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Recycled Mortars with C&D Waste

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Abstract

Nowadays an environmental problem that cannot be underestimated is the increasing amount of waste of different nature. Certainly, an environmental friendly solution is to use waste directly or indirectly in the production of concrete or mortar, which are the most used building materials in the world.
In the production of coarse recycled aggregates (RA), the fine fraction, also called recycled sand (RS), is involuntarily produced and it represents a large amount of the weight of the crushed C&D waste. Generally, the problem of fine fraction has not been much analysed until now.
For this reason, in this work, an innovative mortar mix design for using recycled sand from C&D has been analysed, by partial replacement of standardized sand (SS) with recycled sand (RS) or washed recycled sand (RSW) and by using a fixed w/c ratio equal to 0,5. The main aim of this research has been to investigate if washing and sieving of recycled aggregates can improve the quality of the recycled aggregate. Analyses allowed concluding that the quality of the recycled aggregate could be improved by washing and sieving of recycled aggregates and that in any case the bending strength and the fracture energy increase or decrease simultaneously.

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Keywords: Recycled sand; innovative mix design; mortar; C&D waste; sustainability; mechanical properties

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1. Introduction

Sustainability and performance are the key requirements of the construction products as required by the new Regulation (EU) n.305/2011 (CPR - Construction Product Regulation), concerning the CE marking on the marketing of construction products, entered into force since 1 July 2013. The CPR lists and describes seven "Basic requirements for construction works" that must be satisfied, in particular a significant innovation of this regulation is the introduction of the 7th requirement, "Sustainable use of natural resources". In addition, 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 this way, in recent years, there was a gradual change in the concept of CDW: from waste to product, from problem to opportunity. Very large quantities of waste from C&D are produced every year all over the world; in fact, the recycling of these wastes is important not so much for their dangerousness as for their considerable amount: they constitute a major portion of total solid waste production in the world. Some Standards allow total or partial substitution of coarse NA by coarse RA in the manufacturing of new concrete. However, most standards do not allow the replacement of fine natural aggregate by fine recycled aggregate, because the latter has proven more difficult to incorporate into concrete or mortar, mainly due to a large water demand and fresh mixture workability problems. In the production of coarse recycled aggregates, the fine fraction is involuntarily produced and it represents a large amount of the weight of the crushed C&D waste. Angulo et al. (2009) have shown that the fine fraction is about 50% of them. Therefore, there is a strong need to find an application for this fraction; for example, a part of this could be recycled into concrete or mortar preserving natural resources.

Several authors have investigated the properties of concrete containing fine recycled concrete aggregate (FRCA), showing a reduction of the properties as the replacement percentage increases. Khatib (2005) observed that a systematic reduction in strength of 15-30% occurs in concrete containing fine crushed concrete with a replacement level of 25%-100% respectively. Shi-Cong and Chi-Sun (2009) indicated that, at a fixed w/c, fine recycled aggregate decreased the compressive strength and increased the drying shrinkage of the concrete. In addition, at a fixed slump value, the resistance to chloride-ion penetration of FRA concretes was higher than that of the control concrete. However, Evangelista et al. (2007) believe that the use of FRCA does not jeopardize the mechanical properties of concrete, for replacement ratios up to 30%, but it is noteworthy that FRCA used were obtained from concrete mixes especially produced in laboratory. Mortars manufactured with recycled sand (RS) have been studied by different researchers too. In this case, like concrete, the properties and amount of the fine aggregate strongly influence the rheological properties and workability of mortars, as already confirmed by Westerholm et al. (2008). Lahuerta et al. (1984) affirm that total materials finer than 0,08 mm in the dry mix could be used as a control parameter for the workability of mortars. Moreover, the binder used in the mixture of mortar seems also affect the mechanical properties of the mortar (Stefanidou et al., 2014).

Several authors (Corinaldesi et al., 2009; Vegas et al., 2009; Lee, 2009; Silva et al., 2010; Dapena et al., 2011; Martín-Morales et al., 2011; Braga et al., 2012; Lima et al., 2012; Martìnez et al., 2013; Jiménez et al., 2013; Neno et al., 2014; Zhao et al., 2015) have studied the behaviour of cement-based mortar with partial or total substitution of natural sand with recycled sand.

In this work, an innovative mortar mix design for using recycled sand from C&D has been analysed. In particular by a partial replacement of standardized sand (SS) with recycled sand (RS) or washed recycled sand (RSW) and by using a fixed w/c ratio equal to 0,5. The main aim of this research has been to investigate how improving the quality of the recycled aggregate by an accurate washing and sieving, for a sustainable and more efficient use of C&D waste.

2. Materials

2.1. Cement

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 has been used. It is characterized by the rapid development of the initial resistance, conforms to the harmonized European standard UNI EN 197/1 and is equipped with CE marching according to European Regulation 305/2011 (CPR);

2.2. CEN Standard Sand (SS)

CEN Standard sand, a natural siliceous sand consisting of rounded particles having a silica content of at least 98%, has been used. It is distributed pre-packed in bags with a content of (1350±5)g, whose particle size distribution lies within specific limits according to UNI EN 196-1 (Figure 1).

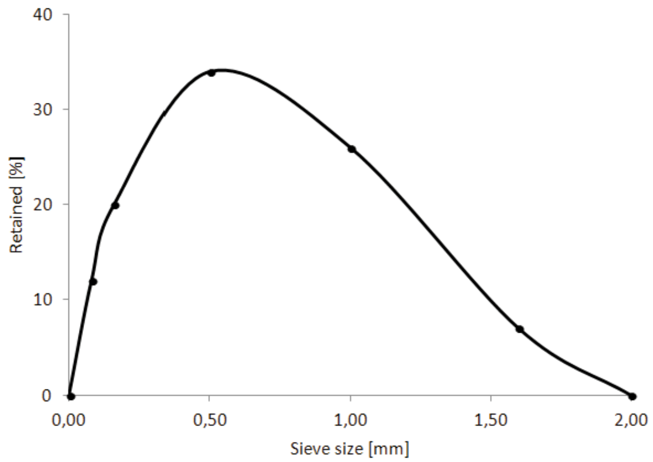

Fig.1. Particle size distribution of Standard Sand SS.

2.3. Recycled Sand (RS)

Recycled sand used was provided by Cavit S.p.A. and it has been treated in the recycling plant of La Loggia in Turin, which is able to crush, select and delete unwanted fractions and finally to separate in different particle size fractions. In particularly, recycled sand used 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. Determination of particle size distribution of "Recycled 0-8" was realized through dry sieve, according to UNI EN 933-1 (Figure 2).

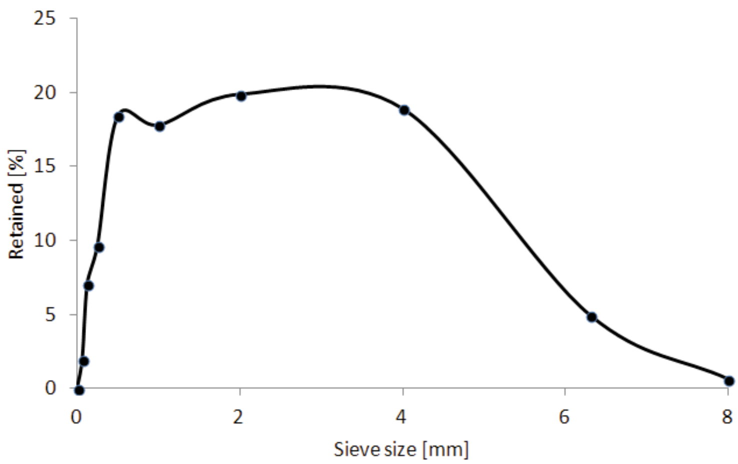

Fig.2. Particle size distribution of "Recycled 0-8".

2.4. Other materials

In this work, deionized water for mixing procedure and tap water for curing of casted samples was used. In addition, 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 this product 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. Finally, sand packets realized with RS_W (25% and 50%) have been made with filler VG1 of the NICEM s.r.l. (Bergamo, Italy). This product is mainly calcium carbonate (≥95%) with a particular characteristic of fineness, obtained thanks to a cycle of grinding and refining.

3. Methods

SS and RS were sieved into six granular fractions: 0/0,08, 0,08/0,16, 0,16/0,50, 0,50/1,00, 1,00/1,60 and 1,60/2,00 mm. Sand packets have been realized by remixing of each granular fraction of standardized sand with the corresponding granular fraction of recycled sand, using two different percentages (50% and 75% of RS) to get the same granular distribution than original standard sand (Table 1).

Table 1. Compositions of sand packets with RS.

Sieve	RS0%		RS50%		RS75%	
	SS	RS	SS	RS	SS	RS
[mm]	[g]	[g]	[g]	[g]	[g]	[g]
1,60	94,5	0	47,25	47,25	23,6	70,9
1,00	351	0	175,5	175,5	87,8	263,3
0,50	459	0	229,5	229,5	114,75	344,25
0,16	270	0	135	135	67,5	202,5
0,08	162	0	81	81	40,5	121,5
< 0,08	13,5	0	6,8	6,8	3,4	10,1

In a second moment, washed sand packets have been realized, with 25% and 50% of RS_W (Table 2).

Table 2. Compositions of sand packets with RS_W.

Sieve	RS_W25%			RS_W50%		
	SS	RS_W	VG1	SS	RS_W	VG1
[mm]	[g]	[g]	[g]	[g]	[g]	[g]
1,60	70,9	23,6	-	47,25	47,25	-
1,00	263,3	87,8	-	175,5	175,5	-
0,50	344,25	114,75	-	229,5	229,5	-
0,16	202,5	67,5	-	135	135	-
0,08	121,5	40,5	-	81	81	-
Filler	-	-	13,5	-	-	13,5

In particular, "Recycled 0-8" have been washed with the following procedure:

- Put the test portion in a basin and add water to cover it, then shake vigorously the test portion and let stand it at least for 24 hours;
- Remove carefully surface water with a ladle and pour 2-3 ladles of the basin contents in a sieve of 2 mm (protection sieve), to which follows a sieve of 63 μm;
- Wash until the water, passing through the sieve of 63 μm, spills clear;
- Dry the residue retained on the sieve of 63 μm in an oven at a temperature of (110 ± 5)°C until constant mass.

According to Standard UNI EN 196-1, mortar specimens have been manufactured with proportions by mass equal to one part of cement, three parts of sand (SS plus different percentages of RS or RS_W) and one half part of water, or with a water/cement ratio 0,5. In particular, the recipe for three prismatic specimens (40x40x160 mm^3) was 450 g of cement, 1350 g of sand (one packet) and 225 g of water. Each mixture also contained superplasticizer (Sp1) in percentage respect to the RS or (RS_W + filler).

Therefore, in this study two different types of mortar specimens have been realized: mortar specimens with 50% and 75% of RS with 1,25% of Sp respect to RS and mortar specimens with 25% and 50% of RSW with Sp1 in percentage respect to (RS_W + filler VG1), in particular 1% (Series1 - S1) and 0,5% (Series2 - S2).

In the mixing procedure, first, the different constituents have been weighed by means of a balance. Further, they were mixed mechanically by a "cup-mixer" with a standard procedure, according to UNI EN 196-1. Immediately after the preparation of the mortar, the test specimens have been molded and compacted in a mold fixed to a jolting apparatus. It is important to emphasize that in the mixing of the mortars with RS procedure times followed corresponded to those indicated in the reference standard, while for the mortars with RS_W has been used a personalized timing, adding 30 s to all the phases in which the mixer is in motion. In addition, in the molding of the specimens of mortar with RS jolts number realized corresponded to those indicated in the reference standard, while for the mortars with RS_W has used a personalized jolts number, equal to 20. In fact, the mixture of the mortars with RS was dry, while the mixture of the mortars with RS_W was very fluid. After 20/24 hours from the molding procedure, marked specimens have been cured in water for 7 days.

4. Test activity

C&D waste material was sieved and the retained 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).

Each specimen has been subjected to three points bending test in crack mouth opening displacement (TPB test in CMOD) and subsequently the two halves of the broken prism have been tested in compression. Before the mechanical tests, 10 mm deep U shaped notches were made in the specimens (Figure 3).

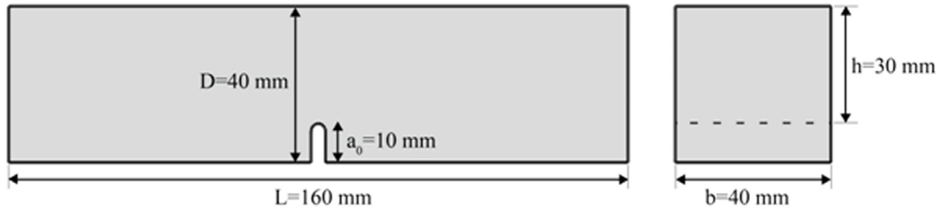

Fig.3. Mortar specimen dimensions.

TPB test has 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 mode (CMOD mode) has been used through a clip-on extensometer and a 0,01 mm/min test speed has been adopted.

Compressive test has 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.

Through statistical analysis of the results of the compression tests, compressive strength $\bar{\sigma}_c$ and standard deviation s have been evaluated. Similarly, through statistical analysis of the results of the bending tests, flexural strength $\bar{\sigma}_f$, elastic modulus $\bar{E}$ and fracture energy $\bar{G}_F$ have been evaluated as average values of the relative values of the n samples of the same mixture.

Fracture energy has been estimated according to two different procedures; one proposed by the RILEM Technical Committee TC50, through experimental curve F-δ and another by Japan Concrete Institute Standard JCI-S-001-2003 through experimental curve F- CMOD.

5. Results and discussion

5.1. Chemical compositions of recycled sand

XRD patterns were rather similar, whatever the retained fraction: they showed the presence in all the samples of calcite (Ca) and quartz (Qz) as major constituents, while mica paragonite, phlogopite (Ph) and clinochlore were secondary phases. Gismondine and kaolinite were found as traces.

Gypsum was never found in the investigated samples. Mica and clinochlore (Cl) come from the aggregate fraction, while calcite could have different origins: from aggregates, as a cement filler and from concrete degradation process. Gismondine is probably due to hydrated cement residues (Figure 4).

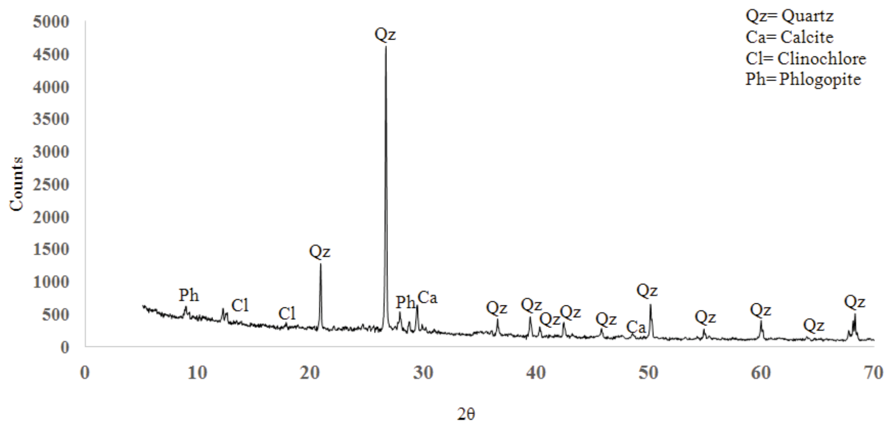

Fig.4. Results of X-ray diffraction analysis on the 0,5mm fraction recycled sand

5.2. Mechanical properties

In absence of superplasticizer, 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.

Adding superplasticizer, flexural mechanical behavior is similar to standardized mortar, while compressive mechanical behavior not.

In particular, in the recycled sand mortar specimens with superplasticizer, the best solution has been obtained with 50% of recycled sand (MRS50%), showing this a reduction in compressive and flexural strength of about 9%

and in fracture energy of about 6% and, at the same time, an increasing in elastic modulus of about 10% with respect to standard sand mortar specimens (M_0,5w/c).

According to Martín-Morales et al., the quality of the recycled aggregate could be improved by washing and sieving of recycled aggregates. In particular, the best solution for mortar specimens manufactured with RSW has been obtained with 50% of RSW with added 1% of superplasticizer (MRS$_W$50%_S1) with respect to (RS$_W$ + filler VG1). This solution has shown about the same compressive and flexural strength with respect to standard sand mortar specimens and an increasing in fracture energy of about 20% but, at the same time, a reduction in elastic modulus of about 20% too. All these considerations are shown in Table 3.

Table 3. Mechanical properties of mortars.

ID Specimen	$\bar{\sigma}_c$	s	$\bar{\sigma}_f$	$\bar{E}$	$\bar{G}_F$ RILEM TC50	$\bar{G}_F$ JCI S-001
	$[MPa]$	$[MPa]$	$[MPa]$	$[MPa]$	$[N/mm^2]$	$[N/mm^2]$
M_0,5w/c	50,2	2,05	4,82	5872	0,064	0,068
MRS50%	45,1	2,31	4,37	6478	0,060	0,064
MRS75%	38,4	2,03	4,11	5542	0,057	0,060
MRS$_W$25%_S1	40,8	5,24	4,08	4100	0,065	0,071
MRS$_W$50%_S1	53,3	1,80	4,81	4777	0,077	0,084
MRS$_W$25%_S2	40,4	1,61	4,39	3908	0,068	0,071
MRS$_W$50%_S2	29,3	1,45	3,15	4630	0,036	0,044

From the Table 3, it is evident that fracture energy value for each mortar specimen is always greater with the Japanese standard procedure with respect to RILEM procedure. Nevertheless, in the fracture energy assessment for small mortar specimens, like those realized in this work, the procedure proposed by JCI-S-001 is probably more correct than that by RILEM TC50 for different reasons. Figure 5 and Figure 6 show the most significant results provided from compression test and three-point bending test respectively. In particular, the figures show the comparison between mortar specimens with SS, 50%RS and 50%RS$_W$.

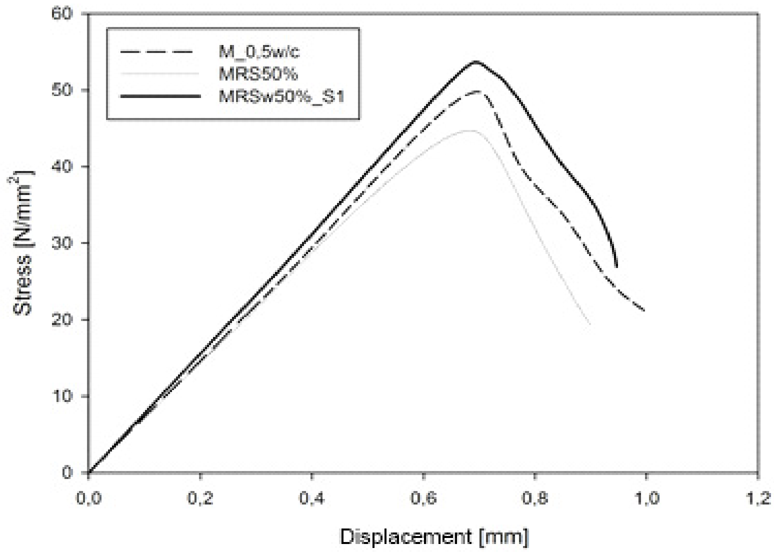

Fig.5. Stress-Displacement curves (Compression tests).

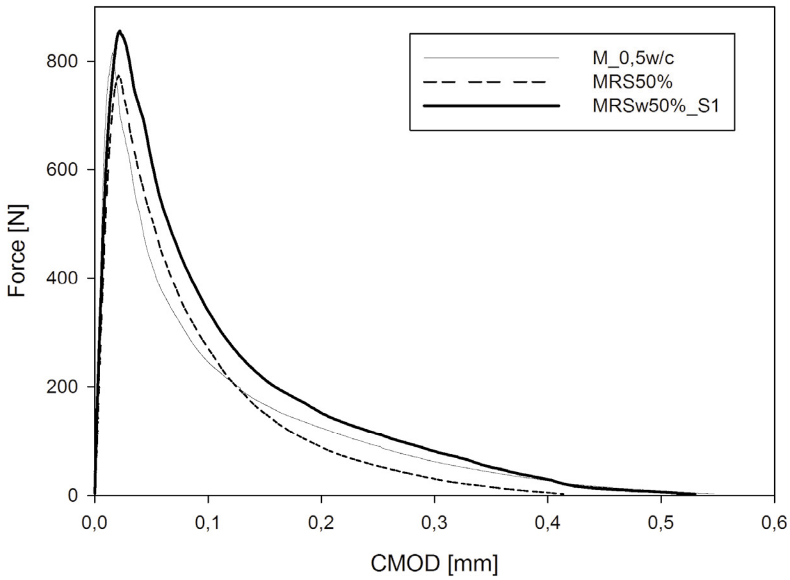

Fig.6. Load-CMOD curves (TPB tests).

6. Conclusions

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

- With replacing the SS with RS, 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 manufactured with 50% of RS adding superplasticizer have shown a reduction in compressive and flexural strength of about 9% and in fracture energy of about 6% and, at the same time, an increasing in elastic modulus of about 10% with respect to standard sand mortar specimens;
- The best solution for mortar specimens manufactured with RS_W has been obtained with 50% of RS_W with added 1% of superplasticizer (series S1) with respect to (RS_W + filler VG1). This solution has shown about the same compressive and flexural strength with respect to SS mortar specimens and an increasing in fracture energy of about 20% but, at the same time, a reduction in elastic modulus of about 20% too.

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