decrease in measured performance.

3.3.3 Tensile strength by diametrical compression

The average results for diametrical compression tensile strength tests are shown in Figures 8 and 9.

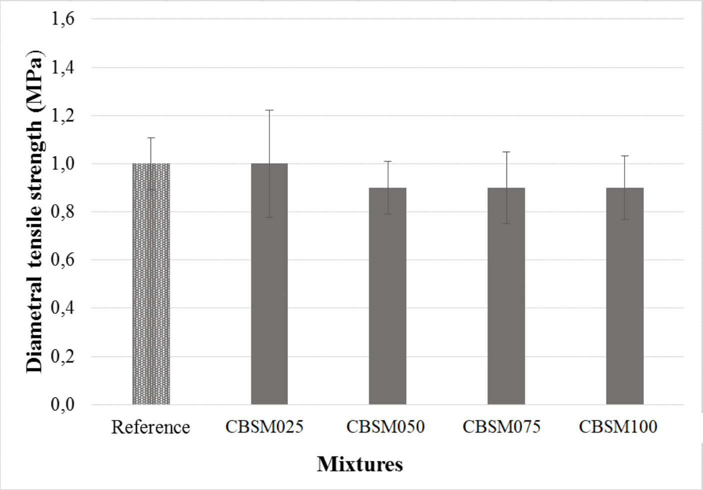


Figure 8. Average values of diametrical tensile strength for samples with coarse blasted slag.

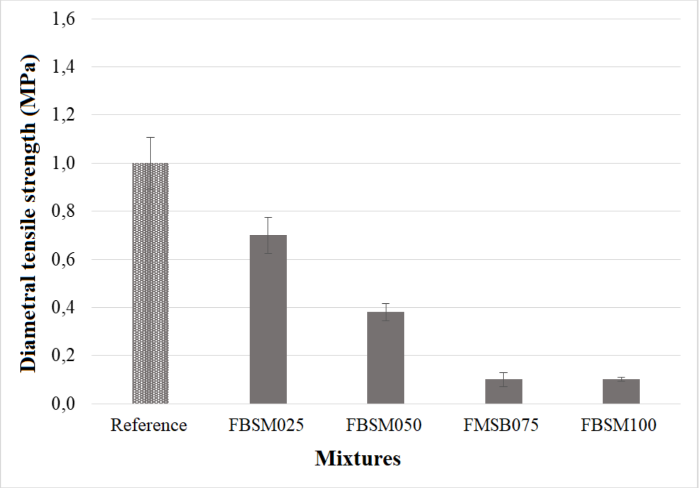


Figure 9. Average values of diametrical tensile strength for samples with fine blasted slag.

There was no significant variation in the diametrical compression tensile comparing the reference mixture with coarse blasted slag mortars (ANOVA, F = 1.25, Fcrit = 2.76; P = 0.31).

Under diametrical compression tensile, there was practically no significant variation of this property, comparing the mixtures with natural aggregate substituted by coarse blasted slag, in relation to the reference mortar (ANOVA, F = 1.25; Fcrit = 2.76; p = 0.31).

When natural aggregate was replaced by fine blasted slag, the reductions in tensile strength were significant, reaching a decrease around 90% for the FBSM100 mixture (ANOVA, F = 90.46, Fcrit = 2.76, p = 1.71E-14). Contrary to the trend, the FBSM050 mixture showed tensile strength by diametrical compression 50% higher than the reference mortar.

4. CONCLUSIONS

In general, mortars with blasted copper slag, both coarse and fine, required lower water contents, relative to the mass of binders, than the reference mixture. The same occurred with the concretes studied by Anjos [26], whose improvement in the consistency was attributed to the low water absorption and to the preferentially spherical shape of blasted slag grains.

Porosity measurement tests indicated that the water absorption of mortars with coarse and fine blasted slag had little variation when comparing them with each other and with reference mixture. On the other hand, the void index of mortars with waste showed significantly higher values than the reference mortar.

Bulk specific gravity of coarse blasted slag mortars had intensifying increments and, for fine blasted slag mixtures, the increments were considerable higher. That behavior could be attributed to the greater granular packing, conferred by the presence of finer grains.

Regarding water absorption by capillarity test, coarse blasted slag mortars had very close absorption values and, for mixtures with fine type of slag, maximum absorption increased, as there was an increase in the natural aggregate replacement.

It was verified, by mechanical tests, that the insertion of fine blasted slag caused a considerable decrease in mortars axial compressive strength. This decline was attributed to the fact that, since it has been used as the abrasive material in a superior number of times, there was a great amount of impurities in its composition, such as ink particles, oxides, and hydroxides that formed the corroded layer of the blasted tanks.

In modulus of elasticity tests, it was observed that, for natural aggregate replacement by coarse blasted slag up to 75%, the variations were not significant. However, the modulus of CBSM100 mixture was reduced by 22.9%, compared to reference mortar. Concerning mortars with fine blasted slag, the stiffness reductions were quite intense, a phenomenon that can be explained by the presence of organic matter in the waste, similar to what happened with the compressive strength.

Regarding the tensile strength obtained by the diametrical compression test, it was observed that there was no significant variation of this property in the coarse blasted slags, with only 10% of reduction in the mixtures with 50%, 75% and 100% of natural aggregate replacement by this waste, in relation to the reference mortar. Contrary to what happened with coarse blasted slag mortars, the mixtures with fine blasted slag had significant reductions in tensile strength, with a maximum reduction of 90% for the FBSM100 mixture.

From the analysis of obtained results, it could be concluded that, for levels between 25 and 50% of natural aggregate replacement by coarse blasted slag, it is possible to indicate the application of mortars studied, considering that, for most mortars, there are not required high levels of resistance and stiffness. Azevedo et al [3] reached a similar result with waste from construction demolition, which results show that it is possible to use it up to 25%, in order to attend standard requirements for mortars.

The use of blasted copper slag in cement mixtures is still incipient in technical literature. However, there are significant recent works where different industrial wastes are used in the production of mortars that are more environmentally friendly and technically acceptable. Amaral et al. [34], using a mathematical model, formulated the best combination of sand and waste from ornamental stone processing to produce mortars. In the same scope, de Azevedo et al [35] also incorporated a valueless material, primary sludgewaste of pulp and paper industry, into mortars, achieving an improvement of their technological, durability and environmental properties.

5. ACKNOWLEDGEMENTS

The authors acknowledge the support of Federal University of Sergipe and FAPITEC/SE (Support Foundation for Research and Innovation of Sergipe).

6. REFERENCES

[1]. Bongaarts, J. 2016. Slow down population growth. Nature, v. 530, p. 409-412.

[2]. Andrade, J. J. de O. 2018. Performance of rendering mortars containing sludge from water treatment plants as fine recycled aggregate, v. 192, p.159-168.

[3]. Azevedo, A.R.G.; Cecchin, D.; Carmo, D.F.; Silva, F.C., Campos, C.M.O; Shtrucka, T.G., Marvila, M. T., Monteiro, S.N. 2020. Analysis of the compactness and properties of the hardened state of mortars with recycling of construction and demolition waste (CDW). Journal of Materials Research and Tecnology, v. 9, p. 5942-5952.

[4]. Singh, S.B.; Munjal, P.; Thammishetti, N. 2015. Role of water/cement ratio on strength development of cement mortar. Journal of Building Engineering, v. 4, p. 94-100.

[5]. Husnain, A.; Qazi, I. A.; Khaliq, W.; Arshad, M. 2016. Immobilization in cement mortar of chromium removed from water using titania nanoparticles. Journal of Environmental Management, v. 172, p. 10-17.

[6]. Al-Jabri, K. S.; Abdullah, H. A.; Taha, R. 2011. Effect of copper slag as fine aggregate on the properties of cement mortars and concrete, v. 25, p. 933-938.

[7]. Khyaliya, R. K.; Kabeer, K. I. S. A.; Vyas, A.K. Evaluation of strength and durability of lean mortar mixes containing marble waste. 2017. Construction and Building Materials, v.147. p. 598-607.

[8]. Martínez, P. S.; Cortina, M. G.; Martínez, F. F.; Sánches, A. R. 2016. Comparative study of three types of fine recycled aggregates from construction and demolition waste (CDW) and their use in masonry mortar fabrication. Journal of Cleaner Production, v.118, p. 162-169.

[9]. de Azevedo, A. R. G.; Marvila, M. T.; Barroso, L. S.; Zanelato, E. B.; Alexandre, J.; Xavier, G. C.; Monteiro, S. N. 2019. Effect of Granite Residue Incorporation on the Behavior of Mortars. Materials, v. 12, p.1449.

[10]. Marvila, M. T.; de Azevedo, A. R. G.; Alexandre, J.; Colorado, H.; Antunes, P.; Vieira, C. M. F. 2020. Circular economy in cementitious ceramics: Replacement of hydrated lime with a stoichiometric balanced combination of clay and marble waste. Applied Ceramic Technology.

[11]. de Azevedo, A. R. G.; Marvila, M. T.; Tayeh, B. A.; Cecchin, D.; Pereira, A. C.; Monteiro, S. N. 2020. Technological performance of açaí natural fibre reinforced cement-based mortars. Journal of Building Engineering, v. 33, p. 101675.

[12]. Marvila, M. T.; Alexandre, J.; de Azevedo, A. R. G.; Zanelato, E. B. 2019. Evaluation of the use of marble waste in hydrated lime cement mortar based. Journal of Material Cycles and Waste Management, v. 21, p. 1250–1261.

[13]. Marvila, M. T.; Alexandre, J.; Azevedo, A. R. G.; Zanelato, E. B; Xavier, G. C.; Monteiro, S. N. 2019. Study on the replacement of the hydrated lime by kaolinitic clay in mortars. Advances in Applied Ceramics, v. 118, p. 373-380.

[14]. Madheswaran, C. K.; Ambily, P. S.; Dattatreya, J. K., Rajamane, N. P. 2014. Studies of use of copper slag as replacement material for river sand in building construction. Journal of The Institution of Engineers, v. 95 (3), p. 169-177.

[15]. Mithun, B. M.; Narasimhan, M. C. 2016. Performance of alkali active slag concrete mixes incorporating copper slag as fine aggregate. Journal of Cleaner Production, v.112, p. 837-844.

[16]. Prem, P. R.; Verma, M.; Ambily, P. S. 2018. Sustainable cleaner production of concrete with high volume copper slag. Journal of Cleaner Production, v.193.

[17]. Nazer, A. S.; Pavez, O.; Rojas, F. 2012. Use of copper slag in cement in cement mortars. Revista Escola de Minas, Ouro Preto, v. 65(1), p. 87-91.

[18]. Gorai, B.; Jana, R. K.; Premchand, 2003. Characteristics and utilization of copper slag – a review. Resources, Conservation & Recycling, v. 39, n. 4, p. 299-313.

[19]. DNPM - DEPARTAMENTO NACIONAL DE PRODUÇÃO MINERAL. Anuário Mineral Brasileiro (Brazilian Mineral Yearbook). 2016. Brasília-DF. Available in: http://www.dnpm.gov.br. Accessed in: 23/07/2018.

[20]. Resende, C. M. A., 2009. Estudo da viabilidade de incorporação de escória de cobre como agregado fino em produtos de construção (Study of copper slag incorporation viability as fine aggregate for construction products). 134 pp. Universidade do Porto, Porto, Portugal.

[21]. Dung, T.T.T.; Cappuyns, V.; Swennen, R.; Vassilieva, E.; Phung, N.K. 2014. Leachability of arsenic and heavy metals from blasted copper slag and contamination of marine sediment and soil in Ninh Hoa District, South Central of Vietnam. Applied Geochemistry, v. 44, p.80-92.

[22]. ABNT. NBR 11579, 2013. Cimento Portland – Determinação do índice de finura por meio da peneira 75 µm (Portland cement – Determination of fineness index by means of the 75 µm sieve). Rio de Janeiro.

[23]. ABNT NBR 16605, 2017. Cimento Portland e outros materiais em pó – Determinação da massa específica (Portland cement and other powdered material – Determination of density). Rio de Janeiro.

[24]. ABNT NBR NM 52, 2009. Agregado miúdo – Determinação da massa específica e massa específica aparente (Fine aggregate – Determination of the bulk specific gravity and apparent specific gravity). Rio de Janeiro.

[25]. ABNT NBR NM 248, 2003. Agregados – Determinação da composição granulométrica (Aggregates – Sieve analysis of fine and coarse aggregates). Rio de Janeiro.

[26]. Anjos, M.A.G.; Ssales, A.T.C.; Andrade, N. 2017. Blasted copper slag as fine aggregate in Portland

cement concrete. Journal of Environmental Management, v. 196, p. 607-613.

[27]. Schlesinger, M. E.; King, M. J.; Sole, K.C.; Davenport, W. G. 2011. Chapter 1 – Overview. Extractive Metallurgy of Copper, 5 ed., p. 1-12

[28]. ABNT NBR 13276, 2016. Argamassa para assentamento e revestimento de paredes e tetos – Determinação do índice de consistência (Mortars applied on walls and ceilings – Determination of the consistence index). Rio de Janeiro.

[29]. ABNT NBR 13279, 2005. Argamassa para assentamento e revestimento de paredes e tetos – Determinação da resistência à tração na flexão e à compressão (Mortars applied on walls and ceilings – Determination of the flexural and the compressive strength in the hardened stage). Rio de Janeiro.

[30]. ABNT NBR 8522, 2017. Concreto – Determinação do módulo estático de elasticidade à compressão (Concrete – Determination of the elasticity modulus by compression). Rio de Janeiro.

[31]. ABNT NBR 7222, 2011. Concreto e argamassa – Determinação da resistência à tração por compressão diametral de corpos de prova cilíndricos (Concrete and mortar – Determination of the tension strength by diametrical compression of cylindrical test specimens). Rio de Janeiro.

[32]. ABNT NBR 9778, 2009. Argamassa e concreto endurecidos – Determinação da absorção de água, índice de vazios e massa específica (Hardened mortar and concrete – Determination of absorption, voids and specific gravity). Rio de Janeiro.

[33]. ABNT NBR 9779, 2012. Argamassa e concreto endurecidos – Determinação da absorção de água por capilaridade (Mortar and hardened concrete – Determination of water absorption by capillarity). Rio de Janeiro.

[34]. Amaral, L. F.; Delaqua, G. C. G; Nicolinte, M.; Marvila, M. T.; de Azevedo, A. R. G.; Alexandre, J.; Vieira, C. M. F.; Monteiro, S. N. 2020. Eco-friendly mortars with addition of ornamental stone waste – A mathematical model approach for granulometric optimization. Journal of Cleaner Production, v. 248, p. 119283.

[35]. de Azevedo, A. R. G.; Alexandre, J.; Marvila, M. T.; Xavier, G. C.; Monteiro, S. N.; Pedroti, L. G. 2020. Technological and environmental comparative of the processing of primary sludge waste from paper industry for mortar. Journal of Cleaner Production, v. 10, p. 119336.

7. MINIBIOGRAFÍA DE AUTORES

RAFAELA LIMA SANTOS MELO is currently a doctoral student at the Graduate Program in Materials Science and Engineering (P²CEM). Graduated in Civil Engineering from the Federal University of Sergipe (2013). Master in Civil Engineering from the Federal University of Sergipe (2017). Postgraduate degree in Work Safety Engineering from the Sergipe School of Administration and Business (2016). She has experience in Civil Engineering, with emphasis on Construction Materials. Acts as a Judicial Expert at the Regional Labor Court of the 20th Region - Sergipe, carrying out inspections and preparing reports of unhealthy and hazardous labor lawsuits.
(ORCID: 0000-0001-8083-1370)

ANGELA TERESA COSTA SALES is Civil Engineer, holds a master's degree in Development and Environment from Federal University of Sergipe (2001) and a doctorate in Civil Engineering from Pontifical Catholic University of Rio de Janeiro (2006). Full Professor at Federal University of Sergipe. Has experience in Civil Engineering, focusing on Construction Materials and Components, acting on the following topics: non-conventional building materials, bamboo pulp, cementitious composites, vegetable fibers, fiber cement, waste utilization.

DANIEL COSTA SALES is Graduated in Civil Engineering from Federal University of Sergipe (2018). He is currently studying for a Master's degree in Structural Engineering at São Carlos School of Engineering at the University of São Paulo EESC/USP (2019-2021), developing research in the field of computational mechanics, with focus on the Generalized Finite Element Method (MEFG) and its stability numerical.

ROSANE MARIA PESSOA BETÂNIO OLIVEIRA is Graduated in Chemical Engineering (1996) from the Federal University of Rio Grande do Norte, Master's (2008) and Ph.D. (2010) in Materials Science and Engineering from the same institution. She is currently associate Professor II at Federal University of Sergipe. Has experience in Materials and Metallurgical Engineering, with emphasis on non-metallic materials, acting on the following topics: refractory ceramics, cement matrix composites, synthesis of functional ceramics and reuse of industrial waste in ceramic matrix. (ORCID: 0000-0002-2726-1863).