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Comparative study of the influence of three types of fibre in the shrinkage of recycled mortar

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ABSTRACT: Construction and demolition waste can be used as a substitution of natural aggregate in mortar and concrete elaboration. A poorer quality of recycled aggregates generally has negative impact on mortar properties. Shrinkage is one of the properties that experiences worse outcome due to the higher absorption of recycled aggregates. This research evaluates the potential shrinkage of mortars elaborated with recycled concrete aggregates both with and without fibres addition, as well as the relation between moisture loss and shrinkage caused by mortar drying process using a capacitive sensor of the authors' own design. Two different mortar dosages 1:3 and 1:4 and three fiber types: polypropylene fiber, fiberglass and steel fiber, in different proportions were used. Obtained results show that the use of polypropylene fiber improves the recycled mortars performance against shrinkage in 0.2%. Moreover, a clear relation between dry shrinkage and moisture loss was observed.

KEYWORDS: Waste treatment; Mortar; Aggregate; Shrinkage; Fiber reinforcement.

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RESUMEN: *Estudio comparativo de la influencia de las fibras en la retracción de los morteros reciclados*. Los Residuos de Construcción y Demolición pueden ser usados como sustitución de los áridos naturales en la fabricación de morteros y hormigones. La peor calidad de los áridos reciclados empeora de manera general las propiedades de los morteros, siendo la retracción una de las que más se ve afectada. Esta investigación, estudia la retracción de los morteros elaborados con arena reciclada de hormigón con y sin adicción de fibras, así como la relación existente entre la perdida de humedad y la retracción por secado mediante un sensor capacitivo de diseño propio. Se han empleado dos dosificaciones diferentes 1:3 y 1:4 y tres tipos de fibras: polipropileno, vidrio y acero, en distintas proporciones. Los resultados muestran que la adición de fibras de polipropileno en un 0,2% mejora significativamente la retracción en los morteros reciclados. Además, se ha obtenido una relación clara entre la retracción por secado y la perdida de humedad.

PALABRAS CLAVE: Tratamiento de residuos; Mortero; Árido; Retracción; Refuerzo de fibras.

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1. INTRODUCTION

The construction sector constitutes a problem of a dual character. On the one hand, it is a sector that consumes a great amount of natural recourses used as a raw material; on the other hand, this sector presents a high resistance towards the use of recycled aggregates arising from its activity. These characteristics contribute to a less sustainable development of the sector and distance it from the objectives fixed by the current legislation on recycling rates (1-2).

In order to improve this situation, during the last years, there were numerous research studies on the feasibility of incorporation of construction and demolition waste (CDW) as a raw material in the fabrication of mortar and concrete (3-7).

Generally, recycled aggregate (RA) coming from CDW presents poorer characteristics compared to natural aggregate (NA), what limits its use, as in case of Spanish standards that restrict to 20% the use of this aggregate in the fabrication of concrete (8). The main difference between RA and NA is the amount of attached mortar in RA (9), being this amount approximately between 40% and 50% as found in some studies (10-11). Other aspects that influence the final quality of RA are the procedures used to eliminate impurities, the characteristics of crushing and sieving equipment used during its production, and the origin of the material (10-12). As a result of these characteristics, RA presents a lower density, higher friability coefficient, higher fines content and higher absorption compared to NA (13-14). Because of these poorer characteristics of RA, recycled mortars present generally poorer properties compared to mortars elaborated with NA, to a greater or lesser extent depending on the percentage of substitution (15-17).

One of the most affected by incorporation of RA properties is shrinkage, what causes a great disadvantage in the use of this type of material. Shrinkage can be caused by two very differentiated effects: by temperature, due to exothermic reaction produced in the hydration of adhered to mortar compounds (18), or by drying produced when free water that remains kept in capillary pores evaporates due to low levels of relative environmental humidity (19).

Recycled mortar due to higher absorption of RA requires higher amount of water for mix elaboration, what causes higher loss of volume comparing to traditional mortar (20-21). Various scientific surveys studied the values of shrinkage reached by recycled mortar at different ages and using different types of RA. Vegas et al (14) studied shrinkage of recycled mortar at 1250 hours, obtaining shrinkage value of 0.07mm/m, more than triple the value obtained in mortars elaborated with NA (0.02 mm/m). Fernández et al (7) performed the tests at 203 days, coming to the conclusion that recycled mortar elaborated with concrete RA obtained more than double shrinkage compared to mortars elaborated with NA.

Furthermore, in relation to ceramic RA, Ledesma et al (22) obtained more than double shrinkage value for recycled mortars at 203 days, reaching values of 1.1 mm/m. Similar behavior was obtained by López et al (16) at 28 days and Martínez et al (6) at 90 days.

Negative effects of shrinkage can be decreased by the control of curing temperatures and by the use of fibers during mixing (23). There is a great variety of fibers in the market, being synthetic fibers such as fiberglass and polypropylene fibers the most used partially due to their low cost (24). Nevertheless, despite of well-known positive effect of fibers in terms of shrinkage, there is a great variety of opinions about the optimum percentage of fibers to be used during mixing, according to their typology and physical properties (25-26).

Hence, along the consulted bibliography, shrinkage is one of the most limiting properties in terms of using RA as a material in fabrication of masonry mortar. Therefore, the aim of this paper is to perform the complete characterization of concrete RA and to decrease shrinkage of recycled mortars through the use of three types of fibers: steel fibers, fiberglass and polypropylene fibers added in different percentages. Moreover, the relation between the loss of humidity of these mortars and dry shrinkage was studied through the use of capacitive sensor of the authors' own design.

2. MATERIALS AND METHODS

2.1. Materials

In the elaboration of the mortar prismatic specimens, the following materials were used: cement, aggregate (natural and recycled concrete aggregates), water and additive.

2.1.1. Cement

The used binder was CEM II B/L – 32.5 N as this is one of the most common binders used in the elaboration of masonry mortars. Spanish and European standard UNE-EN 197-1: 2011 (27) and the Instruction for the cement placing RC-08 (28) specify the properties of these cements. Their main characteristics and chemical composition are shown in Table 1.

2.1.2. Aggregates

The natural aggregate used to elaborate the specimens was provided by CEMEX Company. On the other hand, recycled aggregate used in this research comes from the concrete recycling line of

Table 1. Characteristics of CEM II B/L – 32.5 N

Physical										
Density (g/cm^3)			**Blaine specif. area (g/cm^2)**				**Initial set (min)**		**Final set (min)**	
3.05			4000				175		275	
Chemical										
Al_2O_3	**CaO**	**Fe_2O_3**	**K_2O**	**MgO**	**SiO_2**	**TiO_2**	**MnO**	**P_2O_5**	**NaO_2**	**Loss on ignition**
3.25	60.10	2.56	0.26	1.75	18.13	0.14	0.02	0.16	0.22	11.85

Table 2. Fibres characteristics

Fibre type	Length (mm)	Diameter (mm)	Elasticity module (GPa)	Tensile Strength (MPa)	Density (g/cm^3)
Steel	30	0.5	200	1100	7.80
Glass	12	0.013	72	1950	2.68
Polypropylene	12	0.034	5	450	0.91

an integrated CDW Treatment Plants of Madrid Region (TEC-REC). RA coming from treatment plants was sieved in the laboratory, eliminating material retained on the 4 mm sieve (by definition) and material passing through 0.063 mm sieve. The fine fraction of recycled aggregate was eliminated because this fraction has higher water demand.

2.1.3. Fibres

In order to elaborate the mortar mixes that incorporate recycled aggregate, three fibre types was used to control high shrinkage which these mortar mixes present: fibreglass of type E glass, steel fibre and polypropylene fibre. Fibre percentages for each mortar mix type were: fibreglass (0.2% and 0.3%), steel fibre (0.5% and 1%) and polypropylene fibre (0.1% and 0.2%). Fibre incorporation ratio was chosen according to the amount of aggregate in each mix. Table 2 summarizes the main characteristics of the fibres used in this study.

2.1.4. Additive

RA mortars mixes were elaborated using superplasticizer additive Glenium Sky 604 by BASF Company, as recommended by its technical department to improve RA mortars consistency. This additive is a liquid high-level product based on polycarboxylate without substances that could produce negative effects on mortar. The quantity of additive used in each mix is 1% of the cement weight.

2.2. Prismatic specimens' elaboration

The description of the mortars used in these tests has the following coding [1]:

$$N - D - F - \% \quad [1]$$

where N shows aggregate type, that could be NA for natural aggregate and RA for concrete recycled aggregate; D shows relation between cement and aggregate by dry-weight proportion, letter X describes relation between components 1:3 and letter Y describes relation between components 1:4; F refers to the fibre types that could be: SF for steel fibre, FPP for polypropylene fibre and FB for fibreglass. Finally, percentage sign % shows the fibre percentage added to the mortar mix.

The preparation of all mixes was developed using the same technique and equipment, following the standard UNE-EN 196-1 (29). Prismatic specimens elaborated with recycled concrete aggregate were prepared using 1% of superplasticizer/additive over the weight of cement, complying with the limits established by the manufacturer. According to the specifications, this additive reduces water content of the mix maintaining mortar workability and improving its properties such as hardness, durability and shrinkage.

Due to the format and characteristics of polypropylene fibers, manual separation of this material prior to its incorporation to the mortar mixes was performed. In this way, homogeneous distribution of this material in fabricated samples was achieved.

Dosage by dry-weight used for the different prismatic specimens is shown in Table 3 where their quantities and relations are indicated.

Water content of these specimens was experimentally set in order to achieve a plastic consistency, in other words, to achieve a diameter of mortar in the range of 175±10 mm, according to the standard UNE-EN 1015-2:1998 (30). Because of this, it is necessary to increase the water/cement ratio while recycled aggregates are used due to their higher water absorption during the mix process.

Table 3. Dosages in mortar mixes elaboration

Mix type	Water/cement ratio 1:3 (1)	Water/cement ratio 1:4 (2)	Steel fibre (%)	Fibreglass (%)	Polypropylene fibre (%)
NA	0.55	0.62	-	-	-
RA (3)	0.68	0.89	-	-	-
RA-SF-0.5%	0.68	0.89	0.5	-	-
RA-SF-1%	0.68	0.89	1	-	-
RA-FB-0.2%	0.68	0.89	-	0.2	-
RA-FB-0.3%	0.68	0.89	-	0.3	-
RA-FP-0.1%	0.68	0.89	-	-	0.1
RA-FP-0.2%	0.68	0.89	-	-	0.2

(1) All 1:3 dosages by dry-weight contain 450 g of cement and 1350 g of aggregate.
(2) All 1:4 dosages by dry-weight contain 337.5 g of cement and 1350 g of aggregate.
All prismatic specimens elaborated with recycled aggregates contain 1% of additive over the weight of cement

2.3. Experimental study

The experimental study was divided in two phases. In the first phase main characteristics of recycled concrete aggregates were studied and, subsequently, some tests have been carried out in order to study the fibres influence in this type of mortars. Also, some tests were carried out to obtain the compressive and flexural strength of the mortars to characterize the mechanical properties of the mortar mix containing fibres.

Shrinkage measuring was performed with a manual comparator that is shown in Figure 1(a). This comparator is able to measure the changes in length of the prismatic specimens during each drying phase, since they have been unmoulded, following the standard UNE 80-112-89 (31), and measuring in prismatic specimens of 25 x 25 x 287 mm. Thus, shrinkage is expressed as a proportion ΔL_{nd} (%) of its initial length given by the following equation [2]:

$$\Delta L_{nd} = \frac{M_{nd} - M_{1d}}{L_0} \cdot 100 \ [\%] \qquad [2]$$

where L_0 is the inner length of the mould, M_{nd} is the comparator measure after n days and M_{1d} is the comparator measure on the first day.

On the other hand, this drying shrinkage is associated with a moisture loss of the specimens. This variation in its moisture content was measured with a capacitive sensor of the authors' own design joined to an auto-oscillating circuit. This sensor is shown in figure 1(b). To obtain the maximum current in the circuit, its impedance must be minimum, condition that appears when the circuit is in resonance. So, it is only necessary to obtain the resonance frequency value to obtain the condenser capacitance, which depends on the moisture content of the specimen, because it serves as dielectric, changing the environment permittivity. This is given by the equation [3]:

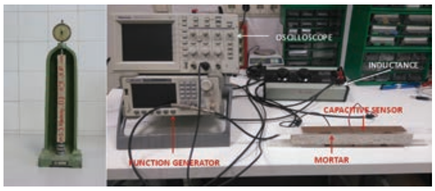

Figure 1. Used measurement systems. (a) Test machine for shrinkage measurements; (b) Capacitive sensor and the auto-oscillating circuit for measuring moisture losses

$$f = \frac{1}{2\pi\sqrt{LC}} \ [Hz] \Rightarrow C = \varepsilon . \frac{A}{d} \ [F] \qquad [3]$$

where f, is the resonance frequency of the measurement circuit, in Hz; L is the induction of the coil, in H; and C is the condenser capacitance in F, that depends on the area of the confronted plates A' on the distance between plates d which is the same that the specimens' thickness and on the material's permittivity ε that, in our case, is the mortar specimens and it varies depending on their moisture content.

The shrinkage measurement period was 180 days since the specimen had been removed from its mould till the last measurement.

Flexural and compressive strength tests were carried out using standard specimens RILEM with the dimensions 40x40x160 mm, after being cured in the curing chamber for 28 days under the temperature of 20°C and following the standard UNE-EN 1015-11:1999 (32) which regulates flexural and compressive strength tests on mortars.

3. RESULTS AND DISCUSSION

3.1. Recycled concrete aggregates characterization

Recycled concrete aggregates characterization was carried out following the standard UNE-EN 13139:2002 (33). Used recycled aggregates comply with the size restrictions and the maximum limit of fineness modulus established for masonry mortars. The results of physical characteristics for recycled concrete aggregates (RCA) and natural aggregates are shown in Table 4.

As it can be seen in Table 2, the density of recycled concrete aggregate is lower than the natural aggregate density, so the mortars elaborated with this type of aggregates have lower density compared to the traditional mortars. On the other hand, water absorption values of the recycled aggregates are much higher than the values obtained by the natural ones. That is a general characteristic of the recycled aggregates and, mainly, this is caused by the amount of mortar adhered to the aggregates in CDW (13). In turn, due to its higher water absorption, recycled mortar shrinkage is much higher than one of the mortar elaborated with natural aggregate, as recycled mortar needs a higher intake of mixing water.

One of the other characteristics that differentiates recycled aggregate from natural aggregate is its higher value of friability coefficient. This higher deterioration of recycled aggregate has a negative impact over the mechanical characteristics of recycled mortar.

To determine particle size distribution of aggregate, a sieving method was used, according to the standards UNE-EN 933-2:1995 (38) and UNE-EN 933-1:2012 (34). Particle size distribution is one of the most important characteristics studied in aggregates (39), being directly relevant to the characteristics of elaborated mortar such as workability, hardness, durability and compactness. Figure 2 shows size distribution curves of two used aggregates, where the continuous size distribution curve can be observed.

In order to complete the characterization of the recycled concrete aggregate (RCA), X-ray diffraction and X-ray fluorescence methods were used. The obtained results are shown in Table 5 and Figure 3.

The obtained results of X-ray fluorescence method for the recycled aggregate type show that there is a high level of silicates SiO_2 (68.2%), followed by a high percentage of Al_2O_3 and CaO. Apart from this, SO_3 content (0.338%) does not exceed the limit of 1% established by the standard UNE-EN 13139:2002 (33) for the aggregates used in mortar fabrication, as higher levels of this chemical harm the mechanical characteristics of the elaborated mortars reducing considerably their durability.

The crystalline structure and the purity of the specimens were analysed by X-ray diffraction (XRD) and it can be noticed that the X-ray diffraction pattern was measured using a Cu-Ka radiation (λ=1.540598 Å) by a diffractometer equipped with a monochromator of graphite. Data were collected at 300K in steps of 0.05°, measured in a range of $10° \leq 2\theta \leq 110°$ taken every 10s with a current of 20 mA and a 40 kV voltage.

As it can be seen in Figure 3, the main crystalline phases obtained with the X-ray diffraction method are quartz and calcite because they show a higher intensity after the test. Other founded phases are gypsum, sanidine and albite.

3.2. Shrinkage

The obtained results of shrinkage for both reference mixes and recycled mortar mixes, that incorporate three different types of fibres, can be seen in

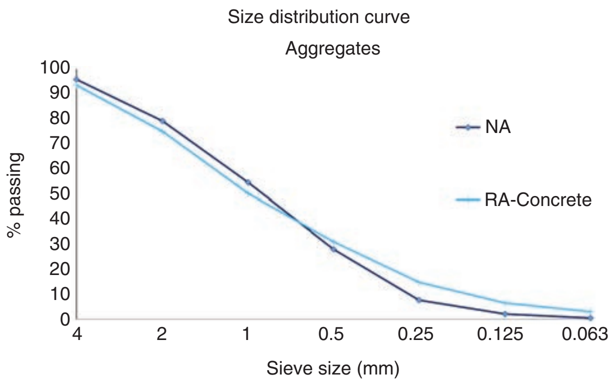

Figure 2. Size Distribution Curve Aggregates

Table 4. Characterization of the aggregates

Test	Fines Content (%)	Fineness modulus (%)	Friability (%)	Bulk. dens, (Kg/m^3)	Dry dens. (Kg/m^3)	Water Absorption (%)
Standard	UNE EN 933-1 (34)	UNE-EN 13139 (33)	UNE-EN 83115 (35)	UNE-EN 1097-3 (36)	UNE-EN 1097-6 (37)	UNE-EN 1097-6 (37)
RCA	3.97	4.28	24.12	1310	2100	6.01
NA	2.58	4.25	22.63	1560	2450	0.95

Table 5. X-ray fluorescence results

Aggr.	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	SiO_2	MnO	TiO_2	SO_3	P_2O_5	Na_2O	I.Loss (%)
RCA	6.98	10.67	1.22	2.16	0.54	68.2	0.022	0.15	0.338	0.1	0.22	9.4

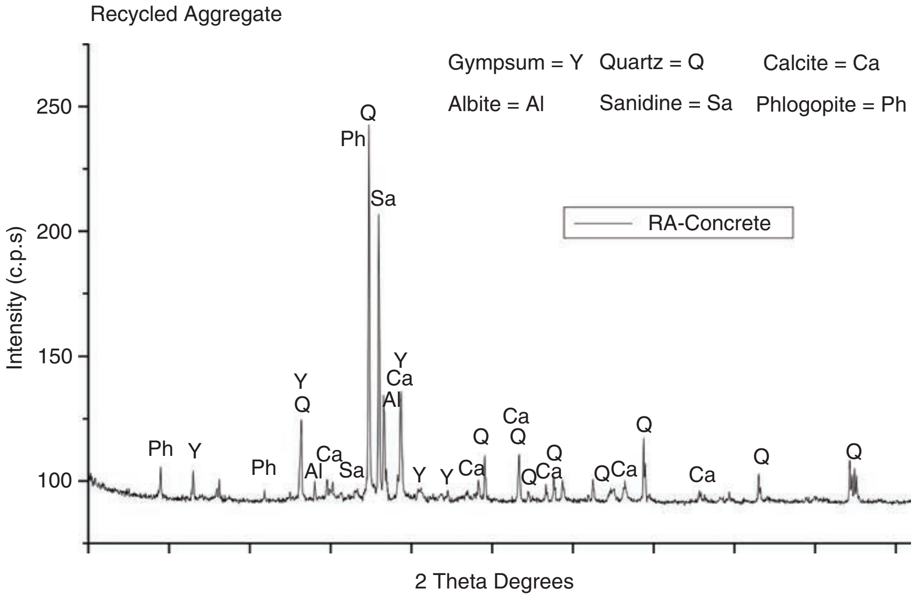

Figure 3. X-ray diffraction for recycled concrete aggregate

Figures 4 and 5, corresponding to 1:3 and 1:4 dosages, respectively.

As it can be observed in Figures 4 and 5, the shrinkage produced in recycled mortars is much higher than that of traditional mortars, according to the theoretical predictions due to its higher water absorption. In the case of natural mortar mix, the shrinkage is higher in the mortar with dosage 1:3; this is related to the higher amount of cement in the mix. On the other hand, in the mix elaborated with recycled aggregates, the dosages with higher aggregate content (1:4) are the mixes that present higher shrinkage, due to the greater influence in this case of the used aggregate type with respect to the amount of used cement.

Moreover, it can be seen that the use of fibres reduces significantly the shrinkage results in recycled mortars. In both dosages 1:3 and 1:4, the mixes which incorporate fibreglass up to 0.2%, were those that have lower shrinkage reduction rate in case of recycled mortars with 30% and 20%, respectively. This decrease of shrinkage results is more important at the ages that are superior to 30 days, as until reaching this point, all specimens performance is similar. Among all these used fibres and percentages, the recycled mortars with 0.2% of polypropylene fibre, are the ones which present the best shrinkage results in both dosages, reaching values similar to the natural aggregates, and with a decrease of 40% in shrinkage in case of dosage 1:3 and 30% in case of dosage 1:4.

To analyse the obtained shrinkage results an analysis of variance (ANOVA) was carried out to determine if the added fibres and the used dosages have influence on the characteristics of recycled mortars. Moreover, a multi-range test was carried out to analyse the significant differences among the fibre types, their percentages and their components relation. The results of the ANOVA analysis and multi-range test are shown in Tables 6 and 7.

As it is shown in Table 6, both the fibre types and the used dosages obtained p-values far below 0.05, so it can be concluded that both factors have a great influence on the mortars shrinkage. In the multi-range test a significant difference between the polypropylene fibre (in 0.2% proportion) and the rest of fibres, with the exception of steel fibre (in 1% proportion) can be observed. In the multi-range test of the used dosages the results show important differences between both components relations, being the dosage 1:4 the one that presents better results.

Moreover, the moisture losses of the specimens at different ages were measured with a capacitive sensor

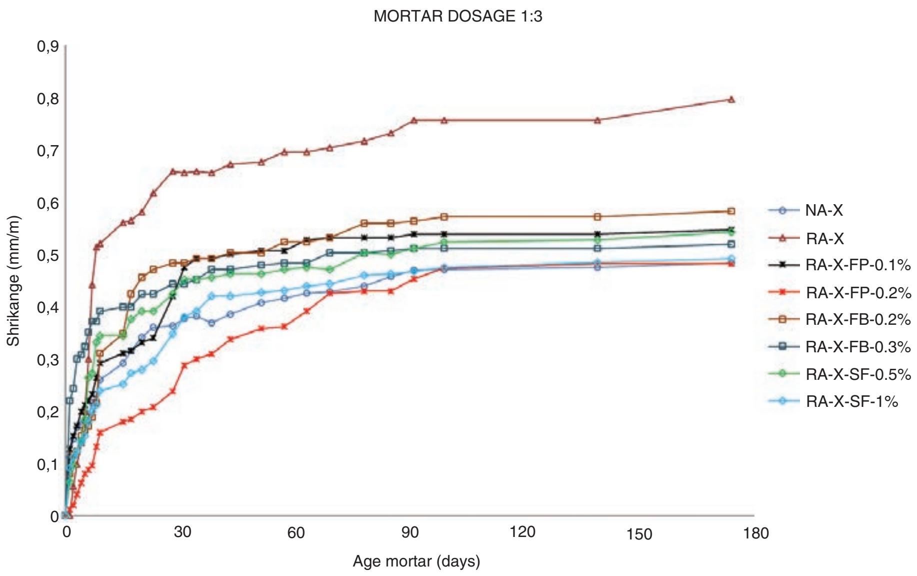

FIGURE 4. Shrinkage test – dosage 1:3

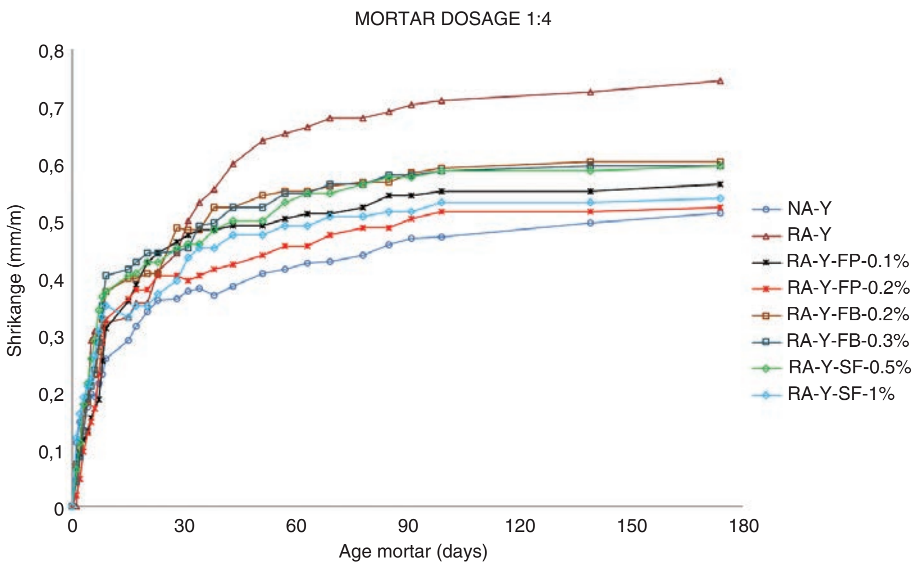

FIGURE 5. Shrinkage test – dosage 1:4

TABLE 6. Analysis of Variance for Shrinkage

Source		Sum of Squares	*Df*	Mean Square	F-Ratio	P-Value
Main Effects	A: Fibre Type.	0.0115584	5	0.00231168	9.50	0.0137
	B: Dosage.	0.00533408	1	0.00533408	21.93	0.0054
Residual		0.00121642	5	0.000243283		
Total (Corrected)		0.0181089	11			

Note: All F-ratios are based on the residual mean square error.

Table 7. Multiple Range Tests for Shrinkage by fiber type

Fiber Type	Count	LS Mean	LS Sigma	Homogeneous groups
0.2% FPP	2	0.503	0.0110291	X
0.1% FPP	2	0.556	0.0110291	X X
1%SF	2	0.516	0.0110291	XX
0.5%SF	2	0.570	0.0110291	X
0.3%FB	2	0.558	0.0110291	X
0.2%FB	2	0.594	0.0110291	X

Note: Method employed, 95,0 percent LSD.

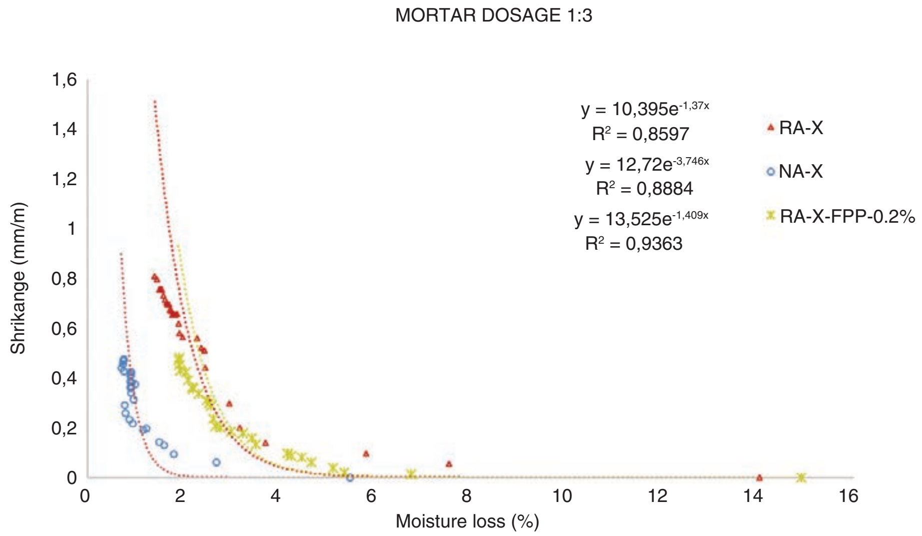

Figure 6. Shrinkage-moisture 1:3

using both mortar dosages, associating this variation with the shrinkage produced in each dosage. As an example, some results are shown in Figures 6 and 7, without including all the curves because of the great number of obtained values. Table 8 shows all the equations of the obtained curves and their R^2 coefficients.

As it can be observed in Figures 6 and 7, the moisture loss is more important in the early days, due to the exothermic reactions produced by the setting process of cement. This moisture loss, in its turn, is much more important in the mortars elaborated with recycled aggregates than that of traditional mortars, in accordance with the shrinkage values, which were higher in case of recycled concrete aggregates. The addition of fibres improves significantly the behaviour of these mortars, reducing the moisture loss. Moreover, it can be appreciated that, at late ages, the moisture loss is virtually zero, while the specimen shrinkage continues along the mortar life since it is placed.

3.3. Mechanical properties

In order to complete this study of recycled mortars with fibres addition, flexural strength, compressive strength and capillary water absorption tests were carried out. Mechanical properties of recycled mortars are in general poorer that those of traditional mortars, due to poorer properties of recycled aggregates, especially absorption. As shown in diverse studies, when the percentage of recycled aggregates rises, mechanical properties decrease (5, 7, 12, 21), being interesting the possibility to improve these properties using fibers in order to obtain higher ratio of recycling with better characteristics. Generally, the results of this paper show a better mechanical behavior of mortars elaborated with fiber compared to recycled mortars without this addition, however, there are no significant differences in terms of improvement of mechanical properties depending on the type of used fiber. The mixes that contain fiberglass obtained an average

TABLE 8. Shrinkage-moisture curves and R^2 coefficient for used dosages

Dosage 1:3			Dosage 1:4		
Mix	**Equation**	R^2	**Mix**	**Equation**	R^2
NA-X	$y = 12.72e^{-3.746x}$	0.888	*NA-Y*	$y = 8.6963e^{-5.56x}$	0.895
RA-X	$y = 10.395e^{-1.37x}$	0.860	*RA-Y*	$y = 4.009e^{-1.501x}$	0.912
RA-X-FPP-0.2%	$y = 13.525e^{-1.409x}$	0.936	*RA-Y-FPP-0.2%*	$y = 9.6943^{e-1.249x}$	0.871
RA-X-FPP-0.1%	$y = 12.843e^{-1.44x}$	0.923	*RA-Y-FPP-0.1%*	$y = 22.664e^{-1.66x}$	0.934
RA-X-FB-0.3%	$y = 3.1083e^{-1.496x}$	0.953	*RA-Y-FB-0.3%*	$y = 7.322e^{-1.416x}$	0.912
RA-X-FB-0.2%	$y = 3.9299e^{-1.491x}$	0.952	*RA-Y-FB-0.2%*	$y = 27.102^{e-1.461x}$	0.860
RA-X-SF-1%	$y = 3.1264e^{-1.468x}$	0.943	*RA-Y-SF-1%*	$y = 10.79^{e-1.574x}$	0.937
RA-X-SF-0.5%	$y = 2.7739e^{-1.499x}$	0.960	*RA-Y-SF-0.5%*	$y = 8.7712e^{-1.423x}$	0.889

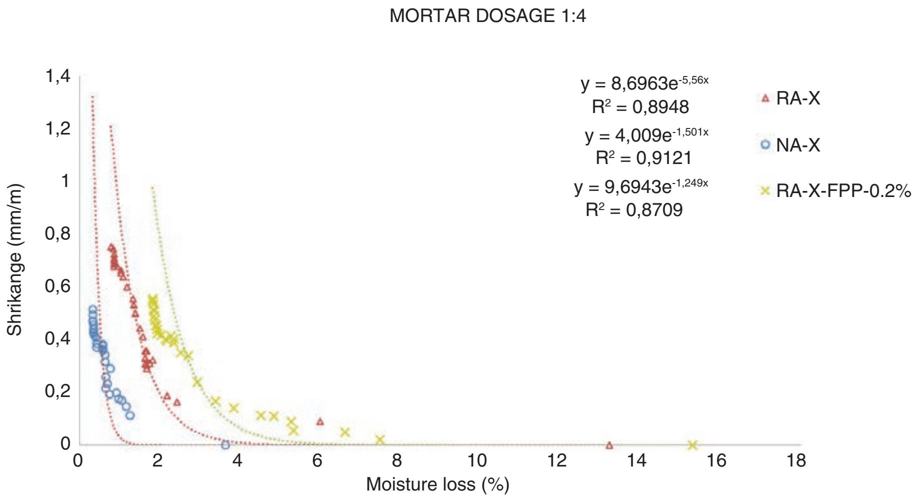

FIGURE 7. Shrinkage-moisture 1:4

improvement of flexural strength of 15.86%. In terms of compressive strength, the average improvement is of 11.27%, being more representative for 1:4 dosages. Steel fibres, improve flexural and compressive strength results up to 15% on average. However, recycled mortar mixes elaborated with polypropylene obtained the poorest results, obtaining some slightly lower values compared to the reference mixes RA-X and RA-Y.

In terms of capillary water absorption test (Table 9), higher absorption coefficient was obtained due to higher content of occluded air in fresh mortars presented by recycled mortars compared to traditional mortars as shown in other papers [40]. In case of fibers incorporation, slight decrease of this coefficient is not significant, that is why it cannot be concluded that incorporation of fibers produces better behavior of the material in this respect. Furthermore, there is no standard that establishes a maximum value for this characteristic of masonry mortars, however it is convenient to take it into consideration in order to avoid water filtrations in walls bases and renderings placed in external facings.

Other observed patterns, is that the increasing percentage of added fibre does not improve flexural and compressive strength of recycled mortars, as their workability decreases causing a worse compaction, which is an essential characteristic in the mechanical capacities of these materials. The results are shown in Figures 8 and 9.

4. CONCLUSIONS

This work studied the influence of polypropylene fibres, fibreglass and steel fibres on the shrinkage of the recycled mortars. Based on results of the tests, the main conclusions of this work are the following:

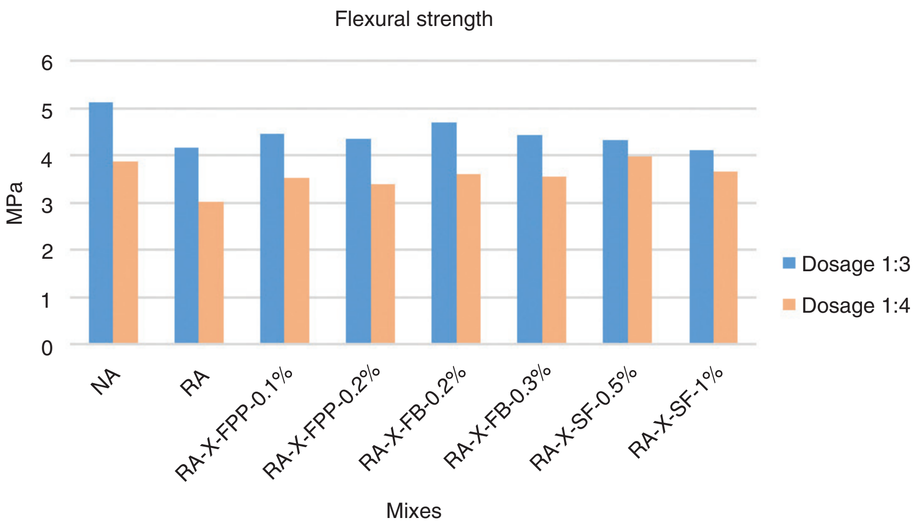

Figure 8. Flexural strength

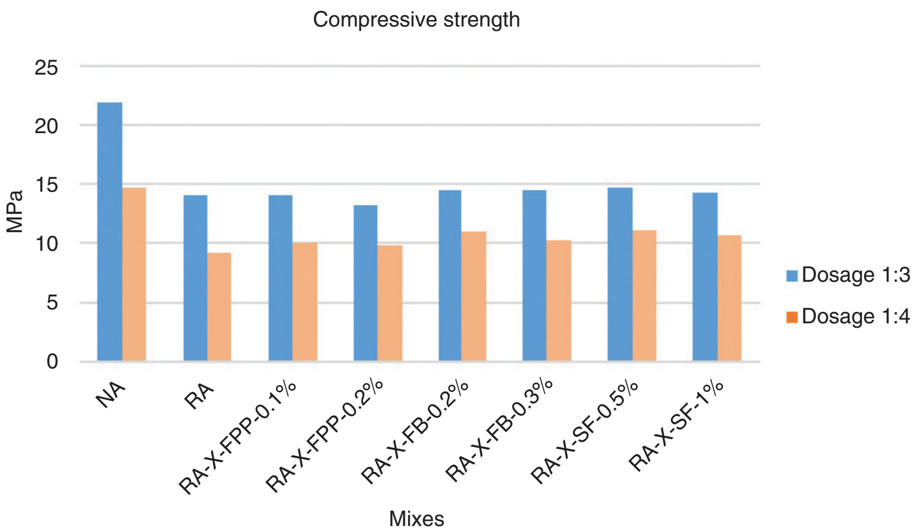

Figure 9. Compressive strength

Recycled concrete aggregates have a lower density, a higher friability coefficient and higher water absorption in comparison with natural aggregates. The recycled concrete aggregates present continuous size distribution curve, which is an essential characteristic for a good workability and mechanical properties of the mortars.

Based on the results of X-ray diffraction and fluorescence tests, it can be concluded that recycled concrete aggregates show phases with a low level of crystallinity, except for quartz and calcite, and it is composed mainly of calcium and aluminium silicates.

Incorporation of three types of fibres used in this work during the mixing allowed to reduce significantly shrinkage of recycled mortars, reaching values similar to those of natural mortars. The statistical analysis that was carried out shows that the factors “fibre types” and “dosage” have an important influence on the recycled mortars shrinkage, being the polypropylene fibre, up to 0.2%, which has better results in terms of reducing negative effects of shrinkage, for both 1:3 and 1:4 dosages.

Generally, the addition of fibres in recycled mortars improves their mechanical characteristics in terms of flexural and compressive strength. Mortars elaborated with recycled concrete aggregates incorporating up to 0.2% of fibreglass achieved an average improvement of 15.86% in flexural strength and 11.27% in compressive strength.

In case of mortars elaborated with natural aggregates, the shrinkage is lower in mixes that contain higher dosage of aggregates, as it builds an internal skeleton that prevents cement from shrinkage. Nevertheless, in recycled mortars the higher water absorption of aggregates causes higher shrinkage of the mixes with 1:4 dosage despite of their lower amount of cement.

Moreover, it was possible to establish a relation between the moisture content and the mortars shrinkage, using a capacitive sensor of the authors' own design, observing that the changes in moisture content are more significant in the early ages because of the conglomerate curing, getting balanced over days.

As expected, recycled mortars present higher water absorption by capillarity due to the characteristics of recycled aggregate. Its higher water demand causes evaporation of excess water during setting process producing larger capillary network.

As a final conclusion, and as the main objective of the paper is to improve the behaviour of recycled mortars in terms of dimensional variation, it can be stated that the incorporation of polypropylene fibres up to 0.2% reduces recycled mortars shrinkage, obtaining a similar to traditional mortars behaviour, making them suitable to be used as masonry mortars. Moreover, this incorporation of fibres improves both flexural and compressive strength of recycled mortars.

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