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► **To cite this version:**

Layachi Berredjem, Abdelhak Bordjiba, Laurent Molez, Nourredine Arabi. Influence of the recycled sand on the cement mortars. *Studies in Engineering and Exact Sciences*, 2024, 5 (1), pp.1152-1165. 10.54021/seesv5n1-060 . hal-04574490

**HAL Id: hal-04574490**

**<https://hal.science/hal-04574490>**

Submitted on 14 May 2024

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## Influence of the recycled sand on the cement mortars

## Influência da areia reciclada nas argamassas de cimento

DOI: 10.54021/seesv5n1-060

Recebimento dos originais: 15/03/2024

Aceitação para publicação: 01/04/2024

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### ABSTRACT

In construction, a recent direction is to examine and integrate alternative sources of building materials with the goal of substituting the use of natural materials. This transition is encouraged by growing concern among policymakers and researchers regarding the environmental footprint of the construction industry. The incorporation of recycled aggregates into cementitious materials, such as concrete or mortar, results in a deterioration of their mechanical performance and their durability. Scientific studies devoted to recycled concrete have demonstrated that it is affected by the introduction of these recycled aggregates, in particular by the use of recycled sand. The latter is characterized by the presence of significant proportions of hardened cement, particularly that coming from a recycling plant. In this work, we aim to study experimentally the influence of the nature of recycled sand on the properties of cement mortars, substituting natural sand, with different percentages by volume: 0, 15, 30, 40, 50 and 75 %, by two types of recycled sand,



one from the crushing of structural concrete and the other from a recycling plant. The mortar mixtures were made from CEM I 52.5 and Sand/Cement ratio = 3. The plasticity of these mortars was kept constant and the recycled sands have been pre-wetted. The comparative study between the different compositions of recycled mortars has shown that the physical and mechanical properties are influenced by the incorporation rate of the recycled sand. Of which, increases in the compressive strengths of recycled mortars were recorded, particularly those based on sand from the crushing of structural concrete, compared to the control mortar based on natural river sand. However, the flexural strengths of the recycled mortars suffered a slight reduction compared to the reference mortar.

**Keywords:** cement mortar, recycled sand, fillers, physical properties, mechanical strength.

### RESUMO

Na construção, uma direção recente é examinar e integrar fontes alternativas de materiais de construção com o objetivo de substituir o uso de materiais naturais. Esta transição é incentivada pela crescente preocupação entre os decisores políticos e investigadores relativamente à pegada ambiental da indústria da construção. A incorporação de agregados reciclados em materiais cimentícios, como betão ou argamassa, resulta numa deterioração do seu desempenho mecânico e da sua durabilidade. Estudos científicos dedicados ao betão reciclado demonstraram que este é afetado pela introdução destes agregados reciclados, nomeadamente pela utilização de areia reciclada. Este último caracteriza-se pela presença de proporções significativas de cimento endurecido, nomeadamente proveniente de uma central de reciclagem. Neste trabalho pretendemos estudar experimentalmente a influência da natureza da areia reciclada nas propriedades das argamassas de cimento, em substituição à areia natural, com diferentes percentagens em volume: 0, 15, 30, 40, 50 e 75%, por dois tipos de areia reciclada, uma proveniente da britagem de concreto estrutural e outra proveniente de uma usina de reciclagem. As misturas de argamassas foram elaboradas a partir de CEM I 52,5 e relação Areia/Cimento = 3. A plasticidade destas argamassas foi mantida constante e as areias recicladas foram pré-umedecidas. O estudo comparativo entre as diferentes composições das argamassas recicladas mostrou que as propriedades físicas e mecânicas são influenciadas pela taxa de incorporação da areia reciclada. Dos quais se registaram aumentos nas resistências à compressão das argamassas recicladas, nomeadamente aquelas à base de areia proveniente da britagem de betão estrutural, comparativamente à argamassa de controlo à base de areia natural de rio. Contudo, as resistências à flexão das argamassas recicladas sofreram uma ligeira redução comparativamente à argamassa de referência.

**Palavras-chave:** argamassa de cimento, areia reciclada, enchimentos, propriedades físicas, força mecânica.



## 1 INTRODUCTION

The actual requirements of sustainability in construction promote the use of materials, which cause a lower environmental impact than those traditionally used. The intense rate of construction and demolition waste generation (CDW) over the years should boost recycling [1]. The use of CDW as constituents of cementitious composites has been considered a feasible alternative to dumping. It is new supply opportunities granular resources as an alternative to natural aggregates [2].

The opportunity for using recycled aggregate (RA) as a replacement of the natural aggregate (NA) in concrete construction has been a subject of intensive research for many years over the world [3-4]. The lack of data on the durability of concrete made with RA is hindering the large-scale use of this economic and “environmentally friendly” material in the construction industry. The recent trend in the construction industry is to use an alternative source of building materials that can replace the use of virgin materials to reduce the environmental impact in terms of energy consumption, pollution, waste disposal and global warming [5].

The use of RA in structural concrete production is still limited probably because of the limited knowledge of the long-term and durability performance of recycled aggregate concrete (RAC). It is generally known that the use of recycled aggregates in concrete would reduce its compressive strength and render the concrete less durable. He uses of recycled aggregate increases the drying shrinkage, creep and water sorptivity and decreases the compressive strength and modulus of elasticity of recycled aggregate concrete compared to those of natural aggregate concrete. The negative effects of recycled aggregate on concrete quality limit the use of this material in structural concrete. However, it has been suggested that the shortcomings of using recycled aggregate can be mitigated by using the double mixing approach in concrete mixing, particularly for concrete prepared with high water-binder ratio as it has been demonstrated that improvements in strength, chloride penetration and carbonation resistances of recycled aggregate concrete can be achieved [6]. The permeability is more dependent than other parameters to mix-proportions and curing conditions. Mixed aggregate concrete is intermediate between RAC and NAC. It can be concluded that the main problems of durability are caused by the use of recycled sand. Therefore, the use of fine recycled aggregate needs to be restricted. Another way



of increasing the durability of RAC is to use extended curing using a moist environment [2, 6].

Today, much of the existing research on recycled aggregates are related to the use of coarse aggregates from the concrete waste in concrete production [7-8]. However, this approach limits the potential use of a large part of CDW composed of the red ceramics (masonry bricks) and cement mortar used. During crushing to produce aggregates from concrete waste, much of the material is reduced to grains less than 5 mm [9-10]. This fine fraction is inevitable and can reach up to 50% of the total amount of recycled aggregates produced [11]. Some researchers [12] consider that this fraction is harmful to durability, due to the presence of impurities (chlorides, sulfates, etc.) in the adhered cement mortar (ACM) and its high demand for water, which is most often not constant. Existing studies on recycled mortars are differently assessed [13].

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 the 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 [14].

The main aim of this work is the physical and chemical characterization of recycled sands, and the study of the influence of their nature and source influence the rheological and mechanical behavior of masonry mortars. To this end, the tests are carried out on 11 mixtures of masonry mortars made with cement CEM I 52.5 ( $C=506 \text{ kg/m}^3$ ), with ratios water/cement = 0.5 and sand/cement = 3.0, with different percentages of voluminal substitution of natural river sand from 0% to 75%.

## 2 EXPERIMENTAL PROGRAM

### 2.1 MATERIALS USED

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

A Portland cement CEM I 52.5, with a relative density of 3.15, produced France, in compliance with NF EN 197-1:2012.

Three categories of fractional sand (0 / 3.15 mm): natural river sand (NS) and two types of recycled sand (RSL) and (RSC). The first (RSL) is obtained from



concrete obtained following the grinding of ordinary concrete specimens less than 6 months old and the second (RSC) purchased from a recycling company in France. It is obtained as a result of screening (0/3.15) of waste deconstruction mixed (concrete, cinderblock and slate tile) of a fraction (0/10).

A superplasticizer/High Range Water Reducer (SP), conforming to standard NF EN 934-2/IN1:2012, with a density of 1.06 kg/m<sup>3</sup>, 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	CEM I 52.5	Natural Sand	RSL	RSC
<b>Oxide weight (%)</b>				
CaO	70.3	0.1	20.7	38.25
SiO <sub>2</sub>	21.2	93.3	64.65	26.52
Al <sub>2</sub> O <sub>3</sub>	3.9	4.3	3.91	2.61
Fe <sub>2</sub> O <sub>3</sub>	0.6	0.1	1.42	1.22
K <sub>2</sub> O	0.3	2.1	0.84	0.22
SO <sub>3</sub>	3.3	0.0	1.73	1.96
TiO <sub>2</sub>	0.0	0.1	0.15	0.15

Source: Authors.

Table 2 – Percentage of calcium carbonate content by calcimetry.

Samples	Percentage of CaCO <sub>3</sub>
Recycled Sand (RSL)	9.0 %
Recycled Sand (RSC)	15.3 %

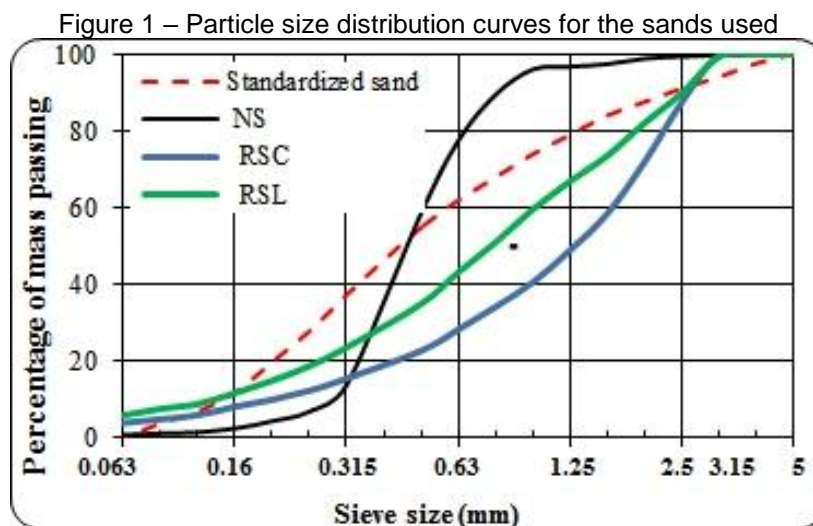
Source: Authors.

Table 1 shows that the RSL contains in its composition a high percentage of silica, which shows that the origin of the aggregates used in the formulation of the parent concrete is siliceous. The chemical composition of the Recycled sands is similar to that of cement in the qualitative aspect, thus reflecting the existence of cement hydration products. Table 2, whose calcium carbonate CaCO<sub>3</sub> content is higher in recycled sands, confirms this conclusion. The levels of these oxides in RS are similar to those found in other studies [13].



### 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.



Source: Authors.

The grain size of the recycled sands is well spread, giving coarse sands with a high fineness modulus, FM (RSC) = 2.94 and FM (RSL) = 2.71. However, the NS consists mainly of the fraction (0.315/1.25 mm), which is a rather fine sand with MF = 2.38. The recycled sands are heterogeneous sands characterized by high levels of ACM, in particular fractions below 250  $\mu\text{m}$ , rich in fillers, which is below the limit of 8% prescribed for use in masonry mortar [15].

### 2.2.3 Physical Characteristics

The physical characteristics, which are determined in accordance with the standards and test results, are presented in Table 3.

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<sup>3</sup>, from which the sand is recycled on the one hand, and the omission of the fine part (<63  $\mu\text{m}$ ) in the density calculation according to the Standard NF EN 1097-6:2013 on the other hand. The water absorption of the recycled sands are consequently, seven times higher than that of the NS. 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, which generates a very high surface area.



Table 3 – Physical Characteristics of Sands Used

Physical properties	NS (0/3.15)	RSL (0/3.15)	RSC (0/3.15)	Norms
Bulk density g/cm <sup>3</sup>	1.406	1.191	1.136	EN 1097-3
Real density g/cm <sup>3</sup>	2.588	2.581	2.538	EN 1097-6
Modulus of Finesse "FM"	2.38	2.94	2.71	EN 933-1
Fillers content "<125 μm" (%)	1.4	10.7	11.61	EN 933-1
Humidity content (%)	1.12	2.91	3.15	P 94-050
Water absorption (%)	2.19	13.37	15.38	EN 1097-6

Source: Authors.

### 2.3 MIXING PROCEDURE

The compositions of the recycled masonry mortars formulated are shown in Table 4.

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<sub>Mass/Mass</sub> and cement/sand ratio of 1/3<sub>Mass/Mass</sub>. The reference mortar mixtures were made with 506 kg/m<sup>3</sup> cement, 1518 kg/m<sup>3</sup> sand and 253 kg/m<sup>3</sup> water. Two 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 and 75. The natural control mortar, gives rise to a plastic and malleable mortar. This plasticity is considered for all the other recycled mortars made. The superplasticizer is added in order to maintain the same plasticity as for the natural control mortar. The range used varies from 0.15% to a maximum content of 3.0%. The SP dosing is lower in the first series than in the second series, which is due to high levels of fillers in recycled sand RSC, they are characterized by high surface areas.

Table 4 –Compositions Of Mortars Formulated

Series	Mortars	Cement (kg/m <sup>3</sup> )	NS (kg/m <sup>3</sup> )	RS (kg/m <sup>3</sup> )	W <sub>Tot</sub> (L)	W/C	SP (% C)
Series 1 (With SRL)	M0	506	1518	0	253	0.50	0.0
	ML15	506	1290	222	255	0.50	0.30
	ML30	506	1062	444	256	0.51	1.00
	ML40	506	911	592	260	0.51	2.00
	ML50	506	759	739	264	0.52	3.00
	ML75	506	379	1109	267	0.53	4.00
Series 2 (With SRC)	MC15	506	1290	218	255	0.50	0.50
	MC30	506	1062	436	257	0.51	1.25
	MC40	506	911	582	261	0.52	2.30
	MC50	506	759	727	264	0.52	3.00
	MC75	506	379	1091	267	0.53	4.00

Source: Authors.





### 3 EXPERIMENTAL METHODS

#### 3.1 FRESH STATE TESTS

##### 3.1.1 Bulk Density

The bulk density of the mortar was determined according to the Standard NF EN 1015-6/A1:2007.

##### 3.1.2 Shear Strength

The shear strength of the mortar was determined using a laboratory scissometer, VJ Technology model VJT5300, which is intended to measure the shear strength of poor soils, according to the Standard NF P 94-112:1991.

#### 3.2 HARDENED STATE TESTS

The test specimens were removed from the mold 24 hours after manufacture and stored in immersion in water at  $T = 20 \pm 2$  ° 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. 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 ( $40 \times 40 \times 160$  cm<sup>3</sup>) and ( $40 \times 40 \times 40$  mm<sup>3</sup>) respectively. The obtained results represent the average of three values for each mixture.

### 4 EXPERIMENTAL RESULTS AND DISCUSSION

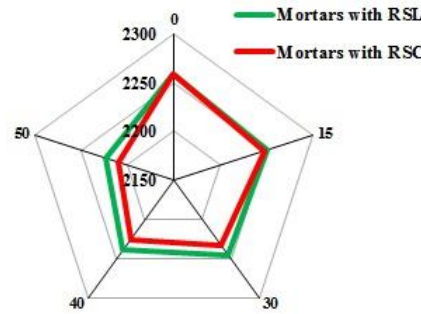
#### 4.1 FRESH STATE

##### 4.1.1 Bulk Density

The results obtained from the bulk density of the different mortars correspond to the average of three values obtained (Figure 2).



Figure 2 – Influence percentage rate of recycled sand on bulk density



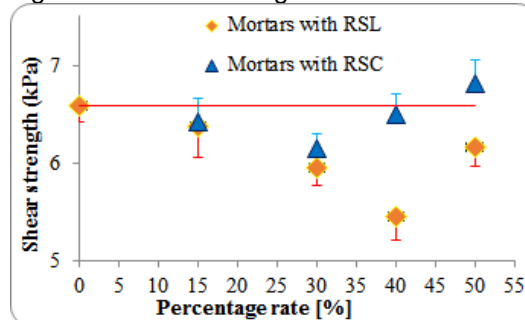
Source: Authors.

As can be seen from Figure 2, the bulk density of the mortars decreases with increasing NS replacement rates, and much more for those containing RSC, with a decrease of 2,6 % for 50% recycled mortar. This decrease is mainly due to the increase in real density of recycled sands and to the superplasticizing effect, which improves the compactness of mortars.

#### 4.2 SHEAR STRENGTH OF MORTARS

The incorporation of the superplasticizer into the mortars favors the scattering of their components, and it is clear that the influence of the fillers and on the cohesion of the recycled mortars with respect to the control mortar is remarkable (Figures 3). For RSC and RSL levels below the optimum 30% and 40% respectively, the shear strength decreases progressively, with decreases of 17 % for RSL and only 2 % for RSC. Over 40% of RS, the mortar cohesion increases with the percentage of recycled sands

Figure 3 – Shear strength of different mortars



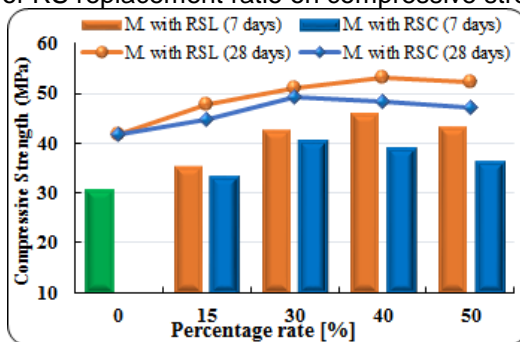
Source: Authors.

## 5 MECHANICAL BEHAVIOR

### 5.1 COMPRESSIVE AND FLEXURAL STRENGTHS

Figure 4 illustrates the results of compressive strength at 7 and 28 days of curing for the mortars depending on the replacement ratio of NS by RSL and RSC.

Figure 4 – Influence of RS replacement ratio on compressive strength at 7 and 28 days



Source: Authors.

In 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. The gains amounted to 47% and 27% for the replacements using 40% RSL and 30% RSC, respectively. These results are consistent with those reported by Zhao et al. (8).

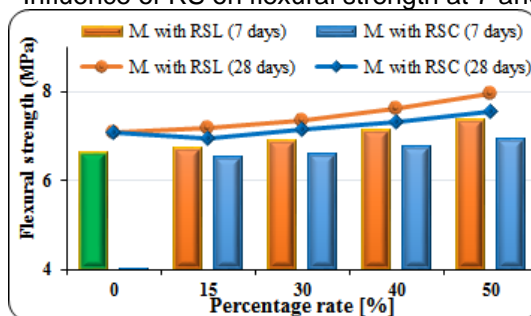
At the age of 28 days, the compressive strengths of masonry mortars based on recycled sands are higher than in the reference control mixture. These improvements in strength may be explained by the probable existence of anhydrous constituents of cement that have not yet undergone hydration. The gains amounted to 27% and 17% for the replacements using 40% of RSL and 30% of RSC, respectively.

### 5.2 FLEXURAL AND SPLITTING TENSILE STRENGTHS

The flexural strength in the 3-point flexure test at the ages of 7 and 28 days are shown in Figure 5.



Figure 5 – Influence of RS on flexural strength at 7 and 28 days.



Source: Authors.

From these results (Figure 5), it can be seen that the flexural strengths show an increasing trend until the replacement rate of natural sand by the recycled sands for a maximum of 50%. The recycled sands are characterized by particles that have a greater angularity, a rough surface and are more porous, thus ensuring a high bond with the cement paste.

The addition of superplasticizer in the mix has been beneficial, and the flexural show a steady increase, particularly for mortars made with RSL. Compared to the control mortar at age 28 days, the strength gains of mortars based on RSL was against 13%. Although the W/C ratio is almost constant, the effect of the superplasticizer is quite remarkable on the decrease of the occluded air, and consequently the compactness of the mortars is improved.

## 6 CONCLUSIONS

This paper discusses the effect of the nature of recycled sands on the rheological and mechanical properties of cement mortars. This study shows several very encouraging findings for the application of recycled sands in the construction sector, whenever its sources are, especially for the manufacture of mortars:

- this practice is particularly relevant for the manufacture of mortars used in a variety of applications such as masonry, sidewalk pavers, fill layers and backfill;
- the incorporation of recycled sand into the construction industry is a promising initiative. It offers significant environmental benefits as well as circular economies by reducing dependence on natural materials and encouraging the reuse of resources. In addition, it contributes to responsible management of construction waste;



- the Recycled sands characterized by high levels of old hardened mortar, in particular, fractions below 250  $\mu\text{m}$ , which resulted in a high-water absorption capacity, seven times greater than that of natural sand;
- the morphology of the recycled sand as well as the rate of fines influenced the compactness of the granular skeleton of the mortar on the one hand and its workability on the other hand;
- the presence of fillers in fine recycled aggregates has significantly influenced positive the mechanical resistance in compression, while the tensile strengths by flexion are particularly affected when the sand content exceeds 30%;
- finally, the rheological properties and mechanical behaviors present a slight difference between mortars using aggregates from controlled sources (concrete specimens) and those from mixtures of deconstruction waste;

## 7 PERSPECTIVES

The conclusions of this study offer encouraging prospects for the application of recycled sands in the field of construction, particularly for the manufacture of cement mortars. However, some limitations were identified and recommendations for future research can be made from these findings:

- study of the main sustainability indicators of recycled mortars: permeability, dimensional stability and resistance to chemical attacks;
- study of the workability and compactness of recycled mortars depending on the methods of preparation and treatment of recycled sand, as well as their impact on the particle size, quality and proportion of fines;
- life cycle analysis of recycled mortars made from various sources of recycled sand;

## ACKNOWLEDGMENTS

The authors express their thanks to LGCGM laboratory staff of INSA Rennes (France) for providing facilities for conducting various tests in the laboratory.



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