Impact of Using Bauxite Residue in Microconcrete and Comparison with Other Kind of Supplementary Cementitious Material

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Abstract

The use of bauxite residue (BR) in association with Portland cement may be an alternative for a large-scale application for the waste. With this strategy, would be possible to reduce both environmental impact (cement – large CO_2 released, and alumina/aluminum production). In works related to this research, it was proved that the hardened properties are not deteriorated by using BR, even with reduction in the binder consumption, because the large amount of silica, aluminum and iron, and the physical properties of BR, can affect the hydration reaction, potentializing the use of cement. However, the high sodium content can be a problem due to the potential of leaching after hardening. Additionally, a comparative evaluation between BR and other kind of supplementary cementitious material (SCM) frequently used in association with Portland cement, is still poorly explored in literature. This work was carried out to evaluate the properties of microconcretes formulated with bauxite residue (dried or calcined at 800°C) and to compare with products with silica fume, metakaolin, limestone filler and ground blast furnace slag. The results indicate that BR do not deteriorate the hardened properties of evaluated products, and there are no losses comparing with the other kind of SCM.

Keywords: Microconcrete, bauxite residue, silica fume, metakaolin, blast furnace slag.

1. Introduction

The United Nation (UN) estimates that up to 2050 the population on the planet will be around 9.6 billion of people, with a projection of 10.9 billion by 2100 [1]. However, other organizations [2] estimate 8.7 billion by 2050, dropping to about 8 billion by the end of the century. Regardless of such controversy, the fact is that the population should grow from just over 7 billion today, in an increasingly urban infrastructure than the estimated 54% of people living in cities on this date, reaching 66% by 2050, meaning an addition of 2.5 billion people to urban areas.

Thus, it can be said that there is a clear need to expand the urban places to follow the population growth, and there is still, a huge deficit of housing and infrastructure, particularly in the developing countries. To illustrate this fact, around 90% of the current urbanization process takes place in Africa, Asia, Latin America, and the Caribbean [3], requiring the construction of more than 70 million new urban homes per year. This scenario, which is independent of economic crises, elevates the society's great challenge for more sustainable growth in an era when the natural resources are headed for depletion if the current patterns of exploitation, consumption, and waste generation will be maintained [4].

Another relevant aspect of this analysis is that the aging of world's population will increase in percentage in the next decades (it is estimated that about 21.1% of the population will be over 60 years old in 2050, as opposed to 11.7% in 2013) [1], reducing the economically active workforce in a more populated and urbanized world.

Consequently, there should be an increase in the use of more advanced technological solutions, resulting in more efficient production processes, with a greater degree of automation and less labor intensive, including construction. So, it can be affirmed that there is a clear tendency to world with growing demand for more efficient and productive solutions of construction, with smaller environmental impacts. Therefore, these assumptions must be considered in the design of the future of building materials.

The modern society has in Portland concrete the most produced and consumed material in the world, being estimated a production of more than 10km^3/year. Basically, these cementitious products consist of the mixture of aggregates, binder and water and, although it is not possible to obtain an exact value for the volume produced, the volume quoted above is estimated considering the production of Portland cement. In this case, this hydraulic binder reached the expressive mark of 4 billion tons/year between 2013 and 2014, with growth prognosis of 2.5 times by 2050 [5].

It is true that in the modern world, the environmental impacts cannot be tolerated in the same proportion as the increase in the production of cement materials, and that the technologies for producing such materials will be charged to achieve efficiency levels that guarantee high productivity with reduced efforts to the workers.

Regardless of this, the main challenge for the future will be: *how to increase production of the most important building materials to meet the demands of population growth, aging and urbanization, without accentuating the impacts of the enormous volumes produced*?

Considering only the aspects related to materials, different routes have been developed to replace clinker as the use of alternative materials, generally obtained as: i. by-product from industrial process (like ground blast furnace slag, fly ash, silica fume, etc.), ii. inert material (like filler), iii. new kind of cement with lower environmental impact, and others. For this reason, the level of efficiency currently practiced in cement technology has been investigated in order to identify new opportunities to increase the production without increasing the cement production.

Without giving up any of the initiatives presented to reduce environmental impacts on cement production, strategies to reduce the use of binders in formulations have the potential to increase the production of cement materials without the need to increase cement production at the same rate. So, it is possible to infer that to obtain a more eco-efficient scenario it is needed to look for new supplementary cementitious materials (SCMs), to improve the understanding of the characteristics of the currently known SCMs and to evaluate in greater depth the physico-chemical interactions with the different types of binders.

On the other hand, another great environmental challenge is to find a large-scale application for bauxite residue, generated in the Bayer process to obtaining alumina. In this process, the bauxite ore is crushed and milled, heated at a temperature of up to 200°C, in a pressure vessel along with a sodium hydroxide solution; the solution of aluminum-rich components follow in the process, while the residue is separated by filtering, and disposed into the lakes of mud, being hazardous environmentally because of its alkalinity. Despite some controversies, and even with the precise control of lake contention, always will have the risk of disruption, like that occurred in October 2010 in Hungary, killing ten people, and contaminating a large area [6].

Because of this, the efforts to find an application for this waste have been stepped up in recent years, focusing in: water treatment, soil remediation, production of structural materials with cement, production of red ceramics, metal coating, production of pozzolanic pigments, treatment of waste from gold mines, selective filtering of SO_2 or H_2S, corrosion inhibitor in Fe-C alloys, support for catalysis, and others [7].

The strategy adopted in this work was to find a large-scale application for the bauxite residue associating it with Portland cement in compositions of microconcrete, trying to reduce the environmental challenges of both process: reduction of CO_2 released from cement production and waste generation from alumina/aluminum production [6-11].

Thus, it was formulated compositions of microconcrete with bauxite residue, dried or calcined at 800°C, evaluated some hardened properties, and the results obtained were compared with results of commonly used mineral additions, illustrating the performance and durability aspects of this products.

2. Experimental

2.1. Particle Characterization

Particle size distribution: coarse aggregates were evaluated in an equipment QicPic, Sympatec using Dynamic Image Analysis and the finer particles quantified in a Sympatec laser particle size analyzer, model Helos KR with range of 0.1 to 350 micrometers.

Specific surface area: it was obtained by nitrogen adsorption (N_2) on the surface of solid sample according to the BET method in an equipment Belsorp Max, Bel Japan, after pre-treatment of samples in an equipment BELPREP-vacII, Bel Japan, at 40°C during 16 hours under vacuum with pressure of 10^{-2} µmHg.

Real density: it was assessed using a gas He pycnometry in an equipment Multipycnometer - Quantachrome Instuments. Around 100 g of cement were placed in the measurement cell. Comparing the applied pressure and volume in a reference cell, previously calibrated, the volume occupied by the particles were obtained. Knowing previously the mass of sample, the real density of the anhydrous cement could be calculated.

Chemical composition: it was evaluated following the general guidelines from ISSO/FDIS 29581-2:2009 (E) "Cement – Test Methods – Part 2: Chemical analysis by X-ray fluorescence" in an equipment Minipal Cement, PANanalytical with melt pastilles in a Claisse M4 model melting machine, using lithium tetraborate/lithium metaborate blend fluxes, with a ratio of 1.0g of sample to 6.75g of melting.

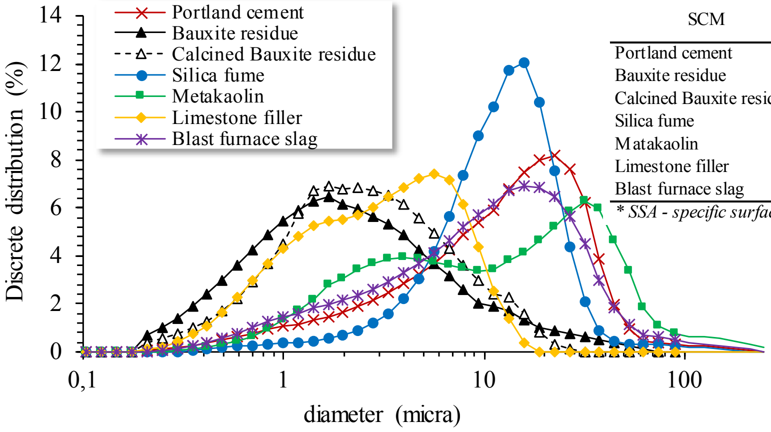
2.2. Materials

The microconcretes were formulated using Portland cement (named CPV; the purest binder commercialized in Brazil), bauxite residue from Alumar (aluminum production plant from northeast of Brazil) and natural and artificial sands. Bauxite residue was received 30%-wet, dried at 105 °C and after, ground and sieved at 75 microns. Part of this material was calcined at 800 °C for 3 hours.

As a comparative criterion, compositions with silica fume, metakaolin, limestone filler and ground blast furnace slag were also evaluated. So, Figure 1 shows the particle size distribution, specific surface area and real density of bauxite residue (dried or calcined) and the other kind of supplementary cementitious materials used in the work.

Bauxite residue (dried or calcined) presents particle size distribution finer than Portland cement, as well as limestone filler. This is an important information because they can result in filler effect in the microconcrete. Despite of silica fume (SF) presents particle size distribution higher than expected for this kind of material, the specific surface area was higher than the other materials: it was observed large amount of agglomerates which, even with the shear imposed during the evaluation, were not broken [12].

It is important to say that the specific surface area of raw materials with different mineralogical compositions do not to be related to its content of finer particles for comparative criteria, because they have different chemical composition, with distinct agglomeration potential and morphology. This comparison must be done just when the materials are made from the same ore [13].



SCM	SSA * (m²/g)	Real density (g/cm³)
Portland cement	1.31	3.29
Bauxite residue	10.6	3.02
Calcined Bauxite residue	20.1	3.05
Silica fume	22.0	2.20
Matakaolin	17.2	2.54
Limestone filler	3.73	2.78
Blast furnace slag	0.6	2.91

** SSA - specific surface area*

Figure 1. Particle size distribution, specific surface area and real density of bauxite residue and others supplementary cementitious materials used in this work.

The chemical composition of supplementary cementitious materials (SCMs) are presented in Table 1. Portland cement presents high amount of calcium and silicon oxides, and smaller amount of aluminum oxide, indicating the predominance of the silicate phases in the clinker (alite and belite) and small amounts of the aluminate phases (tri-calcium aluminate and brownmillerite). The amount of SO_3 indicates high content of the calcium sulfates added as setting regulator.

The most impacting observation is the high loss on ignition (4.18%), illustrating a high volatile material content, mainly CO_2 as a calcium carbonate. The standardization for this type of cement requires that up to 5% carbonate can be added, but based on this result it is estimated that little more than 9% was added in the clinker.

Table 1. Chemical composition of raw material.

Raw material	Portland cement	BR	BRc	SF	MK	LF	BFS
Na_2O	0.22	11.0	12.7	0.17	<0.001	<0.001	0.21
MgO	1.06	<0.001	<0.001	0.27	0.14	7.86	6.46
Al_2O_3	3.71	20.6	22.8	0.12	39.1	0.07	10.5
SiO_2	16.5	15	16.4	94.4	50.8	1.66	34.5
P_2O_5	0.22	0.05	0.06	0.24	0.12	0.04	<0.001
SO_3	3.85	0.22	0.17	0.07	0.04	0.01	2.49
Cl	0.15	0.13	0.10	0.25	<0.001	<0.001	<0.001
K_2O	1.12	<0.001	<0.001	0.82	0.40	0.01	0.54
CaO	65.4	1.05	1.20	0.51	0.06	47.8	43.4
TiO_2	0.22	4.64	5.50	<0.001	1.26	<0.001	0.63
MnO	0.09	<0.001	<0.001	0.04	<0.001	<0.001	0.67
Fe_2O_3	3.02	34.4	41.5	0.13	6.07	0.03	0.30
SrO	<0.001	<0.001	<0.001	<0.001	0.01	0.01	0.14
ZrO_2	0.01	0.40	0.57	<0.001	0.02	<0.001	0.03
Loss on ignition	4.18	12.3	0.90	2.99	1.98	42.6	-

The silica fume and limestone filler present high purity, with more than 95% SiO_2 or $CaCO_3$ respectively in these SCMs. The bauxite residue presents high amounts of iron, aluminum, and silicon oxides, with little calcium oxide and low loss on ignition. There is no technical standardization that discusses the chemical characteristics of this waste, so the results obtained do not have a baseline. An information that deserves to be mention is that according the Brazilian standard (NBR 12653) the bauxite residue evaluated do not present pozzolanic activity and, because of this, cannot to be described as this kind of material.

In the case of metakaolin, as expected, the presence of high amounts of silicon and aluminum oxides was observed, but contamination with iron was quantified, and for the ground blast furnace slag, the main chemical element was calcium, but also significant amounts of silicon, aluminum and magnesium were observed.

2.3. Concrete Evaluated

Compositions using 5% of bauxite residue in partial substitution of Portland cement (in volume) were formulated. The formulations with dried bauxite residue will be named as 5BR, and with calcined material will be named as 5BRc.

As the purpose of this work was to compare the results obtained with results of other supplementary cementitious materials frequently used worldwide, it was evaluated the compositions presented in

Table 2. The consumption of Portland cement, water and sand was kept constant and the sands mix proportion was the same for all concretes. The main differences were the kind of SCM. It deserves to be mentioned that to complete the desired amount of finer particle it was used a dilution filler (calcium carbonate with similar particle size distribution of Portland cement).

All dry powder was inserted into a cup of an equipment Hobart and the water added controlling the flow at 45g/sec. The mixing was carry out using the speed 1 of mixer for 3 minutes. After this step, the concrete was moulded and cured at 23 ± 2°C by 28 days, at 98% of relative humidity.

Table 2. Concrete compositions. Consumption of each raw material per cubic meter.

Raw material	**Consumption (kg/m³)**						
	Ref	5BR	5BRc	5SF	5MK	5LF	5BFS
Portland cement	263						
Dilution filler	408	396	396	398	398	397	396
Bauxite residue	-	12	-	-	-	-	-
Calcined Bauxite residue	-	-	12	-	-	-	-
Silica fume	-	-	-	9	-	-	-
Metakaolin	-	-	-	-	10	-	-
Limestone filler	-	-	-	-	-	11	-
BFS	-	-	-	-	-	-	12
Medium sand	850						
Coarse sand	380						
Natural sand	335						
Water	201						

2.4. Hardened Characterizations

Total porosity: measured according the Archimedes immersion method, based on the dry, wet and immersed mass. Initially, the dry mass of each sample was estimated, then the samples were completely immersed in water and stays under vacuum for 2.5 hours. After this time, the wet and immersed mass were measured. The total porosity was calculated according the eq. 1, where is δ_{REL} is the relative density of concretes:

$$\text{Total Porosity (\%)} = (1-\delta_{REL}) \times 100\% \qquad (1)$$

Mechanical strength: carried out according the Brazilian test, following the standard ABNT NBR 7215, using a Universal Test Machine, EMIC - DL 10.000, controlling the load at 490 N/s, up to total rupture [14].

Modulus of elasticity: measured according to Brazilian standard NBR 15630/08 using equipment with frequency transducers of 200 kHz, and a circular transversal section with 20 mm diameter [15].

Air-permeability: measured according to the vacuum-decay method [16-18]. The apparatus employed was a vacuum pump connected to a suction chamber that is in contact with the surface of the mortar. When the vacuum pump is turned on a transducer registers the pressure variations over time, until the pressure stabilizes. The test starts when the vacuum is turned off and the time it takes for the pressure to subside is quantified. The air-permeability (expressed in k_1 values, in m²) is calculated using the *Forchheimer* equation (eq. 2), considering two basic hypotheses: negligible air-compressibility and using just the linear part of the equation [19].

$$\frac{\Delta P}{L} = \frac{\mu}{k_1} v_s + \frac{\rho}{k_2} v_s^2 \qquad (2)$$

L is the sample thickness, μ and ρ are, respectively, the fluid viscosity and density, vs is the speed of air-percolation and ΔP is the pressure variation, for which vs, μ and ρ are measured or calculated. The term $\mu vs/k_1$ shows the viscous effect of fluid-solid interaction, while the term $\rho vs^2/k_2$ represents the inertial effects. The terms k_1 and k_2 are thus known as *Darcyan* and *non-Darcyan* permeability constants, in reference to Darcy's law, a simpler and earlier empirical model for permeability description. However, k_2 was not used to compare the results in this work [19].

Carbonation: after cure for 28 days, the evolution of carbonation with time was monitored under controlled temperature (24ºC) and humidity conditions (50%), using two methods: i. spraying phenolphthalein, and ii. thermogravimetric analysis [20].

Shrinkage: after cure for 28 days, the evolution of the drying shrinkage with time was measured under controlled temperature (24ºC) and humidity conditions (50%). The mass loss over time, which fundamentally corresponds to the loss of capillary water in the mixtures, was also evaluated to gain a better understanding of the shrinkage dynamics [21].

3. Results and Discussion

The results of hardened properties are presented follow, using statistical evaluations to prove the significance of data. Figure 2 indicates the results of porosity of microconcretes (total and opened) and Table 3 represents the statistical evaluation.

In order to evaluate the significance of the variation of kind of supplementary cementitious materials (SCMs), an analysis of variance (one-way Anova) was used to reject or accept the hypothesis of equality of average, within and between groups.

In the first part of the table are presented the information of the quantity of samples evaluated for each composition, the sum of the results of total porosity, the average, and the variance for each case. However, only with these results it is not possible to evaluate if there was statistical difference between samples in relation to the respective porosities.

P-value, in the table below, indicates the value of proof, and shows whether the hypothesis of equality between the results concerning the variation of SCM in the compositions should be accepted or rejected. If this value is greater than the error, i.e. 0.05, the equality must be accepted, otherwise should be rejected. In the cases evaluated, the value was much lower than the 5% error.

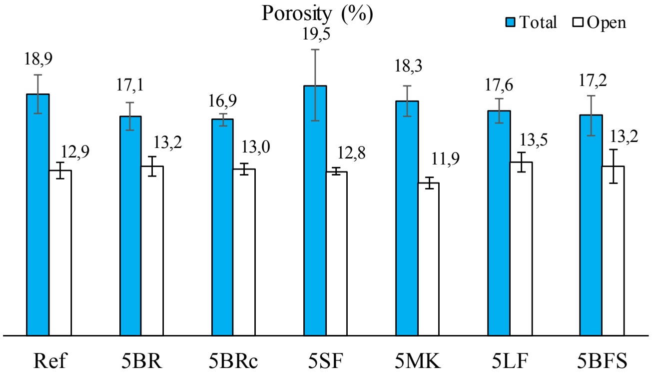


Figure 2. Porosity of microconcretes in function of mineral addition.

Table 3. Statistical evaluation. On the left is the result of one-way Anova and, on the right Tukey's test.

One-way Anova

Group	Count	Sum	Average	Variance
Ref	10	188.73	18.87	2.20
5BR	10	171.34	17.13	1.26
5BRc	10	168.81	16.88	0.23
5SF	10	195.43	19.54	7.73
5MK	10	183.38	18.34	1.52
5LF	9	157.96	17.55	0.91
5BFS	9	154.69	17.19	2.05

Source of variation	SQ	gl	MQ	F calc	P-value	F crit
Between groups	60.1	6	10.02	4.37	*0.0010*	2.25
In the group	140.0	61	2.30			
Total	200.2	67				

Tukey's test

	Ref	**5BR**	**5BRc**	**5SF**	**5MK**	**5LF**	**5BFS**
Ref		0.168	0.074	0.958	0.986	0.476	0.197
5BR	3.573		1.000	0.015	0.586	0.996	1.000
5BRc	4.092	0.519		0.005	0.356	0.958	0.999
5SF	1.377	4.950	5.469		0.586	0.074	0.018
5MK	1.099	2.475	2.994	2.475		0.9120	0.637
5LF	2.715	0.858	1.377	4.092	1.617		0.998
5BFS	3.463	0.110	0.629	4.840	2.365	0.748	

Another way to conclude whether there is equality is to compare the value of F_{calc} with $F_{critical}$: the $F_{critical}$ limits the rejection region, and means that for greater values of F_{calc} the hypothesis of equality must be rejected. Therefore, as the value of F_{calc} was higher than that of $F_{critical}$ in the case of total porosity, it is an indicative that the use of different kind of SCM resulted in changes of porosity, and the P-value lower than 0.05 confirms the significance of this comparative result.

However, this test does not indicate which results are differing from the others. For this, the Tukey's test was used, whose results are in Table 3 on the right, for comparative evaluation of the pairs with different SCM, in order to indicate which are different from the others.

So, it was proved that the total porosity obtained in the compositions formulated with BR or BRc was similar to that obtained for MK, LF and BFS, but different from the composition with silica fume (which was higher than the other ones).

As could be seen in Table 2, the cement consumption was the same for all compositions, but the binder consumption didn't, because SF, MK and BFS are considered binders. So, to evaluate if this affected the concrete hardened properties the results will be presented following, in function of kind of SCM. As the same statistical evaluation was used for accepting or reject the hypothesis of equality between the averages, or to show which results are different from the others, the tables will not be presents again. Just the explanations will be.

Figure 3 indicates the results of mechanical strength and Figure 4 the relation between the binder intensity (BI) and compressive strength for the microconcretes evaluated in this study. The results of Brazilian and International works are a compilation did by *Damineli* [5], and the results obtained in this work were compared to evaluate the sustainability of these compositions: as higher the BI, higher the amount of binder to obtaining the same performance and consequently, lower the concrete eco-efficiency is.

So, it is clear that the composition formulated with silica fume was the only one that presented compressive strength statistically different from the others, and higher than the Reference (formulated just with Portland cement). This is an expected result, due to its higher pozzolanic activity, quickly reacting with the calcium hydroxide formed in the hydration of the cement, and filler effect [6,7].

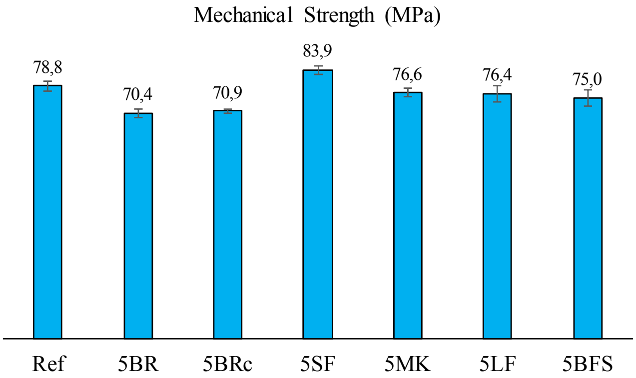


Figure 3. Compressive strength of microconcretes in function of mineral addition.

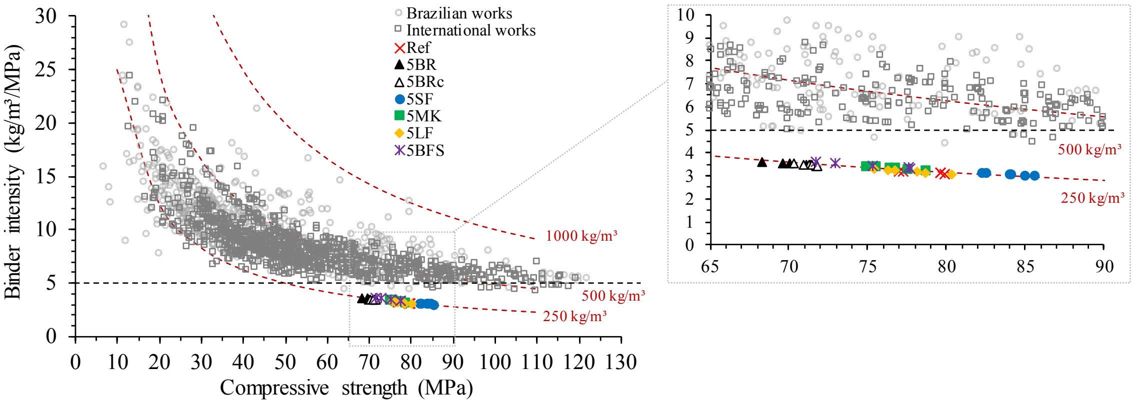


Figure 4. Relation between binder intensity and compressive strength for the microconcretes evaluated in this study. Results from a compilation did by *Damineli* [5] are presented to comparison.

It is common to find in literature, papers associating the mechanical strength with total porosity, but this was not observed in this work, because the compositions were formulated with mineral additions with different physical, chemical and mineralogical characteristics, resulting in different interactions with Portland cement.

The lowest mechanical strength was observed in the compositions with bauxite residue, dried or calcined at 800°C, resulting in a reduction of around 10%, comparing with Reference, but this is not a considerable problem, because as represent in the graph of binder intensity, all compositions evaluated in this work indicate eco-efficient concretes, comparing with the cement compositions developed worldwide.

The minimum binder intensity, according to the literature survey by *Damineli* [5], indicates 5kg/m^3/MPa by concretes with mechanical strength higher than 50MPa, and for compressive strength lower than this, the minimum BI follow the corresponding values for 250kg/m^3 of binder consumption.

This minimum value of binder consumption is probably due to specifications in standards, supposed to obtain the adequate durability conditions: Brazilian standard (NBR 12655) recommend 260kg/m^3 while European standard recommend 240kg/m^3 for concretes exposed in some places with risks of corrosions. However, *Wassermann, Katz and Bentur* [22] proved that some indicative of durability is not affected when the total binder amount is reduced: in some cases, are even improved. *Dhir et al.* [23] concluded that is not adequate to specify the minimum cement content in the compositions, and *Popovics* [24] showed that for the same water-to-cement ratio, as higher the binder content lower the compressive strength is. Summarizing, all the microconcretes developed in this work are considered eco-efficient, independently of kind of SCM.

Hardened concrete is a material considered as a pseudo-solid, because it contains a solid skeleton, water and porosity, and these last two components contribute a lot with their properties, which include deformations under both immediate and slow loads and deformations independent of the action of loads such as hydraulic retraction. So, the evaluation of deformation capacity of concrete is very important, but unlike steel, does not follows the Hooke's Law. It is known that concrete is a heterogeneous material, and its elastic behavior are affected by the volumetric fraction, density and modulus of elasticity of the main components, as well as the characteristics of the transition zone at the interface. As in this work the amount of aggregates were kept constant, as well as the water-to-cement and Portland cement consumption for all compositions, the changes observed in the modulus of elasticity were caused by the impact of kind of SCM, according presented in Figure 5.

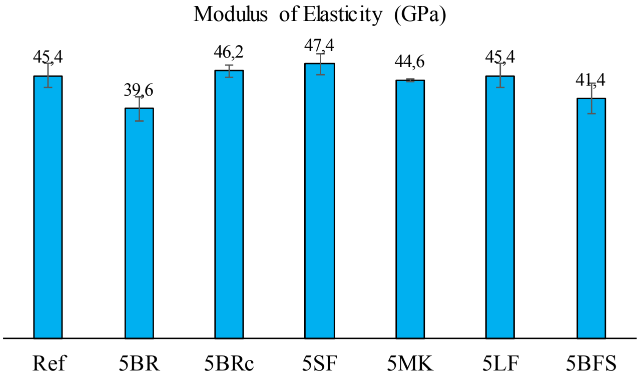


Figure 5. Modulus of elasticity of microconcretes in function of mineral addition.

Statistically, was prove that just the compositions with bauxite residue and ground blast furnace slag were different from the others, and similar between them, presenting lower microstructural stiffness. Compressive strength and deformability capacity are very important properties to evaluate the mechanical performance of this kind of material. However, the air-permeability, carbonation and shrinkage are important to evaluate the durability criteria of concretes.

The most common durability problems are directly associated to the porosity and penetration of aggressive agents into the concrete and, in general, the easier the penetration of such agents, the faster the degradation of the cementitious product. So, the air-permeability has close relation with durability. The results are presented in Figure 6, and indicate that the air-permeability of microconcrete with calcined bauxite residue was lower than the reference and statistically similar to silica fume, limestone filler and ground blast furnace slag. On the other hand, the composition with metakaolin was the most permeable, followed by the composition with bauxite residue and Reference microconcrete.

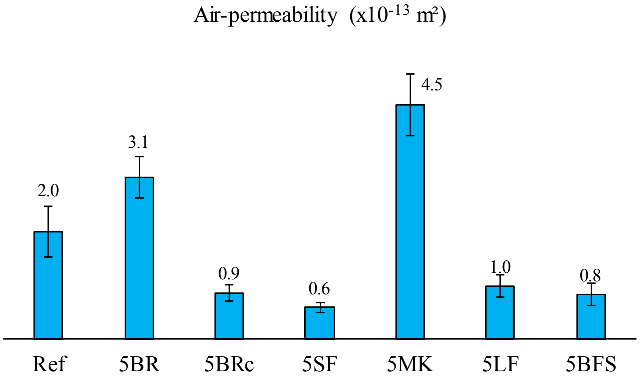


Figure 6. Air-permeability of microconcretes in function of mineral addition.

To minimise the effects of degradation of concrete and increase their lifespan, the dimensional variation needs to be adequate to use. For instance, if the shrinkage is very intense, the tensile stresses can exceed the tensile strength of the material [21], which can cause cracks in the microstructure, facilitating the percolation of degrading agents and reducing the lifetime. According *Bissonnette, Pierre and Pigeon* [25], for a constant volume of paste, the shrinkage in conventional concretes increases with increasing cement content. Thus, a possible strategy to minimize this change is the substitution of the cement by mineral additions. However, there is not a consensus about the use of these materials in association with cement. So, this is a great problem, because many variables can affect the drying shrinkage of concretes.

In the results obtained in this work (Figure 7) was observed that the compositions with bauxite residue, dried or calcined at 800°C, presented a little expansion after 28 days of cure. This occurred due to the formation of large amount of hydrated aluminate products, from the chemical reaction of Portland cement and bauxite residue [26,27]. The other compositions presented lower shrinkage than reference, indicating that the use of SCM can to reduce the dimensional variation.

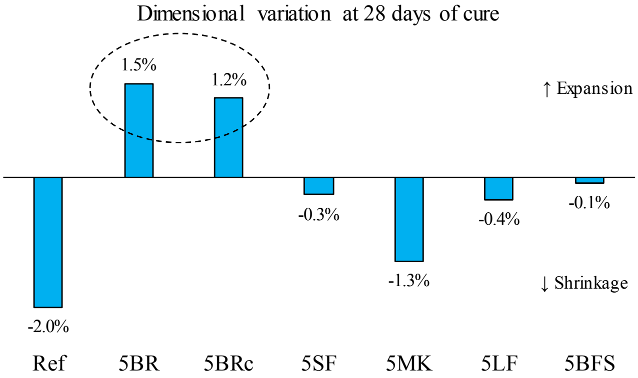


Figure 7. Dimensional variation of microconcretes in function of mineral addition.

It also deserves to be mentioned that no carbonation was observed in any compositions, measured qualitatively by the phenolphthalein method or quantitatively by thermogravimetric analysis. Concrete produced with Portland cement is a fairly alkaline material and, after the production, it presents pH between 11 and 13, a situation that does not favor the corrosion reactions in the steel reinforcement. The carbonation results in a marked decrease in the pH of the concrete, with a consequent reduction in the protection of the reinforcement. So, keeping the alkalinity of concrete in this level of pH, could maintain the resistance of this product to susceptibility to carbonation, and the high alkalinity of bauxite residue can to improve this resistance.

4. Conclusions

The use of bauxite residue in association with Portland cement do not deteriorate the hardened properties of microconcretes: comparing the results with other kind of supplementary cementitious material, in general, the characteristics of microconcretes were statistically similar. The mechanical strength of microconcrete with bauxite residue were around 10% less than the reference, but this is not a problem because the products developed in this work presented a great eco-efficiency, i.e.: high compressive strength associated with low binder consumption (binder intensity ≈ 3 kg/m³/MPa).

Air-permeability of microconcrete with calcined bauxite residue was lower than the reference and statistically similar to silica fume, limestone filler and blast furnace slag. The composition with metakaolin was the most permeable followed by the composition with bauxite residue. This parameter presents a closer relationship with durability, because controls the penetration of aggressive agents into the concrete and, in general, the easier the penetration of such agents, the faster the degradation of the cementitious product.

Different from the other kind of supplementary cementitious materials, the microconcrete with bauxite residue, in nature or calcined, presented a little expansion, indicating that it is a shrinkage compensator, and there was not observed any difference about carbonation in function of kind of SCM.

According the results obtained, is clear that it is possible to use this residue in cement compositions, but is still necessary to evaluate the parameters associated to leaching.

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