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PROPERTIES OF MORTARS CONTAINING TIRE RUBBER WASTE AND EXPANDED POLYSTYRENE (EPS)

Adriane Pczieczek[1], Adilson Schackow[2*], Carmeane Effting[1], Talita Flores Dias[1] and Itamar Ribeiro Gomes[2]

[1]Civil Engineering Postgraduate Program, Center of Technological Sciences, State University of Santa Catarina, Joinville, SC, Brazil
[2]Department of Civil Engineering, Center of Technological Sciences, State University of Santa Catarina, Joinville, SC, Brazil

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Abstract: This study aims to evaluate the application of discarded tire rubber waste and Expanded Polystyrene (EPS) in mortar. For mortars fine aggregate was replaced by 10%, 20% and 30% of rubber and, 7.5% and 15% of EPS. We have verified the consistency, density, amount of air and water retentitivity in fresh state. The compressive strength, water absorption, voids ratio and specific gravity have been also tested in hardened state. The application of rubber powder contributed to the increase in entrained air content and in reducing specific gravity, as well as reducing compressive strength at 28 days. The addition of EPS also contributed to the increase of workability, water absorption and voids ratio, and decreased density and compressive strength when compared to the reference mortar. The use of rubber waste and EPS in mortar made the material more lightweight and workable. The mortars mixtures containing 10% rubber and 7.5% EPS showed better results.

Keywords: Finishing mortar; rubber tires waste; expanded polystyrene; mortar properties.

* Corresponding author: Adilson Schackow. Phone: +55 47 3481-7802.
e-mail address: adilson.schackow@udesc.br

INTRODUCTION

Currently, the civil engineering industry, besides food industry, is the largest consumer of raw materials (Berge, 2009). The construction industry stands out for its heavy utilization of natural resources and consequently significant waste generation, and it is among the main group of economically impacting activities (SNIC, 2015). For a sustainable future the goal is to drastically reduce the use of raw materials (Berge, 2009).

Since the number of vehicles has increased considerably in the cities in recent years, the accumulation of discarded tires has become a major problem for waste management. Disposing waste in landfills is not only postponing a solution for an issue, but it also contributes to a larger problem in the future. The contamination caused by waste is not restricted to disposal site: Soil pollution, as well pollutants due to the burning of materials, can spread through the atmosphere (Kanso, 2014).

In Engineering, recycled tire waste is used in asphalt pavement as binder to improve paving resistance properties as to deformation and appearance of cracks due to fatigue (Shu and Huang, 2014). The recycled tires can be used as fuel for cement kilns replacing conventional fuels, retaining walls, drainage systems and non-structural applications in civil construction (Mavroulidou and Figueiredo, 2010).

Studies with rubber scrap tires waste in cement-based materials are recent. Fiore *et al*. (2014) found that cementitious compounds containing this type of waste had reduced compressive strength and were vulnerable to sulphate attack. However, mixtures containing 50% rubber showed good characteristics as: low thermal conductivity, thaw resistance, and penetration of chloride ions, as well as reduced density. Mavroulidoy and Forbes[5] also found that concrete resistance decreases with the addition of rubber, which can be used in structural applications requiring low compressive strength. Aliabdo *et al*. (2015) found that the thermal conductivity decreases with the increase of rubber in concrete, although compression and flexural strength decrease.

In Brazil, Canova *et al*. (2007) developed a study on mortar containing discarded tires waste. The results obtained by the authors showed lower incidences of cracks in the mortar coating. The behavior of rubber in cement paste was studied by Segre *et al*. (2013). The existence or absence of cracks in cement paste depends on the adhesion of rubber particles and the type of cement used. Rubber particles that went through NaOH treatment showed reduced propagation of cracking on cement paste when compared to that without any treatment.

According to Nacif *et al*. (2013), the size of the rubber particles, the amount of entrained rubber in relation to cement mass, and the water/cement factor significantly affect the density and compressive strength of cement composites. Rubber particles within 0.28/0.18 mm size result in low density cement materials and apparent porosity, and show greater compression strength.

EPS is a material widely used for industry and construction applications that generates large amounts of waste, and can be used in the composition of construction materials (Aciu *et al*., 2014). According to DIN IT-1043/78 EPS stands for Expanded Polystyrene. It is made up of 98% air and only 2% polystyrene as a result of expandable polystyrene foam processing, and its base material is styrene monomer (ABRAPEX, 2015; ACEFE, 2015). Is used in a range of applications due to some important features such as its light weight, good thermal insulation, moisture resistance, durability, acoustic insulation and low thermal conductivity (Chen *et al*., 2015).

In lightweight concrete studies regarding the use of expanded polystyrene has been performed. According to Schackow *et al*. (2014) the best EPS aggregate replacement ratio for lightweight concrete manufacture is 55%. The size of EPS particle and its composition is directly related to the compression strength and concrete volume fraction with EPS (Liu, 2014). Previous studies have shown that the use of EPS in mortar improves its durability and compression strength (Ferrándiz-Mas and Gaicía-Alcovel, 2013).

According to Aciu *et al*. (2014), replacing 50% of sand for polystyrene thermal reduces conductivity to 35% in comparison with standard mortar, thus showing an improvement in thermal resistance.

Studies have shown that the granular form of EPS affects concrete properties, both as plastic and hardened state. Concretes which contained ground EPS waste and replaced by fine aggregate showed compressive strength less than 11.5% and entrained air content higher than 300% compared to concretes which contained spherical EPS granulate (Trussoni and Hays, 2012).

Pecce *et al.* (2015) replaced part of lightweight concrete aggregates for expanded polystyrene particles, resulting in a very compact and resistant material due to filling of voids by residue used. In general, survey results showed good performance in concrete biding behavior with EPS.

A research conducted in insulation blocks using lightweight concrete and EPS resulted in an improvement in thermal conductivity and sound insulation (Sariisik, A and Sariisik, G, 2012).

To that sense, this study is intended to make the use of waste in civil construction materials practicable, mainly mortar coating, so that to evaluate the properties of mortar with different concentrations of discarded tires rubber and EPS.

MATERIALS AND METHODS

Materials

The materials used for the production of mortars were: River sand (quartz), Portland cement CP II Z-32 and Calcium hydroxide (CH-III). These components have been used in mortar and were added of tire rubber powder and EPS. Rubber tires waste used (**Fig. 1**) was obtained by ground discarded tires supplied by Engisul Borrachas Ltda. Expanded polystyrene (EPS) used in this study was provided by Styroville in a granular form (**Fig. 2**). The water was supplied by local water mains supply system.

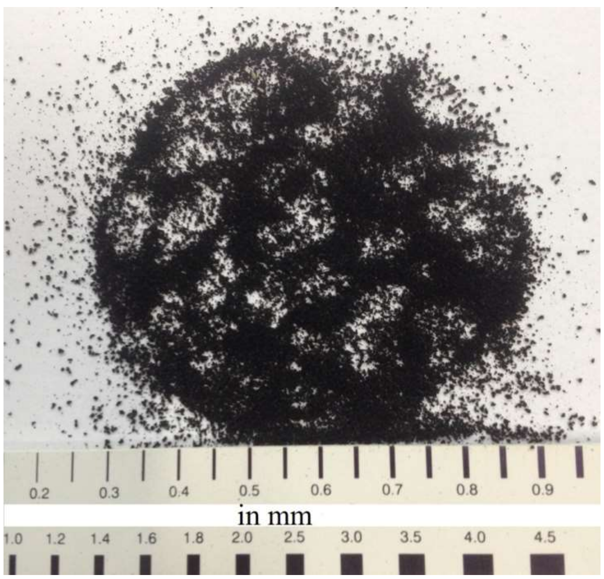

Fig. 1 Waste tire rubber powder.

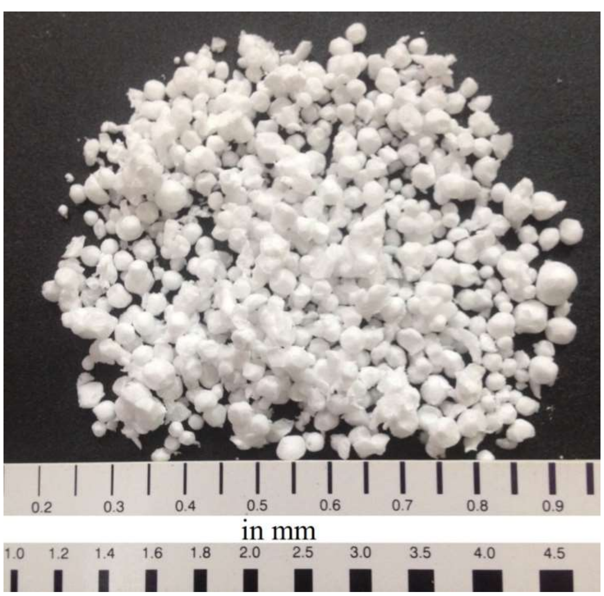

Fig. 2 Expanded polystyrene grains.

Characterization of materials

Particle size analysis of the fine aggregate was determined by sieving test using the set of sieves with the dry sample (ABNT, 2003). This assay procedure determined the maximum diameter of fine aggregate, fineness modulus and the grading curve.

The specific gravity of the fine aggregate was found through NBR NM 52 testing (ABNT, 2009). For residue, the specific rubber mas was determined by pycnometry assay using helium gas, which is a technique used to find the real density of materials in powder form.

The unit mass of granular materials has been determined through NBR NM 45 assay procedure (ABNT 2006). Unit mass helped to determine the required quantity of each material density, considering mortar volumetric trace.

The physical characteristics of cement and calcium hydroxide were supplied by the manufacturer of these products and are displayed in **Tables 1–2**, respectively. The fine aggregate, rubber and EPS characteristics are displayed in **Tables 3–5**.

Mortar preparation

For the reference mortar cement, lime and sand has been used (by volume). Based on unit mass of the constituent materials, the volumetric trace corresponds to the trace in mass of 1: 0.689: 7.944.

The mortar was prepared in accordance with ABNT NBR13276 Recommendations (ABNT, 2005a). The amount of water added to the mix was scaled from the standard mortar consistency index in the range of (260 ± 5) mm according to the Brazilian Technical Standards specification.

Table 1. Physical characteristics of Portland cement CP II Z-32

Type of test	Results	According
Unit mass (g / cm³)	1.08	NBR 6474
Specific gravity (g / cm³)	3.00	NBR 23
Fineness in the sieve # 200 (%)	≤12	NBR 11579
Compressive strength 7 days (MPa)	≥20	NBR 7215
Compressive strength 28 days (MPa)	≥32	NBR 7215

Table 2. Physical characteristics of hydrated lime CH-III

Type of test	Results	According
Unit mass (g / cm³)	0.75	NBR 6474
Specific gravity (g / cm³)	2.40	NBR 23
Grain size # 200 (%)	12	NBR 9289
Grain size # 30 (%)	0.0	NBR 9289
Humidity (%)	0.0	-

Table 3. Physical characteristics of fine aggregate

Type of test		Results	According
Unit mass (g / cm³)		1.43	NBR NM 45/2006
Specific gravity (g / cm³)		2.55	NBR NM 52/2009
Grain size	Sieve (mm)	Accumulated percentage	NBR 13276/2005
	4.75	0.5	
	2.36	2.6	
	1.18	13.0	
	0.6	35.7	
	0.3	64.2	
	0.15	92.5	
	bottom	100.0	
Fineness modulus		2.09	
Maximum diameter (mm)		2.36	

Table 4. Physical characteristics of the rubber

Type of test		Results	According
Unit mass (g / cm³)		0.358	NBR NM 45/2006
Specific gravity (g / cm³)		1.193	Gas pycnometer
Grain size	Sieve (mm)	Limits (%)	NBR 13276/2005
	0.710	Maximum 2.0%	
	0.300	from 55.0% to 80.0%	
	bottom (0.300)	Minimum de 18%	

Table 5. Physical characteristics of EPS

Type of test	Results	According
Unit mass (g / cm³)	0.011	NBR NM 45/2006
Specific gravity (g / cm³)	0.025	–
Approximate diameter (mm)	4.00	–

For the mortars containing rubber powder, the fine aggregate was replaced at concentrations of 10%, 20% and 30% in relation to its mass, while keeping the water/cement factor steady (2.04).

For mortars containing EPS, 7.5% and 15% of sand have been replaced by EPS in volume, keeping the water/cement ratio constant.

The amount of materials used in the manufacture of mortars is shown in Table 6, with REF being reference mortar; M-RU10, M-RU20, and M-RU30 mortars containing 10%, 20% and 30% of rubber respectively; M-EPS7.5 and M-EPS15 mortars containing 7.5% and 15% EPS.

Table 6. Amount of material used

Mortar	Cement (g)	Lime (g)	Fine aggregate (g)	Water (g)	Rubber (g)	EPS (ml)
REF	360	248	2860	734	–	–
M-RB10	360	248	2574	734	71.6	–
M-RB20	360	248	2288	734	143.2	–
M-RB30	360	248	2002	734	214.8	–
M-EPS7.5	180	124	1322	367	–	150
M-EPS15	180	124	1215	367	–	300

Mortar properties

Mortars analysis in fresh state was carried out based on some important properties, since it might interfere in the final quality of mortar. Consistency, water retentitivity, specific gravity and entrained air content for this state have been also evaluated (ABNT, 2005a; ABNT, 2005b; ABNT, 20015c).

To test mortar in hardened state, 6 prismatic specimens were molded with dimensions of [40x40x160] mm³ for each type of mortar and tested with 7 and 28 days old. The compressive strength, water absorption, the voids ratio and specific gravity have been also tested (ABNT, 2005d; ABNT, 2005e).

RESULTS AND DISCUSSIONS

The results obtained in the tests in both fresh mortar and hardened mortar are shown and discussed below.

Analysis of the mortars in the fresh stage

The index of mortar consistency shall be (260 ± 5) mm spread as per ABNT NBR 13276 tested on a Flow Table (ABNT, 2005a). The results are displayed in Table 7 and correspond to given each mix workability. The specific weight of the mortar in the plastic state, the level of air and water retentitivity are also indicated in Table 7.

Table 7. Mortar properties in the fresh stage

Mortar	Water to cement ratio	Consistency index (mm)	Specific gravity (g/cm³)	Entrained air content (%)	Water retentivity (%)
REF	2.04	261	1.998	1.15	83
M-RB10	2.04	290	1.773	10	71
M-RB20	2.04	295	1.686	12	69
M-RB30	2.04	297	1.450	22	62
M-EPS7.5	2.04	263	1.913	1.16	81
M-EPS15	2.04	303	1.827	1.19	75

The mortars containing 10% (RU10), 20% (M-RU20) and 30% (M-RU30) rubber showed greater consistency compared with the reference mortar (REF). This occurs because rubber is an inert and impervious material, unlike a thin material that increases the need of water for the mixture. In this case, as the water/cement ratio of the mixture is maintained, the consistency of mortar with waste increased, and the same occurred to mortars containing EPS.

It was found that, with the increase in the number of EPS and rubber added to mortar, a reduction in specific gravity. This fact is due to low unit mass and specific unit mass of the waste used.

For contents of 30% rubber in mortar, entrained air content was 22%. According to Boyton and Gutschick (1964), entrained air content in mortar above 16% causes it to reduce tensile adhesion strength on the substrate. The mortars containing EPS had a very small increase in entrained air content, about 3% in relation to the reference mortar.

Figure 3 shows that water retentitivity decreases in relation to the increase in rubber mortar content in relation to the reference mortar. It possibly occurs because of the amount of water used in kneading, since the consistency of rubberized mortar has increased. For mortars containing EPS, water retention decreased slightly in relation to the reference mortar, which explains the fact that only 3% increase in the air content. Therefore, the lower water retention higher air content incorporated in mortar.

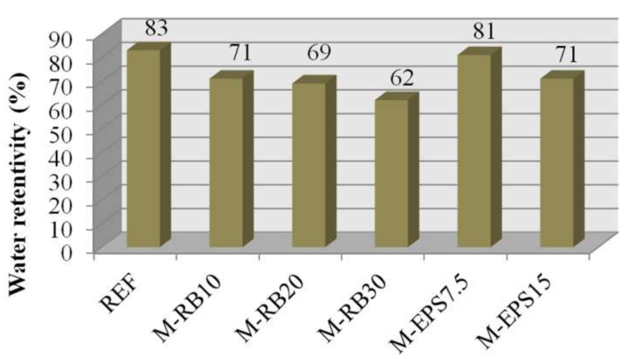

Fig. 3 Water retentivity in the mortar.

Analysis of the mortar in the hardened stage

The results obtained for the compressive strength of the mortar at 7 and 28 days are shown in Table 8. The specific gravity, water absorption and voids index are also presented in the same Table. **Figure 4** shows that the compressive strength decreases with the increase of the levels of rubber and EPS in mortar. This reduction may be associated to the increase in entrained air content in the fresh state and because waste present low specific gravity. The mortar containing 10% rubber has shown a decrease in compressive strength at 28 days of approximately 27% in relation to the reference mortar. For the mortar containing 30% rubber, compressive strength declined from 70%; for the mortar with 20% rubber, this reduction was 55% compared to the standard mortar. With 7.5% of EPS on mortar compressive strength reduction was 26%, with 15% EPS strength reduction was of 40%.

Segre *et al.* (2004) showed that the flexural strength of mortars compositions with rubber was also reduced in relation to the control, almost linearly with the rubber content.

Figure 5 shows that the values found for the specific gravity of the mortar in the hardened state are a little higher than the values found for the mortar in the fresh state, an increase of approximately 30%; this is due to the fact that part of the water has evaporated.

Mortar water absorption by immersion is illustrated in **Fig. 6**. It is observed that the average values indicate an increase in water absorption with the increase of the rubber content in mortar and in the number of EPS, and more significant to mortar containing 30% rubber.

The amount of water absorbed by a material is associated with the void index present in its microstructure, which in turn determines the material permeability. The mortars containing rubber and EPS have had considerable increase in voids index compared with the reference mortar. Thus, the higher the rubber content and EPS in mortars, the higher was the void index; therefore, the permeability of these materials was higher. The chart in **Fig. 7** shows the voids index in mortar studied.

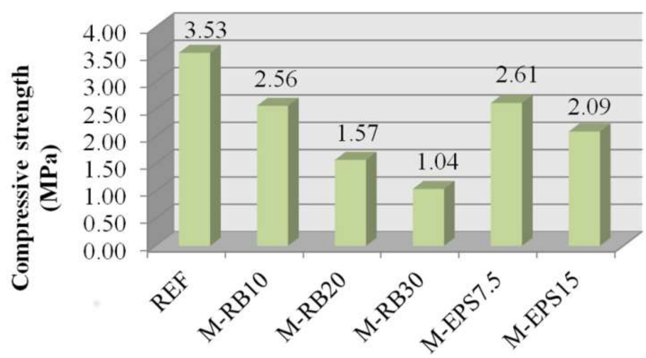

Fig. 4 Compressive strength of mortars at 28 days.

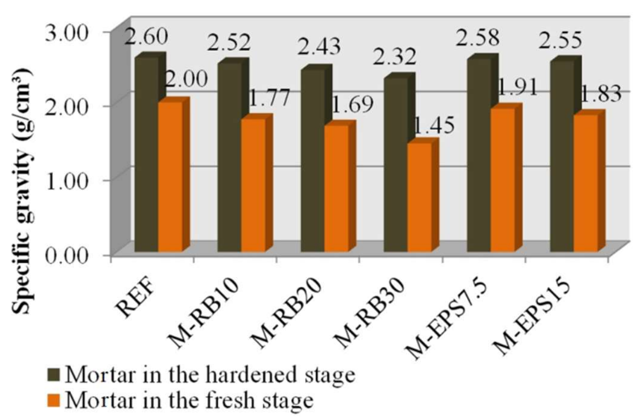

Fig. 5 Specific gravity of mortars in fresh and hardened stage.

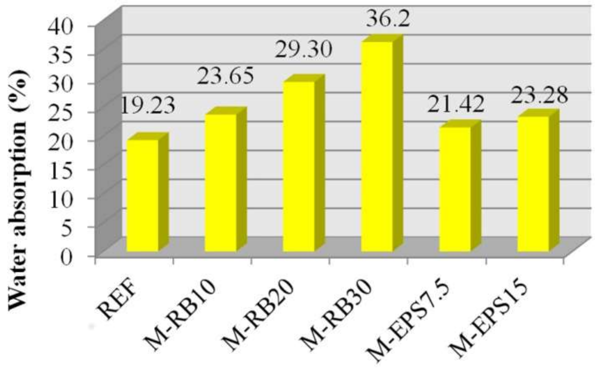

Fig. 6 Water absorption by immersion of the mortars.

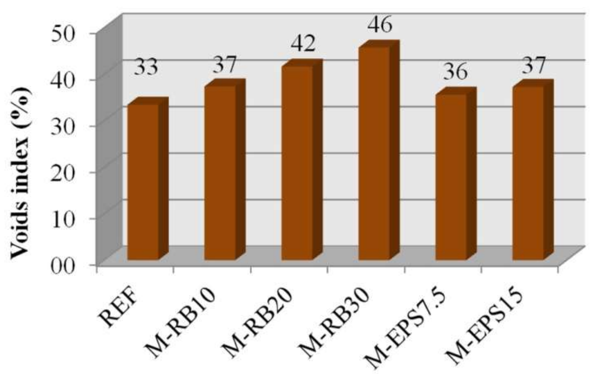

Fig. 7 Voids index of the mortars.

The mortars containing 7.5% and 15% EPS are illustrated in **Fig. 8**, and **Fig. 9** shows mortar aspect with 10% of rubber

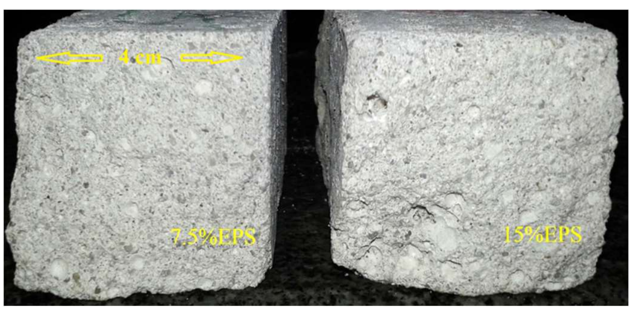

Fig. 8 Aspect of mortar with 7.5% and 15% of EPS.

Fig. 9 Aspect of mortar with 10% of rubber.

CONCLUSION

The fine aggregate replacement for EPS and rubber discarded tires in mortar contributed to the increase in entrained air content and reduced the specific gravity of mixtures.

Compressive strength decreased significantly as the number of EPS and rubber content increased in mortar, which could be due to the increase of entrained air into the mortar in the plastic state.

The use of rubber waste and EPS in mortar made the material more lightweight and workable.

On water absorption by immersion, there has been an increase in the absorption of water, resulting in a more permeable mortar compared with standard mortar.

Water retentivity is one of the important factors of the mortar, because the surface needs to be moisturized for as long as possible, thus avoiding material cracks and brittleness. All mortars containing rubber or EPS had reduced water retentivity, making the material more brittle.

Replacing the sand by tires rubber waste in mortar containing 30% rubber resulted in entrained air content of 22%, and may impair mortar adhesion on the substrate.

The results of this research indicate that the mortars containing 10% rubber and 7.5% EPS showed better results, but further research should be carried out in order to study the behavior of other untested properties, such as substrate adhesion strength, deformation modulus, thermal conductivity and fire spread analysis.

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