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Mortar made of recycled sand from C&D

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Abstract

In the production of coarse recycled aggregates (RA), the fine fraction is involuntarily produced, representing a large amount of the weight of the crushed C&D waste. In this work the mortar has been analyzed, by replacing standardized sand (SS) with recycled sand (RS) and by using a fixed w/c ratio equal to 0,5. The most relevant problem has been occurred during the mixing phase: in fact, RS induced a high water demand which made the mechanical properties worst. The results show that, by adding the optimum dose of superplasticizer, the RS mortars have the same mechanical characteristics of the SS mortar.

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Keywords: C&D waste; recycled sand; mortars; superplasticizer; mechanical properties

1. Introduction

In recent years, the practices of waste treatment have become increasingly a central theme in contemporary society, especially since they are included in the global perspective of environmental sustainability. There is, therefore, a gradual change in the concept of waste: from scrap to resource, from problem to opportunity. This is also due to the fact that the Waste Framework Directive 2008/98/EC of the European Parliament established that countries in the European Union (EU) should achieve a minimum recycling rate of 70% in weight for construction and demolition waste (CDW) by 2020. In Italy, CDW represent approximately 42,1% of non-hazardous waste compared with only 4,5% of the hazardous waste. In addition, about 40% of the total produced in the 2011-2012 period is made up of waste

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identified by the CER 17 code, that is "construction and demolition waste" [1]. Therefore, the recycling of these wastes is important not so much for their dangerousness as for their considerable amount.C&D waste aggregates are produced by crushing materials from demolition of various construction sites and buildings and their composition is very variable. In fact, they can contain different quantities of glass, concrete, ceramic, bricks, wood, clay and for this reason they show a great variation in quality, that is related to the origin of the CDW and to the process type used in the recycling plant [2]. Nevertheless, C&D waste have an high potential for being re-used like aggregates.

The properties of coarse RA from C&D waste and its application in the manufacture of concrete have been widely studied and many researches, performed during recent years, converge to the result that this fraction can be used to substitute NA in concrete successfully [3-6]. Some Standards allow total or partial substitution of coarse NA by coarse RA in the manufacturing of new concrete, while the use of recycled fine fraction is still little used in building materials, due to the workability problems in the mixing phase. Especially the recycled sand, characterized by a particle size less than 4 mm, requires a large amount of water: in particular to optimize the workability is necessary to increase the water to cement ratio (w/c), which however implies a reduction of the mechanical properties. Several studies showed that the properties of concrete [3, 7-9] and mortars [10-14] decreased with the increasing of fine fraction of RA, also called Recycled Sand (RS).

In this work, properties of mortar with different percentage of RS have been investigated. In particular, the aim of the research has been to find the optimal percentage of superplasticizer to add into the mixture.

2. Materials and methods

2.1. Materials

The materials used to manufacture mortars in the present research are the followings.

2.1.1 Cement

The cement used was Ordinary Portland Cement Type-I (Buzzi Unicem 52,5R), light grey color, obtained by grinding of at least 95% of clinker and maximum 5% of minor constituents. This cement is characterized by the rapid development of the initial resistance, it conforms to the harmonized European standard UNI EN 197/1 and is equipped with CE marching as required by European Regulation 305/2011 (CPR).

2.1.2 CEN Standard Sand

CEN Standard sand was used for the manufacture of mortars. It is a natural siliceous sand consisting of rounded particles having a silica content of at least 98%. It is distributed pre-packed in bags with a content of (1350±5) g, whose particle size distribution lies within specific limits as shown below in Table 1.

Table 1. CEN Standard Sand (UNI EN 196-1:2005).

Square mesh size (mm)	2.00	1.60	1.00	0.50	0.16	0.08
Cumulative sieve residue (%)	0	7±5	33±5	67±5	87±5	99±5

2.1.3 Recycled Sand

The recycled sand used was provided by Cavit S.p.A. and it has been treated in the recycling plant of La Loggia (Turin), which is able to crush, select and delete unwanted fractions and finally to separate in different particle size fractions.

In particularly, the material provided to us by the company was "Recycled 0-8", that is characterized by particle size less than 8 mm, with a plasticity index and a liquid limit equal to 0.9 and 26.4 respectively (Atterberg Limits).

This material was sieved into six granular fractions (0/0.08, 0.08/0.16, 0.16/0.50, 0.50/1.00, 1.00/1.60, 1.60/2.00 mm), that were remixed together with specific amounts to obtain the same granular distribution than standardized sand (Figure 1).

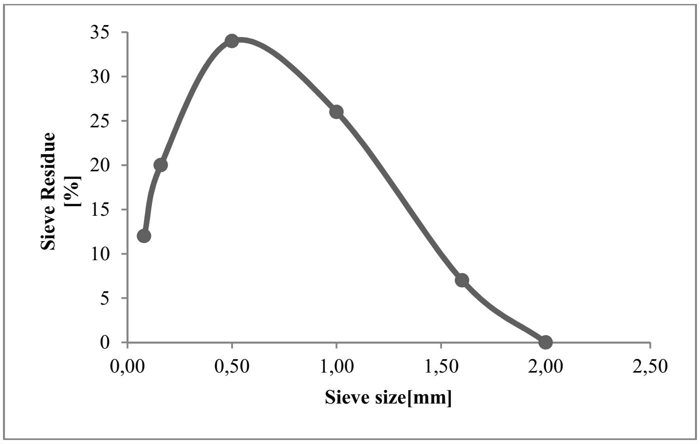

Fig.1. Granular distribution of natural and recycled sands used in mortar specimens.

2.1.4 Other materials

Deionized water for mixing procedure was used. Superplasticizer based on acrylic polymer bearing commercial name Dynamon SP1, part of the MAPEI Dynamon SP system, was used. It consists of a water solution containing acrylic polymers (without formaldehyde) that can efficiently disperse the cement grains.

Cementitious materials with Dynamon SP1 have a high level of workability and are consequently easy to cast when fresh. At the same time it provides excellent mechanical performances when hardened.

2.2. Compositions of mortars

Two series of mortar specimens were manufactured by replacing of each granular fraction of standardized sand with the corresponding granular fraction of recycled sand, using four percentages (0%, 25%, 50%, 75% RS). In this way, for each percentage a sand packet has been realized (Figure 2, Table 2).

Fig.2. Sand packet.

Table 2. Compositions of sand packets.

Sieve	M-RS0%		M-RS25%		M-RS50%		M-RS75%	
	SS	RS	SS	RS	SS	RS	SS	RS
[mm]	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
1.60	94.5	0	70.9	23.6	47.25	47.25	23.6	70.9
1.00	351	0	263.3	87.8	175.5	175.5	87.8	263.3
0.50	459	0	344.25	114.75	229.5	229.5	114.75	344.25
0.16	270	0	202.5	67.5	135	135	67.5	202.5
0.08	162	0	121.5	40.5	81	81	40.5	121.5
< 0.08	13.5	0	10.1	3.4	6.8	6.8	3.4	10.1

Series 1 was realized to study the influence of the content of recycled sand on the workability of mortar mix, while series 2 to find a percentage of adding superplasticizer in order to obtain a workable mix.

According to Standard EN 196-1, the proportions by weight used is one part of the cement, three parts of sand and one half part of water, that is a w/c ratio equal to 0,5.

Each batch for three test specimens consist of 450 g of cement, 1350 g of sand and 225 g of water.

2.3. Experimental methods

Mortar specimens of 40x40x160 mm were manufactured. The mixing procedure was followed according to the Standard EN 196-1. Moreover, for the Series 2, superplasticizer has been added into water. After 20/24 hours from the moulding procedure, marked specimens have been cured in water for 7 days. Before the mechanical tests, 10 mm deep U shaped notches were made in the specimens (Figure 3).

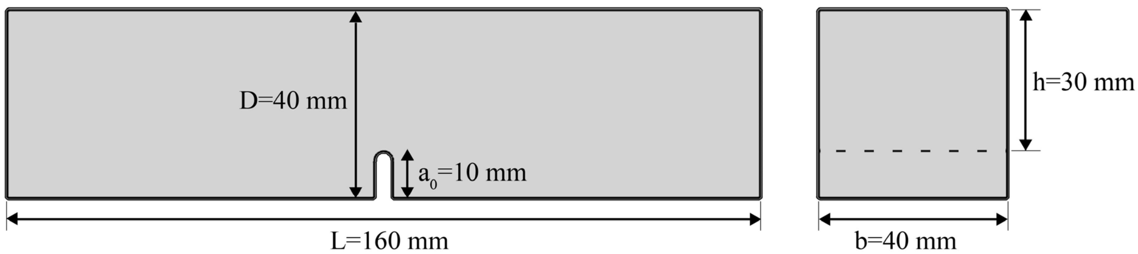

Fig.3. Mortar specimen dimensions.

2.3.1 Instrumentation and test activity

The C&D waste material was sieved and the passing fraction at 0.125, 0.250, 0.500, 1.000 and 2.000 mm was analyzed by means of X-ray diffraction (XRD). XRD patterns were recorded with a Pan Analytical X'Pert Pro diffractometer between 5° and 70° in 2θ, with a step width of 0.026° and 1 s data collection per step (CuKα radiation and graphite secondary monochromator).

Three-point bending tests have been carried out for each mortar notched specimen, by using a Zwick/Roell Z050 machine with load cell capacity of 50 kN. The crack mouth opening displacement (CMOD) mode was used through a clip-on extensometer and a 0,01 mm/min test speed was adopted (Figure 4a)

Compressive tests have been performed for each halves of the prism broken in flexure, by using a MTS servo-hydraulic machine. The test speed adopted was 0,05 mm/s (Figure 4b).

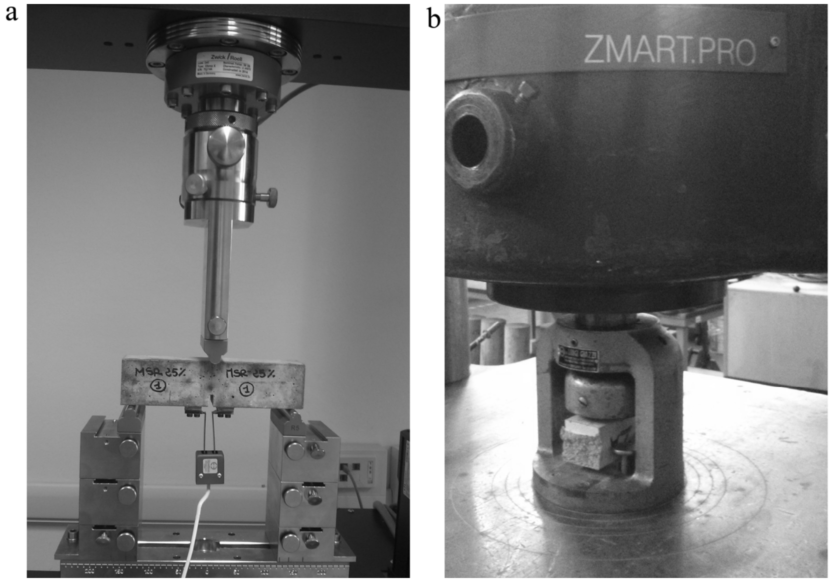

Fig. 4. (a) three-point bending test; (b) compressive test.

The fracture energy is generally calculated by using the following expression:

$$G_F = \frac{W}{A_{lig}} = \frac{W_0 + W_1 + W_2}{A_{lig}} \quad (1)$$

where A_{lig} is the area of the initial ligament and W is the total work of fracture.
Particularly, W_0 is the area under the load-CMOD curve at final fracture, while W_1 and W_2 represent the work due to the self-weight of the specimen and the work due to the weight of the part of the loading arrangement, respectively.

In the present work only the fraction related to the area under the load-CMOD curve has been evaluated, as W_1 and W_2 were the same for all the specimens.

$$G_{F0} = \frac{W_0}{A_{lig}} \quad (2)$$

3. Results and discussions

3.1. Chemical compositions of recycled sand

XRD patterns were rather similar, whatever the passing fraction: they showed the presence in all the samples of calcite and quartz as major constituents, while mica paragonite (a sodium aluminum silicate hydroxide) and phlogopite (a potassium magnesium aluminum silicate hydroxide) and clinochlore (a magnesium aluminum iron silicate hydroxide) were secondary phases.

Gismondine (a calcium aluminum silicate hydrate) and kaolinite (a clay) were found as traces. Gypsum was never found in the investigated samples. Mica and clinochlore come from the aggregate fraction, while calcite could have different origins: from aggregates, as a cement filler and from concrete degradation process (carbonation). Gismondine is probably due to hydrated cement residues (Figure 5).

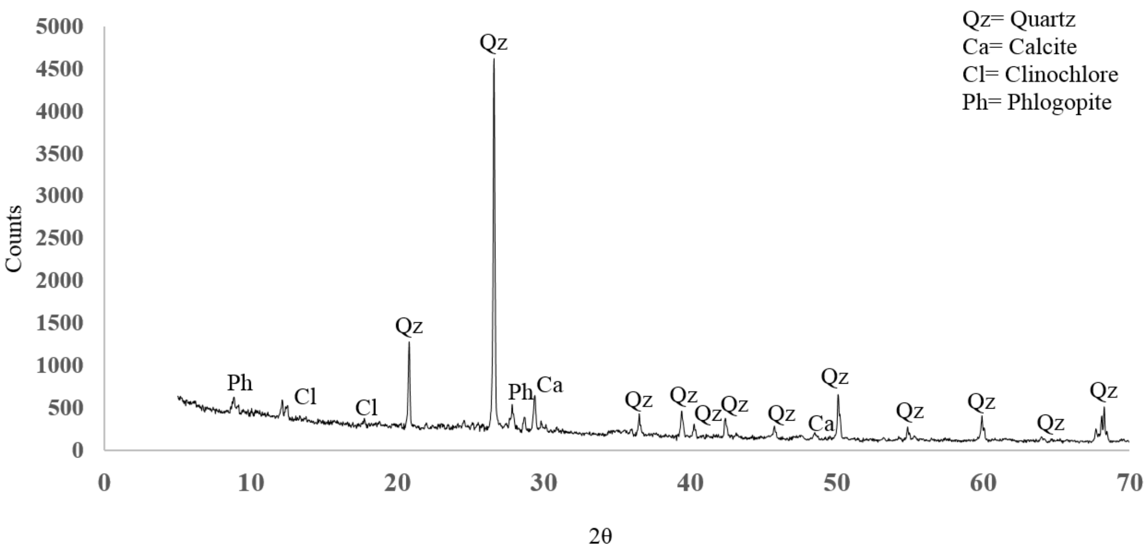

Fig.5. Results of X-ray diffraction analysis on the 0,5mm fraction recycled sand.

3.2. Influence of replacement percentage of recycled sand

Series 1 of mortars with w/c ratio equal to 0,5 was realized to study the influence of the content of recycled sand on the workability of mortar mix.

According to Dapena et al. [15] and Màrtinez et al. [16] it is very difficult to compact the mortar specimens when there is an amount of RS more than 50%.

In this case, water demand increases as the percentage of recycled sand increases, probably due to hydrated cement residues on the fine fraction. Consequently, flexural and compressive strength considerably decreases, having a decrease also as regards the fracture energy, as shown in Table 3.

Table 3. Mechanical properties of mortars Series 1.

		M-RS0%	M-RS25%	M-RS50%	M-RS75%
Average flexural strength	[MPa]	4.58	4.06	2.57	-
Standard deviation	[MPa]	0.18	0.22	0.31	-
Average fracture energy	[N/mm]	0.072	0.070	0.049	-
Standard deviation	[N/mm]	0.015	0.005	0.009	-
Average compressive strength	[MPa]	49.5	40.8	23.2	-
Standard deviation	[MPa]	1.8	3.2	3.8	-

Series 2 was realized to find a percentage of adding superplasticizer to obtain a workable mix in particular for the 50% and 75% RS. After several attempts, the optimal percentage of superplasticizer was found in 1.25% compared to the total weight of the sand recycled. By this adding, flexural mechanical behavior is similar to standardized mortar, while compressive mechanical behavior not, as shown in Table 4.

Figure 6 and Figure 7 show the results provided from three-point bending test.

In particular, Figure 6 shows the comparison between mortars with standard sand SS and mortars with recycled sand RS 50% with and without superplasticizer.

Figure 7 shows the comparison between mortars with standard sand SS and mortars with recycled sand RS and superplasticizer.

Table 4. Mechanical properties of mortars Series 2.

		M-RS0%	M-RS50%*	M-RS75%*
Average flexural strength	[MPa]	4.58	4.37	4.11
Standard deviation	[MPa]	0.18	0.16	0.10
Average fracture energy	[N/mm]	0.072	0.062	0.056
Standard deviation	[N/mm]	0.015	0.008	0.007
Average compressive strength	[MPa]	49.5	40.8	23.2
Standard deviation	[MPa]	1.8	2.3	2.0

* addition of superplasticizer

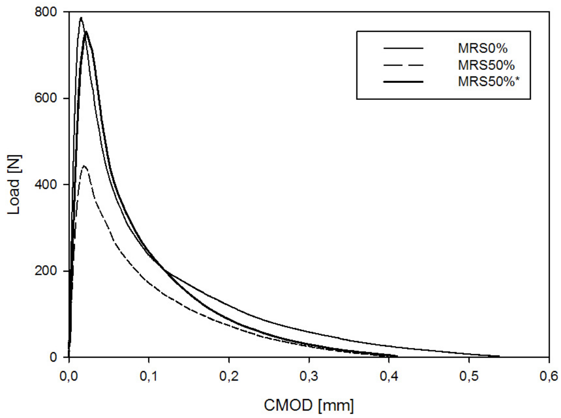

Fig.6. Load-CMOD curves, M-SS and M-RS50% with and without Sp.

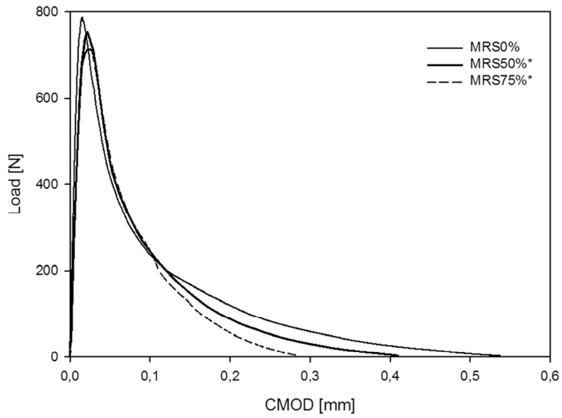

Fig.7. Load-CMOD curves, M-SS and M-RS with SP.

4. Conclusions

In this research, chemical composition by XRD of recycled sand and mechanical properties of mortars with RS have been investigated. Analyses allowed to conclude that:

- The workability of mortar decreases as the percentage of recycled sand increases, probably due to hydrated cement residues on the fine fraction that requires a higher water demand. The increase of required water in the mixing phase may be due to the presence of very fine powder attached to the sand particles;
- With replacing the SS with RS, the flexural and compressive strength generally decrease when the content of recycled aggregates increases. The increase of hydrated cement residues has a negative influence on mechanical behavior of mortar, due to its high water absorption and low mechanical properties. In fact, the difficulty during the mixing resulted in an increase of the standard deviation of the mechanical parameters with the increase of replacement ratio;
- The mortars made with RS adding superplasticizer have been shown a flexural behavior slightly worse than standardized mortars, especially as regards the mortar with a partial substitution of 50%; on the other hand, compressive strength decreases faster;
- The most significant results obtained, by analyzing the properties of different mix design, is that in any case the bending strength and the fracture energy increase or decrease simultaneously. Therefore it can be assumed that with special additions (e.g. carbon nano/micro particles) could achieve better results.

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