

Analysis of water performance of coating mortars incorporated with tire rubber

Análisis del comportamiento al agua de morteros de revestimiento incorporados con caucho de neumáticos

Leticia Martelo Pagoto *, Jorge Luis Akasaki*, José Luiz Pinheiro Melges*, Cesar Fabiano Fioriti ¹*

* Universidad Estadual Paulista (UNESP), Sao Paulo, BRASIL

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Abstract

This paper analyzed the behavior of mixed mortars incorporated with rubber from the tire retreading process, based on partial sand substitution. The content of rubber incorporation in the mortars was 5%, 10%, 15%, and 20% by volume. The different granulometries of rubber were denominated as thick (passed through a sieve # 1.19 mm) and fine (passed through a sieve # 0.60 mm). Tests were performed to evaluate water retention, capillary absorption, drying, immersion absorption, water vapor permeability, and permeability to water under pressure. The results showed that the fine rubber was distinguished by its higher retention of water at the contents of 15% and 20%, lower absorption via both capillary and immersion, higher drying capacity, higher permeability to water vapor, and lower permeability to water under pressure.

Keywords: Coating mortar, tire rubber, composites, behavior in water, alternative material

Resumen

En este trabajo se analiza el comportamiento de las mezclas de mortero con adición de caucho proveniente del recauchaje de neumáticos, sustituyendo parcialmente el contenido de arena, con contenidos de caucho del 5%, 10%, 15% y 20% en volumen. Se usaron dos tipos de granulometría para el caucho: gruesa (que pasa por un tamiz de 1,19mm) y fina (que pasa por un tamiz de 0,60mm). Se realizaron ensayos para evaluar la retención de agua, absorción por capilaridad, secado, absorción por inmersión, permeabilidad al vapor de agua y permeabilidad al agua bajo presión. Los resultados muestran que los morteros con adición de caucho de granulometría fina presentan mayor capacidad de retención usando contenidos del 15% y 20% de caucho, menor absorción tanto por capilaridad como por inmersión, mayor capacidad de secado, mayor permeabilidad al vapor de agua y menor permeabilidad al agua bajo presión.

Palabras clave: Mortero de revestimiento, caucho de neumáticos, compuestos, comportamiento en agua, material alternativo

1. Introduction

Faced with the possible end of the natural resources used in the construction industry, researchers of cementitious composites have sought to partially replace the finite natural aggregates with rubber residues, thus facilitating the reduction of the environmental impacts generated and the final disposal of this type of waste. The incorporation of tire rubber from various production processes into coating mortars changes its properties in the aspect of water behavior in both fresh and hardened states, as highlighted by some authors, who demonstrated the possibility of tire rubber use for this purpose.

In the fresh state, the incorporation of rubber results in the reduction of mass density in comparison with that of the reference, caused both by the low density of the rubber particles compared with that of the sand particles and by the increase in the air content incorporated in the mixture (Angelin et al., 2017); (Pedro, 2011); (Pham et al., 2018); (Canova et al., 2015). Further, a reduction in the consistency by spreading occurs, which does not influence its workability (Choudhary et al., 2019); (Pedro, 2011); (Fioriti et al., 2012). It is not possible to predict its behavior in terms of the water retention, as the incorporated rubber contents can alter the granulometric arrangement of the mixture, causing variations of the retention percentage both higher and lower than the reference with the increase in the rubber content. However, small variations do not cause an improvement or worsening of the water retention property (Medina et al., 2018); (Canova et al., 2015). Rubber mortars under natural laboratory conditions lose less water by evaporation at the initial times when compared with that of the reference, and when subjected to drying conditions in an oven, the opposite phenomenon is observed, i.e., they lose more water by evaporation (Mundo et al., 2018); (Medina et al., 2018); (Pinto et al., 2015).

¹ Corresponding author:

Universidad Estadual Paulista (UNESP), Sao Paulo, BRASIL

E-mail: fioriti@fct.unesp.br



With the coating mortar in the hardened state, the incorporation of rubber reduces the mass density to values lower than the density in the fresh state, owing to the loss of water by evaporation and to the hydration of the cement (Na and Xi, 2017); (Fioriti et al., 2012); (Angelin et al., 2017). There is greater absorption of water via immersion (Pham et al., 2018); (Fioriti et al., 2012); (Angelin et al., 2017), caused by the high porosity of the mixture when incorporating rubber (Angelin et al., 2017). As for the water absorption via capillarity, the capillary coefficients are reduced with the increase in the rubber content, which is due to the increase in the incorporated air content and worse compaction of the mixtures owing to the reduction of mass density (Sofi, 2018); (Na and Xi, 2017); (Pedro, 2011); (Angelin et al., 2015). Regarding the permeability to water in the liquid and vapor states, there is a reduction in the absorbed water and an increase in the water vapor permeability coefficient (Pedro, 2011).

Thus, this paper aimed to evaluate the behavior of mixed mortars in water, incorporated with two different grades of rubber from the tire retreading process.

2. Materials and methods

The cement used was the CP II Z-32, with blaine of 5000 cm/g, absolute specific mass of 3 g/cm³, unit mass of 0.95 g/cm³, the initial and final setting times of 195 min and 270 min, respectively, and compressive strength at 7 and 28 days of 28 and 33 MPa, respectively (ABNT NBR 11578, 1997).

The hydrated lime used was CH-III, with absolute specific mass (ABNT NBR 16605, 2017) of 2.21 g/cm³, unit mass (ABNT NBR NM 45, 2006) of 0.90 g/cm³, fineness (ABNT NBR 9289, 2000) in the sieves 0.6 mm and 0.075 mm of 0.35% and 13%, respectively, and water retention index (ABNT NBR 9290, 1996) of 87%.

The fine sand was of natural origin, with absolute specific mass (ABNT NBR NM 52, 2003) of 2.62 g/cm³, unit mass (ABNT NBR NM 45, 2006) of 1.61 g/cm³, maximum characteristic dimension (ABNT NBR NM 248, 2003) of 0.6 mm, modulus of fineness (ABNT NBR NM 248, 2003) of 1.36, moisture content (ABNT NBR 9775, 2011) 0.052%, and powdery material test result (ABNT NBR NM 46, 2003) of 0.20%.

Rubber was obtained from the process of retreading of truck tires. This rubber was subjected to classification sieving to obtain the two granulometries used; the rubber obtained after passing through the opening sieves of 1.19 mm was called thick rubber (particles with a shape of elongated fibers of 2 to 3 mm) and that obtained after passing through an aperture of 0.60 mm was referred to as fine rubber (particles with rounded shape, powder type); they represent reuse of 65% of rubber waste. The physical characterization of the rubber indicated an absolute specific mass of 1.15 g/cm³ (Archimedes' theorem) and unit mass (ABNT NBR NM 45, 2006) of the thick and fine rubber of 0.39 g/cm³ and 0.32 g/cm³, respectively.

The granulometric curves resulting from the particle size test (ABNT NBR NM 248, 2003) of the sand and rubber are shown in (Figure 1).

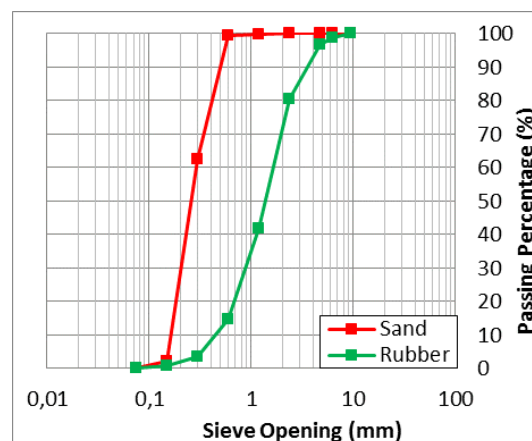


Figure 1. Granulometric distribution of sand and tire rubber

A 1: 1: 5 dry mass (cement, lime, and sand) trait was adopted, equivalent to the mass trace 1: 0.86: 7.67, with the water / binder mass ratio of 1.05. Considering the reference composite Ab0, rubber composites were defined with replacement of 5%, 10%, 15%, and 20% by volume of the fine aggregate by thick rubber (Ab5_C, Ab10_C, Ab15_C, Ab20_C) and fine rubber (Ab5_F, Ab10_F, Ab15_F, Ab20_F).

The composites of mortar were produced in a planetary mortar. Initially, water, cement, and lime were mixed, followed by sand, and the mixing was performed for a total of 4 min and 30 s. In the case of composites with rubber incorporation, rubber was added to the blend immediately after the sand. After the preparation of the composites, they were subjected to the water retention test (CEN EN 1015-8, 1999) in the fresh state. The specimens were molded and placed in a humid chamber for 21 days for curing. After this period, they were placed in an oven at 105° C for 24 h and maintained at room temperature until the 28th day of curing; subsequently, the tests were performed in the hardened state: water absorption via capillarity (CEN EN 1015-18, 2002), drying test (Penacho, 2012), water absorption via immersion (ABNT NBR 9778, 2009), permeability to water vapor (CEN EN 1015-19, 2000); (Temp, 2014), and permeability to water under pressure (CEN EN 1015-21, 2002).

3. Results and Discussion

3.1 Water retention

Water retention is a property of the coating mortar which, at an appropriate percentage, avoids rapid suction of water by the substrate and eventual evaporation of water in the mixture factors that desiccate the mortar and prevent the complete hydration of the cement, in which case a part of the cement starts to function only as a filler (Silva, 2006).

(Figure 2) shows the percentages of water retention obtained for the composites of mortar. Note that, for the contents up to 15% of thick rubber and 10% of fine rubber, the retention decreased with the increase in rubber content: 2.22% (Ab5_C), 3.19% (Ab5_F), 3.03% (Ab10_C), 3.78% (Ab10_F), and 4.19% (Ab15_C), compared with that of the reference (Ab0). The other contents presented different behaviors, failing to reduce the water retention with the increase in the incorporation content, which resulted in a retention rate that was almost the same for the composite of 20% of thick rubber (Ab20_C) and retention rates that increased by 0.83% and 0.22% for the composites with 15% (Ab15_F) and 20% (Ab20_F) of incorporation of fine rubber, respectively, compared with that of the reference.

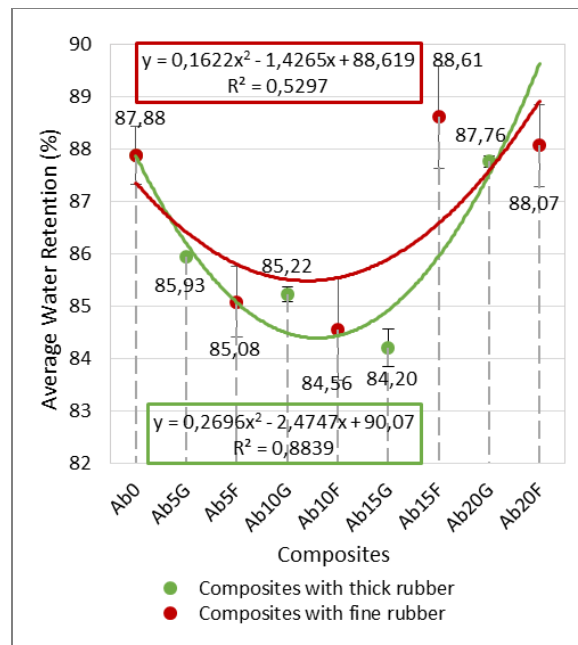


Figure 2. Results of water retention of composites

By adding rubber powder from tire recycling to the volume of fine aggregates, the (Canova et al., 2015) concluded that the contents of 6% and 8% of rubber contributed positively to the water retention. The rubber filled the voids between the grains of sand. As the incorporation levels increased (10% and 12%), the rubber became excessive, causing a reduction in the retention percentages.

Thus, the composites that presented a reduction in the percentage of retention of water in relation to the reference can become damaged owing to the rapid suction of water by the substrate and evaporation of water in the mixture, and the results showed that the incorporation of fine rubber presented lower retention of water compared



with that for the same contents of thick rubber. As for the other rubber additions, the percentages of water retention remained close to the reference. Therefore, they did not result in an improvement or worsening of this property.

Notably, although some rubber composites resulted in lower retention rates than that of the reference (Ab0), as already presented, the difference was small, i.e., 3.68% for the composite that resulted in a lower retention rate (Ab15C).

3.2 Water absorption via capillarity

This test was performed to measure the increase in water mass ascending via capillarity through the section of the semiprism in contact with water.

The results of the average capillary coefficient are shown in (Figure 3). It can be observed that the composites with incorporation of thick rubber presented coefficient results with a trend close to linear ($R^2 = 0.8484$), varying between $1.60 \text{ kg/m}^2 \cdot \text{min}^{0.5}$ and $0.69 \text{ kg/m}^2 \cdot \text{min}^{0.5}$ (a total reduction of 56.87%). In the case of composites incorporated with fine rubber, the values of the capillary coefficients decreased in a practically linear manner ($R^2 = 0.9672$), varying between $1.60 \text{ kg/m}^2 \cdot \text{min}^{0.5}$ and $0.42 \text{ kg/m}^2 \cdot \text{min}^{0.5}$ (a total reduction of 73.75%).

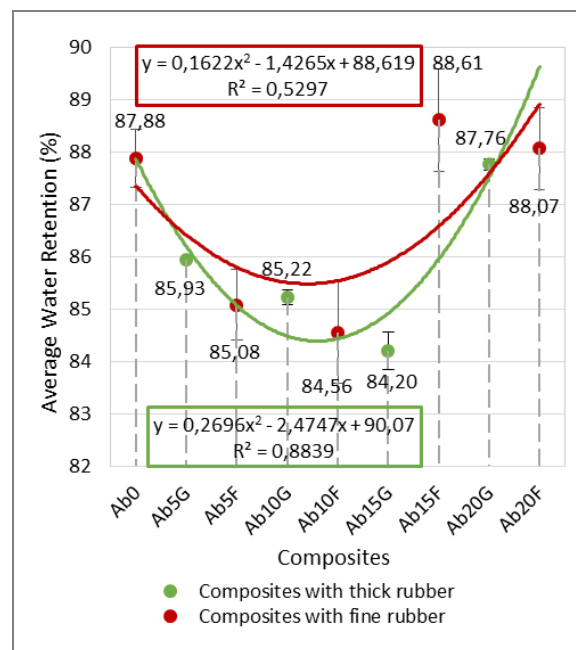


Figure 3. Coefficient of capillarity of composites

The calculation of the capillary coefficient considers the mass readings of the semiprisms at 10 min and 90 min from the beginning of the test. Thus, it can be stated that the incorporation of rubber reduced the rate of water absorption via capillarity at the beginning of the test.

The reduction in the capillary coefficient may not be related only to the increase in the air content with the incorporation of rubber, but also to the path of water flow through the capillaries, which may be more difficult initially as rubber does not absorb water.

The rubber from the tire grinding process was used in coating mortar for substitution (volume) of the fine aggregate and according to the (Pedro, 2011), the results showed that, for the 5% and 15% rubber incorporations, the capillary coefficients were 9.3% and 3.7% lower than that of the reference, respectively, whereas the incorporation of 10% showed a coefficient 6.5% higher than the same. According to the author, the results presented a slight variation owing to two contradictory factors that were balanced by the increase in the rubber content: the increase in the incorporated air content and worse compaction owing to the decrease in the own weight of the mixtures.

The mass of water absorbed in each test reading is shown in (Figure 4). It is observed that, up to 60 min of the test, the reference composite (Ab0) presented higher average absorbed water values than those of all rubber composites, and in the range 90 to 300 min, the values were lower than those of the others, except at 90 min where

the composite that absorbed the lowest amount of water was composed of 20% fine rubber (Ab_{20F}). Thus, it is possible to verify that the incorporation of rubber tends to decrease the speed of water absorption at the initial moments of the test, as already observed through the results of the capillary coefficient.

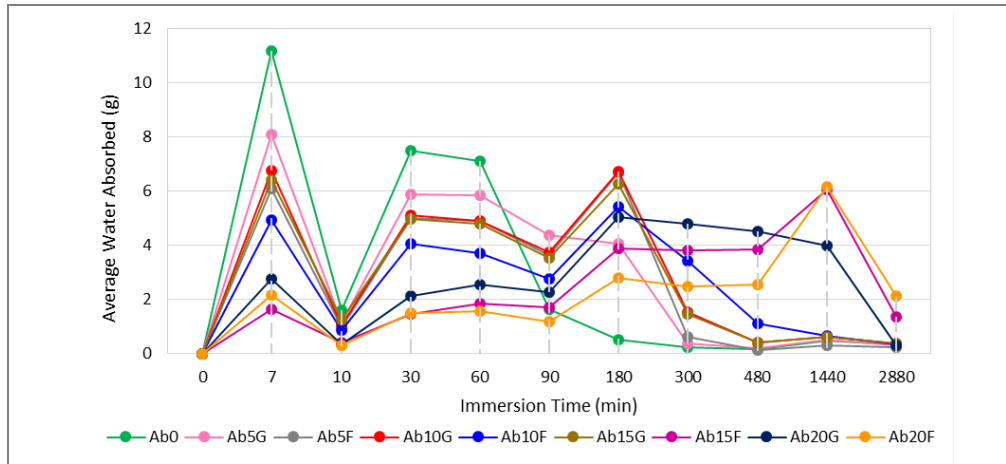


Figure 4. Water absorbed at each reading determined in the test

From the analysis of the rubber composites, it can be observed from the results for both thick rubber and fine rubber up to 90 min that the water mass absorbed from the composites is lower for the composites with higher rubber content. In contrast, the results obtained after 90 min were observed to be different. In general, the composites with higher rubber content presented higher amounts of water absorbed in the readings toward the end of the test (between 180 min and 1440 min).

At the end of the test, it can be stated that the reference composites (Ab_0), those with thick rubber (Ab_{5G} , Ab_{10G} , Ab_{15G} , and Ab_{20G}), and those with 5% (Ab_{5F}) and 10% (Ab_{20F}) of fine rubber were close to the saturation of the test specimens, in which water absorbed in 24 h (between 1440 min and 2880 min) was close to zero.

(Figure 5) shows the evolution of water absorption throughout the test. In all the rubber composites, there was a linear tendency of the results of the total absorbed water (R^2 ranging from 0.8841 to 0.9639), showing an increasing evolution of water absorbed throughout the test. In the case of the reference composite (Ab_0), at 90 min, the water absorbed (29.03 g) was close to the total absorbed water (30.76 g), indicating a higher velocity to reach the total absorbed water, which resulted in a tendency further away from linear ($R^2 = 0.7689$) than that of the other composites.

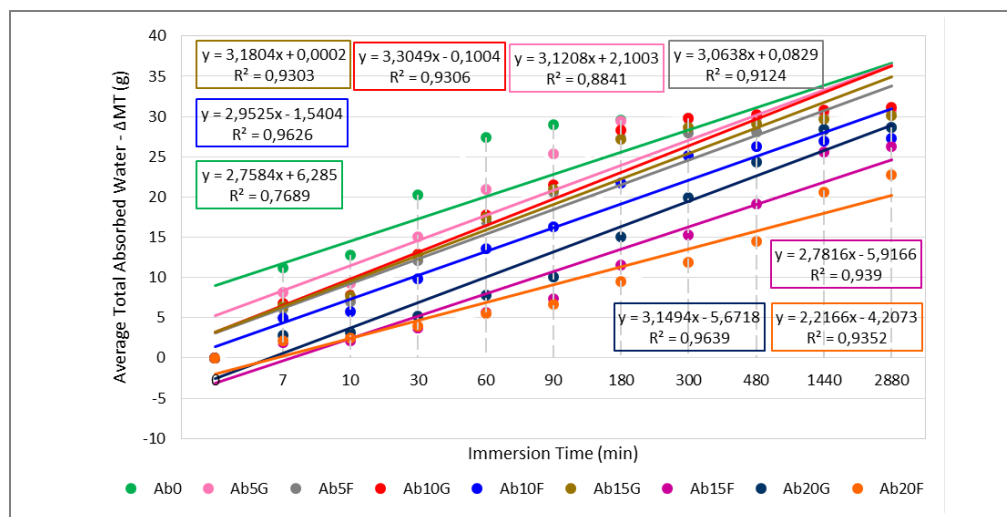


Figure 5. Evolution of total water absorbed over the test



From the analysis of the total mass of water absorbed at the end of the test (2880 min of immersion), it can be confirmed that, as the content of fine rubber increased, the values of the absorbed water mass were lower, representing a total reduction of 26% for the 20% rubber composite (Ab20_F) compared with that of the reference (Ab0). In the case of composites incorporated with thick rubber, although the absorbed water was higher than that of the reference for the contents of 5% (Ab5_C), 10% (Ab10_C), and the others (Ab15_C and Ab20_C), the values were lower than that of the reference with the increase in the rubber content, and there was no significant variation of the values as in the case of composites incorporated with fine rubber.

3.3 Drying test

The drying test was conducted shortly after the end of the capillary water absorption test for the same specimens and it allowed evaluation of the drying capacity of the mortar under atmospheric conditions.

The percentages of evaporated water of the composites studied did not present a trend close to linear as can be observed in (Figure 6) (R^2 values varying between 0.6611 and 0.7206), because they did not result in an increasing evolution as observed, in general, for the results of the total absorbed water in the capillary absorption test.

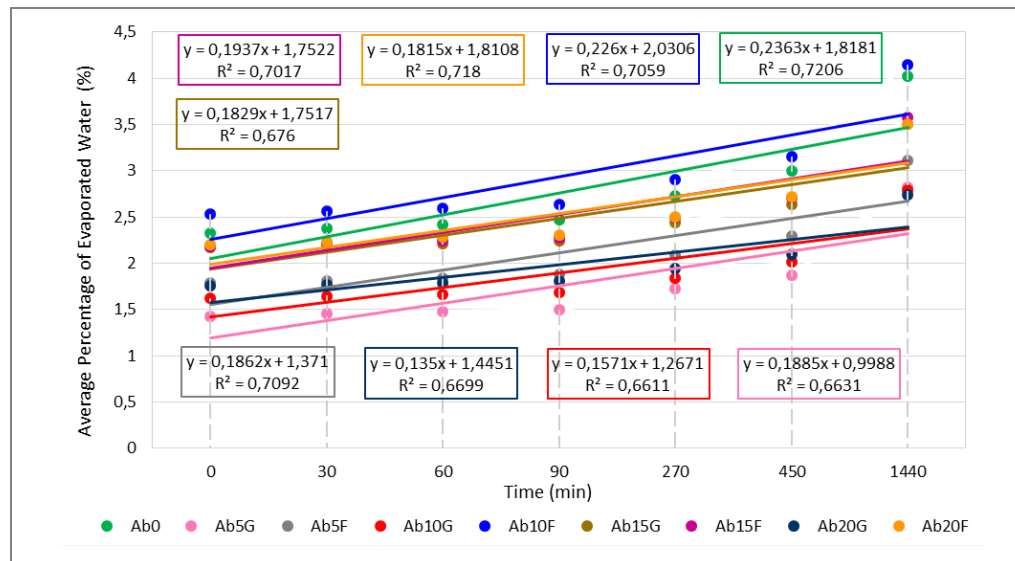


Figure 6. Percentage of water evaporated under atmospheric conditions

At the end of the test, the percentages decreased with the increase in the incorporation content of thick rubber, with the exception of the composite with 15% thick rubber (Ab15_C), and for the incorporation of fine rubber, an increase in the content increased the percentage of evaporation, except for the 10% composite (Ab10_F), whose percentage of evaporation remained higher than that of the others at all test times. Therefore, excluding the exceptions, it can be confirmed that there was a contrary behavior regarding the drying for rubber granulometry.

From the tests of water absorption via capillarity and drying, it is possible to confirm that, for composites with fine rubber (Ab5_F, Ab10_F, Ab15_F, and Ab20_F) and 15% (Ab15_C) and 20% (Ab20_C) of thick rubber, the increase in the rubber incorporation content reduced the total mass of water absorbed, which resulted in less water available for evaporation. Thus, the drying capacity of the mortar is increased, resulting in higher percentages of evaporated water. In the case of composites with 5% (Ab5_C) and 10% (Ab10_C) of thick rubber, the results were contrary to the ones observed for the others, which reduced the drying capacity for these incorporation contents.

3.4 Water absorption via immersion

The absorption test allows evaluation of the percentage of water absorbed by the specimens in 24 h of immersion in water.

In (Figure 7), the water absorption percentages of the composites are presented and it can be observed that the composites with thick rubber showed a trend close to linear ($R^2 = 0.8069$), as all the incorporations were superior to the reference (Ab0). Until the incorporation of 15% of thick rubber (Ab5_C, Ab10_C, Ab15_C), it can be confirmed that there was an increase in the water absorption with the increase in the incorporation of rubber; however, the same did not occur for the incorporation of 20% of thick rubber (Ab20_C), which had a slightly lower absorption rate



than the composite with 15% of thick rubber ($Ab15_C$). Thus, it can be confirmed that there was no change in absorption for the aforementioned rubber contents.

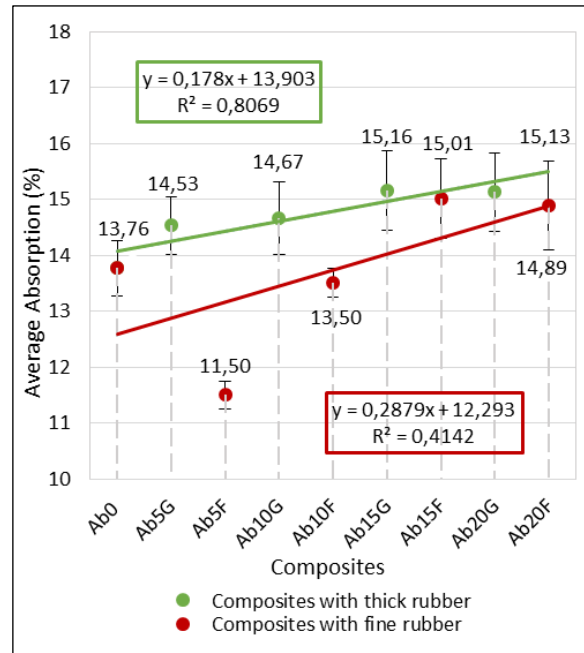


Figure 7. Percentages of water absorbed

For the incorporation of fine rubber, the behavior observed was different from that of the thick rubber. The composites with 5% and 10% of fine rubber showed lower absorption than the reference ($Ab0$), i.e., 2.26% ($Ab5_F$) and 0.26% ($Ab10_F$). In other composites, i.e., $Ab15_F$ and $Ab20_F$, absorption was greater than that of the reference, i.e., 1.25% and 1.13%, respectively. These results did not cause the fine rubber to develop the linearity ($R^2 = 0.4142$) observed in the thick rubber.

Concerning the behavior observed in the results on the interference of the rubber granulometry in the water absorption property, the (Fioriti et al., 2012) highlighted the same when replacing rubber from grinding, milling, and sieving of tires, in which, for the same rate of rubber incorporation, the absorption was greater for the rubber of larger grain size.

3.5 Permeability to water vapor

This test assesses the ability of the mortar coatings to remove the water vapor present inside the constructions. The average mass variation of the composites is presented in (Figure 8). The results showed that the incorporation of rubber significantly interfered in the permeability of the mortar to water vapor. With respect to the reference ($Ab0$), the composites showed higher values, i.e., 50.61% ($Ab5_C$), 56.28% ($Ab5_F$), 42.10% ($Ab10_C$), 64.78% ($Ab10_F$), 42.91% ($Ab15_C$), 51.42% ($Ab15_F$), 51.42% ($Ab20_C$), and 50.61% ($Ab20_F$).



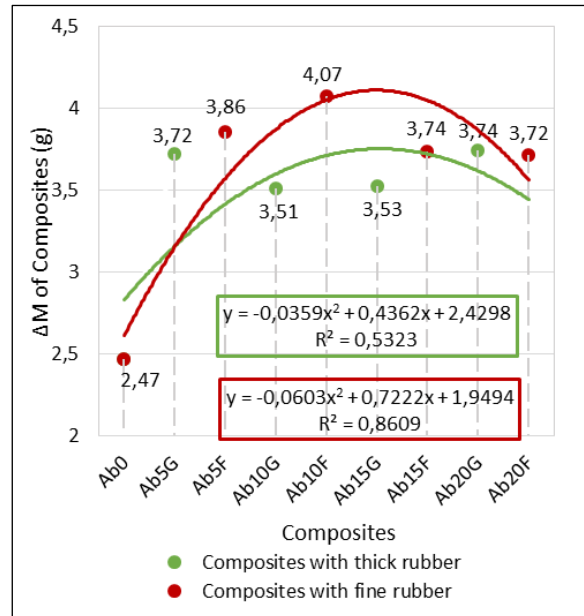


Figure 8. Mass variation of composites

From the analysis of the rubber composites, it was observed that there was no change in the mean mass variation ($\Delta M = 0.02$ g) between composites with 5% (Ab5_C) and 20% (Ab20_C) of thick rubber and 15% (Ab15_F) and 20% (Ab20_F) of fine rubber, which varied between 3.72 g and 3.74 g. The same can be observed for the incorporations of 10% (Ab10_C) and 15% (Ab15_C) of thick rubber, resulting in the same mass variation difference of 0.02 g.

When producing mortars with the incorporation of 15% of rubber of mechanical origin and 15% of cryogenic rubber, the authors concluded that the water vapor permeability coefficients of rubber mortars increased by 48% and 34%, respectively. Comparing the results obtained with those of the author, it appears that, in general, the same results were obtained, i.e., the rubber increased the permeability of mortars, and for the incorporation content of 15%, the mass losses of the tested composites with respect to the reference (Ab0), i.e., 42.91% (Ab15_C) and 51.42% (Ab15_F), were close to the difference in the permeability coefficients of the mechanical mortar compared with its reference (48%).

3.6 Permeability to water under pressure

The water permeability test under pressure simulated the conditions of rainfall and wind pressure to which a coating is subjected. In (Figure 9) and (Figure 10), the values of water absorbed under pressure are presented at 24 h and at 48 h of the test, respectively.

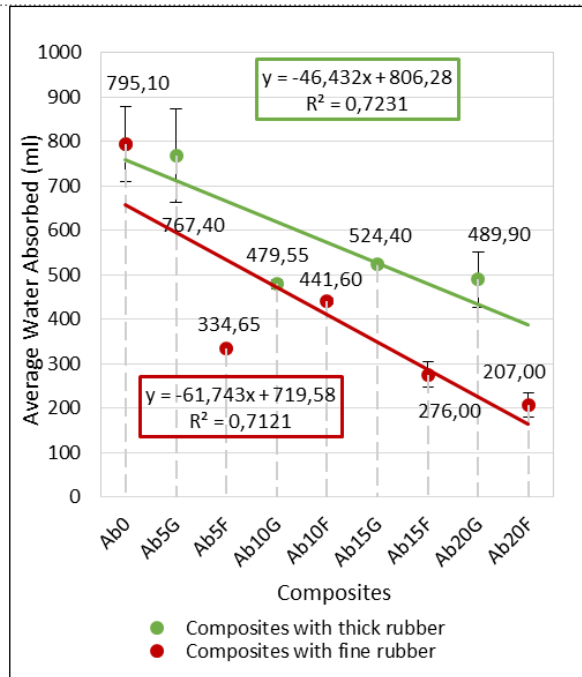


Figure 9. Water absorbed at 24 h

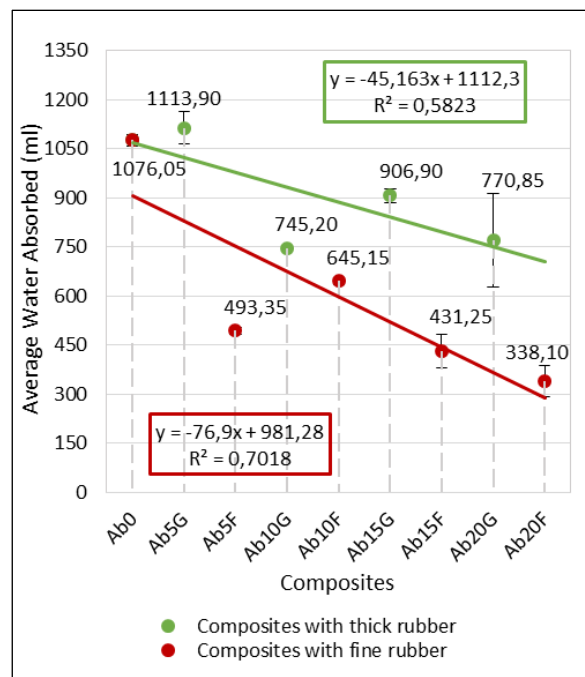


Figure 10. Water absorbed at 48 h

In the first 24 h of the test, all the composites tested showed lower results than the reference (Ab0). For the incorporation of thick rubber, the increase in the incorporation content of rubber tended to decrease the amount of water absorbed compared with that of the reference, with the exception of the 10% composite (Ab10_G), which resulted in a lower value than that of the 15% composite (Ab15_G). In the case of the incorporation of fine rubber, the same tendency of the composites with thick rubber was observed; however, there was exception for the composite with 10% of fine rubber (Ab10_F), which resulted in higher absorption than that of the other incorporations of the same rubber. The exceptions of the 10% incorporation of both the thick rubber and the fine rubber resulted in close values with a difference of 37.95 mL between them.

At the end of the test, after 48 h, the trend and exceptions observed in the results of the first 24 h remained; however, the composite with 5% of thick rubber (Ab5_G) presented absorption 3.52% higher than that of the reference.



During the test, in the composites with 10% of fine rubber ($Ab10_F$) and 15% of fine rubber ($Ab15_G$), small outcrops of water appeared on the surface of the mortar coating (Figure 11), which may have arisen by point (or local) saturation in the mortar, although these outcrops became stabilized and did not interfere with the test, leading to high water absorption by pressure.



Figure 11. Water surfaced on the surface of the mortar coating

4. Conclusions

There was no significant worsening of the water retention property. The best results were observed for composites with 15% and 20% of fine rubber and 20% of thick rubber.

In the capillary water absorption test, it could be observed that the incorporation of rubber reduced the capillary coefficient of the composites and this reduction was greater for the incorporations of fine rubber. The absorption was lower for the composites incorporated with fine rubber.

The composites with fine rubber and 15% and 20% of thick rubber resulted in higher percentages of water evaporated with the increase in the rubber content, owing to the smaller amounts of water absorbed via capillarity, which increased the drying capacity of these composites. For the other composites, the results were contrary to the above ones, which reduced their drying capacity.

Regarding the absorption of water via immersion, it was observed that, in general, the rate of absorption increased with the increase in the incorporation content for both rubber granulometries. The lowest rates of water absorption via immersion were observed in the composites with fine rubber.

In relation to water vapor, the fine rubber composites were distinguished by their higher mass losses, because they increased the permeability of the mortar to water vapor, which partially avoids its deterioration.

As for the permeability to water under pressure, the smallest amount of water absorbed was composed of fine rubber composites, which favors mortars, as the test simulates rainfall conditions and wind pressure.

Thus, it can be concluded that the incorporation of fine rubber provided improvements in most of the studied properties.

5. Acknowledgment

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