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Influence of recycled sand containing fillers on the rheological and mechanical properties of masonry mortars

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Abstract

In this work, we aim to study experimentally the influence of the fillers (<125 µm) of recycled sand on the properties of masonry mortars, with the same consistency, from the observation of the rheological behavior, slump, plasticity and shear strength and comparison of mechanical strength, compressive, flexural and tensile by splitting at 7 and 28 days. The formulation of the reference mortar based on natural river sand is made with cement CEM I 52.5 (C=506 kg/m^3), with ratios water/cement = 0.5 and sand/cement = 3.0. The other recycled mortars were shown to have the same plasticity as the reference mortar, and the amount of water added was determined using the weight of the recycled sand. The study was carried out on four series of mortars based on recycled sand with and without superplasticizer, replacing natural sand with recycled sand with and without fillers with different percentages of 0, 15, 30, 40, 50, 75 and 100%. The obtained results show that the recycled sand has relatively low physicochemical properties compared to natural sand due to the heterogeneity and the large percentage of the old hardened mortar contained in the recycled sand, in particular the fractions below 250 µm, a high percentage of fillers greater than 10% and a very high water absorption, seven times higher. The comparative study of different mortar compositions with different percentages of recycled sand with and without fillers showed that fillers require more water, which negatively affects the physical and rheological behavior, but in most cases,the the mechanical performance is better than that of the control mortar, in particular the mortars with admixtures.

1. Introduction

The construction industry, which is a driving force for economic development, is ranked third in terms of energy consumption. Therefore it is a major emitter of greenhouse gases, accounting for 33% of the total quantity of carbon dioxide (CO_2) [1], and one of the generators of billions of tons of solid waste [2–3]. It is becoming clear that the recycling of construction and decommissioning waste (CDW) is a major environmental issue and can be reused as aggregates for manufacturing new concretes which contribute in the natural resources preservation and would protect the environment, and also promote sustainable development principles [4–9].
The use of CDW as aggregates in concrete production for structural and non-structural applications has been one of the main research activities on concrete materials [2, 10–12].

Today, much of the existing research on recycled aggregates is related to the use of coarse aggregates from concrete waste in concrete production [11–12]. However, this approach limits the potential use of a large part of CDW composed of the red ceramics (masonry bricks) and used cement mortar. During crushing to produce aggregates from concrete waste, much of the material is reduced to grains less than 5 mm [4, 13–17]. This fine fraction is inevitable and can reach up to 50% of the total amount of recycled aggregates produced [15]. Some researchers [13, 18–19] consider that this fraction is harmful to durability, due to the presence of impurities (chlorides, sulphates, etc.) in the adhered cement mortar (ACM) and its high demand for water, which is most often not constant.

Other existing studies on recycled mortars are differently assessed [4, 7, 20–23]. The main result of this work is that the properties of these mortars are highly dependent on the quality, particle size and nature of the Fine Recycled Concrete Aggregates (FRCA) on one hand, the dosage and type of cement used, the sand/cement ratio, the quantity and type of additions such as lime and limestone fillers on the other hand, and even the specific mortar composition [20–21].

The substitution of natural sand by FRCA in masonry mortars leads to an increase in the quantity of mixing water [22–27], which can reach 75% in order to achieve the same plasticity [24]. Generally, this is related to the absorbency of the recycled aggregates, which is a constraining factor for widespread use of this type of aggregate [14, 23–27]. Recently, Lima et al. [28] showed that the fluidity of the mortars decreased with the increase in the rate of FRCA in mortars. Thus, the presence of the recycled aggregates results in a reduction of the yield strength and the plastic viscosity beyond 30 min at the beginning of the hydration of the cement compared with the natural aggregate mortar. Note that the morphological aspect of aggregates is an essential parameter on the rheological behavior of mortars and concretes [29–32]. This aspect is further accentuated for recycled aggregates, by crushing of which develops strongly their specific surface area, which requires additional quantities of mixing water to ensure adequate flows [19, 31–35].

It is worth mentioning that the workability of the mortars depends mainly on the water condition of the sands used, especially the recycled ones. It is inversely proportional to the rate of recycled sand (RS). It is more delicate with dry RS than with RS saturated with water. However, the workability of recycled mortars decreases when RS is used in a saturated state [36]. In this context, Mefteh et al. [37] tested the influence of the humidification of recycled aggregates on the workability of concrete and it emerged from their study that the loss was significant for the first 30 minutes.

Concerning mechanical behavior, the incorporation of the FRCA is particularly determinant to the mechanical performance and durability of concrete and mortar. Interestingly, Corinaldesi [25] found that 100% recycled mortars with a dosage of 450 kg/m^3 of CEM II / AL 42.5 R had significantly lower mechanical strength than that of the reference natural mortar, particularly when using brick aggregates of masonry. However, these mortars behaved well in masonry assemblies under shear loads due to the better quality of the interfacial zone.

The results obtained by Dapena et al. [38] indicate that the use of RS in excess of 20% results in a decrease in compressive and flexural strength. Similarly, Samiei et al. [22] found that the mechanical strengths of cement mortars with 100% recycled aggregates dropped by 40% and 32% respectively in compression and flexion. On the contrary, cement–lime mortars (50/50%) exhibit an improvement in mechanical properties up to 60% by increasing the quantity of recycled aggregates, and similarly for the modulus of elasticity, which improves by 28%. Furthermore, Neno et al. [20] indicated that with volumetric proportions of a cement-to-aggregate ratio of 1:4 and cement CEM II/B-L Class 32.5 R, the mechanical properties of recycled mortars are higherthan those of natural mortar at all maturities.

Zhao et al. [14] studied the influence of different granular classes of RS on mortar properties. They found that the compressive strength of the mortars decreased almost linearly as the percentage of replacement with recycled sand increased. Moreover, it is shown that the finest fraction of recycled sand (0/0.63 mm) has a detrimental effect on the mechanical properties of mortars.

These experiments based on the use of CDW can be extended to developing countries like Algeria, where the ban on the extraction of alluvial materials, the saturation of public dumps in demolition materials, and the search for new sources of concrete aggregates can be solved.

1.1. *Objectives*

The main aim of this work is the physical and chemical characterization of recycled sand, and study of the influence of their fillers (<125 µm) on the rheological and mechanical behavior of masonry mortars with and without superplasticizer. To this end, four series of mortars have been made, in two of which the recycled sand is used in the raw state (with fillers). The tests are carried out on 24 mixtures of masonry mortars, with different percentages of voluminal substitution of natural river sand from 0% to 100%.

2. Experimental program

2.1. *Materials used*

In this study, the constituents of the mortar mixtures are basically cement, sand, water and superplasticizer:

An artificial Portland cement CEM I 52.5, with a relative density of 3.15, produced by the Lafarge cement plant in Teil, France, in compliance with NF EN 197-1:2012.

Two types of fraction sands (0/3.15 mm): Natural river sand (NS) and recycled sand with fillers (RS). The latter is produced in the laboratory, and is obtained as a result of crushing ordinary concrete specimens of an average strength of 30 MPa, aged for less than 3 months and crushed in a jaw crusher.

A superplasticizer / High Range Water Reducer (SP), type SikaViscocrete TEMPO 11, conforming to standard NF EN 934-2/IN1:2012, with a density of 1.06 kg/m^3, dosage range of 0.3 to 3.0% by weight of the binder and the dry extract = 30.0 ± 1.5%.

2.2. *Characterization of materials*

2.2.1. *Chemical characteristics*

Chemical analysis data from X-ray fluorescence spectroscopy (XRF) of the cement and sands used are shown in Table 1.

Table 1: Chemical composition of cement and sands used

Raw material	Oxide weight (%)								
	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	SO_3	TiO_2	MgO	Total
CEM I 52.5	70.3	21.2	3.9	0.6	0.3	3.3	0.0	-	99.7
Natural Sand	0.1	93.3	4.3	0.1	2.1	0.0	0.1	-	99.8
Recycled Sand	15.4	66.7	6.2	0.6	1.2	1.1	0.3	-	91.5
Fillers of RS	25.1	48.0	8.8	0.8	1.6	1.6	0.4	-	86.2

Table 2: Percentage of calcium carbonate content by calcimetry

Samples	Percentage of $CaCO_3$
Recycled Sand	9.0 %
Fillers of RS (<125µm)	19.6 %
Fines of RS (<63µm)	32.0 %

Table 3: Dissolution of the different fractions of fine RCA in hydrochloric acid (0.1N)

Granular fraction	< 63 µm	63 µm-250 µm	250 µm-1 mm	1 mm-3.15 mm
Weight loss (%)	9.4	14.4	9.3	5.7

Table 1 shows that the RS contains in its composition a high percentage of silica, which shows that the siliceous origin of the aggregates used in the formulation of the parent concrete. The chemical composition of the RS is similar to that of cement in the qualitative aspect, thus reflecting the existence of cement hydration products. This conclusion is confirmed by Table 2, where calcium carbonate $CaCO_3$content in fines of RS (<63 µm) is twice that in fillers and three times higher than in RS. The levels of these oxides in RS are similar to those found in other studies [39–40]. Table 3 shows that the amount of calcium carbonate and Portlandite $Ca(OH)_2$ is noteworthy in the fraction 63–250 µm of RS, following the large percentage of the 14.4% weight loss of the dissolution in hydrochloric acid by chemical reactions (Eq. 1 and Eq. 2) [41]:

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O \quad (1)$$

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O \quad (2)$$

2.2.2. *Particle size analyses*

Granulometric analysis of the sands used was carried out according to the Standard NF EN 933-1:2012, as shown in Figure 1.

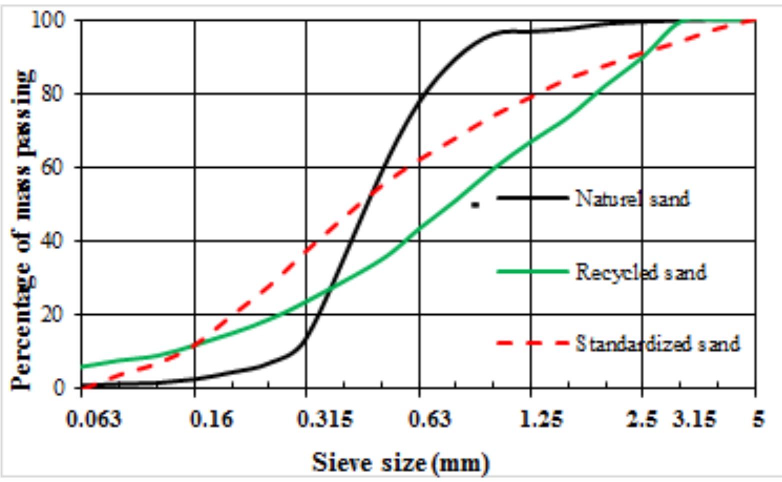

Figure 1: Particle size distribution curves for the sands used

The grain size of the RS is well spread, giving a coarse sand with a Fineness Modulus (FM) of 2.94. However, the NS consists mainly of the fraction (0.315/1.25 mm), which is a rather fine sand with FM = 2.38. The RS is heterogeneous sand characterized by high levels of old hardened mortar, in particular fractions below 250 µm (Table 3), rich in 11% fillers and fines 6%, which is below the limit of 8% prescribed for use in masonry mortar [39]. The volume substitution of NS by RS generates almost uniform sands. Note that recycled sand without fillers (RS-F) is obtained by dry sieving of the RS.

2.2.3. *Physical characteristics*

The physical characteristics, which are determined in accordance with the standards and test results, are presented in Table 4.

Table 4: Physical characteristics of sands used

Physical properties	NS (0/3.15)	RS (0/3.15)	RS-F(0.125/3.15)	Norms
Bulk density g/cm^3	1.406	1.191	1.238	NF EN 1097-3
Real density g/cm3	2.588	2.581	2.594	NF EN 1097-6
Modulus of Finesse"FM"	2.38	2.94	3.15	NF EN 933-1
Sand equivalent (%)	92.52	87.33	-	NF EN 933-8
Fillers content "Filler than 125 µm**" (%)**	1.4	10.7	-	NF EN 933-1
Fines content "Finer than 63 µm**" (%)**	0.4	5.6	-	NF EN 933-1
Humidity content (%)	1.12	2.91	-	NF P 94-050
Water absorption (%)	2.19	13.37	13.75	NF EN 1097-6

The bulk density of the NS is greater than the RS, but their actual densities are equivalent. This can be explained by the nature of the rubble, whose density is about 2.7 g/cm^3, from which the sand is recycled on the one hand, and the omission of the fine part (<63 µm) in the density calculation according to the Standard NF EN 1097-6:2013 on the other hand. The water absorption of the RS is consequently seven times higher than that of the NS. This value appears to be greater than that found in the literature [11, 14 and 36]. This can be explained by the roughness of the RS, which increases during crushing, as well as the porosity of the ACM and the large percentage of fillers (11%), which generates a very high surface area.

3. Mixing procedure

The mortars were mixed in a standard mixer (NF EN 998-2: 2010); the mortar mixtures were made with a fixed water/cement ratio of $1/2_{Mass/Mass}$ and cement/sand ratio of $1/3_{Mass/Mass}$. The reference mortar mixtures were made with 506 kg/m^3 cement, 1518 kg/m^3 sand and 253 kg/m^3 water. Four series of mortars manufactured with different replacement ratios of volume of natural sand by fine recycled concrete aggregates were tested: 0, 15, 30, 40, 50, 75 and 100%. The compositions of the recycled masonry mortars, based on recycled sand with and without fillers, are shown in Tables 5 and 6 respectively.

Table 5: Compositions of mortars formulated with RS

Series	Mortars	Cement (kg/m^3)	NS (kg/m^3)	RS (kg/m^3)	W (L)	W_{ad} (L)	W_{Tot} (L)	W_{Tot}/C	SP (% C)
Serie 1	**M0**	506	1518	0	253	0	253	0.50	-
	M15	506	1290	227	253	20	273	0.54	-
	M30	506	1062	454	253	41	294	0.58	-
	M40	506	911	605	253	54	307	0.61	-
	M50	506	759	757	253	68	321	0.63	-
	M75	506	379	1135	253	102	355	0.70	-
	M100	506	0	1514	253	136	389	0.77	-
Serie 2	**M15A (*)**	506	1290	227	253	2	255	0.50	0.5
	M30A (*)	506	1062	454	253	4	256	0.51	1.0
	M40A (*)	506	911	605	253	7	260	0.51	2.0
	M50A (*)	506	759	757	253	11	264	0.52	3.0
	M75A (*)	506	379	1135	253	14	267	0.53	4.0
	M100A (*)	506	0	1514	253	21	274	0.54	6.0

(*) A: Mortars with superplasticizer

Table 6: Compositions of mortars formulated with RS-F

Series	Mortars	Cement (kg/m^3)	NS (kg/m^3)	RS-F (kg/m^3)	W (L)	W_{ad} (L)	W_{Tot} (L)	W_{Tot}/C	SP (% C)
Serie 3	**M15-F**	506	1518	0	253	0	253	0.50	-
	M30-F	506	1290	226	253	11	264	0.52	-
	M40-F	506	1062	453	253	23	276	0.54	-
	M50-F	506	911	604	253	33	286	0.57	-
	M75-F	506	759	755	253	45	298	0.59	-
	M100-F	506	379	1132	253	68	321	0.63	-
Serie 4	**M15A-F (*)**	506	1290	226	253	1	253	0.50	0.15
	M30A-F (*)	506	1062	453	253	1	254	0.50	0.25
	M40A-F (*)	506	911	604	253	2	255	0.50	0.5
	M50A-F (*)	506	759	755	253	4	256	0.51	1.0
	M75A-F (*)	506	379	1132	253	11	264	0.52	3.0
	M100A-F (*)	506	0	1510	253	0	253	0.50	6.0

(*) A: Mortars with superplasticizer

The natural control mortar, which is formulated from dry natural sand, gives rise to a plastic and malleable mortar. This plasticity is considered for all the other recycled mortars made. To eliminate the probable absorption by the recycled sands of the mixing water [13] and to have a dry surface saturated state, these sands were pre-wetted during kneading for 10 min before the addition of the other constituents. Preliminary tests to quantify the pre-saturation amounts of water gave 9% of optimum weight of the RS in the first series and only 6% of the weight of the RS-F in the third series, from which the influence of the fillers appears remarkable.
In series 2 and 4 for the mortars with admixtures, all the sands are used in the dry state, and superplasticizer is added in order to maintain the same plasticity as for the other series. The range used varies from 0.15% (M30-F) to a maximum content of 3.0% (M50 and M75-F). The recommended range of use of the superplasticizer is exceeded for the mortars M75A, M100A and M100A-F, it was not possible to put them into the molds by simple vibration, and the mixtures lacked cohesion. The dosage of SP is higher in the 2nd series than in the 4th series, which is due to the effect of the fillers, which are characterized by large specific surfaces.

4. Experimental methods

4.1. *Fresh state tests*

Five properties of the fresh mortar were characterized to assess the use of RS in mortar mixtures: the consistency, bulk density, air content, plasticity and shear strength.

4.1.1. *Consistency*

The consistency of the mortar was determined by measuring slump, using a mini cone "MBE" (Concrete Equivalent Mortar). The test was carried out by filling the cone in two vibrated layers for a duration of 5 seconds each. The cone was lifted vertically and the slump was measured in time (t = 0), then the mortar was vibrated for (2s) at a frequency of 50 Hz and the subsidence was measured at (t = 2s).

Slump at (t=0)

Slump at (t=2s)

Figure 2: Measurement of slump using the MBE

4.1.2. *Bulk density and air content*

The bulk density of the mortar was determined according to the Standard NF EN 1015-6/A1:2007. The air content was measured using a mortar aerometer "Controlab 1L", according to the Standard NF EN 1015-7:1999.

4.1.3. *Plasticity of mortars*

The fluidity of the mortar was evaluated according to the Standard NF EN 413-2:2006, using a cubic plasticimeter (110x110x110 mm^3) fixed to a vibrating table with a frequency of 50 Hz and fitted with a rectangular opening (10x30 mm²) located at the base of one of the faces of the cube. The plasticity of the mortar was characterized by the mass flow, which was calculated by means of the following formula (Eq. 3):

$$Q = M/t \tag{3}$$

where $\boldsymbol{Q}$is the flow rate of mortar (g/s), $\boldsymbol{M}$ is the mortar mass recovered in grams (g) and $\boldsymbol{t}$ is the mortar flow time in seconds (s).

4.1.4. *Shear strength*

The shear strength of the mortar was determined using a laboratory scissometer, VJ Technology model VJT5300, as shown in Figure 3, which is intended to measure the shear strength of poor soils, according to the Standard NF P 94-112:1991. The shear strength was calculated according to the following formula (Eq. 4):

$$\tau_v = (1000\,.\,\theta.\,FE)/\left(\pi.\,D.\left(\frac{H}{2}+\frac{D}{6}\right)\right) \tag{4}$$

where $\boldsymbol{\theta}$ is the maximum angular deflection of the spring (degree), $\boldsymbol{FE}$ is the spring calibration Factor (N.mm/degree), $\boldsymbol{D}$ is the width of the pallet (mm) and $\boldsymbol{H}$ is the height of the pallet (mm).

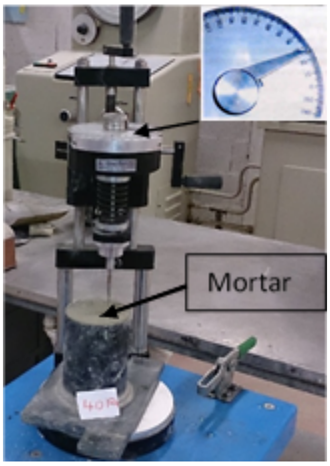

Figure 3: Laboratory scissometer

4.2. *Hardened state tests*

The test specimens were removed from the mold 24 hours after manufacture and stored in immersion in water at T = 20 ± 2 ° C until the test period, in accordance with the Standard NF EN 12390-2:2001. The mechanical properties of the hardened mortars were evaluated using compressive and flexural strength according to the Standard NF EN 1015-11/A1:1999 and splitting tensile tests. These mechanical tests were carried out on a Zwick/Roell press with a loading capacity of 200 kN according to NF EN 196-1:2016 standards. The three-point flexural strengths and uniaxial compression were determined on prismatic test pieces (40×40×160 cm^3) and (40x40x40 mm^3) respectively, while the splitting tensile tests were carried out on cylindrical specimens (40x80 mm²). The obtained results represent the average of three values for each mixture.

5. Experimental results and discussion

5.1. *Fresh state*

5.1.1. *Bulk density and air content*

The results obtained from the percentages of air content and bulk density of the different mortars correspond to the average of three values obtained (Table 7 and Figure 4).

Table 7: Percentage of air content in different mortars

Mortars with fillers	M0	M15	M30	M40	M50	M75	M100	M15A	M30A	M40A	M50A	
Air Content (%)	6.4±0.3	7.2±0.5	6.3±0.3	7.6±0.4	7.0±0.3	6.1±0.4	5.7±0.2	6.5±0.4	5.2±0.4	4.5±0.4	2.7±0.3	
Mortars without fillers	**M0**	**M15-F**	**M30-F**	**M40-F**	**M50-F**	**M75-F**	**M100-F**	**M15A-F**	**M30A-F**	**M40A-F**	**M50A-F**	**M75A-F**
Air Content (%)	6.4±0.3	7.3±0.4	6.9±0.2	6.7±0.4	7.4±0.5	7.1±0.6	6.1±0.6	4.6±0.3	4.3±0.5	4.1±0.4	4.3±0.3	3.4±0.2

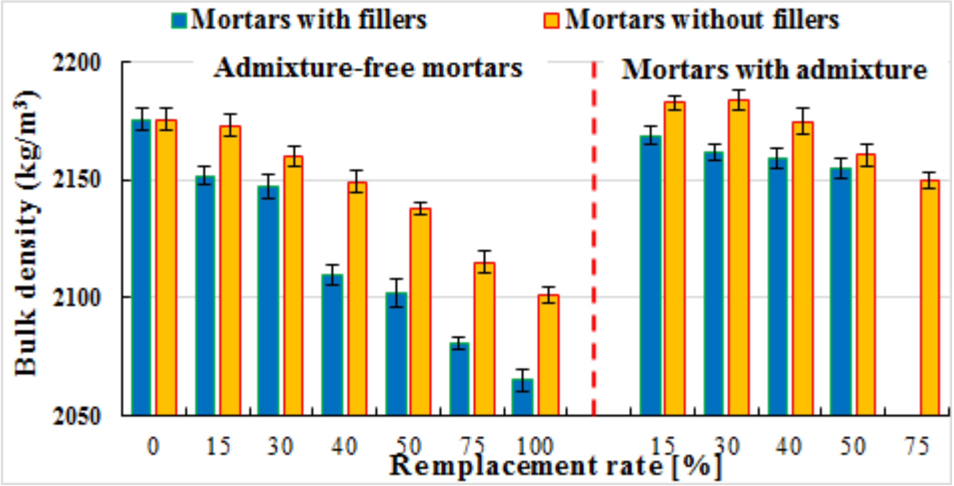

Figure 4: Influence of recycled sand replacement ratio on bulk density

Table 7 shows that the air contentin all the admixture-free mortars with and without fillers fluctuates according to the NS substitution rate, reaching 19% for RS = 40% and only 16% for RS-F = 50%. Conversely, with the incorporation of the superplasticizer, the rheological behavior is modified. It is worth observing that the percentage of air contentregisters a progressive decrease with increase of the dosage of the SP and for a maximum dosage of 3.0% of the superplasticizer, showing significant air content decreases of 58% for M50A and 47% for M75A-F.

As can be seen from Figure 4, the bulk density of the admixture-free mortars decreases with increasing NS replacement rates, and much more for those containing RS, with a decrease of 5% for 100% recycled mortar (M100) and 3% for those without fillers (M100-F). Due to the equivalence of the actual sand mass densities, this decrease is mainly due to the increase in water content with the increase in the RS content. As concerns the densities of the mortars with admixtures, a slight decrease was expected due to the slight increase in water content, showing only a maximum decrease of 1.2% for RS-F = 75%. This is probably due to the superplasticizing effect, which improves the compactness of mortars [19, 26 and 42].

5.1.2. *Slump and flow rate*

The results of the slump and flow rate are shown in Figures 5 and 6. Figure 5 shows that the subsidence of mortar increases with the increase in the rate of recycled sand in the mortars. These variations are due to differences in morphology and particle size between natural rolled sand and coarse recycled sand with rough texture. However, the subsidence at t = 0 second remains similar for all admixture-free mortars, of which there is a correlation between the percentage of SR incorporated and the amount of water added. However, the amount of fillers increases with the increase of the RS rate, it negatively affects the workability of these mortars.On the other hand, under the effect of the superplasticizer, the variations of slump of the mortars with adjuvants are greater, slump = 14% for SR = 30% to slump = 35% for RS-F = 50%.

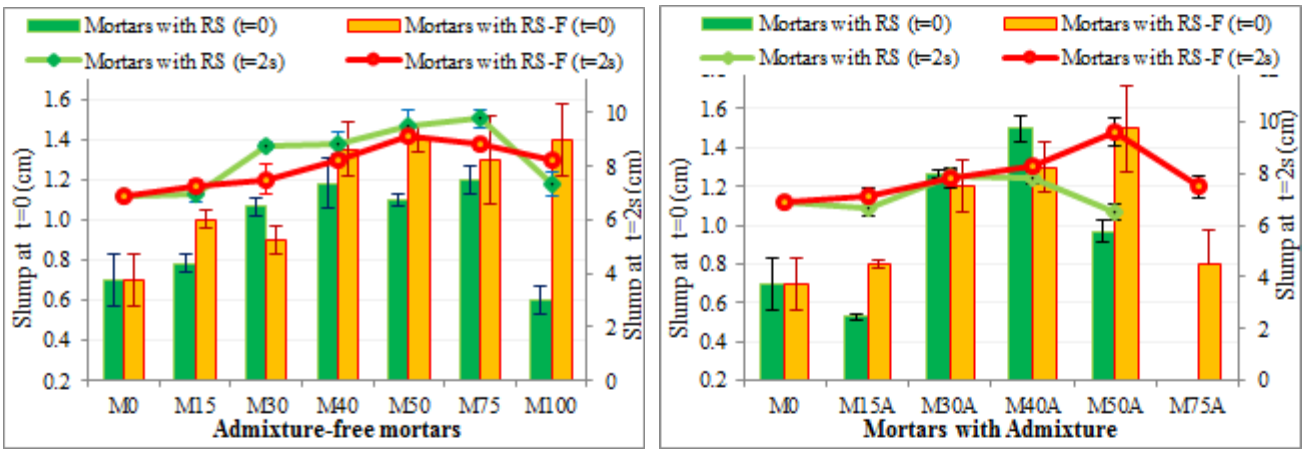

Figure 5: Slump of different mortars

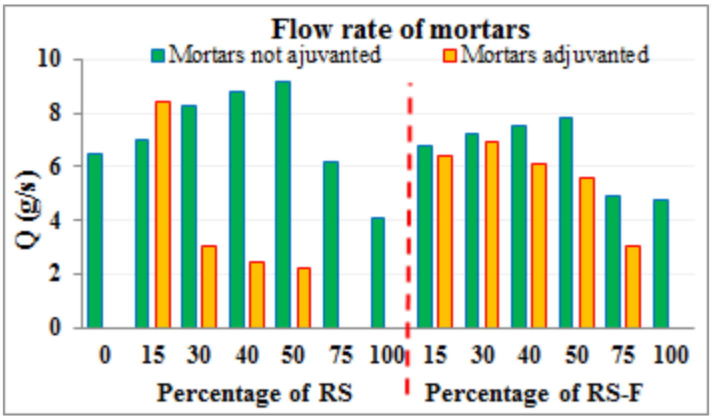

Figure 6: Flow rates of different mortars

Through Figure 6, the fluidity of all the admixture-free mortars was related to the quantity of mixing water (W/C) regardless the nature of the recycled sand with and without fillers. It increases with the increase in the rate of RS up to 50%. The decrease in the plasticity of mortars M75, M100, M75-F and M100-F was due to clogging at the outlet hatch of the plasticimeter. On the contrary, the plasticity of the mortars with superplasticizer decreases with the increase in the dosage of the latter. This decrease was more important for the mortars containing RS whose dosage of the SP is higher. These variations, however, remain low as a consequence of the constant rheology objective fixed for the composition of the masonry mortars.

5.1.3. *Shear strength of mortars*

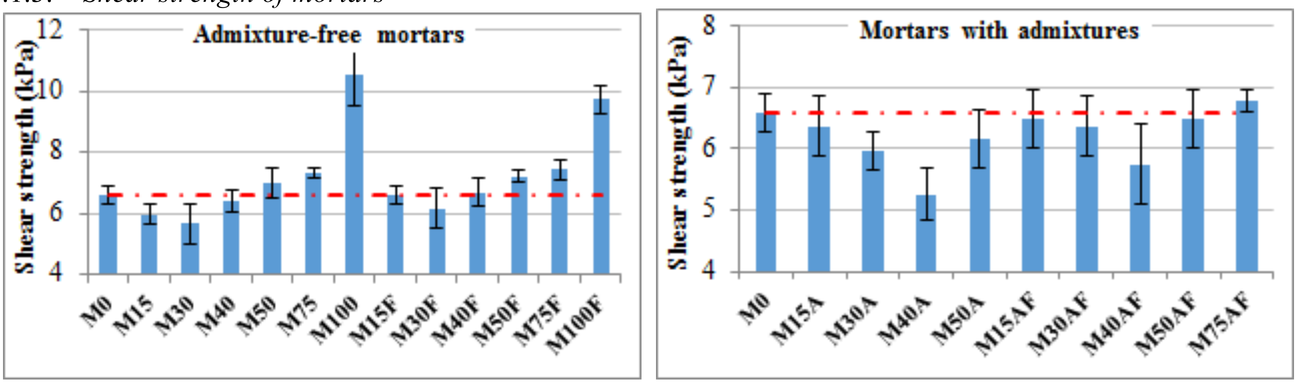

Figure 7: Shear strength of different mortars

It is clear that the influence of the fillers on the cohesion of the recycled mortars with respect to the control mortar is remarkable. For RS and RS-F levels below the optimum (30%), the shear strength decreases progressively, with decreases of 14 % for RS = 30% and only 6% for RS-F = 30%. Over 30%, the mortar cohesion increases with the percentage of recycled sand, and reaches the maximum of 60% for 100% RS and 48% for RS-F = 100%. The incorporation of the superplasticizer into the mortars favors the scattering of their components, particularlythe RS-based mortars, and the M40A shear strength with a reduction of6% compared to M40 and that of the M75A-F was 11% compared to M75-F.

5.2. *Mechanical behavior*

5.2.1. *Compressive strength*

Figure 8 illustrates the results of compressive strength at 7 and 28 days of curing for the mortars depending on the replacement ratio of NS by RS with and without fillers. In this figure, the effect of superplasticizer was also taken into account. The dispersion of the results, which seems almost identical in magnitude for all mortar mixes, have statically no significant difference between the mean values. This indicates that the tested mixtures are homogeneous.

At short-term (at 7 days), the compressive strengths of masonry mortars based on RS are higher than in the reference control mixture. These improvements in strength may be explained by the probable existence of anhydrous constituents of cement that have not yet undergone hydration [43–44]. In this study, the crushed concretes used to make fine recycled aggregates are less than 3 months of age. The gains amounted to 25% and 40% for the replacements using 30% RS (with filler) and 40% RS without filler (RS-F), respectively. These results are consistent with those reported by Zhao et al. [14] and Neno et al. [20].

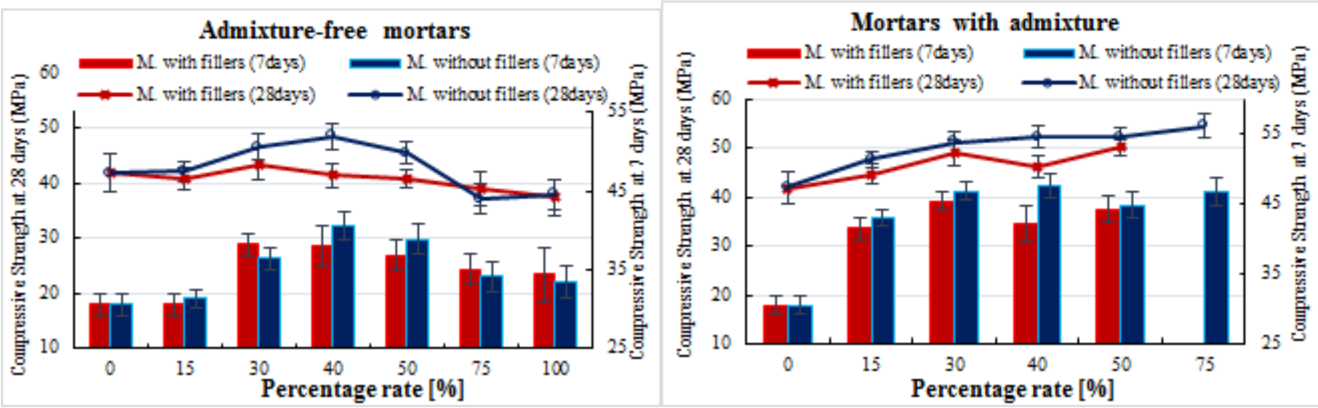

Figure 8: Influence of RS replacement ratio on compressive strength at 7 and 28 days

At the age of 28 days, the same trends are observed, and the compressive strengths of the recycled mortars decrease beyond the optimums (ranging from30 to 50% RS). These results were in agreementwith those obtained by Sajedi et al. [45]. The addition of superplasticizer in the mix considerably improved the compressive strengths for all recycled mortars, in particular those made of RS-F. The contribution of superplasticizer provides a W/C ratio that remains almost constant to maintain proper workability.

5.2.2. *Flexural* and splitting *tensile strengths*

The flexural strength in the 3-point flexure test and splitting strength at the ages of 7 and 28 days are shown in Figures 9 and 10, respectively.

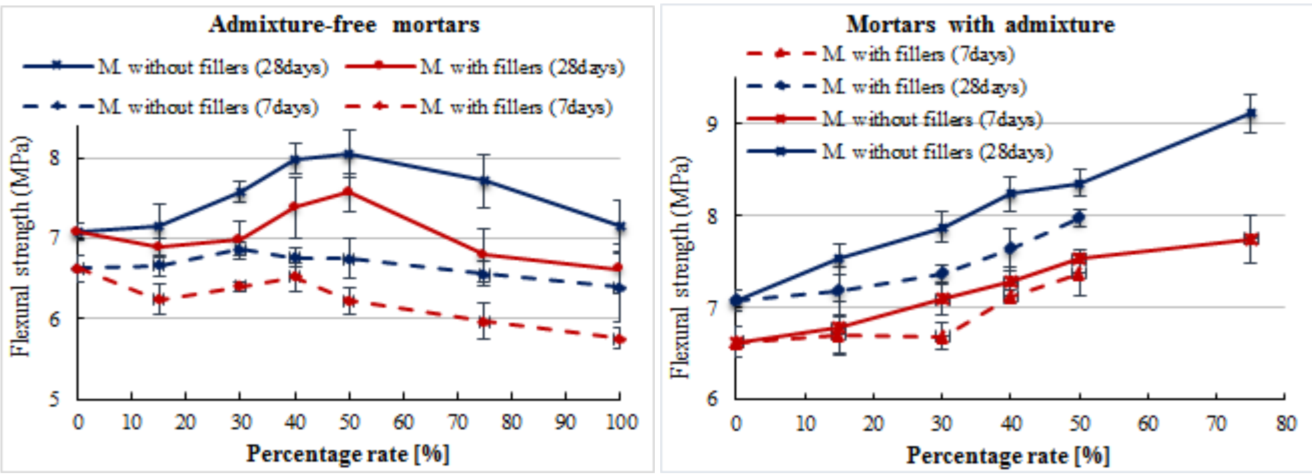

Figure 9: Influence of RS replacement ratio on flexural strength at 7 and 28 days.

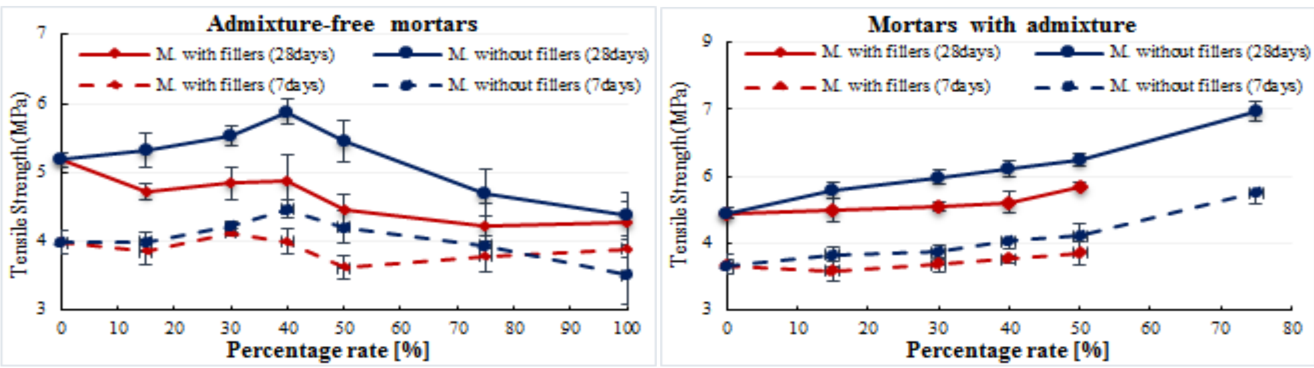

Figure 10: Influence of RS replacement ratio on splittingstrength at 7 and 28 days.

From these results (Figure 9), it can be seen that the flexural strengths show an increasing trend until the replacement rate of natural sand by the recycled sand with and without fillers reaches the optimum of 50%. At the age of 28 days, for the RS-F mixture, there is a 14% higher gain than the M0 mixture. The recycled sand without fillers (RS-F) is characterized by particles that have a greater angularity, a rough surface and are more porous, thus ensuring a high bond with the cement paste [22, 32]. However, for mortars based on recycled sand

(RS), the flexural strengths were significantly affected. This drop in resistance is due to poor characteristics of fine particles: a higher content (11%), a higher water absorption coefficient and poor mechanical properties. These findings were discussed by Zhao et al. [14], following the incorporation of the fine fraction (<0.63mm) in mortars. The same trends are observed for the splitting strengths (Figure 10) of recycled mortars based on RS-F are, in general, relatively low compared to the reference mortar and also lower in mortars made with RS.Nevertheless, it must be noted that there were improvements in mortars'resistance whose rate of recycled sand without fillers did not exceed 40%. These results are in perfect agreement with the results of the literature review [7, 22, 34 and 46].

Various factors may be the cause of this difference. The Recycled sand contains a large amount of fine particles (as fillers) which give a high specific surface area and therefore this will strongly influence the water demand of the recycled sand and which largely affects the W/C ratio. In addition, a large quantity of fine particles may disrupt the granular packing during mixing and thus cause a reduction in strength [13-14]. Whereas, the recycled sand without fillers requires less water (6% by weight) following these morphological characteristics, which results in the resistance of these much improved mortars. Conversely, the addition of superplasticizer in the mix has been beneficial, and the flexural and splitting strengths show a steady increase, particularly for mortars made with RS-F. Compared to the control mortar at age 28 days, the strength gains of mortars based on SR-F-based was 40% for splitting strength against 29% for flexural strength.Although the W/C ratio is almost constant (Tables 5 and 6), the effect of the superplasticizer is quite remarkable on the decrease of the occluded air (Table 7), and consequently the compactness of the mortars is improved.

Conclusions

This paper discusses the effect of the replacement of natural sand by fine recycled concrete aggregates with and without fillers on the rheological and mechanical properties of masonry mortars. From the obtained results, several findings emerge from this study:

On rheological behavior:

- Fine recycled concrete aggregate is a heterogeneous sand, characterized by high levels of old mortar, particularly, fractions below 250 μm that are rich in fillers (11%) and fines (6%), which resulted in a high water absorption capacity of the order of 13%, seven times higher than that of natural sand.
- The pre-wetting of recycled sand is essential, in order to quantify the mixing water and to control the workability of fresh mortars. The amount of pre-wetting water determined is about 9% for RS with fillers and 6% for RS without fillers. This depends on the quality of the fine recycled aggregate and its fine particle fraction rate.
- The morphology of fine recycled aggregates, particularly fillers, has influenced the compactness of the granular skeleton on one hand and the workability of the fresh mortar on the other. However, the use of a percentage of recycled sand with fillers greater than 30% adversely affects the plasticity and shear strength of mortar.
- The addition of superplasticizer in the mortars gave the desired effect on rheological behavior.

On hardened behavior:

- The presence of fillers in fine recycled aggregates has considerably influenced the mechanical strength. A replacement over 30% of recycled sand containing fillers will compromise the strength.
- The replacement rate of recycled sand can reach as high as 50% if no fillers are used, without affecting the mechanical behavior.
- The effect of superplasticizer was obvious, it allowed the mechanical behavior to be improved mainly for the flexural and splitting strengths.

The replacement of natural sand by recycled sand for the formulation of masonry mortars proved to be profitable not only for the obvious environmental advantages, but also for its feasibility and mechanical properties, especially for mortars without fillers and where the substitution of natural sand does not exceed 50%.

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References

1. S.O. Ajayi, L.O. Oyedele, M. Bilal, O.O. Akinade, H.A. Alaka, H.A. Owolabi, K.O. Kadiri, *Resour Conserv Recycl.*102 (2015) 101–112.
2. D. Pedro, J. de Brito, Evangelista L., *Constr. Build. Mater.* 71 (2014) 141–151.

3. J. Pacheco, J. de Brito, J. Ferreira, D. Soares, *J. Clean. Prod.* 142 [4] (2017) 4195–4205.
4. S. Manzi, C.Mazzotti, M. C.Bignozzi, *Cem. Concr. Compos.* 37 (2013) 312–318.
5. C. Shi, L. Yake, J.Zhanga, W.Li, L.Chong, Z.Xie, *J. Clean. Prod.* 109 (2016) 139–145.
6. J. Zhang, C.Shi, Y.Li,X.Pan, C.S.Poon, Z.Xie, *Constr. Build. Mater.* 98 (2015) 1–7
7. I. Martínez, M. Etxeberria, E. Pavón, N. Díaz, *Constr. Build. Mater.* 49 (2013) 384–392.
8. C. Faella, C. Lima, E. Martinelli, M. Pepe, R. Realfonzo, *Cem. Concr. Compos.*71 (2016) 85e96
9. R. V. Silva, J. de Brito, R. K. Dhir, *J. Clean. Prod.* 143[1] 2017 598–614,
10. I. González-Taboada, B., Martínez-Abella Belén González-Fonteboa F., J. L. Juan Luis Pérez-Ordóñezb, *Mater. Construcc.* 66[323](2016)e089.
11. F. Özalp, H. D.Yılmaz, M.Kara, Ö.Kaya, A.Şahin, *Constr. Build. Mater.* 110 (2016) 17–23.
12. S. W. Tabsh, A. Abdelfatah, *Constr. Build. Mater.* 23 (2009) 1163–1167.
13. C. Rodríguez, C. Parra, G. Casado, I. Miñano, F. Albaladejo, F. Benito, I. Sánchez, *J. Clean. Prod.* 127 (2016) 152–160.
14. Z. Zhao, S. Remond, D. Damidot, Xu Weiya, *Constr. Build. Mater.* 81 (2015) 179–186.
15. C. Ulsen, H. Kahn, G. Hawlitschek, E. A. Masini, S. C. Angulo, V. M. John, *Constr. Build. Mater.* 40 (2013) 1168‑1173.
16. H. Gomart, E. Ghorbel, G. Wardeh, *31st AUGC Meetings – E.N.S. Cachan* 1245 (2013) 1–10.
17. E.F. Ledesma, J.R. Jiménez, J. Ayuso, V. Corinaldesi, F.J. Iglesias-Godino, *Mater. Construcc.* 66[321] (2016) e075.
18. L. Evangelista, J. de Brito, *Cem. Concr. Compos.* 29 (2007) 397–401.
19. P. Pereira, L. Evangelista, J. de Brito, *Cem. Concr. Comp.* 34 (2012) 1044-1052.
20. C. Neno, J. de Brito, R. Veiga, *Mat. Res.* 17 [1] (2014) 168–177.
21. Ö. Çakır, *Constr. Build. Mater.* 68 (2014) 17–25.
22. R.R. Samiei, B.Daniotti, R.Pelosato, G.Dotelli, *Constr. Build. Mater.* 84 (2015) 84–94.
23. J. Silva, J. De Brito, R. Veiga, *J. Mater. Civ. Eng.* 22 [3] (2010) 236–244.
24. C.S. Poon, Z.H. Shui, L. Lam, *Constr. Build. Mater.* 18 [6] (2004) 461–468.
25. V. Corinaldesi, *Cem. Concr. Compos.*31[7] (2009) 505–510.
26. G.M. Cuenca-Moyano, M. Martín-Morales, I. Valverde Palacios, I. Valverde-Espinosa, M. Zamorano, *Constr. Build. Mater.* 70(2014) 71-79.
27. J. Garcia-González, D. Rodríguez-Robles, A. Juan-Valdés, Mª J. Morán-del Pozo, M. I. Guerra-Romero, *Materials* 7 (2014) 6224-6236.
28. P. R. L. Lima, R. D. Toledo Filho, O. F. M. Gomes, *Key Eng. Mater.*600 (2014) 297-307.
29. Z.H. Duan, C.S. Poon, *Mater. Design* 58(2014) 19-29.
30. A. Akbarnezhad, K.C.G. Ong, C.T. Tam, M.H. Zhang, *J. Mater. Civil Eng.* 25 (2013) 1795–1802.
31. D. Xuan, B.Zhan, C. S.Poon, *Cem. Concr. Comp.* 65 (2016) 67e74.
32. V. Corinaldesi, M. Giacomo, *Constr. Build. Mater.* 23 (2009) 289–294.
33. H.Z. Cui, X.Shi, S.A.Memon, F.Xing, W.Tang,*J. Mater. Civ. Eng.* 27 [4](2015) 1-9.
34. P. Saiz-Martínez, M. González-Cortina, F. Fernández-Martínez, *Mater. Construcc.* 65 [319](2015) e058.
35. I. Martínez, M. Etxeberria, E. Pavón, N. Díaz,*Revista construcc.*15[1](2016) 9-21.
36. LeThang, R.Sébastien, S.Gwenn Le, G. D.Eric,*Constr. Build. Mater.* 106(2016) 35-42.
37. H. Mefteh, O. Kebaïli, H. Oucief, L. Berredjem, N. Arabi,*J. Clean. Prod.* 54 (2013) 282–288.
38. E. Dapena, P. Alaejos, A. Lobet, D. Pérez, *J. Mater. Civ. Eng.* 23 (2011) 414–22.
39. M. Braga, J. de Brito, R. Veiga, *Constr. Build. Mater.* 36 (2012) 960–968.
40. Vegas I., Azkarate I., Juarrero A., Frías M., *Mater. Construcc.* 59[295](2009) 5-18.
41. M. Mouli, Y.Senhadji, A. S.Benosman, H.Khelafi,*Sci.& Tech. Comm.* 08(2010) 57-63.
42. P. Pereira, L. Evangelista, J. de Brito, *Constr. Build. Mater.* 28(2011) 722-729.
43. A.I. Torres-Gómez, E. F. Ledesma, R. Otero, J.M. Fernández, J.R. Jiménez, J. de Brito, *Materials* 9 [9] (2016) E729.
44. E.F. Ledesma, J.R. Jiménez, J.M. Fernández, A.P. Galvín, F. Agrela, A. Barbudo, *Constr. Build. Mater.* 71(2014) 289–298.
45. F. Sajedi, H. A. Razak, *Constr. Build. Mater.* 25 [4](2011) 2036-2045.
46. C. Feys, M.Joseph, L.Boehme, Y.Zhang,*CESB16 Prague*(2016) 1071–1078.

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