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Dry ripened mortar with quarry waste and rubber powder from unserviceable tires

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ABSTRACT. Stone-quarry fines have been evaluated in mortar and concrete, but have presented drying shrinkage and consequently higher incidence of cracks than those with natural sand. This study compared the dry ripened mortar in two types of aggregates added of 8% rubber powder. It was used quicklime, artificial and natural sand in volumetric proportions of 1:6. Mixtures were oven-dried, received the cement, establishing the volumetric proportion of 1: 1.5: 9. In plastic state, we evaluated aspects such as consistence, air content, water retention and bleeding; whereas compressive strength, static deformation modulus and water absorption by capillarity was determined in hardened state. Cracking aspects were evaluated in substrate. As a result, the mortar with artificial sand showed higher increases in compressive strength, capillarity rate and cracking, and greater reductions in air content and bleeding. As for the rubber powder, exhibited a greater reduction in the cracking rate and capillarity was found.

Keywords: plastering, deformation modulus, cracking.

Argamassa maturada seca com resíduos de pedreira e pó de borracha de pneus inservíveis

RESUMO. Finos de pedreira têm sido avaliados em argamassas e concretos, porém têm apresentado maior retração por secagem e consequentemente maior incidência de fissuras que as com areia natural. Este estudo compara a argamassa maturada seca nos dois tipos de agregados acrescido de 8% de pó de borracha. Utilizou-se cal virgem, areia natural e artificial no traço 1:6 (em volume). As misturas maturadas foram secas em estufa, recebeu o cimento compondo o traço 1: 1,5: 9 (em volume). Avaliou-se a massa específica, o teor de ar, a retenção e exsudação de água no estado fresco. A resistência à compressão, o módulo de deformação e absorção de água por capilaridade no estado endurecido. A fissuração foi medida ao substrato. Como resultado, a argamassa com areia artificial apresentou maiores aumentos na resistência à compressão axial, na taxa de capilaridade e fissuração, maiores reduções no teor de ar e na exsudação. Quanto ao pó de borracha, apresentou maior redução na fissuração e taxa de capilaridade.

Palavras-chave: revestimento, módulo de deformação, fissuração.

Introduction

The growing demand for materials used in civil construction in Brazil is increasing every year. With this, the consumption of raw materials increases, including natural sand which is mostly extracted from riverbeds, and causing damages to the environment. Government agencies such as IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) have restricted this practice as a form of environmental conservation.

An alternative material to replace the natural sand is the quarry waste, called stone-quarry fines or artificial sand, resulting from the process of crushed stone production in quarries. This material has been examined for use in mortar and concrete replacing natural sand.

One of the factors that distinguish artificial from natural sand is the higher content pulverulent materials. For Bonavetti and Irassar (1994) accelerating cement hydration due to the effect of stone dust contributes to gain strength at early ages, and with this there are drying shrinkage and a positive effect of filler, increased water retention and improved plasticity. Jadhav and Kulkarni (2012) also reported an increase in mechanical properties, in addition to the reduction in workability, requiring increased water consumption, although the authors have obtained a more cohesive concrete.

Ilangovana et al. (2008) also verified a higher drying shrinkage in concrete with artificial sand, but the permeability was lower given the increased content of fines. And Donza and Cabrera (2002) mentioned that the increase in mechanical properties, even with a higher water / cement ratio, can be associated with the improvement of the paste-fine aggregate transition zone, which can be attributed to the rough texture of the artificial sand.

By using up to 15% artificial sand in high-performance concrete, Beixing et al. (2009) verified that it had not affected the permeability of chloride ions, freezing and thawing. However, in low strength concrete the freezing was affected. Raman et al. (2011) evaluated the high-performance concrete with artificial sand and rice husk ash, and obtained a negative impact for the workability in fresh concrete, but it was compensated with a good dosing design, and by the use of a superplasticizer and a mixture of rice husk ash.

An alternative material with characteristics and conditions to be used to reduce the drying shrinkage and crackings in mortar lining with stone-quarry fines is the rubber powder from unserviceable tires, which can be used either as replacement or in addition to mortar and concrete. Several authors have developed studies with this material as rubber aggregate of various sizes (SEGRE et al., 2004; HERNANDES-OLIVARES et al., 2004; GANJIAN et al., 2009; MOHAMMED, 2010).

In the study conducted with rubber aggregate in concrete, Ho et al. (2012) achieved a reduction in the brittle index of concrete with increasing rubber content and reached nearly zero with 40%, and that the kinetics of the fracture process of concrete with rubber is slower in relation to concrete without rubber. For Turatsinze and Garros (2008) despite the reduction in tensile and compressive strength of concrete, there was an improvement in the ability to absorb deformation and a reduction in potential detrimental effect of cracking, while the study of Turatsinze et al. (2007) showed that free shrinkage is improved as well as the reduction of cracking of resistant mortar.

Canova et al. (2012) analyzed mortar of quicklime and natural sand (which was oven-dried and added of rubber powder from unserviceable tires), and observed an improvement in relation to conventional mortar, with reduced water exudation, free shrinkage and cracking. The addition of 8% rubber powder from unserviceable tires was the most suitable ratio. In other study of Canova et al. (2009), the water absorption by capillarity was significantly reduced by adding rubber powder for the oven-dried mortar, and still reduced drying shrinkage with restricted surface and the void content, besides presenting a mortar with great tenacity

In this study we examined the plastering mortar with artificial sand replacing natural sand, and addition of 8% rubber powder form unserviceable tires, in which it was used the process described in Canova et al. (2012) that resulted in dry ripened mortar and established that this addition was the most suitable.

In this way, we sought to minimize environmental impacts problems and mainly to reduce the cracking of coatings, which were more pronounced in mortars with artificial sand.

Material and methods

In order to compose the volumetric proportion of mortars, it was used powder quicklime type CV – C (common quicklime), artificial sand (stone-quarry fines), natural river sand, class 32 compound Portland cement (CP II Z – 32) and addition of rubber powder from ground unserviceable tires with diameter below 0.5 mm. The characterization of materials and of the addition employed is presented in Tables 1 – 6.

Table 1. Physical and mechanical characteristics of the Portland cement (CP II Z – 32).

Tests		Results	Methods
Setting time	Start	2 hours and 50 minutes	NBR 7215 (ABNT, 1995)
	End	7 hours and 18 minutes	
Normal consistency		Water / cement ratio = 0.30	NBR 7215 (ABNT, 1995)
Fineness – (% retained on sieve # 200)		1.62	MB 3432 (ABNT, 1991)
Unit weight (g cm^{-3})		1.45	NBR 7251 (ABNT, 1982)
True density (g cm^{-3})		3.09	NM 23 (ABNT, 1998)
Compressive strength (MPa) at 28 days		34.7	NBR 7215 (ABNT, 1995)

Table 2. Physical characteristics of quicklime powder dolomitic.

Tests	Results	Limits CV-C	Methods
Unit weight (g cm^{-3})	0.96	-	NBR 7251(ABNT, 1982)
True density (g cm^{-3})	3.10	-	NM 23 (ABNT, 1998)
Fineness - (% retained)			NBR 9289 (ABNT, 2000)
sieve # 30	0.7	≤ 5.0	
sieve # 200	0.22	≤ 30	

Table 3. Physical characteristics of the fine aggregate – fine washed river sand.

Tests		Results	Methods
Unit weight (g cm^{-3})		1.55	NBR 7251 (ABNT, 1982)
True density gravity (g cm^{-3})		2.63	Pycnometer
Particle size distribution	Sieve (mm)	Accumulated % retained	NBR 7217 (ABNT, 1987)
	2.4	0	
	1.2	1	
	0.6	7	
	0.3	67	
	0.15	99	
	max Ø (mm)	1.2	
	Fineness modulus	1.74	

Table 4. Physical characteristics of the rubber powder.

Determination	Results		Methods
Unit mass ($g\ cm^{-3}$)	0.44		NBR 7251 (ABNT, 1982)
True density ($g\ cm^{-3}$)	0.79		Pycnometer
Particle size distribution	Sieve (mm)	Accumulated % retained	NBR 7217 (ABNT, 1987)
	0.6	0	
	0.3	34	
	0.15	99	
	Ø máx (mm)	0.42	
	Fineness modulus	1.33	

Table 5. Chemical characteristics of the rubber powder - weight in mg kg^{-1}– analysis - atomic absorption spectrometry.

Fe	Cu	Mn	Zn	Pb	Cd	Cr (total)	Ni
710.00	52.60	Nd*	646.00	108.00	Nd*	32.00	4.00

Note: *Nd = not detected

Table 6. Characteristics of the fine aggregate (artificial sand – stone-quarry fines).

Determination	Results		Methods
Unit mass ($g\ cm^{-3}$)	1.7876		NBR 7251 (ABNT, 1982)
True density ($g\ cm^{-3}$)	2.93		Pycnometer
Particle size distribution	Sieve (mm)	Accumulated % retained	NBR 7217 (ABNT, 1987)
	4.8	0	
	2.4	1	
	1.2	34	
	0.6	50	
	0.3	69	
	0.15	85	
	0.075	96	
	max Ø (mm)	2.4	
	Fineness modulus	2.39	

Mortar preparation

Simple mortars were prepared with quicklime and fine aggregate (artificial and natural sand) both in volumetric proportions of 1:6, were previously prepared in a 320-L inclined axle cement mixer and ripened for seven days in metal containers for quicklime hydration in laboratory ambient. After maturation, the mortar mass was determined and it was dried into a constant mass in an oven at (105 ± 10)°C. The dry mortar mass was determined and then it was grinded and sieved with a mesh of (2.4 mm), packed in grained state in plastic bags and stored for 60 days in closed dry wooden containers. Ripened and dried mortars were tested with cement composing the volumetric proportions of 1:1.5:9 – equivalent in weight 1:0,993:9.623 and added 8% rubber powder from unserviceable tires and named as:

As^0_{RP} – Oven-dried mortar with artificial sand (stone-quarry waste), packed, and stored for 60 days. The index '0' indicates reference mortar, that is, without rubber powder and likewise As^0_{AN} - with natural sand.

As^8_{RP} - Oven-dried mortar with artificial sand. The index '8' indicates the addition of 8% rubber powder and likewise As^8_{AN} - with natural sand.

Measured properties

The volumetric proportion of ripened and dried mortars was evaluated through properties at plastic and hardened states, by means of standardized laboratory tests, as presented in Table 7. For testing mortars in the hardened state were molded the series with six cylindrical specimens with 5 cm diameter and 10 cm height, for all tests developed and tested with 28 days of age.

Table 7. Measured properties at plastic and hardened states.

State	Properties	Methods	Observations
Plastic	Consistency index	NBR 13276 (ABNT, 1995)	
	Specific gravity and incorporated void content	NBR 13278 (ABNT, 1995)	
	Water retention	NBR 13277 (ABNT, 1995)	The filter paper discs used had 80 g m^{-2} weight and air permeability of 26 l s^{-1} m^2.
	Water bleeding	MR-6 RILEM (1982)	With measurement in weight, in five samples in times of 15 min., 30 min., 60 min. and 120 min.
Hardened	Axial compressive strength	NBR 13279 (ABNT, 1995)	
	Static deformation modulus	NBR 8522 (ABNT, 1984)	In the initial tangent module, the loading speed was 0,05 MPa s^{-1}
	Water absorption by capillarity	NBR 9779 (ABNT, 1995)	

Crackings – It was measured the length of visible crackings on mortar panels with 1.5 cm thickness, in the dimension of 1.0 m^2, with 1:3 usual roughcast (cement and sand, by volume), on ceramic block masonry at once, in environment outside of the laboratory. Measurements were taken with 24 hours and after 90 days.

Results and discussions

Results in the plastic state

Table 8 shows the ratio parameters of the mortars.

Table 8. Ratio parameters of the mortars.

Mortar	Water / dry materials ratio (mass)	Water / cement ratio (mass)	Water / binders ratio (mass)	Aggregate / binders ratio (mass)
As^0_{RP}	0.216	2.59	1.356	5.27
As^0_{AN}	0.231	2.64	1.328	4.79
As^8_{RP}	0.207	2.52	1.322	5.39
As^8_{AN}	0.224	2.60	1.289	4.90

Specific gravity and void content

In Figure 1 is observed the increase in specific gravity in the plastic state for the ripened dried mortar with stone-quarry wastes in relation to natural sand. This is due to the higher specific gravity of the quarry waste. However, with the addition of rubber powder that has low specific gravity, there was a decrease for both mortars.

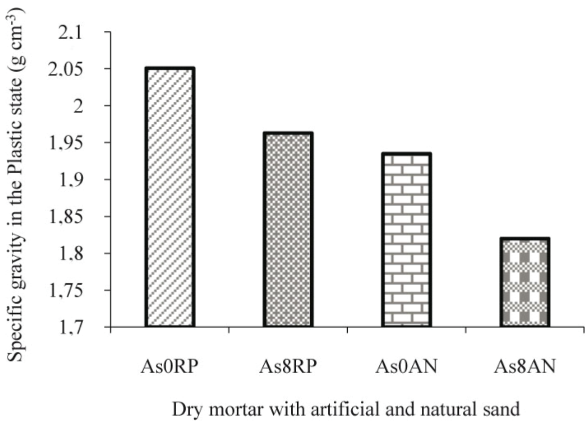

Figure 1. Specific gravity of the mortars As^{0}_{RP}, As^{8}_{RP}, As^{0}_{AN}, As^{8}_{AN}.

The dried mortar with quarry waste presented a reduction in the incorporated air content (Figure 2). This may have occurred owing the greater amount of pulverulent material of the artificial sand compared with natural sand. As for the rubber powder, there was an increase in air content because the rubber grain has a lower compactness.

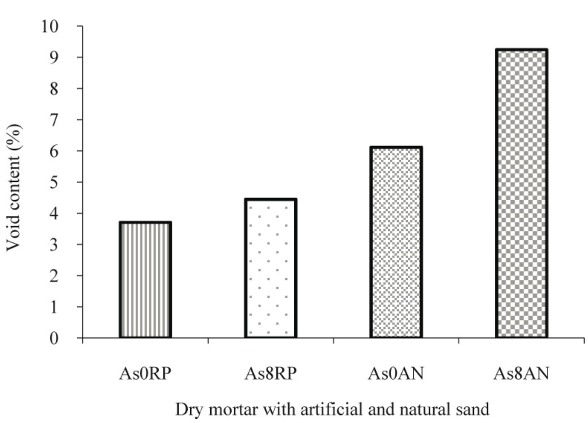

Figure 2. Void content of the mortars As^{0}_{RP}, As^{8}_{RP}, As^{0}_{AN}, As^{8}_{AN}.

Water bleeding

A sharp reduction was found in water bleeding from dried mortar with quarry waste in relation to natural sand (Figure 3). In the same way, a decrease for both mortars with 8% rubber powder was observed, with a greater reduction for mortar with quarry waste. The rubber powder and the fine material from artificial sand may have favored the closure of the pore structure of the mortar, contributing to reduce the water bleeding.

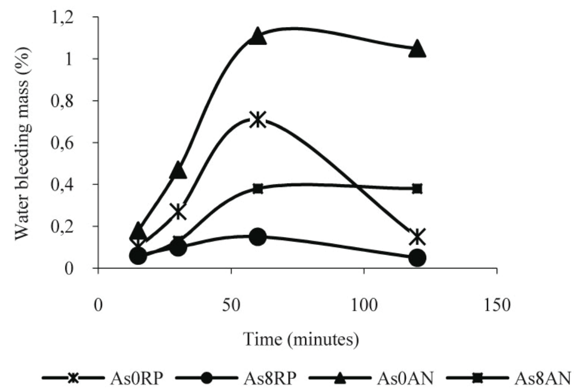

Figure 3. Water bleeding of the mortars As^{0}_{RP}, As^{8}_{RP}, As^{0}_{AN}, As^{8}_{AN}.

Water retention

The ripened dried mortar with quarry waste presented a greater retention of water compared with the mortar with natural sand (Figure 4), due to the higher amount of fines in the aggregate. The addition of rubber powder contributes even more for the closure of the pore structure of the mortar, generating thus a greater retention of water in the mortar with artificial sand in relation to the mortar with natural sand.

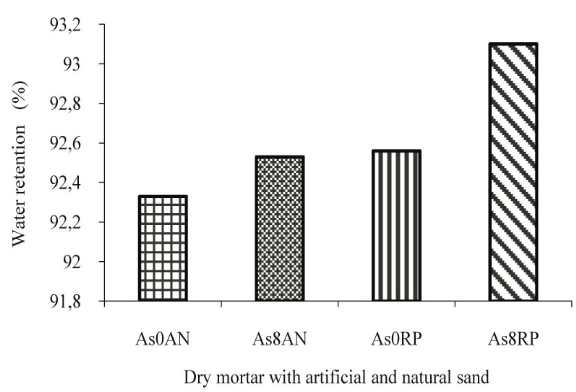

Figure 4. Water retention of the mortars As^{0}_{RP}, As^{8}_{RP}, As^{0}_{AN}, As^{8}_{AN}.

Hardened state results

Axial compressive strength

There was a slight increase in axial compressive strength at 28 days for the dried mortar with artificial sand in comparison with natural sand (Figure 5). This probably occurred given the reduction in incorporated air content, which leads to a higher compactness, directly proportional to the higher compressive strength; this corroborates the observations made by Bonavetti and Irassar (1994), with reduction for both mortars with addition of rubber powder, once it presented a low mechanical strength.

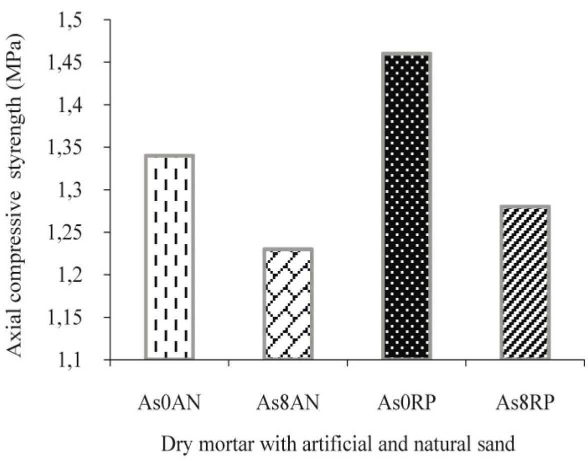

Figure 5. Compressive strength of the mortars As^0_{RP} , As^8_{RP}, As^0_{AN}, As^8_{AN}.

Static deformation modulus

The static deformation modulus of the dried mortar with artificial sand was slightly higher than of the mortar with natural sand (Figure 6), as also observed for the compressive strength. The addition of rubber powder led to a reduction in static deformation modulus, in the same way with further reduction for the mortar with natural sand, presenting an improvement in the ability to absorb deformation; confirming the observations of Turatsinze and Garros (2008).

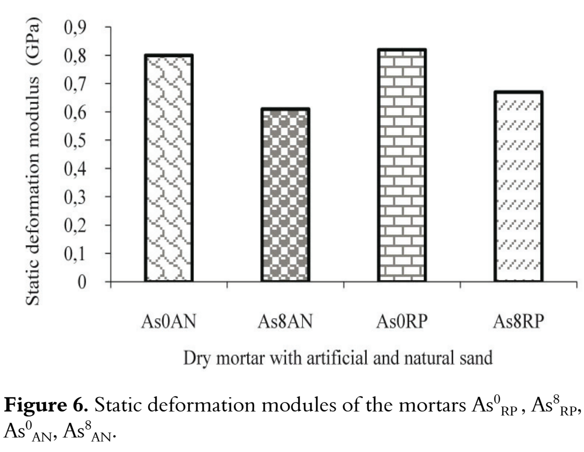

Figure 6. Static deformation modules of the mortars As^0_{RP} , As^8_{RP}, As^0_{AN}, As^8_{AN}.

Water absorption by capillarity

The water absorption by capillarity of the dried mortar with artificial sand was higher than of the mortar with natural sand (Figure 7). The greater content of fines in the artificial sand might have led to a greater microcraking of this mortar, or even to a reduction in the radius of capillary, increasing thus the surface tension. Considering the addition of 8% rubber powder, although with lower rates, the mortar with artificial sand also had a much higher capillarity rate compared with the mortar with natural sand, and a much shorter time to reach the top of the specimen, as registered by Canova et al. (2009).

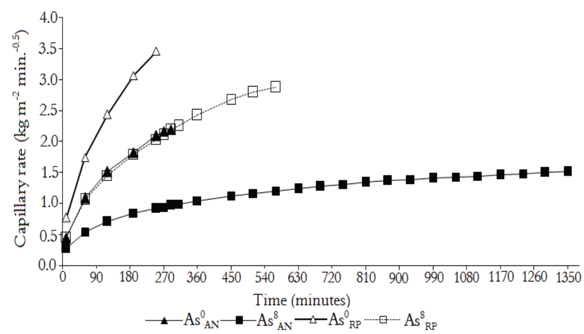

Figure 7. Water absorption of the mortars As^0_{RP}, As^8_{RP}, As^0_{AN}, As^8_{AN}.

Visible cracking

The mortar with artificial sand cracked more than the mortar with natural sand (Figure 8), probably due to the higher amount of fines present in the quarry waste.

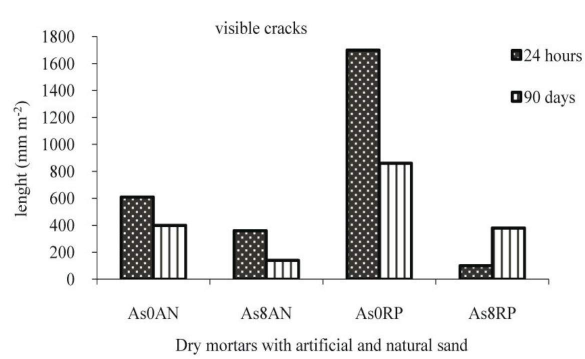

Figure 8. Visible crackings with 24 hours and at 90 days of the mortars As^0_{RP}, As^8_{RP}, As^0_{AN}, As^8_{AN}.

Besides, with 24 hours the incidence of crackings was higher than at 90 days. The addition of rubber powder has positively contributed to both mortars. This may have occurred due to increased retention of water and/or reduction in deformation modulus. Figure 9 illustrates the total sum of crackings of times of 24 hours and 90 days. The mortar with quarry waste had a higher amount of crackings than the mortar with natural sand.

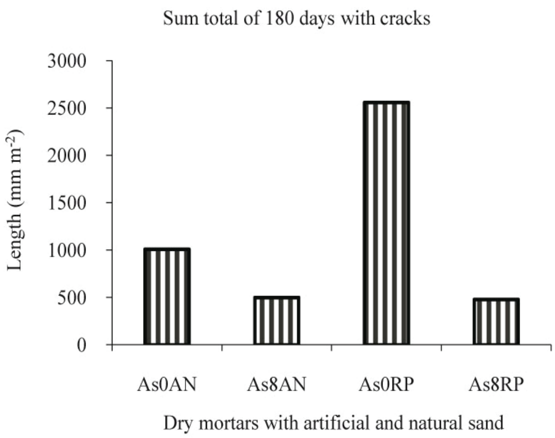

Figure 9. Total sum of visible crackings of the mortars As^{0}_{RP}, As^{8}_{RP}, As^{0}_{AN}.

Conclusion

Replacement of the natural sand in the quarry waste in dried mortar contributed to reduction in water bleeding, increase in compressive strength and water retention. But reduced the void content and increased the static deformation modulus and visible cracking.

The addition of rubber powder in dried mortar with quarry waste contributed to the increase in void content and water retention, with reducing to the water bleeding, water absorption by capillarity and significantly reduced the appearance of visible cracking. Although there was been decrease in mechanical properties. We conclude that use of 8% rubber powder is feasible to reduce cracking.

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