Recycled Plaster and Red Ceramic Waste Based Mortars

Sara B. Ferreira, Paulo C. Domingues, Silvete M. Soares, and Gladis Camarini

***Abstract*—Construction is the activity that generates more waste in the world. Even with international actions being done to seek sustainable solutions in human activities, few changes in the construction have been observed. In Brazil, measures are being taken to adapt the waste-generating activities to new environmental commitments. In 2002, a specific law on construction and demolition waste (CDW) (Res. 307 Law 12,305) was established to reduce its production or use its material and ensure its proper destination. In 2011 the plaster recycling was established by resolution 431 amending Res. 307. Thus, this work had the objective of using waste gypsum and red ceramic as building material. Different proportions were mixed and tests were made to evaluate their physical and mechanical performance and also optical microscopy. The results indicated that the mortar produced with recycled plaster and ceramic waste meets Brazilian technical standards as components of brick wall.**

***Index Terms*—Ceramic waste, construction and demolition waste, plaster, recycling.**

I. Introduction

Construction is the human activity that generates more waste in the world, whose raw material consumption represents about 50%, in mass, of any residue generated on the planet. In the last century the use of construction materials increased by eight times, resulting in an annual production of 60 million tons. The consequences go beyond the reduction of raw materials, where part of it is not renewable, but causes environmental impacts such as the destruction of biodiversity, air and water pollution [1].

In 2000, 189 countries signed the Millennium Development Goals (MDG), an important document in which they compromise to seek strategies to ensure environmental sustainability, strengthening the agreement of the Kyoto Protocol. However, since the agreement signed, few studies of the construction area have been directly related to sustainability, such as the environmental issue of building materials. The proportion of scientific publications in the construction area in which the object of study was related to sustainability is of around 10% of all publications released in one decade by Elsevier magazine. However, when it comes to studies regarding construction and demolition wastes (CDW), the proportion is even smaller, around 0.2% [1]. Even with the environmental and economical advantages (CDW activities generated an income of 744 million Euros in 2010), the percentage of recycling of CDW in Europe is about 47%. The low activities related to the use of the CDW in the market are partially due to the profile of the civil construction companies which behave in a resistant way towards new technologies, even thought if they are beneficial to the environment. It may take from 10 to 20 years to develop a new composite until it is well accepted. It is necessary to create mechanisms so that research in the area of the CDW is aligned to their market viability, reducing time and costs by the companies [2]. An alternative would be to stimulate partnerships between companies and research centers, aligning the goals of research on issues of importance to their large-scale production. Another important action is related to updates and revisions of technical standards. Without proper monitoring of standardization with the innovations of construction materials, its feasibility remains committed [1]. And, finally, other attitudes could also take part, as stimuli to the consumption of materials and more environmentally responsible construction processes, such as mandatory environmental seals, reductions in taxes and government fees for anyone who manufactures more sustainable products and for who uses them [1].

In Brazil, the context of environmental concerns and recycling in the construction sector are similar. In 2002, it was appended to Law 6,938 of 1981, which deals with National Environmental Council (CONAMA) [3], the theme of solid wastes, including CDW. In 2010, the Law 12,305 establishes the National Solid Waste Policy (PNRS), making clear the responsibility of waste management taken by the public administrations, as well as establishing deadlines for the implementation of solid waste management. In 2002, the 307 CONAMA resolution specifically addresses the CDW establishing deadlines for the local governments to deploy their policies for appropriate disposal. With the change of 307 by 448, in 2012, the deadline was extended for 2014. However, it can be observed that little or no change is seen in the Brazilian municipalities. The priority for such policy is the reduction of the CDW, followed by reuse and recycling, involving therefore, the generating companies: construction companies and all other activities in the construction industry.

The percentage of recycling of CDW in the country in 1999 was about 500 kg/inhab./year [4]. However, it represents a much larger volume today.

Brazil has 5,561 municipalities [5] and just around 310 recycling plants [4], which is insufficient for this number corresponds to a proportion of one plant for each 18 municipalities. If one considers the population of the country, in 2014 of approximately 170 million inhabitants and an

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output of 500 kg of CDW per capita per year, there are 85 million tons of CDW generated a year for only 310 recycling plants.

Despite the growth of CDW plants, about 10 new plants per year [4], more incentive is yet to be given, whether by public administrations or the private sector in the use of recycled materials, or in the supervision, triage and destination of the CDW's in the municipalities [4].

As a way of developing alternatives for a product that has qualities and applications in construction, we developed this study to use two construction wastes: gypsum waste and ceramic waste (residue from the production of ceramic tiles) to evaluate the performance of this composite as a construction material.

Gypsum plaster and ceramic are among the most present materials in the CDW. Their percentages in the residue composition vary greatly according to region of the country. Such variation is related to some factors like availability of materials, type of construction (new, demolition, remodeling), constructive processes, quality of workmanship, among others. In São Paulo, for example, ceramic material represents 33% of all CDW, while in Salvador-BA, it represents 15% [6]. Gypsum plaster also presents a great variety of CDW composition depending on the region of the country. In Campinas-SP, it represents 28% of all CDW. In São Carlos-SP, plaster represents 1% of CDW [7].

In the metropolitan region of São Paulo-SP, the estimate is about 120 thousand tons per year of construction gypsum plaster waste. The main sources of this waste are renderings (88%), drywall (8%) and components (4%). Due to its advantages in relation to lower power consumption for its production and its relative simple recycling process, gypsum plaster has been an important material for recycling, mainly for representing a danger when wasted in locations without proper treatment. The material can contaminate the soil and groundwater.

Plaster is a material applied in various areas of a building such as finishing of walls, drywall, ceilings and masonry blocks. Its production is relatively simple and the process of reversibility of its reactions allows it to be used in the production of new materials. Its use was already known in 7,000 BC in constructions in Turkey as mortar for floor [7].

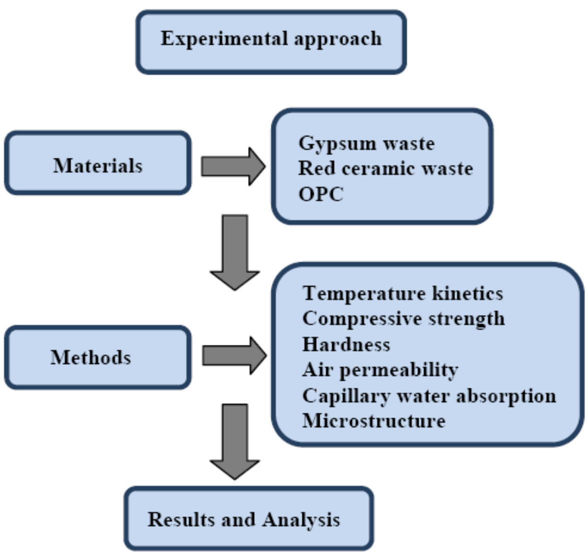

Fig. 1. Experimental approach

The use of gypsum waste and red ceramic waste meets the new aspirations and commitments of the construction activities both in environmental and economic terms. Applicability studies of waste materials in construction that meet regulatory requirements and user needs, stimulate a whole chain: exploitation of CDW and its consequent decrease in the environment, increase in the number of recycling plants, reducing consumption of raw materials for manufacturing of constructive elements, creation of jobs, among others [7].

The red ceramic (type of clay with higher iron content) represents an important market corresponding to 4.8% of the entire construction industry and consuming 10,300,000 tons of clay per month [8].

The objective of this study was to evaluate the physical and mechanical characteristics of composites produced with these residues (plaster and red ceramic) so it can be obtained a product with mechanical performance compatible with the requirements of standards for application in construction as brick walls [9].

The Fig. 1 shows the proposal approach of this experimental work.

II. Materials

The materials used in this study were: construction plaster residue red ceramic waste and Portland cement.

A. Gypsum Waste

Gypsum waste was collected in construction sites and sent to the laboratory for recycling. The calcination was made at a temperature of 150° C for a period of 2 hours. The material was cooled and the recycled gypsum was used as a binder to produce the composite. Physical and mechanical properties were evaluated. The specific gravity, bulk unit weight and sieve analysis were determined according to the Brazilian Standards [10]. Fig. 2 shows the grading curve of the recycled gypsum plaster. The specific gravity was 2570 kg/m³ and the bulk unit weight was 970 kg/m³

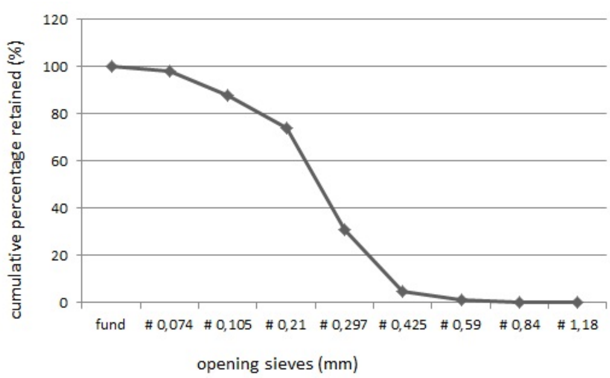

Fig. 2. Grading curve of the recycled gypsum plaster

B. Red Ceramic Waste

The red ceramic waste used was the residue from ceramic tiles [11]. This ceramic waste was supplied in grounded form. The specific gravity of the red ceramic was 2390 kg/m ³ and the bulk unit weight was 1313 kg/m³. Fig. 3 presents the grading curve of red ceramic waste [10].

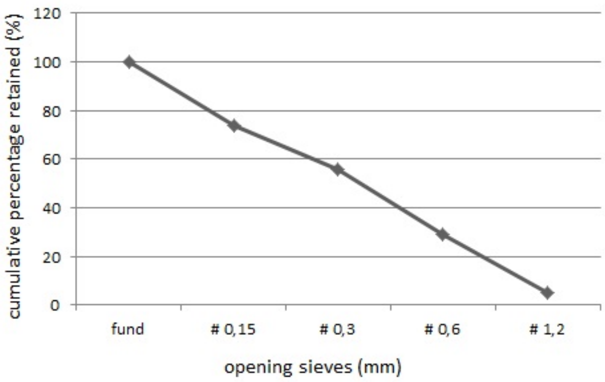

Fig. 3. Grading curve of the red ceramic waste.

C. Portland Cement

The cement used in this study was the High Initial Compressive Strength Portland Cement (CPV-ARI) with a specific gravity of 3100 Kg/m³.

III. Experimental Mixtures

TABLE I: Experimental Mixtures

Mixtures	Materials	water/dry materials ratio	Water/ plaster ratio
GR	Recycled plaster (RP)	0.8	0.8
GS30	RP + 30% red ceramic waste (RC)	0.8	1.14
GS60	RP + 60% RC	0.8	2
GS70	RP + 70% RC	0.8	2.66
GSC60	RP + 60% RC + 5% cement	0.8	2
GSC70	RP + 70% RC + 5% cement	0.8	2.66

The mixtures were proposed so that the mortar could be easily molded and could gain the minimum mechanical performance within the relevant standards for the ceramic blocks for masonry walls [9]. So, we have adopted the proportions of materials with focus on water/dry materials ratio.

We used the water/dry materials ratio equal to 0.8 for a mortar with good workability, searching a more fluid one and, thus, filling the molds easily. Experimental mixtures are described in Table I.

In mixtures with 60% and 70% of red ceramic waste we added a small proportion of cement CPV-ARI (5% in mass of the quantity of dry material) to assess whether there was any contribution in terms of mechanical performance.

The dry materials (recycled gypsum and red ceramic) were mixed in advance and then added to the water. The mixture was manual until obtaining a homogeneous mixture. Specimens were molded and kept in the laboratory environment (temperature 23° C and relative humidity 60%) until the date of the tests.

IV. Methods

The composite was tested in the fresh and hardened state. Temperature kinetics were determined in fresh state. In the hardened state, compressive strength, hardness, air permeability and capillary absorption were determined, and observations by optical microscopy.

A. Temperature Kinetics

In the fresh state, we evaluated the hydration of the experimental mixtures by means of temperature kinetics. In this test, we observed the variation of temperature of the mixture through the release of heat that indicates the beginning and end of setting.

The equipment is a semi-adiabatic calorimeter in which the studied mixtures are placed in order to isolate them from the external environment (Fig. 4). The temperature is measured by thermocouples inside the mixtures and thetemperature variations are recorded by a datalogger model Testo177-T4, with four reading channels [7].

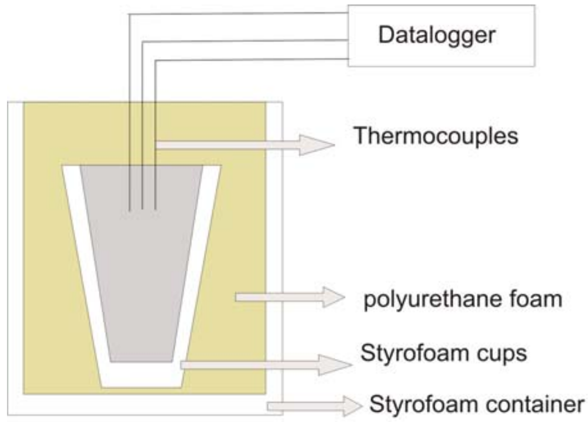

Fig. 4. Schematic illustration of the pseudo adiabatic calorimeter [8].

B. Compressive Strength

Compressive strength was determined on cubic specimens of 50 mm on edge. Six specimens were molded for each of the six mixtures, 3 specimens tested at 7 days and 3 at 28 days [12].

C. Hardness

The hardness was a measure of the depth of impression of a steel ball with 9 mm diameter, under a load of 500 N, on three sides of a cubic specimen with 50 mm edge. For each series, the arithmetic average of the depths obtained from 3 specimens was taken [12]

D. Microstructure of the Mixtures

Mixtures were observed in an optical microscope registering images on surface fractures of cubic specimens remaining from the compressive strength test.

E. Air Permeability Test

The air permeability test of the specimen was carried out in a permeameter of constant load (Fig. 5) [13]. For this test, a cylindrical specimen of 50-mm diameter by 100-mm high was molded. Before the test, the specimen is dried in an oven, and the lateral surface was sealed. In the apparatus, the air is forced to flow through the specimen. Details of the test can be found in [14]-[15].

F. Capillary Water Absorption

Capillary water absorption was measured in 50-mm diameter by 100-mm high cylindrical specimens.

The specimens were placed in an oven for 24 hours at a temperature of 50 °C. Then they were cooled and the lateral surface was sealed. Then they were placed in a vessel containing water and supported on a metallic tray so that only 10 mm of height of the specimens were in direct contact with the water (Fig. 6).

The water absorption determined by mass variation. The specimens were weighted dry placed in water and weighted, after 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours and 8 hours.

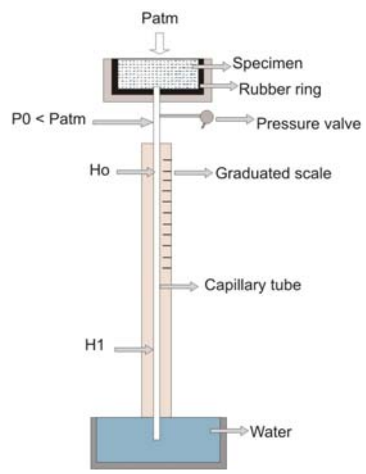

Fig. 5. Apparatus for air permeability test

V. Results and Discussions

A. Temperature Kinetics

Recycled plaster (RP) was the mixture that presented higher temperature kinetics, reaching a maximum temperature of 57 °C. (Fig. 7)

The mixture GS-30 with 30% of red ceramic waste presented maximum temperature of 44 °C.

The release of heat by the experimental mixtures in decreasing order was: GR, GS30, GSC60, GSC70, GS60 and GS70, showing that the bigger the quantity in mass of the plaster, higher will be the release of heat during the binder hydration, an expected result due to the presence of a higher binder quantity.

The presence of cement, though in small quantity (5%), contributes to the increase of the temperature of the mortar (GSC60 and GSC70).

B. Compressive Strength

The results showed that, even by reducing the amount of recycled gypsum and increasing the amount of red ceramic, results of compressive strength reached values that meet the conditions for masonry hollow blocks according to the Brazilian standards (Fig. 8).

Fig. 6. Capillary water absorption test.

The mixture GS30had the best result (4.19 Mpa at 7 days and 4.49 MPa at 28 days). And reaches the minimum value established by Brazilian standards for masonry hollow blocks (3.0 Mpa) [9]. The GSC70 mixture was the second mixture with a best result of compressive strength, even showing a higher amount of aggregate compared to mixtures GS60GSC60. However, GSC70 did not reach the minimum values required by the Brazilian standard [10].

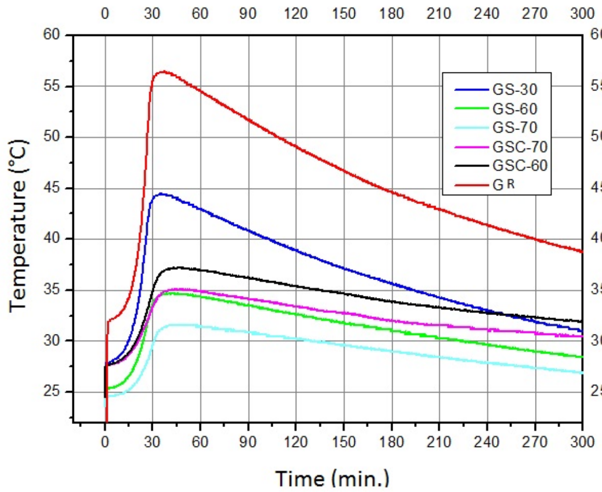

Fig. 7. Hydration kinetics of the mixtures used in the test.

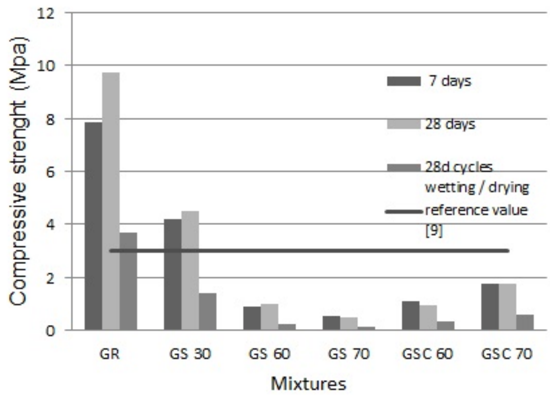

Fig. 8. Compressive strength results.

C. Hardness Test

The mixture GS30 had the best results in relation to the reference mixture (GR). At 28 days the best mixture had half of the value of the reference (GR) (Fig. 9).

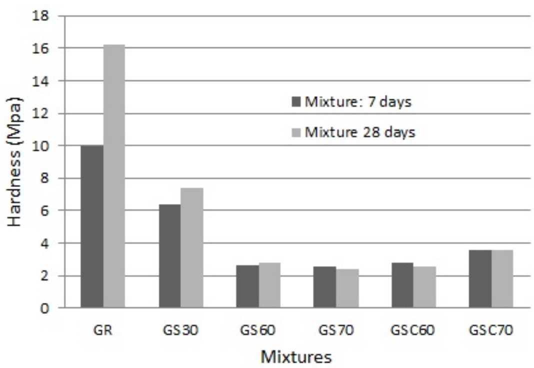

Fig. 9. Results of hardness test.

D. Microstructure of the Mixtures

Fig. 10 presents images of mixtures GR, GS30, GS60. Fig. 11 shows the images of mixtures, GS70 GSC60, GSC70. The mixture GR has a homogeneous distribution with some voids. GS30 mortar has a uniform distribution of red ceramic of different grain sizes. GS60 an increase of small grains of ceramic waste and well distributed in the matrix. The higher amount of red ceramic in the mortar modifies the color of the hardened mortar. Mortars with cement addition show a more compact matrix.

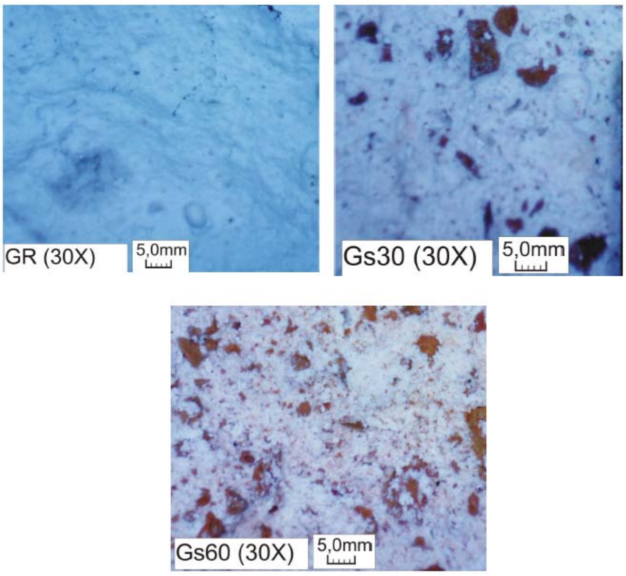

Fig. 10. Optical microscopy images of the mixtures GR, GS30 and GS60.

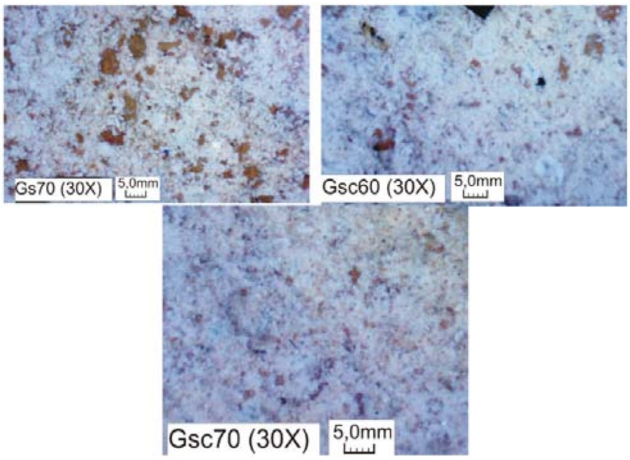

Fig. 11. Optical microscopy images of the mixtures GS70, GSC60 and GSC70.

It can also observe that the presence of voids (air bubbles) decreases as increases the amount of ceramic waste into the mix.

E. Air Permeability Test

Mixtures GS30, GS60 and GS70 obtained a reduction of their value of air permeability over time (Fig.12). Mixtures with cement addition (GSC60 and GSC70) were less permeable than the same mixture without cement. And their values increased between ages 7 and 28 days.

F. Capillarity Test

The mixture GS30 presented the best result of capillarity with a very close value to the reference mixture (GR), especially after an hour of testing, because the difference of capillarity between the two mixtures (GR and GS30) was around 4.0. kg/m² (Fig. 13). Mixture GSC60 accompanied the performance of the mixture GS30 until the 30 minutes of testing, then it began to absorb more water per m², obtaining results very close to the values obtained from the mixture GS70, from 1 hour of the test until its completion. The GSC60 mixture was the second mixture with less increase in weight by water absorption per m², with 48.85 kg /m² at the end of the experiment. Mixture GSC60 was following the same capillarity behavior of GS30, however, after 30minutes from the beginning of the test, GSC60 started to increase the values of capillarity, staying closer to mixtures GSC70 and GS70, even having a smaller quantity of ceramic waste.

Mixture GS70, despite being the one which more absorbed water up to 30minutes of testing, was the only paste that kept its weight, not absorbing more water from 2hours of testing until its completion, with capillarity value of 49.10 kg/m². Similarly to the tests compressive strength and hardness, mixture GS30 obtained the best result of capillarity, following mixture GSC70.

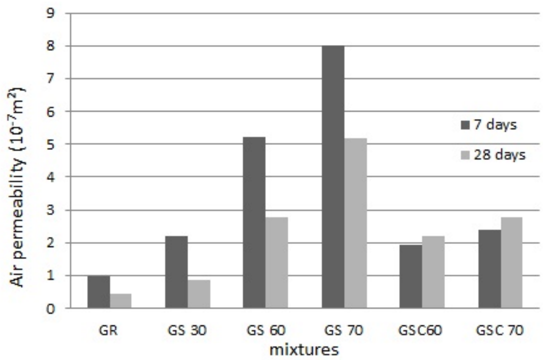

Fig. 12. Air permeability at 7 and 28 days.

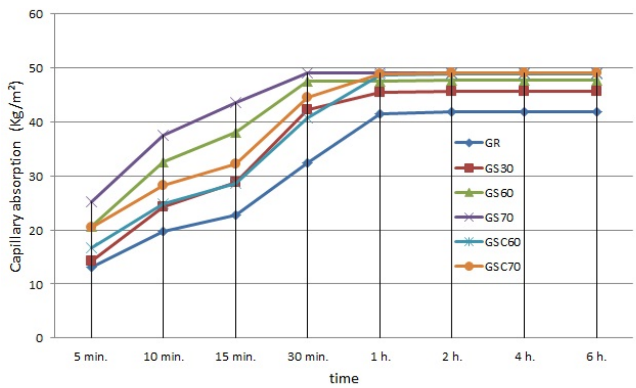

Fig. 13. Capillary water absorption results at 28 days in kg/m².

VI. Conclusions

Data showed that the mixture with 30% of ceramic waste (GR30) had the best results in terms of compressive strength, hardness, permeability and capillarity in relation to the reference mixture (GR). In the compressive strength test, GR30 obtained values above the minimum required for sealing blocks, according to Brazilian standards. In the hardness test, it was the mixture that obtained a higher increase over time of around 1Mpa. In the permeability test, at 28 days it obtained a considerable drop, staying closer to the results of the reference mixture (GR). In the capillarity test, it was also the mixture which got closer to the behavior of the reference mixture, especially after 1 hour from the beginning of the test.

Mixture GSC70, even with a bigger quantity of aggregate in relation to mixtures GS60 and GSC60 was the second mixture with better results in relation to compressive strength and hardness.

The objective of studying a mixture to mold sealing hollow blocks with good workability was achieved: mixture GS30 has good workability, presents a value of compressive strength that meets the minimum values required for that end according to the Brazilian standards.

Thus, the experimental study showed promising results in which recycled materials may become raw material for sealing blocks which meet the technical requirements, making it viable the adequate and responsible use of the CDW.

This way, it will be possible to produce elements and constructive materials with quality as well as they will be products that will carry environmental and economic responsibility by taking CDW from the environment and this way reducing the extraction of raw material.

The study allowed to prove real possibilities of realizing the use of CDW by civil construction and, therefore, putting into practice the new aspirations and responsibilities of the civil activity that most generates waste in the world.

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