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EFFECT OF RECYCLED PET FIBERS INCLUSION ON THE SHRINKAGE OF ADOBE BRICK

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Abstract

In recent decades, the importance of sustainability and the use of recyclable materials have led to the development of numerous investigations related to natural materials linked to un-conventional technologies. Earthen materials construction, such as adobe, however, is both an ancient and sustainable technique, since it relies on locally found unfired soil, eliminating or greatly diminishing pollutants emission. This paper aims to investigate the influence of recycled PET fibers (polyethylene terephthalate) on the shrinkage of adobe bricks. Specimens with dimensions 5 x 5 x 30 cm were used for shrinkage tests. A compressive strength test was also carried out to study the influence of recycled PET (R-PET) fiber on mechanical behaviour. Soil characterization by liquid limit, plastic limit, plasticity index, density and particle size distribution tests were performed. The natural soil was then mixed with other soil, rich in clay, allowing for two different mixes, both suitable for adobe mixes. Finally, R-PET fibers of 32 mm length and 14 μm diameter were added in the mixtures with 0.25% and 0.5% contents in order to verify the effectiveness of R-PET fibers on the shrinkage control of the material. Shrinkage tests showed the R-PET fiber had little influence on the mixture with lower clay content and a greater influence on the mixture with a higher clay content, reaching a reduction in shrinkage of up to 48%. Similar effect was observed regarding to compressive tests. The highest mechanical strength was reached in the specimen made of adobe with higher clay content and 0.5% R-PET fiber.

Keywords:
Adobe; recycled PET fibers; shrinkage.

1 INTRODUCTION

Adobe is a relevant building material in many regions of the world. The handmade bricks consist basically in earth (clay and sand) and water. The volume proportions of these components can be around 50% sand, 25% clay and 25% water [Van Lengen 2014].

Nowadays, adobes are considered to be non-conventional materials and have been employed in housing, rural constructions and modern ecological buildings. Advantages compared with industrial materials include low cost, thermal and acoustic comfort, minimum water and energy consumption and waste reduction [Corrêa 2006].

Adobe properties depend on physical, chemical and mineralogical soil characteristics, water content, production procedures, drying, and type of stabilization [Barbosa 2010, Corrêa 2012, Ruiz 1983]. The compressive strength of adobe in laboratory tests depends of the specimen form and size. Strength values derived from cubes and cylinders after application of shape correction factors were reported to range from 0.6 to 1.75 MPa. Prisms, on the other hand, tend to overestimate the compressive strength due to platen restrain effects [IIlampas 2014]. Water absorption and shrinkage during drying of adobes, are important issues that require investigation. The wet compressive strength of adobe is near zero: the buildings are eroded after each rainy season and their impermeability to water has to be restored. Generally, one of two methods is applied to improve the water resistance: protection of the walls with plaster, or stabilization of the adobes [Degirmenci 2005]. Traditionally, adobes are stabilized by adding a small amount of quicklime, cement or natural fibres [Ghavami 1999, Reddy 2002, Piattoni 2011, Yetgin 2008, Reddy 2005a, Reddy, 2005b, Walker 1995, Millogo 2012, Tironi 2014, Khelifi 2013, Millogo 2014, Millogo 2015, Laborel-Preneron 2016].

A large number of papers have reported the impact of cement or lime on some physical and mechanical properties of adobe blocks [Reddy 2002, Reddy, 2005a, Reddy, 2005b, Millogo 2012].

The fibres also serve to control the cracking of the adobe during its drying process and give it an increase in the flexural strength, acting as microarmour against tensile stresses [Hejazzi 2012, Ghavami 1999, Yetgin 2008]. A wide variety of natural and synthetic fibres has been used for soil reinforcement [Yetgin 2008]. Mud bricks reinforced with plastic fibres, straw, and polystyrene along with a mix of clay, pumice, cement, lime gypsum and water produced significantly higher strengths [Binici 2005]. The addition of hibiscus cannabinus fibres has contributed to a homogenous microstructure with reduced pore sizes having positive effect on the mechanical properties of adobe [Millogo 2014]. The addition of straw has also been reported to act as shear reinforcement and increase energy absorption [Turanli 2011].

The objective of the present investigation is to provide a small contribution to the investigation and improvement of the quality of adobe, verifying the viability of using recycled PET fibers (R-PET) to control drying shrinkage and possible cracking of the adobe bricks. The interest in the waste materials originates mainly from environmental reasons, due to the fact that postconsumer plastics are the most relevant wastes with a low rate of biodegradation, and in consideration of the severe environmental problems created by the scarcity of space for landfilling. Thus, the waste utilization has become an attractive alternative to disposal.

2 EXPERIMENTAL PROGRAM

2.1 Materials

The raw materials used on the preparation of the adobe specimens were: residual soil, water and recycled PET fibers (R-PET). The original soil used was collected in Tijuca, located in the north region of the city of Rio de Janeiro, near a rock called "*Pedra da Babilônia*", constituted by gneiss. The characterization of the soil included moisture content [NBR 6457 2016], liquid limit [NBR 6459 2016], plastic limit [NBR 7180 2016], particle density [NBR 6458 2016] and granulometric analysis [NBR 7181 2016]. The results of the soil characterization are presented in Tab. 1 and Fig. 1.

Tab. 1: Results of the analysis of the soils.

	Original soil	Added soil	Soil1	Soil 2
Humidity (%)	2.80	16.69	4.58	7.67
Density (g/cm³)	2.65	2.74	2.68	2.69
Liquid limit - LL (%)	47.08	63.21	36.29	42.06
Plastic limit - PL (%)	27.65	34.04	21.29	23.21
Plasticity index - PI (%)	19.43	29.17	15.00	18.85
Gravel (%)	4.00	0.00	0.00	0.00
Sand (%)	75.00	27.00	66.50	57.50
Silt (%)	12.00	16.00	13.50	12.50
Clay (%)	9.00	57.00	20.00	30.00

Grain size distribution indicated that the original soil was composed of 4% gravel, 75% sand, 12% silt and 9% clay. This soil exhibited LL = 47%, PI = 19.43% and PL = 27.65%. Australian Standard AS 3700 [2001] proposes that the ideal soil for fiber stabilization must have LL between 30% and 50% and PI between 15% and 35%. Furthermore, Barbosa [2010] propose that the appropriate soil for adobe must have 0-10% gravel, 45-75% sand, 10-45% silt and 15-30% clay and the ideal soil must have 0% gravel, 60% sand, 15-20% silt and 20-25% clay. In this case, the particles of earth larger than 4.8 mm were eliminated by sieving and the original soil was mixed with other soil, rich in clay, in order to decrease sand content and increase clay content. Two different mixtures composition were produced: soil 1 with 68% soil and 32% clay and soil 2 with 50% soil and 50% clay. So, the soil 1 presents LL=36.29%, PI=15%, PL=21.29%, 66.5% sand, 13.5% silt and 20% clay and the soil 2 presents LL=42.06%, PI=18.85%, PL=23.21%, 57.50% sand, 12.5 % silt and 30% clay. The results of the corrected soils characterization (soil 1 and soil 2) are also presented in Fig. 1 and Tab. 1.

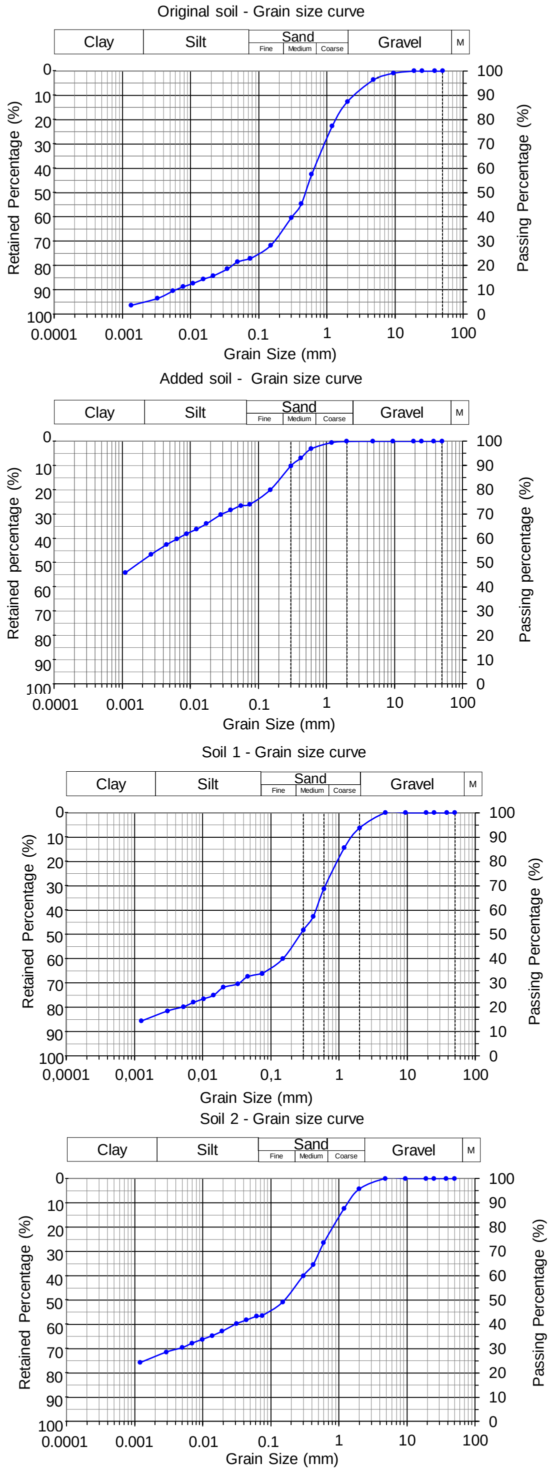


Fig. 1: Particles size distribution of natural soil, added soil, soil 1(original soil: 68% and added soil: 32%) and soil 2 (original soil: 50% and added soil: 50%).

The recycled PET fiber (R-PET) used in this study, see Fig. 2, is produced by M&G Fiber Brazil S.A with a length of 32 mm, a 14 µm diameter, and density of 1.43 g/cm³. The fibers were produced by mean of an extrusion of plastic filaments from flakes of recycled polyethylene terephthalate (PET).

Fig. 2 : R-PET fibers.

2.2 Mixture details

Five experimental adobes mixtures were manufactured to investigate the influence of R-PET fibers on the shrinkage of mixtures. Two different mixtures were produced without R-PET fiber: the M01-0 mixture with the soil 1 and M02-0 with the soil 2. the other three mixtures were produced with R-PET fibers contents equal to 0.25% (M02-0.25) and 0.5% (M01-0.5 and M02-0.5) by volume of dry materials. Tab. 2 presents the proportion of each constituent used for the preparation of adobe mixtures.

Tab. 2: Details of the constituents of adobe mixtures.

Mix	Proportion in the mix (by mass)			
	Original soil (%)	Added soil (%)	Water/s[1] (%)	Fiber/s[1] (%)
M1-0	68.0	32.0	16.5	-
M1-0.50	68.0	32.0	16.5	0.50
M2-0	50.0	50.0	18.0	-
M2-0.25	50.0	50.0	18.0	0.25
M2-0.50	50.0	50.0	18.0	0.50

[1]s: corrected soil (original soil + added soil)

The suitable water content was estimated according to the ‘‘Falling Ball’’ [Barbosa 2010] test (Fig. 3). The suitable amount of water estimated in this test for each formulation is presented also in Tab. 2.

The soil and the clay were crushed and screened before being mixed with water and the fibres. The mixing water was incorporated subsequently until same plastic consistency of the mixture was obtained, and the fresh mass did not stick in the hands. In the last step, fibers were added manually to the matrix and the mixture was stirred for 3 more minutes.

Once obtained the mixture, the mould was filled with the mixture, which was distributed homogeneously and lightly pressed to avoid cavities. Finally, it was grazed at the top, the remaining material was removed, and the mould was lifted. The mould was made of wood. Before use, it was moistened to prevent the soil mixture from adhering to the walls and to avoid the loss of surface water from the mass by suction of the wood.

Fig. 3: Technique for estimation of suitable water content (Falling Ball test).

The drying process was carried out in laboratory (Fig. 4) with the specimens at ambient temperature and humidity (23+ 2°C and 65%R.H). This phase is very important to avoid surface cracks due to shrinkage caused by rapid drying [Van Lengen 2014].

Fig. 4: Specimens used in shrinkage tests.

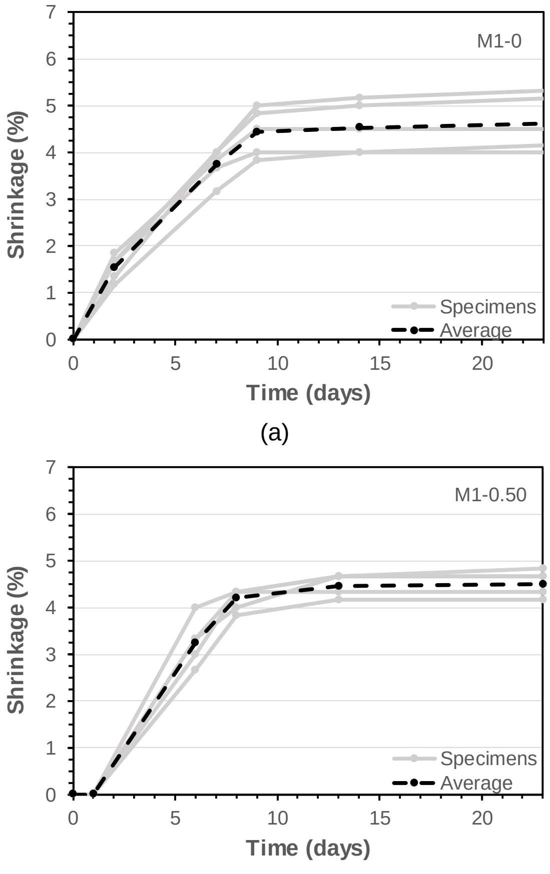
2.3 Experimental methods

Tests were carried out on 4 or 5 prismatic specimens with 50 x 50 x 300 mm. Length variation were evaluated at regular time intervals during 23 days after casting.

A compressive strength test was performed on six cubic specimens by size 100 x 100 x 100 mm in a mechanical testing machine.

3 EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 5 and Fig. 6 show the dependence of linear shrinkage on the time for all mixtures up to 23 days after casting. Average results and standard deviation (in parentheses) of linear shrinkage at 7 and 23 days are presented in Tab. 3. Experimental curves exhibit at the initial stage (approximately 7 days) a large increase of shrinkage, after the shrinkage rate reduces as time goes by. At 7 days, shrinkage values of all specimens were between 81% and 93% of its shrinkage at 23 days.



(a)

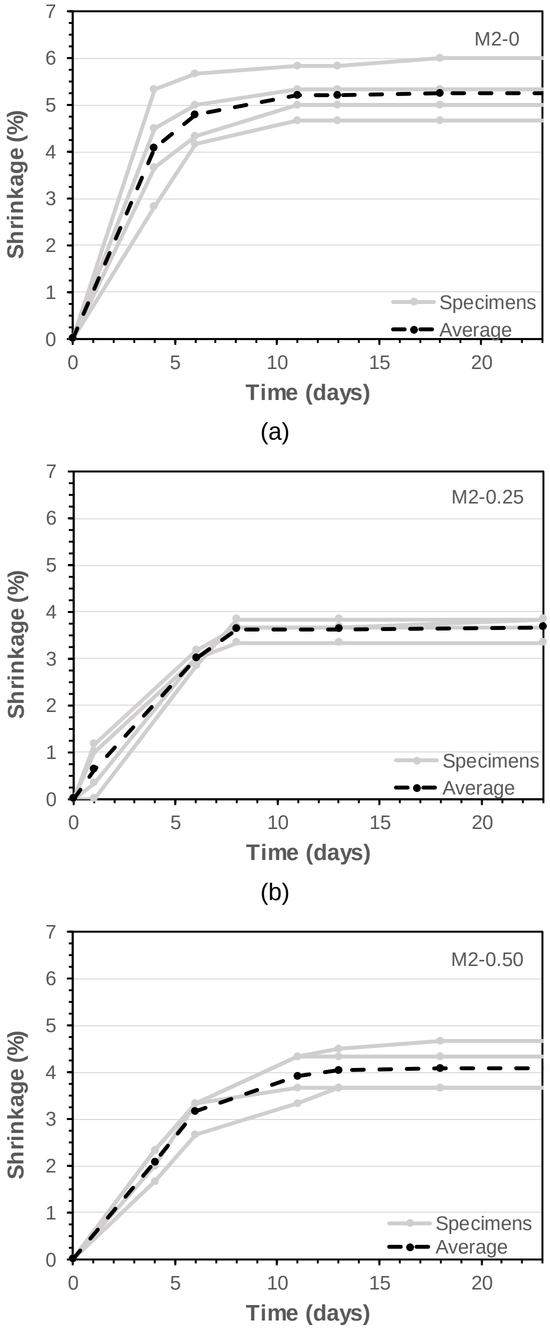
(b)

Fig. 5: Average and individual values of the linear shrinkage of specimens used for shrinkage test: (a) M1-0 and (b) M1-0.50 mixtures.

Tab. 3: Average values and standard deviation (in parentheses) of the shrinkage tests.

Mixture	Time	
	7 days	23 days
M1-0	3.73 (0.35)	4.62 (0.59)
M1-0.5	3.72 (0.33)	4.53 (0.27)
M2-0	4.88 (0.65)	5.25 (0.57)
M2-0.25	3.31 (0.10)	3.57 (0.30)
M2-0.5	3.32 (0.35)	4.37 (0.77)

There is an interaction between soil and R-PET fiber, which contributed to the reduction of linear shrinkage, as can be seen in Fig. 7. However, this effect was more visible in M02 mixture with more clay content. For instance, the shrinkage value of M1-0.5 was 2% lower if compared to the mixture with no fiber (M1-0); instead, the shrinkage value of M2-0.5 was 17% lower than reference mixture with no fiber (M2-0). The explanation for this effect is still unknown and needs more studies.



(a)

(b)

(c)

Fig. 6: Average and individual values of the linear shrinkage curves of specimens used for shrinkage test: (a) M2-0, (b) M2-0.25 and (b) M2-0.50 mixtures.

Concerning the fiber content (M2-0.25 and M2-0.50 mixtures), it was observed that an increase of the fiber content from 0.25% to 0.50% had negative effect on the shrinkage. The shrinkage value of M2-0.25 and M2-0.5 were, respectively, 32% and 17% lower than reference mixture with no fiber (M2-0). The negative effects of increasing fiber content on shrinkage could be attributed to fiber agglomeration in the M2-0.5 specimens that caused heterogeneous fiber distribution.

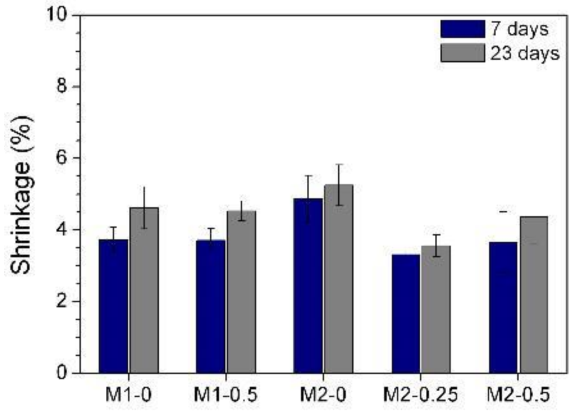


Fig. 7: Average values of the linear shrinkage of M1-0, M1-0.5, M2-0, M2-0.25 and M2-0.5 mixtures.

When compared M1-0 mixture with M2-0 mixture, in Fig.7, it was observed that the M2-0 mixture present higher shrinkage value at 7 and 23 days, as was to be expected given that the M01-0 mixture contain higher content of coarse particle that control the drying shrinkage [Blondet 2004]. In contrast, the shrinkage value of M2 mixture with R-PET fiber (M2-0.25 and M2-0.5) were lower, when compared with the values of M1-0.5.

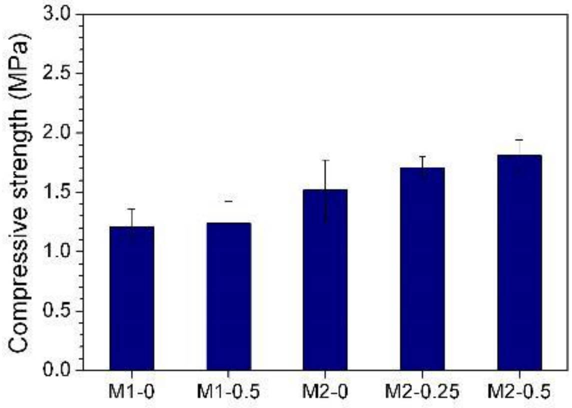


Fig. 8: Average values of the compressive strength of M1-0, M1-0.5, M2-0, M2-0.25 and M2-0.5 mixtures.

Regarding the compression behaviour (Fig. 8), the mechanical resistances reached by the M2 mixtures are much higher than those obtained for the M1 mixtures (with fiber addition or not). The highest mechanical strength is reached, in this case, in the specimen made of adobe with 0.5% R-PET fiber. This indicate the efficient effect of the R-PET fiber in the compressive behaviour. However, the increase of compressive strength is not noticed in the M1 mixture. The M1-0.5 is practically equal to that manufactured with no fiber (M1-0 specimen).

Finally, the fracture behaviour of the typical specimens, shown in the Fig. 9 indicate that the compressive ductility was increased with R-PET fiber addition for all specimens.

(a)

(b)

Fig. 9: Typical fracture after the tests of (a) specimens with no fiber and (b) specimens with fiber.

4 CONCLUSIONS

The paper presents an analysis of the properties of traditional adobe as a construction material, based on results obtained from shrinkage tests for five mixtures which differed in the soil composition and fiber content. In one mixture, recycled PET (R-PET) fiber reached the 0.25% of total mass of soil, whilst in the other, for each soil type, R-PET fiber represented 0.5% of total mass of soil. In addition, a prior analysis was carried out of the soil used to prepare the adobe bricks, the results of which, when compared with the data indicated in various reference sources, demonstrated that this soil has suitable properties for the use. As a result of the findings of the tests carried out on the five different types of adobe, the following conclusions can be reached.

This work showed that it is possible to improve the control of drying shrinkage of adobes using R-PET fibers as reinforcement. The use of R-PET fibers reduced linear shrinkage, especially for high dosages of fiber (i.e., 0.5%) in the mixture with higher clay content, reaching a reduction in shrinkage values of up to 48%.

Similar behaviour was observed in the compressive tests. The highest mechanical strength was reached in the specimen made of adobe with higher clay content and 0.5% R-PET fiber.

These results contribute to the better understanding of the stabilization mechanisms of adobes and widespread use of this kind of block for rural or urban housing. However, further tests are required with different R-PET fiber content and mixtures composition.

5 ACKNOWLEDGMENTS

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