MORTAR WITH UNSERVICEABLE TIRE RESIDUES

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Abstract: This study analyzes the effects of unserviceable tire residues on rendering mortar using lime and washed sand at a volumetric proportion of 1:6. The ripened composite was dried in an oven and combined with both cement at a volumetric proportion of 1:1.5:9 and rubber powder in proportional aggregate volumes of 6, 8, 10, and 12%. Water exudation was evaluated in the plastic state. Water absorption by capillarity, fresh shrinkage and mass loss, restrained shrinkage and mass loss, void content, flexural strength, and deformation energy under compression were evaluated in the hardened state. There was an improvement in the water exudation and water absorption by capillarity and drying shrinkage, as well as a reduction of the void content and flexural strength. The product studied significantly aided the water exudation from mortar and, capillary elevation in rendering.

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INTRODUCTION

Unserviceable tires can affect the environment due to their carcass shape and the lifetime of rubber fiber, as it is very resistant to environmental degradation.

The disposal of unserviceable tires to inappropriate places poses public health risks due to the proliferation of mosquitoes and other vectors, while tire burning pollutes the air with smoke and the water table with oil.

Whole unserviceable tires are unsuitable for waste landfill disposal due to their low compressibility, thereby reducing the life of landfills and possibly causing waste slides and gas buildups (D'Almeida & Sena, 2000).

In effect since January 2002, CONAMA's (*Conselho Nacional do Meio Ambiente* – National Environment Council) resolution n. 258/99 says that tire producers and importers are responsible for the collection, recycling, and final disposal of unserviceable tires in appropriate places.

In the European Union, the regulations on unserviceable tire management have two directives that are adjusted based on the conditions of the member states. Since 2003, the directive on the disposal of wastes in landfills (Directive 99/31/CE – European Community, 1999) has established that whole unserviceable tires cannot be disposed in landfills. Since 2006, tires cannot be sent to landfills even after grinding (Freires & Guedes, 2006).

One major consequence of the environmental impact of worn tires is the search for environmentally correct alternatives for their disposal. The use of tires in asphalt paving has been demonstrated to be highly viable, while their use in concrete and mortar has the disadvantage of degraded mechanical properties. However, their performance in rendering mortar with cement and lime, which does not require high strength, still requires further investigation.

Canova (2002) attempted to produce a ready mortar mixture that would have the advantage of a constant composition that would be adequate for rendering. Mortar consisting of lime and sand ripened and dried in an oven has given good results, such as improved mechanical properties and tensile bonding strength, reduced water sorption by immersion and void content, as well as better workability as a result of a larger air entraining. In this way, mortar combined with unserviceable tire rubber powder is more viable than conventional mortar composed of only ripened lime and sand.

One property related to rendering mortar workability that also influences its consistency is water exudation. Mehta & Monteiro (1994) analyzed exudation in concrete and found that inadequate consistency and a small amount of fine particles are generally two of the causes of exudation. They pointed out that the granulometry of the aggregate and the addition of minerals and air entraining may counter exudation. Rubber power may help reduce mortar water exudation and permeability, which is evaluated in terms of the absorption of water by capillarity, which must be lower than the base absorption to protect against the passage of rainwater through mortar (Cincotto *et al.*, 1995).

Another fundamental performance property of rendering mortar regarding waterproofing and durability is drying shrinkage. The mortar paste is potentially responsible for shrinkage (Cincotto *et al.*, 1995; Bastos, 2001). Concerning this shrinkage, the ideal granulometric content and composition of the aggregate, which determine the void content to be filled, allow for a reduction in the amount of paste required. At the same time, the appropriate workability and mechanical properties are maintained with the addition of the rubber powder to mortar, ensuring its good performance. Among these mechanical properties, flexural strength, which is part of the MERUC classification created by CSTB (1993), influences the durability of mortar in relation to cracking.

Lime is a second binder in rendering mortars that will be subject to internal efforts. It provides for a great capacity of deformation; that is, it allows for deformation without rupture or microcracks that might affect bonding, waterproofing, and durability (Selmo, 1989). Since rubber is highly elastic, it tends to contribute to a better elasticity, giving the matrix the capacity to absorb energy, thereby improving the resistance of mortar to cracking.

Several studies have investigated the influence of rubber as an aggregate on the properties of concrete (Eldin & Senouci, 1993; Topçu, 1996; Toutanji, 1996). They reported a reduction in the mechanical properties of concrete, a higher capacity to absorb energy, and greater durability. Toutanji (1996) observed that the loss of flexural strength is proportionally smaller than the loss of compression strength. Studies on the addition of rubber residues to resistant mortar (Raghavan & Huynh, 1998; Bignozzi *et al.,* 2000; Meneguini, 2003; Segre *et al.*, 2004) also found losses in the mechanical properties. Meneguini (2003) reported a decrease in water absorption by capillarity. In a study on cement paste, Segre (1999) observed a reduction in the mechanical properties and water absorption by capillarity and a slight increase in drying shrinkage.

In an effort to evaluate the feasibility of adding unserviceable tire residues to a cement and lime base, Canova *et al.* (2205) tested rendering mortar with 5% rubber powder. The results of the development of mortar added with tire rubber residue were favorable. In another study on the addition of unserviceable tire rubber powder at the ratios of 6, 8, 10, and 12% to conventional rendering mortar, Canova *et al.* (2007) found a reduction in the amount of mixture water required, the mechanical properties and visible cracks, while the tensile bonding strength remained constant.

Table 1. Materials and characteristics.

Material	Type	Characteristics	Results	Standard
Cement	Compound *Portland* (CPIIZ – 32)	Fineness – sieve #200 (retained %)	1.62	MB – 432/94
		Specific mass (g/cm^3)	3.09	NM – 23/98
		axial compression strength (MPa) 28 days	34.7	NBR – 7215/96
		Unit mass (g/cm^3)	1,45	NBR – 7215/96
Lime	Common lime	Unit mass (g/cm^3)	0.96	NBR – 7251/82
		Real specific mass (g/cm^3)	3.10	NM – 23/98
		Fineness – (retained %)	–	NBR – 9289/98
		Sieve #30	0.7	
		Sieve #200	0.22	
Sand	Washed river sand	Unit mass (g/cm^3)	1.55	NBR – 7251/82
		Specific mass (g/cm^3)	2.63	Picnometer Method
		Ø max (mm)	1.2	NBR – 7217/87
		Fineness module	1.74	

The present study investigates other performance-related properties of rendering mortar using the same unserviceable tire rubber powder ratios used by Canova *et al.* (2007), but with simple mortar oven drying.

MATERIAL AND METHODS

Materials and specimen preparation

The materials used in the composition of the rendering mortar (ready mixture) and their characteristics are given in **Table 1**.

The solid residue (rubber powder) was supplied by Relastomer Tecnologia e Participações S.A., which recycles vulcanized rubber at low temperatures (80°C maximum). The rubber and steel are magnetically separated after heterogeneous catalysis.

The chemical characteristics of the solid rubber powder residue are given in **Table 2**. The results of the chemical assay revealed the presence of heavy metals in the rubber residue, such as plumb and total chrome; however, after the rubber was added to the mortar, the values fell within the standard limits.

The granulometric analysis of the air-dried rubber powder sample was performed manually using a series of regular sieves, in accordance to NBR 7217: 1987. The results are presented in **Table 3**, together with other physical characteristics.

Table 2. Solid residue characteristics – rubber powder

Chemical characteristics – Mass in mg/kg							
Fe	Cu	Mn	Zn	Pb	Cd	Cr*	Ni
710	52.6	Nd	646	108	Nd	32.0	4.0

* Total.

Table 3. Physical characteristics of the rubber powder

Characteristics	Results	Standard
Unit mass (g/cm^3)	0.44	NBR – 6474/84
Real specific mass (g/cm^3)	0.79	Picnometer Method
Ø max (m)	0.42	NBR 7217/87
Fineness module	1.33	

The thermogravimetry results of rubber powder submitted to a temperature variation from 0 to 1,000°C showed mass losses at the curve inflexions (TG), which are necessary for the dissociation of the rubber compounds. The thermogravimetry heating rate used was 10°C/min and the carrier gas (nitrogen) gas entrainment content was 20 mL/min. The mass loss of the powder rubber as a function of the increase in temperature in the thermogravimetric analysis started at 195.94°C.
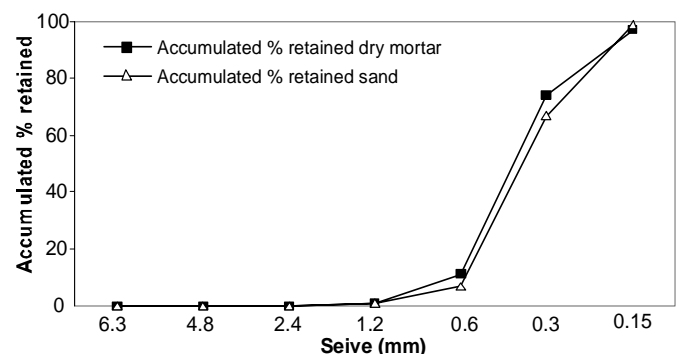
Mortar

The experiments were carried out with mortar composed of simple lime and natural washed fine sand at volumetric proportion of 1:6.

The mortar volumetric proportion was 1:1.5:9 cement, lime, and sand, which is equivalent to the mass proportion of 1:0.993:9.623.

The lime and sand mortar with 2.46 dm^3 water per kg lime was previously prepared in a 320-L inclined axle cement mixer. After mixing for 5 min, the mass was determined and ripened for 7 days in metal containers for lime hydration, as specified in NBR 7200: 1998.

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,

Fig. 1 Granulometric curve of sand and dry mortar.

packed in grained state and stored for 60 days in closed dry wooden containers, as described by Canova (2002). **Figure 1** shows the granulometric curve of sand and dry mortar.

The dry mortar was added with cement and assayed with rubber powder contents of 0, 6, 8, 10 and 12%. The mortar samples were labeled (Mt0) (reference mortar), (Mt6), (Mt8), (Mt10), and (Mt12), respectively; the rubber powder containing mortar was labeled (Mtx).

After determining the amount of evaporated water during mortar drying in an oven plus the water added to the mixture after the addition of cement and rubber powder, the standard mortar consistency index was determined to be in the range of (255 ± 10) mm, according to the standard NBR 13276: 1995.

Measured properties

The properties selected for investigation in this study were evaluated by standard laboratory assays: water exudation in the plastic state, water absorption by capillarity, drying shrinkage, the mass loss of specimens with free surfaces and with one restrained surface, void content, flexural strength and the deformation energy under compression in the hardened state.

Water exudation

The water exudation was evaluated using the RILEM method (MR-6): 1982. The amount of exudated water was assayed in five specimens with a graduated pipette. However, the volumes of water obtained were negligible and thus not measurable. The time periods used were 15, 30, 60, and 120 min, as the method proposes only one measurement per specimen for a given rest time.

Water absorption by capillarity

Based on NBR 9779: 1995, six cylindrical specimens with 5 cm diameter and 10 cm height were assayed on the 28th day. However, it was observed that water reached the top of the specimen in less than 5 h. Since the standard says that the assay is invalid if water reaches the top of the specimen, it was necessary to change the measurement times as follows: up to 90 min every 10 min, from 90 to 150 min every 15 min, from 150 to 360 min every 20 min, from 360 to 450 min every 45 min, and from 450 to 1350 min every 60 min. Marks were made at the height at every 1 cm in three marks to make reading the moisture measurement on the specimen surface easy.

Free face drying shrinkage and mass loss

Based on NBR 8490: 1984, three prismatic specimens (285 × 25 × 25 mm) were molded for each rubber powder proportion and kept in the laboratory until demolding. The specimens were demolded after 24 h

and the first shrinkage and mass loss were measured. The specimens were kept in a dry chamber according to the standard until the 10th day and measurements were carried out every 24 h at 13, 16, 21, and 28 days of age.

Mass loss and drying shrinkage with one restrained surface

Specimens with one surface restrained with a metal grid were used to simulate rendering in the drying shrinkage experiment. The influence of the base on water loss by suction and mortar bonding to the metal grid were simulated with filter paper.

The method we used is similar to that of Lejeune (1995) and Bastos (2001). Our experiment was aimed at evaluating the restrained shrinkage, which corresponds to the deformation of the mortar as measured immediately after demolding. The specimens were 285 mm long, 100 mm wide, and 25 mm thick, and the measurements were performed in triplicate. The metal grid used for mortar bonding was 1 mm thick and 50% perforated with 15-mm diameter round holes 3 mm away from each other. Filter paper was placed between the base and the metal grid to allow for water suction and mortar demolding as shown in **Fig. 2**.

Shrinkage was measured on specimen free top surface, which was exposed to air, and on the metal grid shrinkage restrained surface; the mass was also measured. The specimens were kept in a dry chamber at (23 ± 2)°C and a relative humidity of (50 ± 4)%. Measurements were performed every 24 h until the 10th day, and then only on the 13th, 16th, 21st, and 28th days. The molding, demolding, and measurement procedures are described in Canova (2008).
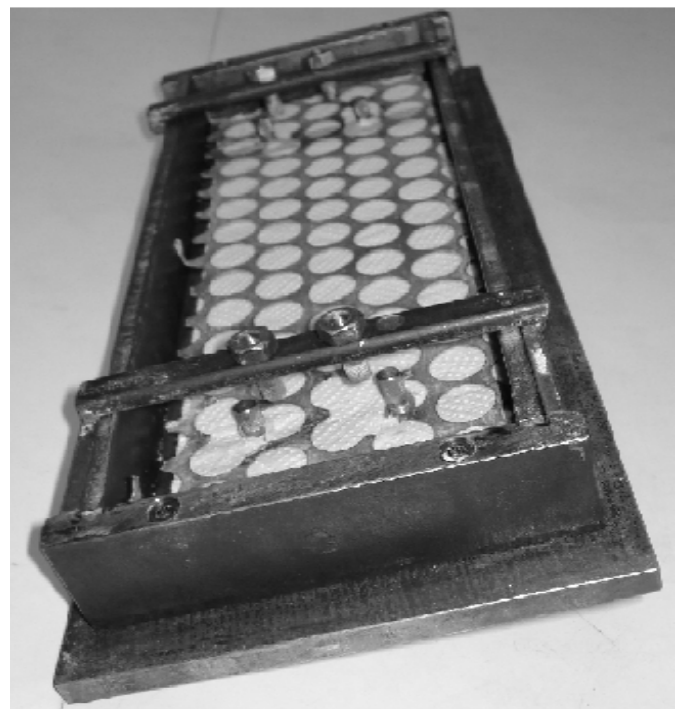

Fig. 2 Mold prepared for molding specimens of restrained shrinkage by metal grid.

Table 4. Mortar parameters.

Mortar	Consistency index (mm)	Water/dry material ratio (mass)	Cement/water ratio (mass)	Binder/ water ratio (mass)
Mt0	254	0.231	2.64	1.328
Mt6	250	0.226	2.60	1.303
Mt8	252	0.224	2.60	1.289
Mt10	253	0.223	2.60	1.289
Mt12	251	0.222	2.60	1.289

Void content

Based on NBR 9778: 1987, six cylindrical specimens measuring 5 cm in diameter and 10 cm in height were assayed after 28 days.

Flexural strength

ISO/DIS 679: 1993 was adapted for specimens measuring 40×40×160 (mm). Triplicate measurements were performed on molds 200 mm long, 75 mm wide, and 25 mm thick. The assays were performed at the 28th day of age with the load uniformly distributed on the middle cross section of the bi-supported specimens. The flexural strength was calculated with **Eq. 1**:

$$\sigma = 1.5 PL / bd^2 s \qquad (1)$$

where:
σ = flexural strength (MPa)
P = load applied on the middle of the prism (N)
L = distance between the supports (160 mm)
b = larger cross section side of the specimen (mm)
d = specimen thickness (mm)

A distance of 160 mm between the two specimen supports was also maintained, according to the ISO/DIS 679 method. The load application speed was about 0.02 MPa/s due to the low values obtained for the mortar under study, according to Canova *et al.* (2007).

Deformation energy at compression

The area under the compression assay curve of strength versus deformation was analyzed. Measurements were performed on six cylindrical specimens that were 5 cm in diameter and 10 cm high after 28 days in a simple compression machine. Based on NBR 13279: 1995.

RESULTS AND DISCUSSION

The measurements for both the plastic and hardened states of mortar are presented below.

The pre-defined consistency index was (245–265) mm specific scattering, as determined in NBR – 13276: 1995, assay in flow table. The results given in **Table 4** allowed for the characterization of the workability of each mixture.

Table 4 also presents the variation in the total water content in relation to the amount of cement, the total amount of binders and the total content of dry materials of the mortars in mass with and without rubber powder. The reference mortar (Mt0) required the largest amount of water to reach the pre-defined consistency index, suggesting that the rubber powder lubricated the mortar components.

Water exudation

Table 5 gives the mean values of five water exudation measurements in mass and accumulated exudated water for plastic state mortar and the rubber powder contents used.

Figure 3 shows a sharp reduction in the water exudation for the oven-dried mortar combined with different rubber powder concentrations in relation to Mt0. The Mt6 and Mt8 show different curve inflexions after 90 min when compared to the mortar with other rubber concentrations. The water exudation time of Mt6 increased from 60 to 120 min; however, this value is 59% lower than that of the reference mortar. The addition of rubber powder efficiently improved particle cohesion and the closure of the granulometric package of mortar. The increase in the amount of fine rubber aggregate reduced the amount of mixture water; this probably due to the thinner capillaries produced, which may have contributed positively to the reduction of water exudation.

Table 5. Mortar water exudation (mass)

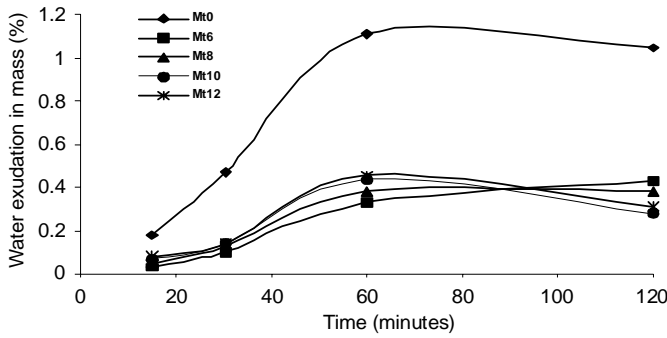| Mortar	Exudated water (%)					Accumulated exudated water (%)
	Time (min)					
	15	30	60	120	240	
Mt0	0.18	0.47	1.11	1.05	0	0.56
Mt6	0.03	0.10	0.33	0.43	0	0.18
Mt8	0.05	0.13	0.38	0.38	0	0.19
Mt10	0.07	0.14	0.44	0.28	0	0.19
Mt12	0.08	0.14	0.46	0.31	0	0.20

Fig. 3 Water exudation of oven-dried mortars, Mt0 and Mtx.

Water absorption by capillarity

Figure 4 shows that the water absorption time of Mtx is much longer than the time necessary to reach the top surface of Mt0. This indicates that the addition of rubber powder to the rendering mortar contributes to capillary elevation, thus requiring a longer time to reach the same rendering mortar layer thickness. Both the reduction of capillarity, which is a function of the increase in the fine aggregate content from the addition of rubber powder, and the water/binder ratio worked to reduce the material porosity. This result suggests that the pores became better distributed, thus reducing capillary formation. This hypothesis agrees with the results found by Grigoli & Helene (2001).

Table 6 gives the fitted curve equation, the correlation coefficients and the water absorption of the oven-dried mortar. The water absorption coefficient was calculated from the straight segment of the capillarity curve slope between the square root of the time and water absorption by capillarity. **Table 6** also shows that the values of water absorption by capillarity obtained for oven-dried mortar agree with the curve in **Fig. 4**. The water absorption by capillarity for Mt0 is much higher than the values for Mtx.

Free drying shrinkage

Figure 5 shows that over 65% of the oven-dried mortar free shrinkage occurred in the first post-demolding stages of the specimens. Mt0 produced the largest shrinkage values in the first stages (until the third day) and the largest total shrinkage. Mtx showed a reduction in the drying shrinkage that was proportional to the amount of rubber powder added, except for Mt12, which had a lower reduction than Mt10. Mt6 had a reduction of 9% in relation to Mt0, while Mt10 presented the largest reduction, reaching over 15% in relation to Mt0.

The larger concentration of fine aggregate after the addition of rubber powder and the reduction of the water/binder ratio may have contributed to less mortar shrinkage, as well as to a significant reduction in the water exudation. These factors may have contributed to reduce the negative effects of accelerated drying, supposing that the reduction in drying shrinkage is an indication of the possible plastic shrinkage, a hypothesis that agrees with the conclusions of Metha & Monteiro (1994).
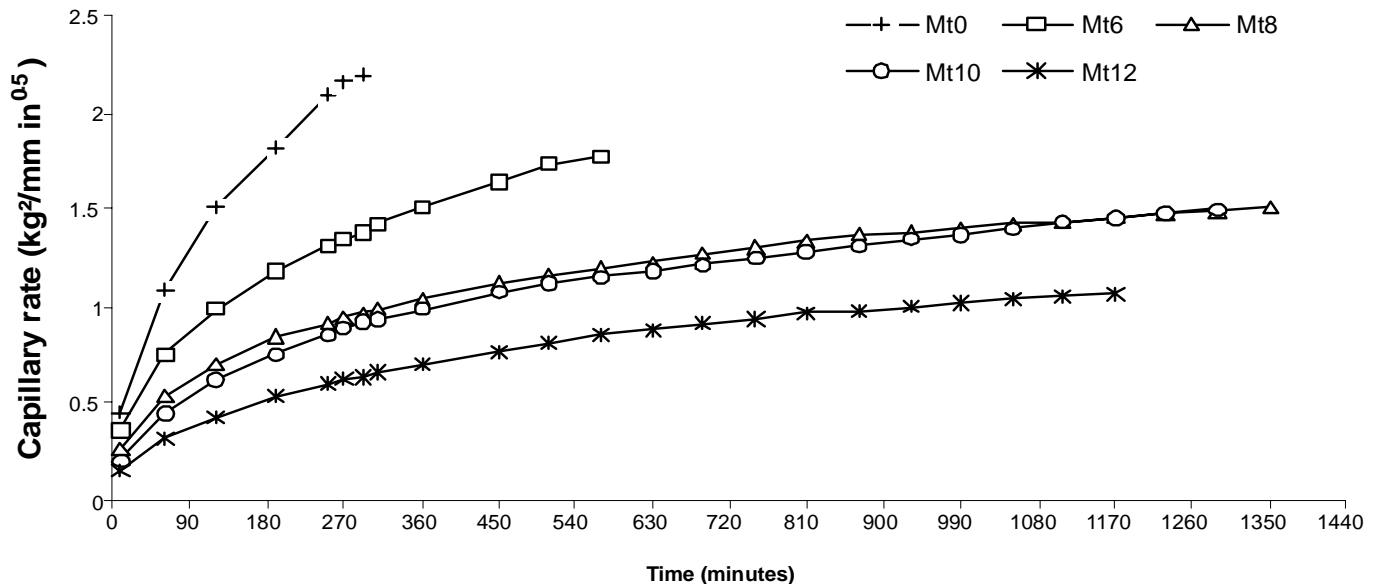

Fig. 4 Water capillary absorption of oven-dried mortars Mt0 and Mtx.

Table 6. Correlations obtained with the equations of mortar water absorption by capillarity

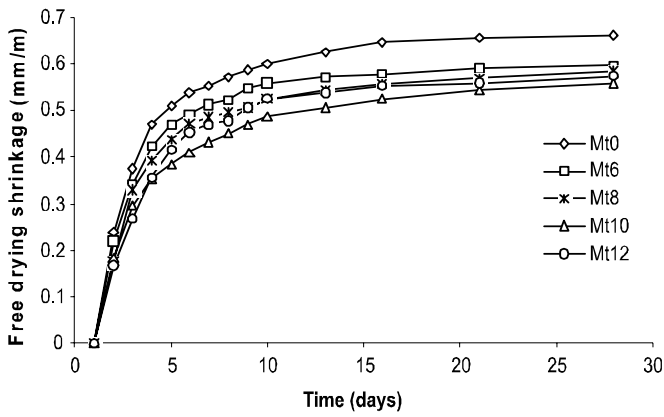| Mortar	Curve equation	Correlation coefficient (R^2)	Absorption coefficient
Mt0	$y = 1.3051x + 0.5862$	0.9987	1.3051
Mt6	$y = 0.7533x + 1.4862$	0.9965	0.7533
Mt8	$y = 0.5257x + 1.1548$	0.9968	0.5257
Mt10	$y = 0.5104x + 0.5156$	0.9988	0.5156
Mt12	$y = 0.3436x + 0.5069$	0.9981	0.3436

Fig. 5 Free drying shrinkage of oven-dried mortars Mt0 and Mtx.

Water loss at free shrinkage

Figure 6 shows that most of the water loss in the free shrinkage assay, which was about 90% on average, occurred during the first two days after specimen demolding. Oven-dried Mt0 had the largest water loss. The Mtx that was the closest to Mt0 on the second day after demolding was Mt8, presenting only 4% shrinkage, and the samples that was the most different was Mt10 with 12% shrinkage. After 28 days, the mortar that was the closest to Mt0 was Mt12 with 7% shrinkage, and the mortar that was the most different
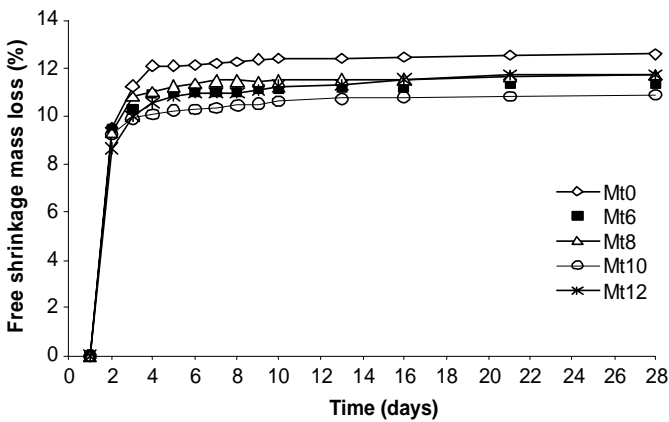

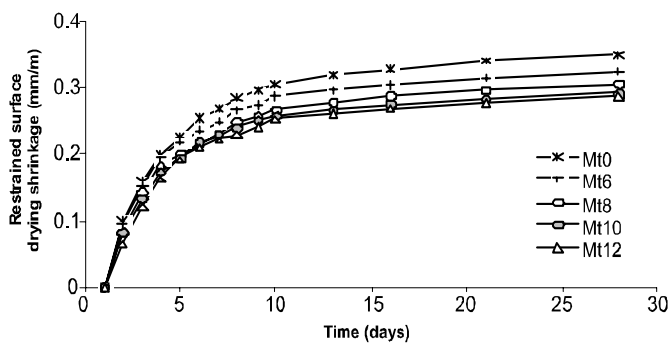**Fig. 6** Mass loss from free shrinkage for oven-dried mortars Mt0 and Mtx.

was Mt10 with 13% shrinkage. The large mass loss observed after specimen demolding was similar to the results obtained by Fiorito (1994) for a cement, lime, and sand volumetric proportion of 1:3:12 and by Kopschitz *et al.* (1997) for a cement, lime, sand volumetric proportion of 1:1:6.

Restrained drying shrinkage

Figure 7 shows that ripened Mt0 had the largest restrained drying shrinkage, which was similar to the free shrinkage result. In contrast with free shrinkage, however, Mt10 had the lowest restrained drying shrinkage, reaching approximately 17%. The mortar that was the closest to Mt0 was Mt6, which had a reduction of over 10%. On average, over 50% of the restrained shrinkage occurred in the first three days after specimen demolding, which was the same as the free shrinkage case. Aside from a few exceptions, the behaviors of the restrained and free shrinkage curves were similar. The average restrained shrinkage values were about 55% lower than the free shrinkage values on the side without the metal grid.

The graph for the specimens with metal grid is shown in **Fig. 8**. In the assay conditions used, the metal grid used as a substrate bonding prevented shrinkage until the 28th day.

Water loss at restrained shrinkage

Figure 9 shows that the oven-dried Mt0 (larger water/binder ratio) lost the most mass by the third day after demolding. Although the difference in Mt10 was negligible until that day, it increased in relation to the reference mortar after the 4th day of demolding. However, from the 7th day on the Mt6 values gradually moved closer to the Mt0 values, while the other mortars had over 5% shrinkage in relation to Mt0. Mt12 showed the largest shrinkage 4 days after demolding, reaching over 10% and a difference of 14% on the 28th day. Although the Mt6 and Mt0 values are similar, the behavior of the curves is consistent with the amounts of rubber powder used.
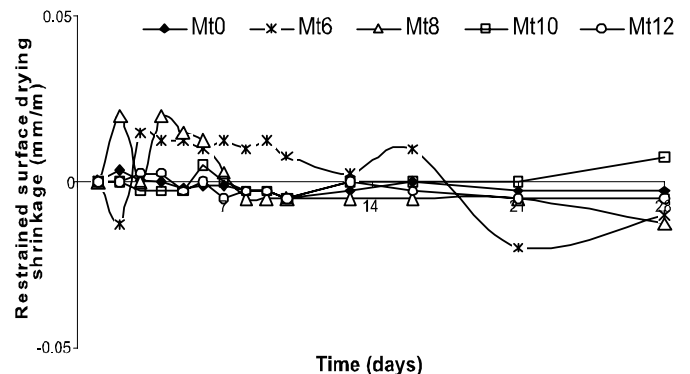

Fig. 7 Drying shrinkage for one restrained surface of Mt0 and Mtx – side without metal grid.

Fig. 8 Shrinkage by restrained drying of Mt0 and Mtx on the metal grid side.

Table 7. Mortar flexural strength

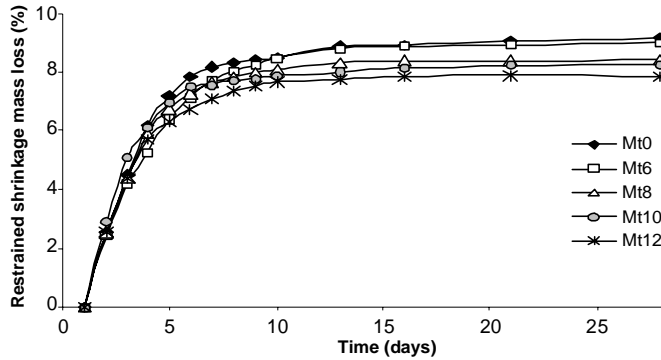| Mortar	Flexural strength (MPa)	Consistency index (mm)	Standard deviation (MPa)
Mt0	0.43	254	0.0044 721
Mt6	0.38	253	0.0109 545
Mt8	0.37	252	0.0109 545
Mt10	0.36	251	0.0000 000
Mt12	0.34	253	0.0100 000

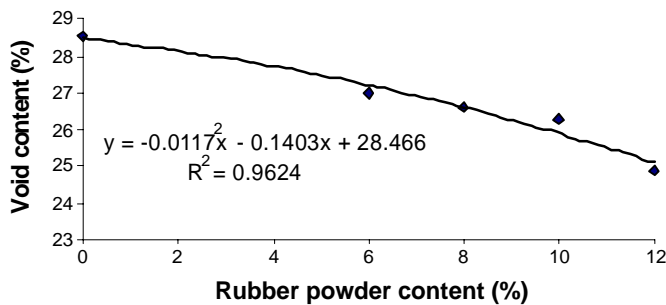**Fig. 9** Mass loss for restrained shrinkage of Mt0 and Mtx.

Fig. 10 Void ratio of Mt0 and Mtx at $(105 \pm 10)°$C.

Void content

In **Fig. 10**, we can see that the void content of the oven-dried mortar mixed with unserviceable tire rubber powder was over 5% smaller than that of Mt0, while the void content of Mt12 was about 13% smaller. The reduction in the void content contributes to the closure of the granulometric package; however, the void closure only contributes to the passage of water and does not increase the strength, as rubber is impermeable and has a low mechanical strength.

Flexural Strength

Table 7 gives the average flexural strength of three measurements of oven-dried Mt0 and Mtx, along with the consistency index and the standard deviation.

Table 8. Mortar deformation energy under compression

Mortar	Deformation energy (MPa mm)
Mt0	0.00 814
Mt6	0.00 834
Mt8	0.00 865
Mt10	0.00 886
Mt12	0.00 937

Figure 11 shows the flexural strength behavior of oven-dried Mt0 and Mtx. The flexural strength decreased as the rubber powder content increased. The reduction for Mt8 was 12%, reaching 17% for Mt12, which agrees with the low mechanical strength of rubber. However, the results obtained for oven-dried mortar were 6% higher than those obtained by Canova *et al.* (2007) for the same conventional mortar volumetric proportion of cement, lime, and sand.

Compression deformation energy

Table 8 gives the average values of four deformation energy measurements of oven-dried mortar with and without rubber powder. The compression strength was set at 1.5 MPa for the calculations. As shown in **Fig. 12**, the energy necessary for the oven-dried mortar added with rubber powder to reach the same strength values using 1.5 MPa is larger than that of Mt0, despite the larger strength values of the latter in relation to Mtx. Therefore, Mtx had a more elastic behavior than that of Mt0, which agrees with the values in **Table 8**.
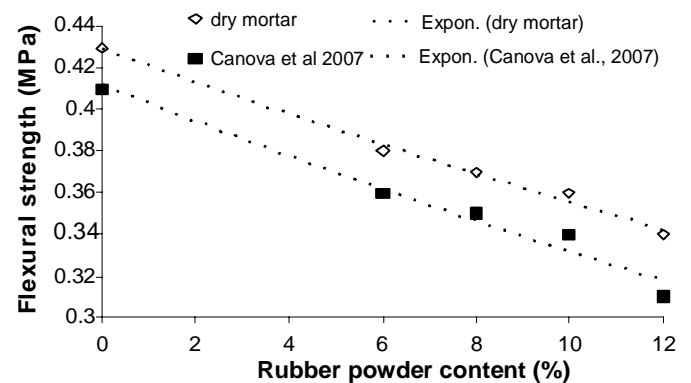

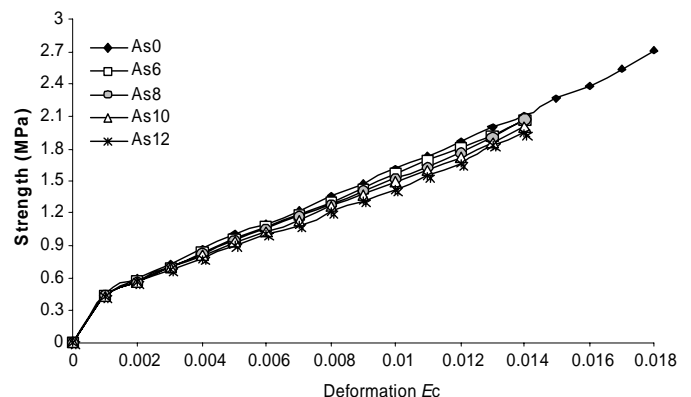**Fig. 11** Flexural Strength of oven-dried mortar Mt0 and Mtx.

Fig. 12 Deformation energy for the compression of Mt0 and Mtx.

CONCLUSIONS

The addition of rubber powder to oven-dried mortar in proportions reaching 12% of the aggregate volume resulted in a significant reduction in water exudation in relation to the reference mortar, thereby improving the mortar workability.

Water absorption by capillarity was significantly reduced by the addition of rubber powder to the mortar in relation to the reference mortar. The capillary elevation decreased due to the increase in the time necessary to reach the same rendering layer thickness.

Drying shrinkage with free surface and mass loss was smaller for the mortar added with rubber powder than for the reference mortar. The reduction in the drying shrinkage helped reduce fissures because of the larger concentration of fine aggregate and the reduction of the water/binder ratio. In the case of drying shrinkage with restrained surface and mass loss were lower than those of the reference mortar; however, the restrained shrinkage was 55% smaller than the free shrinkage.

The void content was also smaller in the mortar combined with rubber powder than in the reference mortar, which favored the reduction of the capillary elevation in rendering. The flexural strength of the mortar gradually decreased as the rubber powder content increased. The deformation energy under compression of the mortar added with rubber powder was more tenacious for the same compression strength than for the reference mortar.

This study demonstrated that the addition of rubber powder to rendering mortar favored the properties studied, except for flexural strength due to the low mechanical strength of rubber. Among the rubber powder contents studied, the addition of 8% rubber powder to the rendering mortar was the most favorable.

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