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M.J.B.Moraes[a], J.C.B. Moraes[a], M.M. Tashima[a], J.L.Akasaki[a]

[a] Department of Civil Engineer, Unesp,Brazil Avenue 56, 15385-000 Ilha Solteira, Brazil.

Estudio de materiales alternativos para la sustitución de cemento Portland en la construcción civil

RESUMEN

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La propuesta de este trabajo es estudiar materiales, que inicialmente fueron clasificados como desechables, en la construcción de edificios como nuevos materiales alternativos. Desta manera, se estudió la sustitución parcial del cemento Portland en morteros por las puzolanas siguientes: ceniza de caña de azúcar (SCBA), ceniza de cáscara de arroz (RHA), metacaolín (MK) y humo de sílice (SA). Se compararon estas composiciones con una mezcla de control, que no sustituye el cemento Portland, en las siguientes pruebas: resistencia a la compresión, consistencia, capilaridad de agua e inmersión en agua. Los porcentajes de sustitución realizados fueron de 5, 10, 15, 20, 25 y 30% para SCBA, RHA y metacaolin, y 5, 10 y 15% para humos de sílice en peso. La prueba de resistencia a la compresión se realizó a los tiempos de curado de 3, 7, 28 y 90 días, mientras que la capilaridad de agua y la inmersión en agua se llevaron a cabo a los 28 días. En las edades tempranas, pocas mezclas mostraron resistencia por encima de la referencia, pero con 90 días, seis mezclas pasaron el control. Todas las mezclas con puzolanas presentaron menor absorción de agua por inmersión y capilaridad. De manera sostenible, el uso de SCBA, RHA, MK y SA es viable.

Study of alternative materials for Portland cement replacement in civil construction

ABSTRACT

Keywords:
Civil construction
Sustainable Materials
Pozzolan

The proposal of this work is to study materials, which initially were classified as disposable, in building construction as new alternative materials. In this way, this research studied the partial replacement of Portland cement in mortars by the following pozzolans: sugar cane bagasse ash (SCBA), rice husk ash (RHA), metakaolin (MK) and silica fume (SA). Theses composites were compared with a control mixture, which no Portland cement replacement, in the following tests: compressive strength, consistency, water capillarity and water immersion. The replacements percentages carried out were 5, 10, 15, 20, 25 and 30% for SCBA, RHA and metakaolin, and 5, 10 and 15% for silica fume by weight. The compressive strength test was performed at curing times of 3, 7, 28 and 90 days, whereas water capillarity and water immersion were carried out at 28 days. In the early ages, few mixtures showed resistance above the reference, but with 90 days, six mixtures passed the control. All mixtures with pozzolans presented less water absorption by immersion and capillarity. Sustainably, the use of SCBA, RHA, MK and SA is viable.

Autor de contacto: M.J.B Moraes
e-mail: maju.bamoraes@gmail.com

1 Introduction

Pozzolan is a material known since the Roman Empire, which were mixed with lime to produce compounds with cementitious properties. Currently, these pozzolans are classified as “natural pozzolan”, since there were basically a kind of volcano tuff, extracted mainly of the Pozzuoli region, hence the name pozzolan [1]. The “artificial pozzolan” is a pozzolan derived from human activities, a byproduct or waste from different industries. This work studied four artificial pozzolans from different sources as partial replacement of Portland cement in mortars: sugar cane bagasse ash (SCBA), rice husk ash (RHA), metakaolin (MK) and silica fume (SA).

Brazil is the sugar cane world’s biggest producer, also the major producer of sugar and ethanol [2]. To transform the sugar cane in those two products, milling is a part of the process, resulting in a byproduct known as sugar cane bagasse, which is burnt to generate energy, becoming the polluting residue sugar cane bagasse ash. The SCBA presents physic-chemical properties appropriate for its use as an alternative cement partial replacement in building constructions [3] and reduces the carbon dioxide’s emissions when used in blended cementitious matrices [4].

The rice husk is a byproduct of the rice agroindustry, is also use to generate energy through its burning, as result of this process the rice husk is reduced into ashes, the rice husk ash (RHA). The use of the ash as cement replacement contributed to a higher mechanical strength and a lower water absorption due to its high pozzolan activity and particle size [5].

Metakaolin (MK) is a byproduct from the calcination of kaolinite-rich clays, it is an aluminum-siliceous material with high pozzolan activity, which improves the properties of hardened concrete, lowering the porosity and providing a higher mechanical strength [6].

Silica fume is also derived from industries, more specifically the silicon metal or iron silicon industry. This mineral admixture enhances the mechanical behavior of concrete and reduces its total porosity [7].

The pozzolan improves the cementitious matrices’ mechanical behavior and durability by acting physically, due to its fineness, and chemically, known as pozzolanic reaction, in the blended admixtures. Furthermore, contributes to sustainability by providing an appropriate finality for materials initially classified as disposable and potentially pollutants.

In this way the aim of this research is to study the SCBA, RHA, MK and SA as a sustainable mineral admixtures for cement partial replacement by means of compressive strength, workability and water absorption analyses, comparing the pozzolan-content mortars with a control mixture, no Portland cement replacement.

2 Experimental Section

The materials used in this research were the Brazilian cement CP V – ARI, presenting no pozzolan, sugar cane bagasse ash (SCBA), a noncommercial material, produced by auto-combustion process in a furnace, then milled and sieved, rice husk ash (RHA), metakaolin (MK) and silica fume (SA), obtained commercially.

The cement was replaced by each pozzolan in a rate of 0% (control), 5%, 10%, 15%, 20%, 25% and 30% (by mass). The proportion of water/ cementitious material was 0.5 and the ratio of cementitious material to sand was 1:2.5. Specimens of 5 cm x 5 cm x 5 cm were molded for the hardened mortar analyses.

The compressive strength was tested in a EMIC Universal Machine after 3, 7, 28 and 90 curing days at 25°C. A statistical treatment was performed in the mechanical results following the Brazilian standard NBR 7215 [8]. The consistency was performed in a flow table according to the Brazilian standard NBR 13276 [9].

Water absorption analyses were carried out regarding to capillarity and immersion of the specimens after 28 curing days at 25°C. The tests were performed by following the Brazilian standards NBR 9779 [10] and NBR 9778 [11], respectively.

3 Results

3.1 Compressive strength of mortars

The strength results of the mortars containing SCBA are shown in **Table 1**. The SCBA XX nomenclature represents the cement replacement percentage by mass, thus SCBA 5 represents that 5% of the cement mass was replaced by SCBA.

Table 1. Compressive strength data (MPa) of control and SCBA mortars

Specimens/Curing age	3	7	28	90
Control	39,17	40,89	50,57	59,53
SCBA 5	28,77	34,02	48,62	49,73
SCBA 10	35,34	35,84	45,33	50,86
SCBA 15	33,24	36,84	48,16	51,61
SCBA 20	29,55	30,29	40,31	51,61
SCBA 25	23,46	32,34	38,26	47,65
SCBA 30	28,15	30,49	39,39	45,42

All mortars presented a continuous increasing with curing time, although the mortars containing SCBA presented a lower compressive strength when compared with the control mortar, it happens for all percentages of replacement at all ages, similar results were found in the literature [12].

The mortars containing RHA presented better results as shown in **Table 2**. In early ages, is possible to observe higher mechanical strength from the control mortar, which is common in pozzolanic studies. After 28 curing days, most of RHA-containing mortars presented a better compressive strength than the control mortar. This lateness in resistance gain is probably due to time which the cement hydrates and form calcium hydroxide which reacts with the pozzolan to produce more hydrated products.

Table 2. Compressive strength data (MPa) of control and RHA mortars

Specimens/Curing age	3	7	28	90
Control	39,17	40,89	50,57	59,53
RHA 5	25,69	52,13	53,23	66,6
RHA 10	36,48	41,51	57,09	62,24
RHA 15	33,62	40,52	52,77	63,29
RHA 20	25,68	31,46	46,55	54,52
RHA 25	28,41	35,98	41,76	52,59
RHA 30	28,51	38,06	53,91	59,6

Mortars containing more than 15% cement replacement by MK resulted in very dry matrices, which resulted in very irregular specimens, due to its difficult molding. **Table 3** shows the results of the percentages which were possible to mold.

Table 3. Compressive strength data (MPa) of control and MK mortars

Specimens/Curing age	3	7	28	90
Control	39,17	40,89	50,57	59,53
MK 5	30,77	46,06	48,95	57,2
MK 10	41,08	44,87	45,65	57,64
MK 15	43,66	44,51	51,03	62,11

After 28 curing days, the only dosage which overcome the control was the MK 15, but the other specimens presented similar results as the control mortar. Silica fume presented similar problem as the MK, it was only possible to mold specimens with cement replacement above 10%. This problem probably is due to fineness of both pozzolans. **Table 4** shows the compressive strength results.

Table 4. Compressive strength data (MPa) of control and SA mortars

Specimens/Curing age	3	7	28	90
Control	39,17	40,89	50,57	59,53
SA 5	36,03	47,26	63,77	66,76
SA 10	35,53	49,89	53,44	58,2

In early ages, the SA specimens presented similar results as the control mortar. After 7 curing days, the SA containing mortars overcomes the specimens with no pozzolans.

It is possible to observe that large majority of the pozzolans containing specimens presented similar compressive strength as the control after 28 curing days. The pozzolans contributed to the mechanical behavior, since no compressive strength decay proportionally to the cement replacement. Sustainable, the four pozzolans presented optimistic results.

3.2 Consistency

The influence of the pozzolans on the consistency of the mortars is shown in **Figure 6**, which shows the opening diameter (cm) x dosage of the mortar. It's possible to observe an inversely proportional relation between the diameter and the percentage of replacement, which means that the workability decreases as the pozzolan percentage increases.

The SCBA and RHA curves present a soft variation from a dosage to another, whereas the MK and SA diameter decreases abruptly as the cement replacement increases, which reflects in the moldering difficulty.

3.3 Water Absorption by Immersion

This test was performed on specimens after 28 curing days, measurements were taken 24, 48 and 72 hours from the start of the test. **Figure 1** shows the percentage of absorption (%) in relation to the time (hour) which the measurement was taken for the SCBA-content specimens.

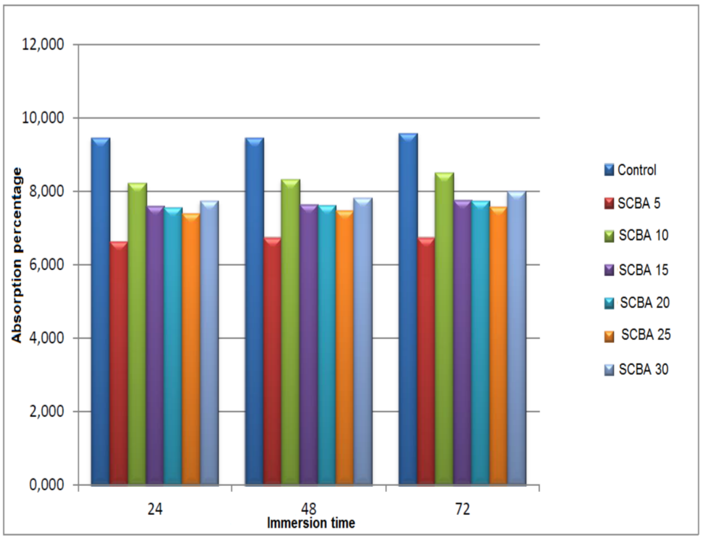

Figure 1. Water absorption x immersion time (hour) - SCBA specimens.

The samples containing SCBA presented lower water absorption than the control mortar. **Figure 2** shows the water absorption of the mortars containing RHA.

The mortars containing RHA as a mineral admixture presented less water absorption comparing to the control.

It's possible to observe the effect of the fineness in the blended admixtures, it leads to a dryer mortar, but improves the durability of the cementitious matrix by lowering the water absorption.

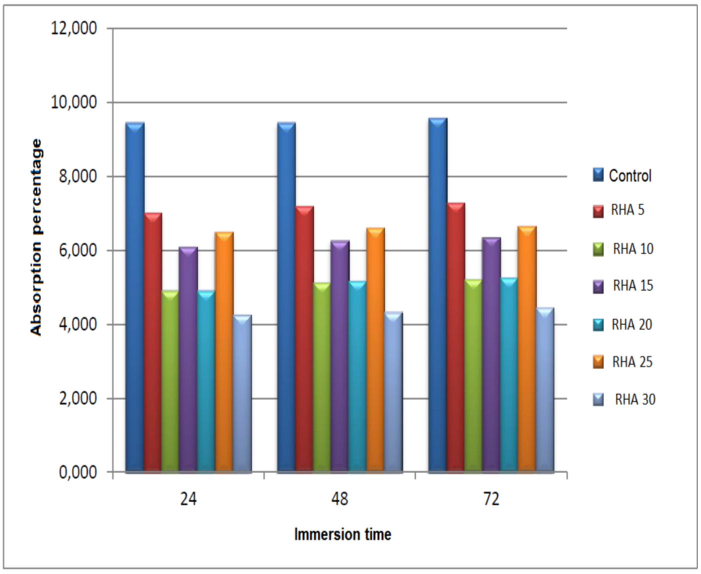

Figure 2. Water absorption x immersion time (hour) - RHA specimens

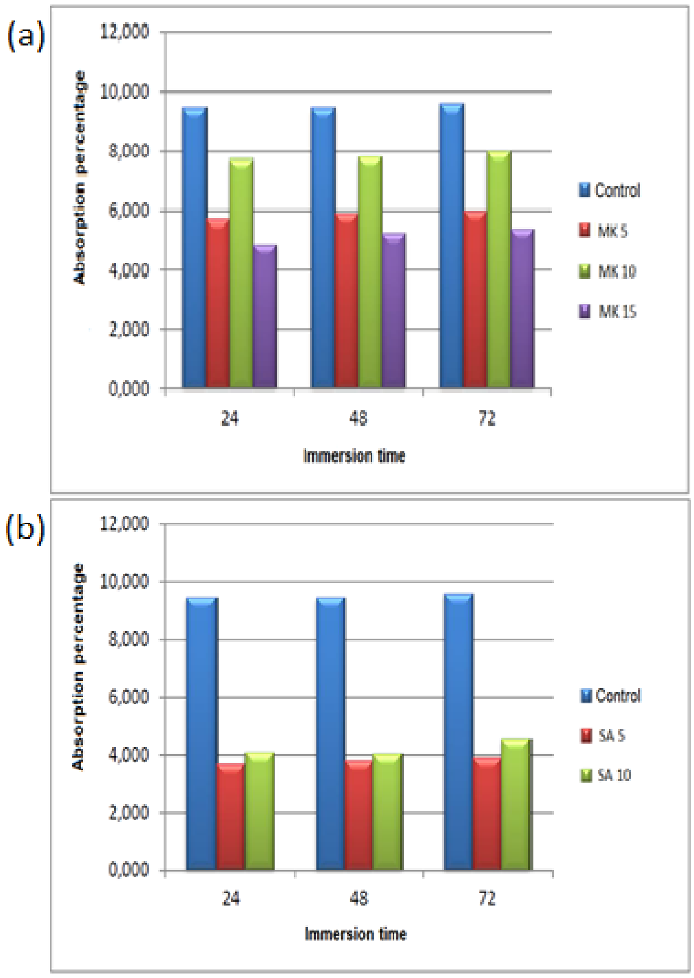

Figure 3. Water absorption x immersion time (hour) - MK (a) and SA (b) specimens

The admixtures containing MK also showed lower absorption than the control mortar as shown in **Figure 3 (a).** The mortars containing SA presents the specimens with lower water absorption as shown in **Figure 3 (b).**

3.4 Water Absorption by Capillarity

This test was performed on specimens after 28 curing days, measurements were taken 3, 6, 24, 48 and 72 hours from the start of the test. The water absorption by capillarity (g/cm²) x immersion time (hour) for the SCBA-content specimens is shown in **Figure 4.**

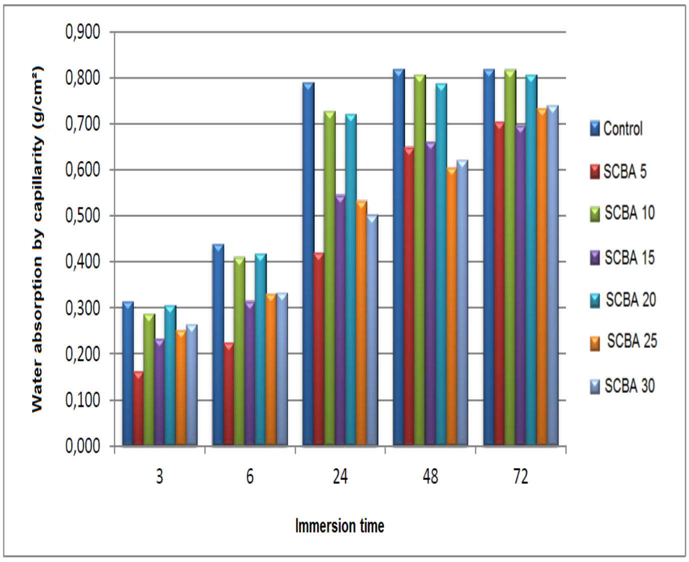

Figure 4. Water absorption by capillarity (g/cm²) x immersion time (hour) - SCBA specimens

The admixtures containing 10% and 20% of cement replacement by SCBA presented a similar water absorption as mortar with no pozzolan. SCBA 5, 15, 25 and 30 maintained a lower water absorption.

Samples containing the RHA pozzolan exhibited a lower water absorption by capillarity and immersion.

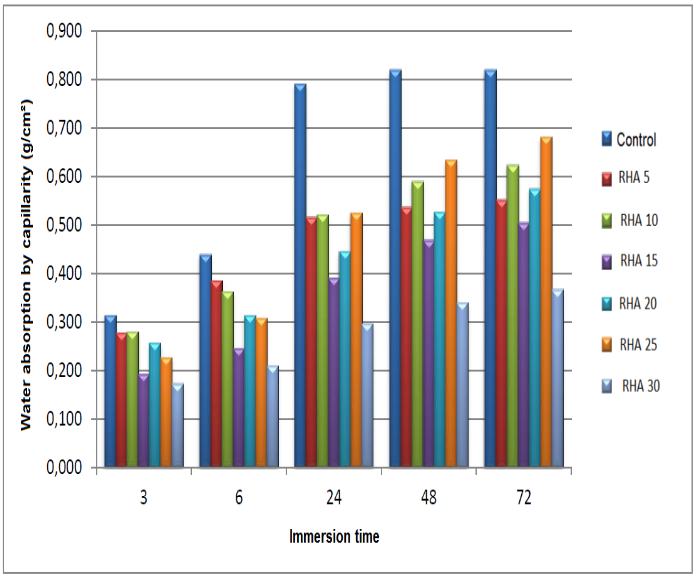

Figure 5. Water absorption by capillarity (g/cm²) x immersion time (hour) - RHA specimens

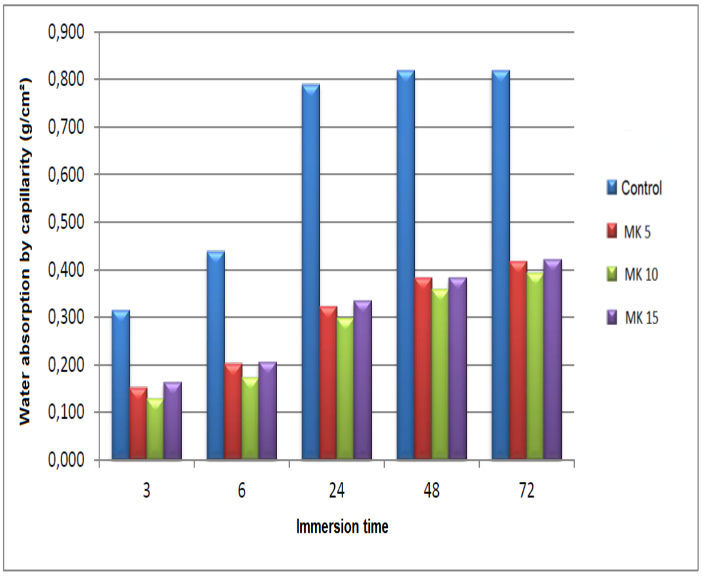

Figure 7. Water absorption by capillarity (g/cm²) x immersion time (hour) - MK specimens**.**

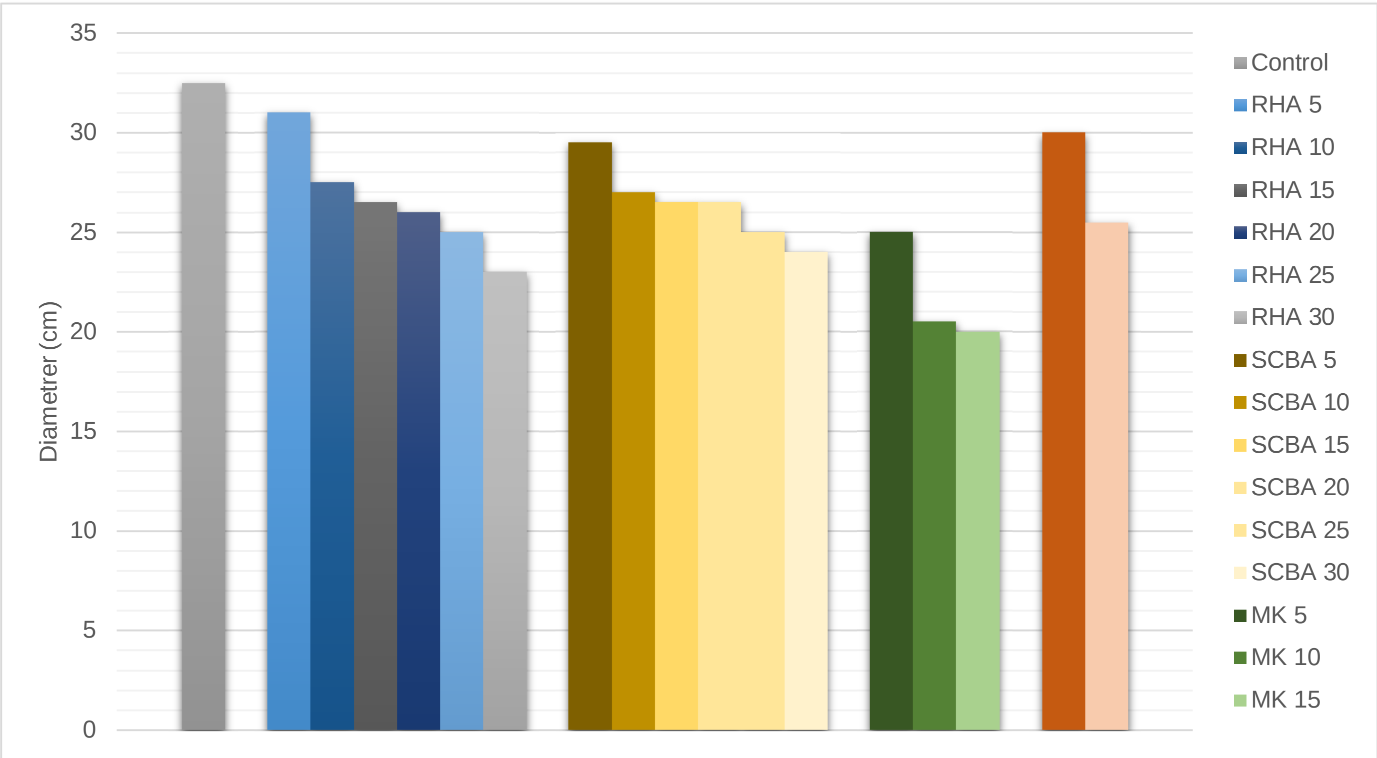

Figura 6. Consistency of mortars

MK 10 presented the higher water absorption by immersion and lowest by capillarity as shown in **Figure 7.**

The SA results also presented an inverted configuration of the observed in absorption by immersion as shown in **Figure 8.**

The finesses of the pozzolan provides dryer mortars, but also improves the durability of the matrices, which is possible to observe as the pozzolans which presented a lower diameter in the consistence test, also showed a lower water absorption.

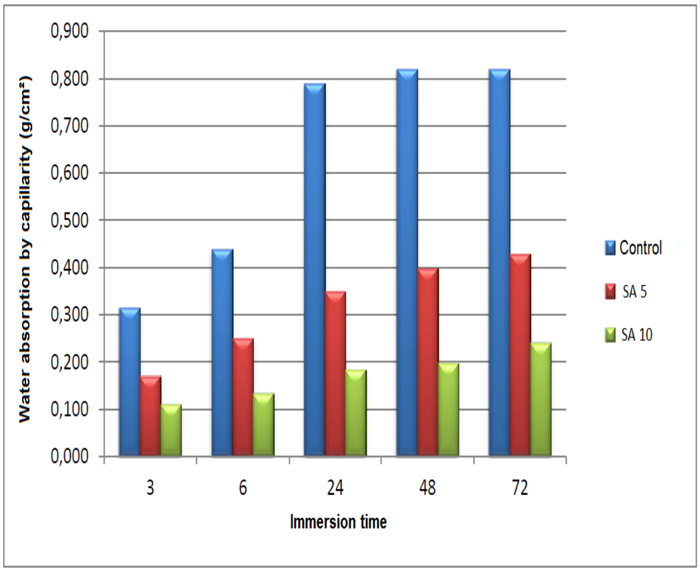

Figure 8. Water absorption by capillarity (g/cm²) x immersion time (hour) - SA specimens

4 Conclusions

The blended admixture presented a continuous increasing with curing time. The pozzolans contributed to the mechanical behavior, since no compressive strength decay proportionally to the cement replacement. In long ages, mortars containing pozzolans presented similar or higher compressive strength than the no replacement specimens. The fineness in the blended admixtures leads to a dryer mortar, but improves the durability of the cementitious matrix, the specimens containing

pozzolans obtained lower water absorption than the control mortar. Sustainable, is viable to use the pozzolans in compendious matrices.

Acknowledgments

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