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Influence of Water Absorption in the Performance of Mortars Made with Manufactured Fine Aggregates

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ABSTRACT

The performance of renders is directly related to the mortar properties and substrate conditions. This paper discusses the influence of the brick water absorption in the performance of renders made with manufactured fine aggregates of crushed stones. Six mortars mixtures of 1:1:6 (cement, lime, manufactured fine aggregate), with 3 different particle size distributions and 2 different proportions of microfines (≤ 75 μm) were produced. The consistency was fixed in 240mm ± 10mm. The physical characteristics of these mortars were determined in the fresh and hardened state. Susceptibility to cracking (namely due to shrinkage) and bond strength of these mortars were determined by prisms. The result shows that the substrate pore distribution is very important for shrinkage and adhesion of renders made of manufactured fine aggregates. Mortars with higher water absorption reduce the renders adhesion. With higher microfines proportion, the mortar needs higher water content, resulting in higher shrinkage and cracking.

INTRODUCTION

Construction industry is responsible for extracting a large quantity of sand and gravel from rivers, for use as aggregates for production of mortars and concrete, causing a great environmental damage. In Brazil only, the aggregate consumption is estimated at 320 million cubic metres per year [Bastos 2006]. In the whole world, the needs for housing are estimated at more than two million units and some construction materials like sand are becoming rare [Kenai et al. 1999]. Due to natural reserves reduction and increase in monitoring by environmental authorities, sand extraction occurs now at each more distant and less accessible places, which increases its cost and diminishes the quality of sand.

The use of crushed fine aggregates resulting from production of coarse aggregates has been introduced in the market as an alternative to natural sands. Although crushed fine aggregates is already being used in construction since 1940 [Ohashi 2006], there are still many doubts about its behaviour. Among the main features of crushed fine aggregates particle shape, grain size distribution and chemical composition should be pointed out. Aggregate characteristics alter workability and mechanical properties of mortar [Lanas et al. 2004]. Their particle shape harms its packaging, demanding an increase in fine content or in water quantity or the use of additives to ensure a proper mortar workability. Typically, 10% to 25% of microfines are generated during production of crushed fine aggregates [Namshik 2000]. The high content of microfines in crushed fine aggregates facilitates mortar application and can collaborate to increase resistance. On the other hand, growing amounts of microfines increase the necessary amount of water to adequately wet particle surfaces and to maintain the specified workability [Celik and Marar 1996], which may result in the appearance of cracking due to shrinkage. The particle size distribution was found to have a greater influence in the properties of concrete [Hewlett 1998]. Some authors argue that the maximum dimension of manufactured fine aggregates should be adjusted so as to improve concrete or mortar properties. According to Hu [2001], the compressive strength increases with the growth of the maximum size of the aggregate, up to 15 mm.

Adhesion to the substrate and the absence of cracking due to shrinkage are some of the main properties required in hardened mortars. Despite its importance, the incidence of problems related to the loss or lack of adhesion of mortar/substrate has become one of the biggest causes of pathological problems in renders. The adhesion results from mortar mechanical anchoring into the brick’s cutouts and also from cement penetration into the pores, being influenced by mortar characteristics, by substrate properties, and by application technique [Carasek 1996]. The substrate influences mortar adherence due to their surface characteristics (such as texture and roughness) and, especially, its water absorption.

This paper analyses the influence of two substrate types (with different water absorption coefficients) in adherence and shrinkage of mortar made with crushed fine aggregates having 3 different particle size distribution and 2 different proportions of microfines.

EXPERIMENTAL INVESTIGATION

Materials

The mortars used were made with Portland Pozzolan Cement, lime and crushed fine aggregates. Their properties are shown in table 1.

Table 1. Characteristics of the cement and of the lime

Property	Portland cement	Lime
Bulk density	0.87 g/cm³	0.74 g/cm³
Specific gravity (ASTM C 188)	2.78 g/cm³	2.40 g/cm³
Specific surface (Blaine fineness)	3975 cm²/g	13508 cm²/g
Compressive strength (cylindrical Ø5x10cm specimens)	39.2 MPa	-
Initial setting time (ASTM C 191 – Vicat)	03h 58min	-
Final setting time (ASTM C 191 – Vicat)	05h 09min	-

The aggregate used is a crushed fine aggregate obtained by using a vertical shaft impactor cone crusher, with specific gravity of 2.70 g/cm^3 and bulk specific gravity of 1.31 g/cm^3. The particle size distribution and length/width ratio of the crushed fine agregates are listed in table 2. The shape of the grain was determined by using an optical microscope, from a sampling of 40 particles on each track.

Table 2. Particle size distribution and length/width ratio of the crushed fine aggregates, at their original state

Sieve #	% Acumulated	Length/Width ratio
4.8	1	1.30
2.4	21	1.39
1.2	43	1.52
0.6	62	1.52
0.3	74	1.37
0.15	83	1.38
0.075	100	1.37

The crushed fine aggregates were used for the production of three different sands, changing their particle size distribution, each of these with two different levels of microfines, as viewed in table 3. The lower content of microfines (6.92%) was produced by sieving the crushed fine aggregates in a 0.075mm sieve, without washing.

Table 3. Characteristics of the sands used in production of the mortars

Aggregate	Size	Microfines content (%)
4.8F6.92	4.8mm – 0.075mm	6.92
2.4F6.92	2.4mm – 0.075mm	6.92
1.2F6.92	1.2mm – 0.075mm	6.92
4.8F16.92	4.8mm – 0.075mm	16.92
2.4F16.92	2.4mm – 0.075mm	16.92
1.2F16.92	1.2mm – 0.075mm	16.92

The aggregates were used for the production of six mortars, all in a 1: 1: 6 (cement, lime and sand by volume) proportioning. The quantity of water of all mortars was adjusted for a consistency of 240 ± 10 mm. Immediately after the mixing of mortars, their behaviour was determined by using Squeeze-flow, a method which consists in a compression of a cylindrical mortar sample between two parallel plates [Cardoso et al. 2005]. The tests were carried out in a universal machine with displacement control, by using a load cell of 2000N. Mortar samples were moulded in a cylindrical shape, with 100 mm in diameter and 10 mm high, and subjected to 1500N with a displacement rate of 0.1 mm/s (Figure 1). The work has been carried out in a room with a temperature of 23±2°C and relative humidity of 70 ± 10%. For all other tests, the samples measured 40mmx40mmx160mm. After 28 days of cure, six samples were destined for the compressive strength and three for the tensile strength. The sonic modulus of elasticity was determined in dry samples, after 28 days of cure at a temperature of 20°C, and a relative air humidity of 70%. A Portable Ultrasonic non-destructive Digital Indicating Tester was used, according to BS-1881 Part 203: 1986. Water absorption of mortar and capillary coefficient were determined according to the NBR 15259 standard (2005).

Fig. 1. Mortar workability characterization using Squeeze-flow

Mortars characteristics

Mortar properties in fresh state are shown in table 4.

Table 4. Mortar properties in fresh state

Mortar	Water (%)	Air content (%)	Relative density in fresh state (Kg/m3)	Water retentivity (%)	Squezze-flow displacement (mm)
4.8F6.92	31.5	1.1	2.13	90	1.1
2.4F6.92	33.1	1.4	2.05	90	1.2
1.2F6.92	37.5	1.7	2.00	89	1.8
4.8F16.92	32.5	1.0	2.18	91	1.2
2.4F16.92	34.6	1.3	2.12	93	1.8
1.2F16.92	37.9	1.6	2.07	93	2.1

Mortar rheological properties and water demand are strongly dependent on fine aggregate properties [Westerholm et al. 2008]. Water consumption increases as the aggregate maximum diameter decreases. The displacement in squeeze-flow test show that the greatest amount of water makes mortar more plastic (providing greater displacement for the same load level). Higher amounts of microfines demand higher water contents to achieve the designed consistence for mortars, and as a consequence, the mortar plasticity is increased. Mortars with the higher microfine level (16.92%) required approximately 10% more water than the others with lower level. In all mortars, water retention values are low, indicating possible issues for its use as mortar for rendering.

The air entrained levels achieved were considered suitable for mortars with lime, and they increase according to water content in the mortar. In all mortars analysed, the thinner the aggregate used, the greater the air content. Larger air content in mortars made with fine aggregates of crushed stone probably is due to differences in particle drag force of the fine aggregates arising from the aggregate size and the quantity of water entrained into the mortar. Mortars with higher level of microfines showed a small decrease in air content.

Relative density of the mortar in fresh state is influenced by aggregate grading: the thinner the aggregate, the higher the relative density of the mortar in fresh state. The increase of microfines also increases the relative density of the mortar. The relative density of the mortar in fresh state is in inverse proportion to the air content.

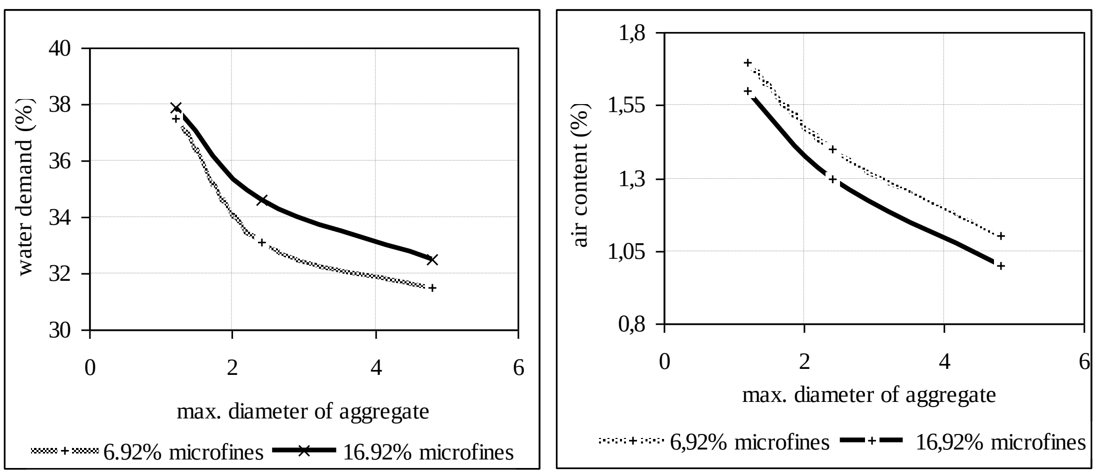

Fig. 2. Relationship between some properties of the mortar

Hardened state tests were made at 28 days of age, after submerse curing (table 5).

Table 5. Mortars characteristics in hardened state

Mortar	Compressive strength (MPa)	Flexural strength (MPa)	Modulus of elasticity (MPa)	Capilarity coefficient
4.8F6.92	2.4	0.7	2514	17
2.4F6.92	2.4	0.9	1448	18
1.2F6.92	1.9	0.7	1330	18
4.8F16.92	3.1	1.2	2465	19
2.4F16.92	3.2	1.2	2177	21
1.2F16.92	2.5	1.3	1775	21

Compressive strength is a direct function of aggregate size and microfines content, and the values obtained are in accordance with those of fresh state, where mixtures with higher water content and air entrained resulted in smaller compressive strength. However, changing aggregate size did not turn into meaningful changes in the flexural strength of mortars, which was influenced only by microfines content.

As well as compressive strength, mortar elasticity dynamic modulus is a direct function of aggregate size. Higher size sands have greater modulus of elasticity. The higher the air entrained level the lower the elasticity modulus, and also the relative density of mortar. This behaviour has been observed by a study which aimed to identify the influence of air content in mortar elasticity modulus, by using ordinary sand [Monte et al. 2007].

Production of walls to be coated with the mortars

The prisms to be coated with the mortars were produced by using two kinds of blocks, sintered at two different temperatures. The characteristics of the blocks produced are shown in table 6.

Table 6. Characterization of ceramic blocks

Absorption of block	Compressive strength (MPa)	Density (kg/ m³)	Inicial rate of absorption (g/cm².min)	Water absorption (%)
average absorption	0.6	1826	21.22	16.18
low absorption	3.7	1973	24.82	9.84

The low absorption blocks (burned at a higher temperature) presented the greater compressive strength and the greater density. The pore size distribution of the blocks were determined by mercury pore intrusion (PIM), using a Quantachrome Poromaster 33. The values are shown in Figure 3.

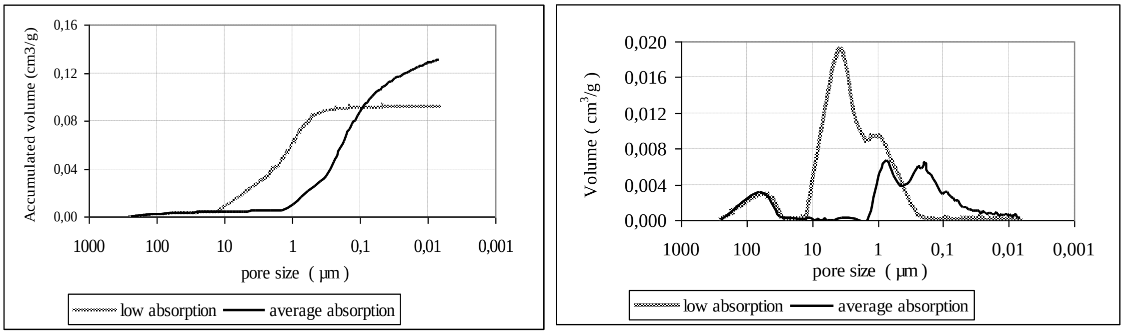

Fig. 3. Pore size distribution in ceramic substrates

There is a greater volume of intrusion in blocks of average absorption, which corresponds to a greater quantity of interconnected pores.

Mortars workability

It was noticed that the mortars with best workability were those with the smaller aggregate grading. These mortars were easier to implement and had the best finishing. The addition of microfines also provided better workability and a better finish to the renders. The mortars made with higher maximum size of the aggregate and a small amount of microfines (2.4F6.92 and 4.8F6.92) were not appropriate for use as a wall render, because they have no initial adhesion to the substrate (figure 4). According to Cincotto [1995] the mortar workability is improved with lower rates of sharper aggregate particles.

Mortar bond strength

The mortar bond strength was determined after cure for 28 days. It was impossible to determine the bond strength to the mortars 2.4F6.92 and 4.8F6.92.

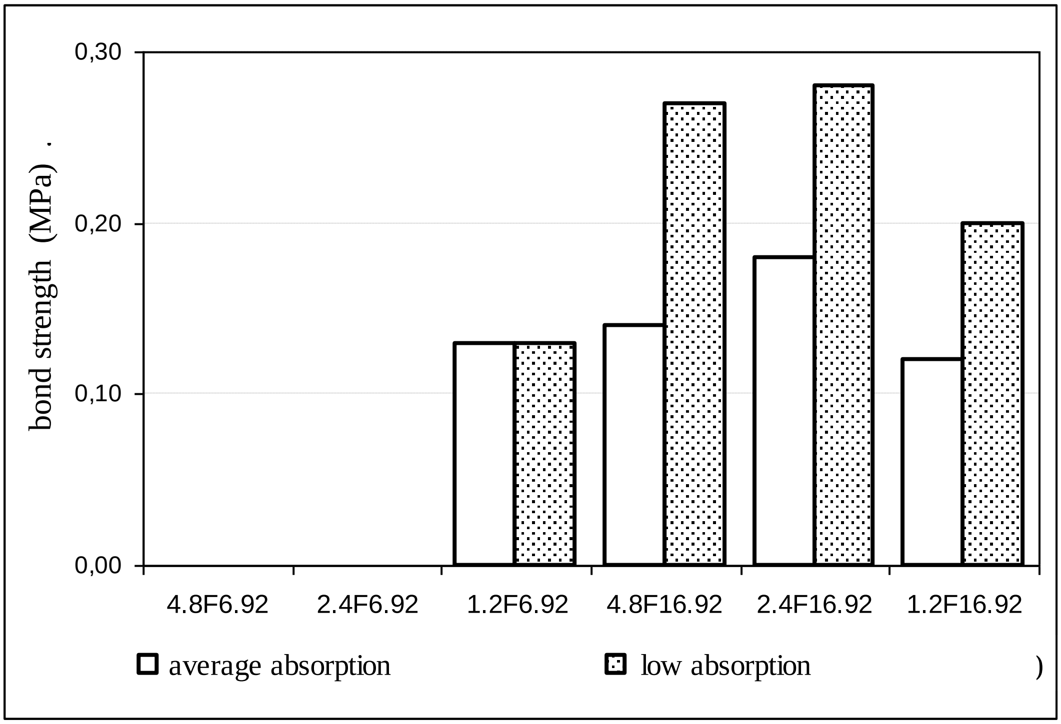

Fig. 4. Mortar bond strength

The difference in absorption rates between the two types of blocks has had a great influence on mortar bond strength. The adhesion values for low absorption substrates are higher, and in most cases almost double when compared to the results of subtrates of average absorption. The only exception occurred with the mortar 1.2F6.92, which did not change its resistance for the two different substrates. The loss of mortar bond strength in average absorption substrates is probably due to mortar water loss, which harms its cure and consequently reduces its strength.

Cracking due to shrinkage

Coating crack level after a 28-day cure in a laboratory environment can be seen in figure 5.

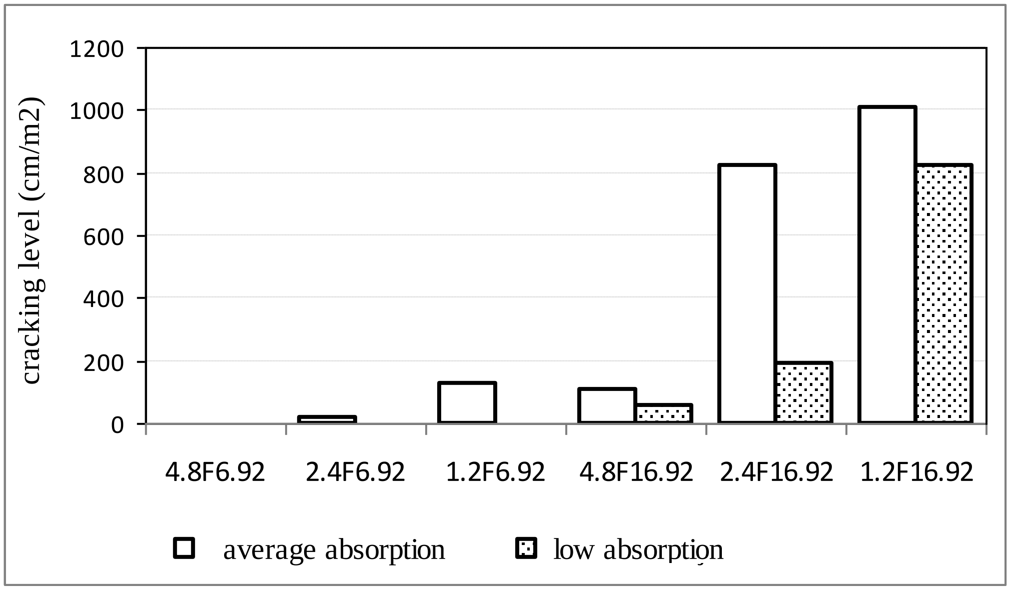

Fig. 5. Coating crack level on the 28th day of cure

It can be noticed that cracking in mortar renders are much more intense in mortars with thinner aggregates. According to Angelim et al. [2003], adding microfines has had a strong influence in cracking. The finer the mortar, the larger the amount of water is needed to keep its consistence. If the water leaks due to substrate absorption, evaporation, or other factor, it will leave empty spaces that promote mortar retraction and consequently cracks in coating will appear.

In the mortars studied, those with highest level of microfines had the highest levels of cracking (as seen in figure 6). The different behaviours of mortars with high level of microfines were very significant.

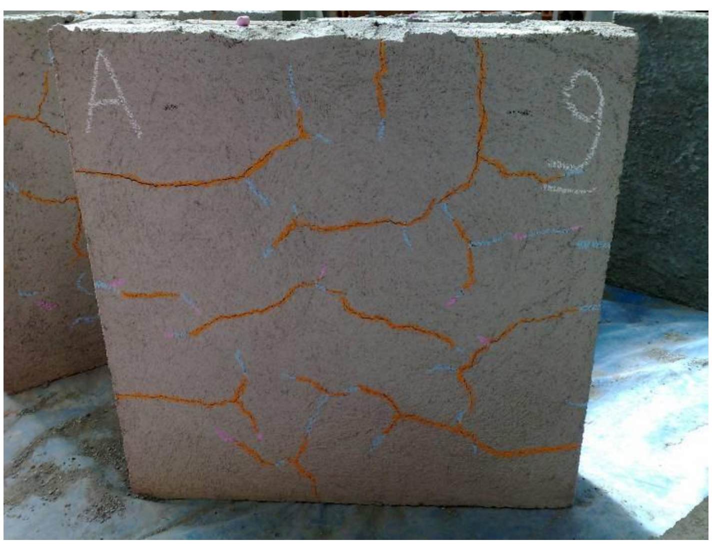

Fig. 6. Example of high level of crackings due to schrinkage in a mortar with thinner aggregates and high microfine amount

CONCLUSIONS

The results obtained demonstrate the need that studies on bond strength and cracking, particularly regarding crushed fine aggregates, necessarily have to consider the substrate properties.

All properties studied, such as particle size distribution of the aggregate and mortar microfines content, as well as the substrate absorption characteristics, visibly affect the renders behaviour.

The difference in water absorption between the two types of blocks had a strong influence on the bond strength of the mortars. The bond strength for low absorption substrates almost doubled when compared to the results of average absorption substrates.

High levels of microfines improved mortar bond strength, but result in high levels of cracking.

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