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Waste wash water recycling in ready-mixed concrete plants

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Abstract

Production of large amounts of waste wash water coming from ready-mixed concrete plants leads to problems of environmental impact. National laws usually prohibit the disposal of such types of water, due to their extremely high pH value and suspended matter amount, and require the water to be treated prior to discharge. prEN 1008 provides for recycling waste water in the production of new concrete, but gives some restrictions for its composition and use. In this paper, the use of waste wash water (coming from a medium-size ready-mixed concrete plant) in mixing water for concrete and mortars has been investigated: the effects on physical–mechanical properties and microstructure are investigated as a function of the characteristics of waste water used. The results have shown that mortar and concrete prepared with recycled water exhibit 28-day mechanical strength in no way lower than 96% of the reference materials (90% is the minimum allowed in prEN 1008) and, in some cases, even better. Moreover, the use of wash water in concrete leads to a reduction of the concrete capillary water absorption and mortar microporosity, which surely improves the durability of the material. This effect can be ascribed to the filling action of the fines present in the wash water and to the slight reduction of the actual water/cement ratio.

Keywords: Ready-mixed concrete; Wash water; Recycle; Mortar; Concrete plants

1. Introduction

It has been calculated that a 9-m^3 ready-mixed concrete truck contains, at the end of each working day, approximately 200–400 kg of returned plastic concrete [1,2]: this material can be left overnight in the truck with the addition of hydration control admixtures [3,4] or washed out. When washed out, with the addition of about 700–1300 l of water, the material can be mechanically separated into aggregates ready for reuse and water containing amounts of suspended fine particles. According to Italian law [5], such water cannot be discharged into urban sewers because of its content of suspended matter (usually exceeding the maximum allowed content of 2 ml/l) and pH value (usually higher than 9.5). Consequently, partial and complete recycle of waste wash water are usually adopted in the manufacturing plants. By the former method, water is collected in sedimentation basins: hence, clarified water is reused in the production, while sediment must be disposed of in authorised landfills; on the contrary, full recycle represents an environmentally safe and cheap procedure, because wash water is totally reused as mixing water in the production and no disposal procedure is involved.

The use of recycled waste wash water for the production of new concrete is dealt with by prEN 1008 standard [6]: mixing water must meet severe requirements in composition and may be used only if concrete exhibits 7- and 28-day compressive strengths higher than 90% of the value exhibited by samples prepared with distilled water (in Table 1, the main requirements of pr EN1008 are shown in comparison with those of ASTM C94 [7]). In spite of the so far achieved requirements by prEN 1008, building companies often fear the use of ready-mix truck wash water in the production of fresh concrete, also because limited investigation has been carried out on this topic [2]: for this reason, the effect of waste wash water on the properties (strength, microstructure and durability) of mortars and concretes has been investigated in this paper, referring to a ready-mixed concrete plant where waste water recycling is daily carried out in the production after the removal of the aggregates >0.15 mm from wash water by a reclaimer system. The plant is a

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Table 1
Main criteria of prEN 1008 and ASTM C94 for the assessment of mixing water

Parameter	prEN 1008	ASTM C94
Cl^- content	≤ 600 mg/l (prestressed concrete/grout)	Optional requirement: ≤ 400 mg/l (prestressed concrete or bridge desks)
	≤ 1200 mg/l (reinforced concrete)	≤ 1200 mg/l (reinforced concrete)
SO_4^{2-} content	≤ 2000 mg/l (otherwise, water fits for use in certain cases only[a])	Optional requirement: ≤ 3000 mg/l
Solid material content	Recommendation: ≤ 1% of the total amount of aggregate in the concrete	Optional requirement: ≤ 50,000 mg/l
Suspended matter	≤ 4 cc[b] (otherwise, the water fits for use in certain cases only[a])	–
Comparative samples strength	The mean 7-day and 28-day compressive strength of the mortar or concrete samples prepared with wash water must be at least 90% of the mean strength of the control samples (prepared with distilled or tap water)	The mean 7-day compressive strength of the concrete samples prepared with wash water must be at least 90% of the mean strength of the control samples (prepared with distilled or city water)

[a] It means that the final assessment depends on an assessment of each individual case and/or the comparative concrete test.
[b] Measured as the volume of solids settled, in a 30-min period, out of 80 cm^3 of water.

middle-size one (Calderara di Reno, Bologna) producing about 70,000 m^3 of concrete per year.

2. Experimental

2.1. Water

Water samples were collected from an outdoor stocking basin (diameter 5 m, depth 3 m), which contains the wash water from the plant diluted with variable amounts of clear well water in order to maintain the water level at the right height; to prevent solids settling, water is stirred for 4 min every 15 min. The water samples were collected on different days and at different hours, always during active stirring. Well water, certified by an authorised laboratory for the production of concrete, and distilled water were used as control samples.

The samples were analysed by both visual inspection and chemical tests. The pH value, the suspended matter and the evaporation residue were measured according to prEN 1008 testing procedure. The suspended matter is the volume of solids settled, in a 30-min period, out of 80 cm^3 of water and depends on the solids grain size distribution and maximum particle size (small particles will require a longer time to settle than big ones); on the contrary, the evaporation residue is simply the total solid matter contained in the water (g/l). The comparison between these parameters pertaining different water samples may provide information about the fineness of the solid matter. The total soluble salts, chlorides and sulphates content were determined, respectively, according to Italian R.D. 16/11/1939 N. 2228, ISO 9297 and ISO 9280. Results are reported in Table 2: all the requirements of prEN 1008 were met. Moreover, the total solids never exceeded 50,000 ppm, according to the optional requirements in ASTM C94 [7].

In addition, some tests were performed on the evaporation residues of the water. Grain size distribution was determined by a laser grain size measuring apparatus (Mastersizer 2000 equipped with a Hydro 2000 MU, by Malvern Instruments): the samples were dispersed in a 0.05% sodium hexametaphosphate (NaHMP) solution and exposed to ultrasounds (10 μm) for 1 min before measurement. The composition of the residues was investigated by X-ray diffraction (Philips Diffractometer PW 1840), determination of the $CaCO_3$ content (Dietrich-Frulig apparatus) and scanning electron microscopy (Philips 501 B).

2.2. Concrete and mortar

In order to investigate the effect of waste wash water on the resulting concrete performance, water samples A, B, C,

Table 2
Water samples characteristics

Sample	Description	pH	Suspended matter (vol.%)	Evaporation residue (g/l)	Total soluble salts (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)
A	distilled water	7	–	–	–	–	–
B	well water	8	–	–	633	31.0	71.2
C	tank water	13.5	5.0	11.4	1214	29.3	198.9
D	tank water	13	18.1	39.9	1576	23.1	703.6
E	tank water	13	10.3	34.0	1492	19.9	362.7
F	tank water	13.5	20.0	25.6	1354	5.3	521.9
G	obtained adding well water to F	13	6.3	8.2	1111	4.6	427.7

Table 3
Concrete samples mix proportions (water/cement ratio = 0.57)

Component	Quantity per 1 m^3 of concrete
Cement (CEM II/A–L 42,5 R)[a]	350 kg
Aggregate 1 (sand, 0–6 mm)	805 kg[b]
Aggregate 2 (fine gravel, 6–15 mm)	537 kg[b]
Aggregate 3 (gravel, 15–25 mm)	447 kg[b]
Water	200 l
Additives	none

[a] According to 197-1.
[b] At saturated surface dry conditions.

D and E were used, within 1 h from the sampling, to prepare normal concrete cubes (15 × 15 × 15 cm) according to the procedures of UNI 6128 and 6130. The mixture proportions correspond to a concrete daily manufactured in the plant and are reported in Table 3. The coarse aggregate is limestone, while the sand is silica–limestone. Solid material added through recycled water never exceeds 1 wt.% of the total amount of aggregates, thus meeting the requirements of prEN 1008. The whole cement and aggregates used in the tests were sampled from the plant silos and hoppers in one single operation, in order to prevent any nonhomogeneity of the materials, and then stocked in sealed containers before use.

Workability of fresh concrete was investigated by slump test (ISO 4109). Compressive strength measurements were carried out on the concrete samples, cured at room temperature for 7 and 28 days at RH>90% (UNI 6127), by a Tecnotest Cement Prova AT300 machine (300 t). Water absorption test at atmospheric pressure was performed on hardened concrete cubes according to UNI 7699.

In order to investigate the effect of waste wash water on the material microstructure without taking into account the contribution of coarse aggregate, prismatic mortar specimens (40 × 40 × 160 mm) were prepared as well. The same water samples as for concrete specimens were used; in addition, F and G, characterized by different amounts but same type of solids, were used in order to investigate the mortar properties as a function of the solid content only. Sample preparation and curing were made according

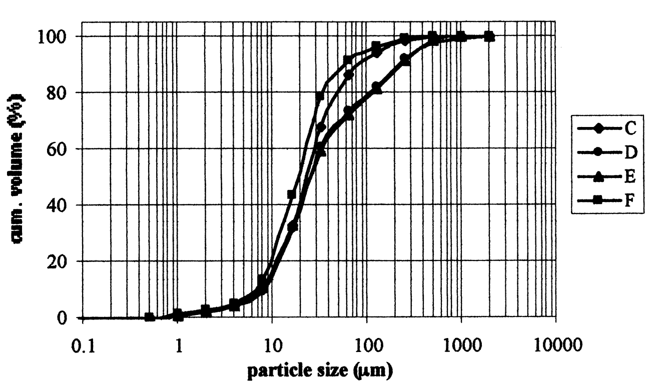

Fig. 1. Grading curves of the evaporation residues of the water samples.

Fig. 2. Microstructure of the evaporation residue of water sample F (marker = 1 µm).

to EN 196-1; water was added by volume as in the plant. After 7 and 28 days of curing, the prisms were tested for flexural and compressive strengths in an Amsler Wolpert machine (100 KN) according to EN 196-1. Afterwards pore size distribution measurements were carried out on the samples, after drying for 1 h at 80 ± 5°C and then for 3 h under vacuum at the same temperature, by a mercury porosimeter Carlo Erba 2000 equipped with a Fisons Macropore Unit 120.

3. Results and discussion

Grain size distribution of the wash water evaporation residues are reported in Fig. 1. It can be observed that the residues contain very fine particles: about 80 vol.% of D and E and 90 vol.% of C and F are sized less than 100 µm, while the particles dimensions are mainly assessed around 20 µm. As regards the residues composition, the $CaCO_3$ percentage was found equal to 37.1 for C, 34.3 for D, 35.1 for E and 29.9 for F and presence of SiO_2 was found by X-ray diffraction; even if amounts of hydrated cement are present, scanning electron microscopy performed on the residues showed only very few acicular formations whose small dimensions (few micrometers) are surely due to the disrupting action undergone by water during stirring as shown in Fig. 2.

In Table 4, fresh concrete samples slumps are reported. It is noteworthy that the use of recycled water causes a slight

Table 4
Concrete samples slump

Sample	Slump (cm)	Consistency class
A	13.5	S3
B	14.5	S3
C	12.3	S3
D	11.0	S3
E	12.0	S3

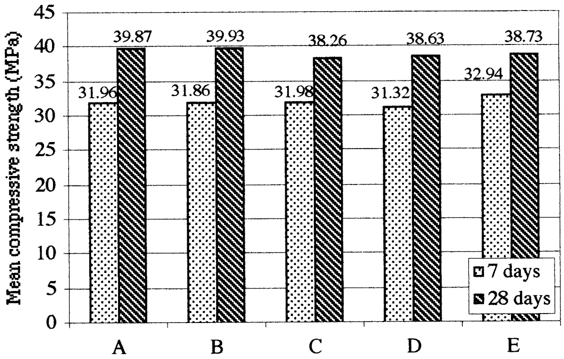

Fig. 3. Concrete cubes compressive strengths.

workability decrease, but the consistency class (S3, according to ISO 4103) does not change. As a matter of fact, even if the recycled water volume is the same for all the samples, the presence of sediment makes the actual water/cement ratio decrease, resulting in a slight workability loss and slump decrease as a function of the solid content.

In Fig. 3, the concrete samples compressive strengths, after 7 and 28 days of curing, are reported. The following can be noticed.

- After 7 days, samples prepared with recycled water exhibit a mean compressive strength (32.08 MPa) higher than those of the control samples.
- After 28 days, samples prepared with recycled water exhibit compressive strengths slightly lower than those of the control samples. However, their mean strength (38.54 MPa) is about 96.5% of the reference samples, well higher than 90% of the strength of the sample prepared with distilled water, thus meeting the requirement of prEN 1008.
- In the range of concentrations investigated, small differences exist among the samples prepared with recycled water and no apparent relationship can thus be detected between solid content and compressive strength.

Water absorption is reported in Fig. 4: a significant decrease in water absorption can be observed when recycled water is used. These data suggest that fine suspended particles in the water can act as fine fillers in the hardened concrete. Of course, the water absorption decrease depends also on the reduction of the actual water–cement ratio.

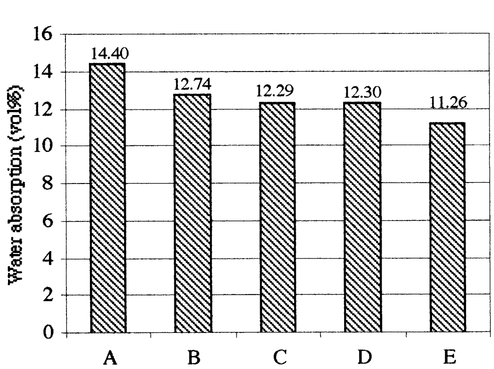

Fig. 4. Concrete samples water absorption.

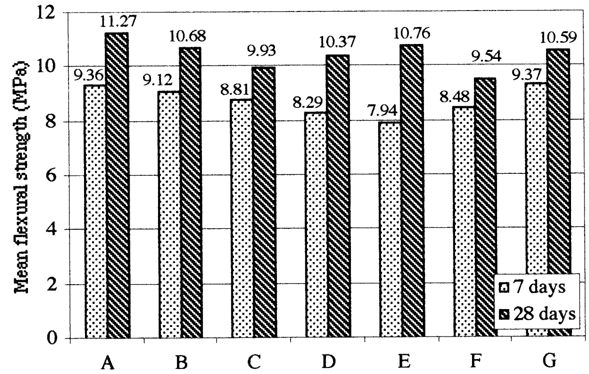

Fig. 5. Mortar flexural strengths (each value is average of three measurements).

Sample E, which shows the highest strength, exhibits also the lowest water absorption.

In Figs. 5 and 6, the mortar samples flexural and compressive strengths after 7 and 28 days of curing are reported. The following can be noticed.

- Samples prepared with recycled water exhibit 7-day compressive strengths slightly lower than sample prepared with distilled water (A), but higher than sample prepared with well water (B).
- Samples prepared with recycled water exhibit 28-day compressive strengths comparable with and even better (D, E, G) than the control samples. The lowest value detected (C) is 97% in comparison with the reference samples. As for concrete samples, mortar samples prepared with recycled water also have compressive strengths much higher than 90% respect to the sample prepared with distilled water.
- Samples prepared with recycled water exhibit 28-day flexural strengths lower than reference samples: their mean strength (10.24 MPa) is 90.9% of A and 95.9% of B. Even if prEN 1008 does not specify any requirement for flexural strength, it is important to underline that the recycled samples mean flexural strength is higher than 90% of that of the reference samples.

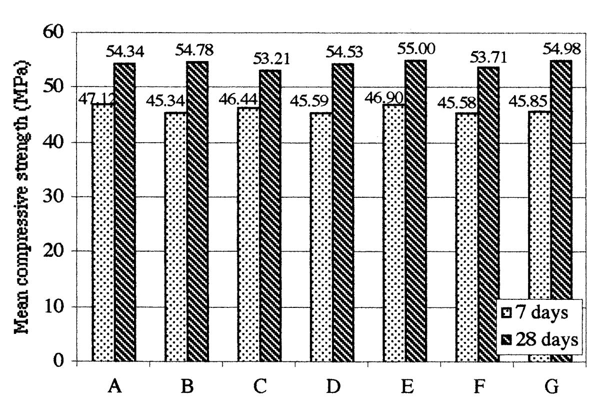

Fig. 6. Mortar compressive strengths (each value is average of five measurements).

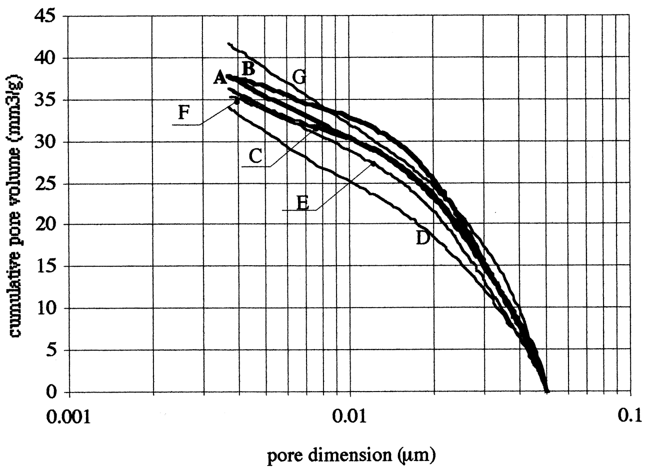

Fig. 7. Micropore size distribution (< 0.05 μm) of the 28-day mortar samples.

• Sample F exhibits mechanical strength lower than G, which contains the same type of solid material in a smaller amount.

The comparison between F and G samples suggests that, when the solid matter has the same composition, mechanical strength decreases as a function of the residue amount increase. However, samples C and D seem to show an opposite effect, perhaps depending on the suspended matter composition, grain size distribution and particles maximum size.

As regards the mortars microstructure, the samples microporosity has been investigated: only pores < 0.05 μm have been considered for this purpose because, for all the samples, the pores average sizes are assessed mainly around 0.05 μm. Therefore, in Fig. 7, the relevant pore size distribution curves are reported for values exceeding the curve inflection point: they reveal that in the range of the micropores, the samples with recycled water generally show a lower porosity than the control ones. This might be ascribed to both the fine filler action performed by the sediments and the lower actual w/c ratio; accordingly, the effect is particularly marked for D and E, which were prepared with water with high residue content. Moreover, sample F exhibits a microporosity lower than G, which contains the same type of solid material, but a smaller amount of it.

4. Conclusions

The following conclusions for the use of recycled wash water as mix water can be drawn.

• The investigated recycled water, having solid content up to 40 g/l (which is quite close to the limit of 50 g/l in ASTM C94) give mortars and concretes having 28-day compressive strengths in no way lower than 96% in comparison with clear water (90% is the minimum allowed by prEN 1008) and, in some cases, even higher.

• Even if prEN 1008 does not specify any requirement for flexural strength, the samples prepared with wash water exhibit, nevertheless, a mean 28-day flexural strength slightly higher than 90% of the distilled water sample (and equal to 95.9% of the well water sample).

• In the range of concentrations investigated, small differences occur among the samples prepared with recycled water, and no apparent relationship is envisaged between solid content and compressive strength; this is probably due to the different composition and grain size distribution of the was water solids.

• The use of recycled water leads to a slight reduction of the fresh concrete workability, due to the addition of fines and the reduction of the actual water content.

• The use of recycled water leads to a reduction of the concrete capillary water absorption and mortar microporosity, possibly improving the durability of the material; this might be due to the fine-filler action performed by the wash water fine solids and actual water/cement ratio reduction.

Therefore, poor confidence of users in concrete containing waste wash water does not seem well-grounded, particularly considering the environmental benefits resulting from reuse of water.

Presently, additional aspects as setting time, microstructure and effect of additives are under investigation.

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