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Petrochemical and Petrophysical Characterisation of Construction and Demolition Inert Materials for Concrete

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ABSTRACT

Use of recycled aggregates is promoted by EU with guidelines for common strategies for a correct re-use of construction and demolition (C&D) [Poon et al., 2001]. In Italy, the legislation is encouraging the re-use of C&D inert materials but, due to the scarcity of suitable plants for processing, this resource is used as a lower quality materials for low grade application. In this study, different grain-size fractions, obtained by a grain-size sorting, from a C&D processing plant in Rovigo (NE Italy), were investigated through chemical and physical testing, to evaluate their composition, assisting in the development of improved recycling methodologies for concrete. Chemical-mineralogical and physical analysis have shown that the material is roughly homogenous. Several concrete mixes were prepared using different percentage of recycled aggregate and tested. The data have shown that the introduction of 30% of inert recycled coarse fraction, substituting natural coarse aggregate, does not affect the concrete.

INTRODUCTION

The aim of this study is to verify the possible reusing of recycled construction and demolition aggregates coming from the Fenza Daniela Plant in Rovigo, in the building activities.
More in details two different fraction produced in the plant were sampled
-Recycled sand
-Recycled material 0-30 mm fraction
Accordingly with the current national (UNI 8520/2:2005) and international (UNI EN 12620:2005) technical normatives for the reuse of recycled aggregates in the concrete production, chemical and physical characterisation were performed on the two mentioned fractions.
In the first phase of this study all the recycled aggregates were characterized, then several concrete mixes were performed in order to identify the best composition for the conglomerate and the possible composition of the additive to add in the mix [ATECAP, 1996; Collepardi, 2003; Alunno-Rossetti, 1999].

After that, it has been carried out the complete physical and mechanical characterisation of the concretes produced, following the normative:

<u>Fresh concrete:</u>
- Density in pile (UNI EN 12350-6);
- Air content (UNI EN 12350-7);
- Abrams workability (UNI EN 12350-2);
- Shock table workability (UNI EN 12350-5);

<u>Harden concrete</u>
- Density (UNI EN 12390-7);
- Compressive strenght (UNI EN 12390-3);
- Withdrawal humidity (UNI EN 12390-6).

PHYSICAL PROPERTIES OF AGGREGATES

Granulometric characterisation of aggregates

The granulometric distribution of aggregates were determined accordingly with the EN 12620 European Normative by a sieving using several sieves each with a specific dimension of the filter.

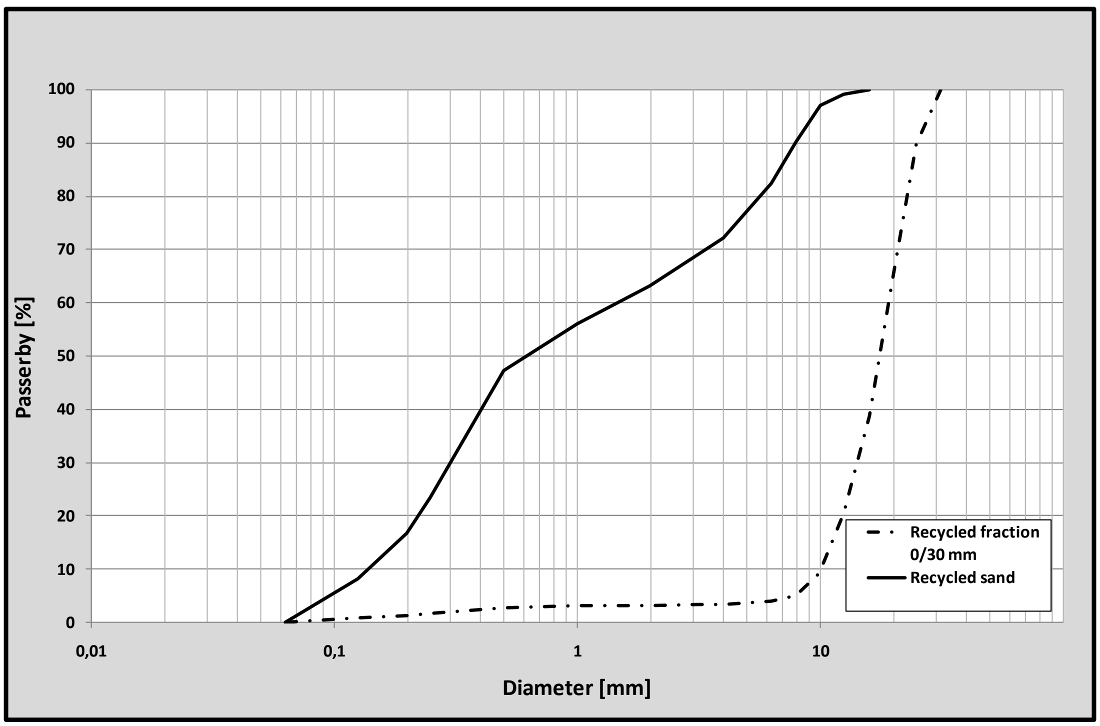

Figure 1- Granulometric Analysis of Recycled Aggregates Fraction 0/30.

The granulometric analysis of recycled coarse and fine aggregates (Figure 1) have shown that the aggregates fraction 0-30 mm were roughly homogeneous and have a correspondence with typical gravel, on the other hand the recycled aggregates called “recycled sand” showed a more heterogeneous distribution and could be compared with a coarse sand.

Shape and angularity of the aggregates.

The rheology of the concrete is directly related with the granulometric distribution of the aggregate and also with the shape, the wear and the texture of the aggregate. The shape indicates the prevalence of specific dimension of the aggregates with respect to the others and this features can be detected with the shape index, following the UNI EN 933-4.
As for EN 12620 and UNI 8520/2 there are no strictly rules regarding this features of the aggregates, nevertheless the concrete producers have to consider that aggregates with shape index over 15 can be characterized by a bigger specific surface than rounded inert materials. This can produce a more necessity of water in the mixes.
In order to classify the inert materials shape it have been follow the Zingg methods (1935), (Figure 2).

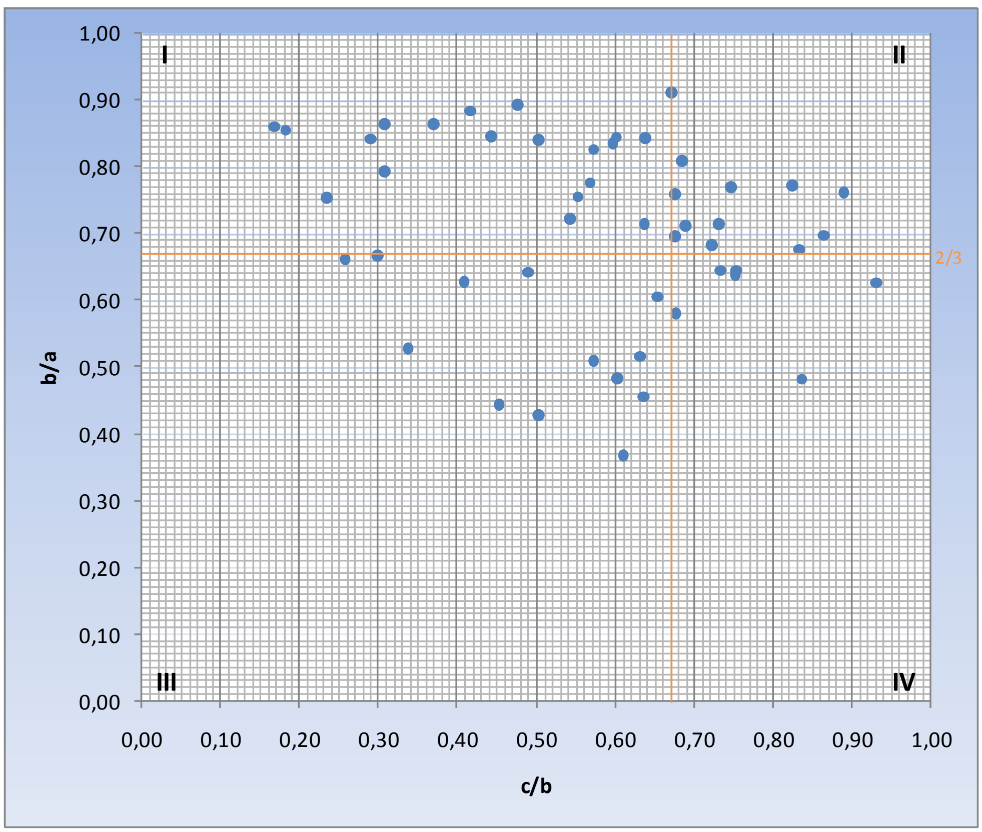

Figure 2- Zingg Diagram for Recycled Fraction 0-30 mm.

The Zingg diagram (Figure 2) shows the following shapes:
I: disk shaped (20 points) 40%
II: round shape (12 points) 24%
III: flat shape (12 points) 24%
Iv: longed shape (6 points) 12%

As for the shape of the aggregates, the flat shape of the particles is an important parameter and for this reason it have been measured the flakiness index (UNI-EN 933-3), that represent the percentage of the particles that have been characterized by one of the dimension 0,6 times lower than the average of their granulometric fraction (Table 1).

Table 1- Measured Values for Recycled Fraction 0-30 mm.

M_1	M_2	FI
9544,4	1903,7	19,95

Nevertheless in UNI 8520/2 normative there is no limitations in the percentage of flat particles in a concrete mix, a big quantity of particles with this peculiar features can cause an anisotropic behaviour of the concrete.

Density in pile
The density in pile of dried aggregates is defined by EN 1097-3 normative. It has been determined by weighting after drying of samples in a defined volume and calculating the ratio between the material mass and its volume (Table 2).

Table 2- Density in Pile for Recycled Aggregates (EN 1097-3:1998).

	Recycled sand	Recycled fraction 0-30 mm
Density in pile [Mg/m^3]	1,40	1,04

Density for the grains and water absorption

The open porosity of the aggregate is defined following UNI 8520/13 e /16 by weighting the sample before and after water absorption. This is an important feature that have to be consider during the concrete mixes preparation. In Table 3 indicates samples with high water absorption

Table 3- Average Density (m), Average Density Dry Surface (msa), and Absorption.

Sample	m [Kg/m^3]	msa [Kg/m^3]	A [%]
Recycled fraction 0-30 mm	2080	2270	9,13
Recycled sand	2136	2283	6,91

Fragmentation resistance determination by Los Angeles test

This parameter is determined following UNI EN 1097-2.
The test were performed on recycled fraction 0-30 mm and the results were collected in Table 4.

Table 4- LA Values for Recycled Fraction 0-30 mm.

	m [g]	LA [%]
Recycled fraction 0-30 mm	3133	37

The LA value determined for the recycled fraction 0-30 mm is comparable with typical values for soft rocks, this induce to think that this material have a low abrasion resistance.

CHEMICAL PROPERTIES OF AGGREGATES

It is well known that not all the inert materials, natural and recycled, are suitable for concrete production. In the list of harmful substances for concrete there are chloride, sulphate, silica reactive to alkali, clay and silt and organic substances. Moreover the inert materials used in concrete have to be resistant to freeze and thaw cycles.

This study has considered only some of the above harmful substances, more in detail have been analysed the alkali-silica reaction properties, the presence of silt and clay particles and the organic material.

Alkali-Silica Reaction (ASR)

The Alkali-Silica Reaction (ASR) is a reaction which occurs over time in concrete between the highly alkaline cement paste and reactive non-crystalline (amorphous) silica, which is found in many common aggregates. This reaction causes the expansion of the altered aggregate by the formation of a swelling gel of Calcium Silicate Hydrate (CSH). This gel increases in volume with water and exerts an expansive pressure inside the material, causing spalling and loss of strength of the concrete, finally leading to its failure. So, ASR can cause serious expansion and cracking in concrete, resulting in critical structural problems that can even force the demolition of a particular structure.

The results obtained from the accelerate expansion have shown after 16 days a value of 0,113%, slightly higher than 0,1%, the maximum value accepted by law. Consequently the aggregates in this study were tested again. Nevertheless also the results of the this test were slightly higher than requested, it has been decided to continue, considering the aggregate suitable. In fact in the tests the aggregate used were all composed by recycled fractions, but in real mixes only a part of the aggregate were constituted by recycled fraction, lowering the ASR values.

Clay and silt particles

The mechanical performance of concrete are directly influenced by the presence on the surface of particles of very fine materials such as clay and silt that can reduce the adherence with the cement matrix. The UNI 8520/2 gives a limit in the content of very fine fractions passing through the 0,063 mm sieve. In this study the percentage of very fine fractions passing through the 0,063 mm sieve are showed in Table 5, where it can be observed that the quantity of this fraction in the recycled sand fraction is quite high. For this reason, the reuse of the recycled sand fraction needs a second test.

Table 5- Values of Percentage of Passing 0,063 fraction.

	Recycled sand [%]	Recycled fraction 0-30 mm [%]
PERCENTAGE OF PASSING THE 0,063 mm	19,6	2,8

The UNI EN 933-8 normative requests a test for the determination of sand equivalent (SE). The aggregate is suitable for the using if the SE value is not lower than 80, for natural aggregates, 70, for secondary aggregates. For the recycled sand investigated in this study the SE value were 28, clearly lower that requested, and for this the sand were further tested accordingly with the UNI EN 933-9 normative, using the Methylene blue test. The results of this test for the recycled sand aggregate were clearly over the normative limits.

Organic substances

The organic substances in the inert materials have usually a prevalent vegetal origin and can negatively interact with the cement hydration processes, slowing down or reducing the development of mechanical strengths. The organic matter content were defined following the UNI EN 1744-1 normative, using the colorimetric method (Figure 3).

Recycled fraction 0-30 mm	Recycled sand

Figure 3- Colorimetric test on Recycled fraction 0/30mm and on recycled sand.

The colorimetric test results have shown that the recycled material fraction 0/30mm is more suitable for concrete mixes. The darker colour of tests for recycled sand suggested that it can be not a suitable material for the preparation of concrete mixes.

CONCRETE MIX DESIGN

After the characterisation of the aggregates, some preliminary mixes were prepared and tested in order to identify the best composition for the conglomerate, and for the definition of the compatible additive.

Several mixes (30 liters) were prepared to best identify maximum two mixes to be reproduced in higher quantity and to be completely characterized. The trial mixtures were obtained mixing recycled aggregates previously characterized together with natural aggregates, called “Sataf”, with known features and usually used for concrete preparation. In particular, 7 granulomeric curves were realised for preliminary mixes obtained studing the mix-design [ABC del Calcestruzzo, 1999; Collepardi, 2003; Alunno-Rossetti, 1999]. As for the water quantity it has been decided to used 200 Kg/m^3, for obtaining a concrete with workability S3-S4. As for the cement it has been used CEM II A/L 42,5, considering a water/cement ratio of 0.66, 300 Kg/m^3 of cement , were used. During the mix preparation, only some of the mixtures realised the additive creactive L (Axim Italia) were added [ABC del Calcestruzzo, 1999; Collepardi, 2003; Alunno-Rossetti, 1999].

MIXING OF THE INGREDIENTS AND CHARACTERISATION OF PRELIMINARY CONCRETE MIXTURE

The preliminary mixes prepared (Table 6) were characterized following UNI EN 206-1 normative:
as for the fresh properties

- Density
- Workability
- Cohesion

And as for the harden state
Mechanical features and compressive strength.

As for the recycled aggregates they were used after water saturation in order to reduce the water request of the mixes. Moreover it were calculated the real quantity of water requested, taking away from the 200 Kg/m^3 hypothesised, the water absorption of “Sataf” aggregate.

Table 6 Characterization of preliminary mixes according with UNI EN 206-1.

	mixes	A	B	C	D	E	F	G
Sataf aggregates	filler Cremaschi	2%	-	-	2%	-	-	-
	113	10%	5%	5%	10%	7,6%	8,5%	-
	103	13%	6,5%	6,50%	13%	10%	11%	-
	117F	7,5%	3,75%	3,75%	7,5%	5,7%	7,0%	-
	117R	7,5%	3,75%	3,75%	7,5%	5,7%	7,0%	-
	107	5%	2,5%	2,5%	5%	4%	5,0%	-
	109	25%	12,5%	12,5%	25%	19%	20%	-
	10.15	15%	15%	-	-	-	-	-
	15.20	10%	10%	-	-	-	-	-
dam's aggregates	6,3-31,5	5%	5%	-	-	-	-	-
recycled aggregates	Recycled sand	-	36%	36%	-	18%	12%	70%
	Recycled frac. 0-30mm	-	-	30%	30%	30%	30%	30%
	cement	300	300	300	300	300	300	300
	water	177	156	199	184	189	187	200
	additive	-	1,5%	1%	-	0,5%	0,5%	2%
	density (Kg/m^3)	2369	2211	2129	2281	2206	2205	1996
	water-cement ratio	0,59	0,53	0,66	0,61	0,63	0,62	0,72
Workability [mm]	0'	160	110	110	150	195	210	130
	15'	140	70	110	150	175	165	-
	30'	90	-	90	125	125	140	-
Compressive strength Rcm [Mpa]	1 day	15,5	12,0	6,5	11,5	8,0	9,8	8,5
	3 days	24,0	20,0	13,0	21,1	15,5	16,5	-
	7 days	29,0	23,5	15,0	25,0	18,5	20,1	10,5
	28 days	35,5	28,5	19,1	30,0	23,0		-
Air contenet [%]		1,7	7,5	5,7	2,2	3,2	5	8

PREPARATION OF DEFINITIVE MIXES

After the characterisation of the mixes produced, a selection of the mixes were identified and reproduced in higher quantity, then the concrete obtained were characterised accordingly with the UNI-EN 206-1.

Three mixes were prepared, and more in detail: mix A, completely produced using natural aggregates and used as standard, mix D and F, prepared mixing natural and recycled aggregated (Table 7).

Firstly it was possible to observe that mixing bigger quantity of materials produced an improvement in the concrete. The final mixes were then completely characterized, moreover as for the harden state it was defined:

Total absorption

Capillary absorption

Igrometric shrinkage

Table 7- Table of main physical and technological properties of final mixes.

		A	D	F
Sataf's aggregates	filler Cremaschi	2%	2%	-
	113	10%	10%	8,3%
	103	13%	13%	11%
	117F	7,5%	7,5%	7,0%
	117R	7,5%	7,5%	7,0%
	107	5%	5%	5%
	109	25%	25%	20%
	10.15	15%	-	-
	15.20	10%	-	-
dam's aggregates	6,3-31,5	5%	-	-
recycled aggregates	Recycled sand	-	-	12%
	Recycled fraction 0-30 mm	-	30%	30%
	CEM II/A-LL 42,5 [Kg/m^3]	300	300	300
	water [Kg/m^3]	172	184	187
	additive	-	-	0,5%
	density [Kg/m^3]	2367	2239	2241
	water-cement ratio	0,57	0,61	0,62
Workability [mm]	0'	220	200	190
	15'	210	170	175
	30'	175	170	160
Compressive strength Rcm [Mpa]	1 day	18,0	14,0	13,0
	28 days	36,0	28	25,5
	60 days	37,5	29	27
	90 days		30,0	28,0
Air contenet [%]		2,3	2,2	2,2
Total absorption [%]		4,94	8,38	9,24
Capillary absorption [%]		0,47	0,71	0,61
Dimensional changes following the igrometric shrinkage average variation [mm/m]	1 day	- 0,028	- 0,027	- 0,020
	3 days	- 0,080	- 0,075	- 0,067
	7 days	- 0,155	- 0,141	- 0,159
	14 days	- 0,257	- 0,248	- 0,301
	28 days	- 0,365	- 0,400	- 0,495
	60 days	- 0,514	- 0,608	- 0,709

CONCLUSION

As for the workability of the mixes prepared, the tests have shown that using recycled aggregates it remain in the S4 class, as measured for the mix A, completely prepared with natural aggregates. Moreover the workability of the mixes seems to be constant in the time (Figure 4.)

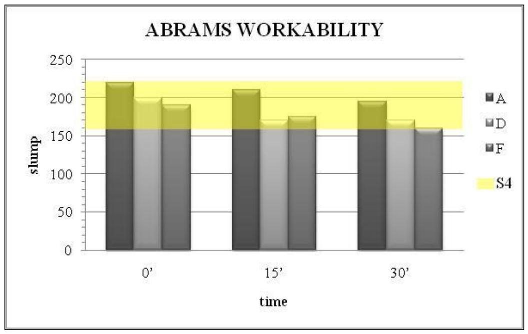

Figure 4- Variation of Workability and compressive strength in the time.

As for the properties of harden concrete, the compressive strength values measured at 28 days (Figure 5) in the mixes produced using part of recycled fractions shown to be in the range of the acceptable values of 25MPa. Before preparing the mixes were decided to have concrete with this average values of compressive strength.

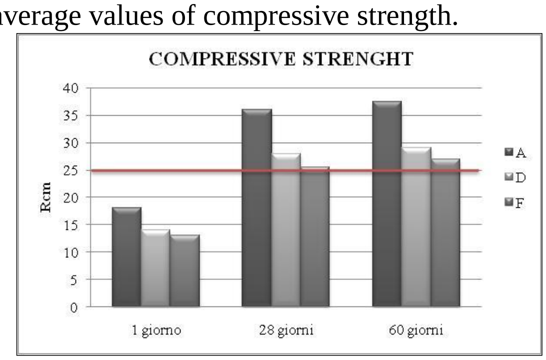

Figure 5- Compressive strength variations.

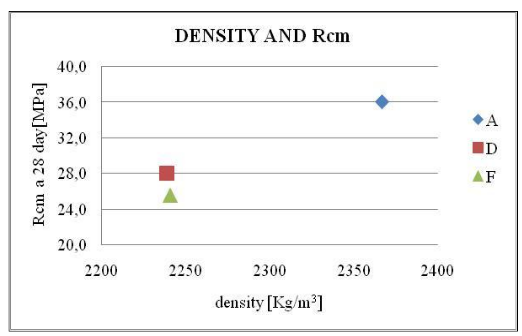

Figure 6- Correlation between compressive strength and density.

The relation between compressive strength (28 days) and density (Figure 6) shown that there is a direct relation between these two values: high values of density correspond at higher values of compressive strength. In particular, it can be observed that the reference concrete (A) shows high values of both parameters, concrete prepared with recycled fractions show lower values of both parameters.

As for absorption (Figure 7), the mixes produced using recycled fractions (D and F) have shown an increase in the absorption values. This can be justified considering the features of the recycled aggregates that inevitably influence the features of the mixes.

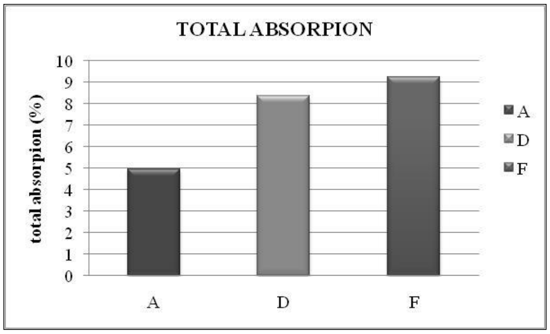

Figure 7- Total Absorption.

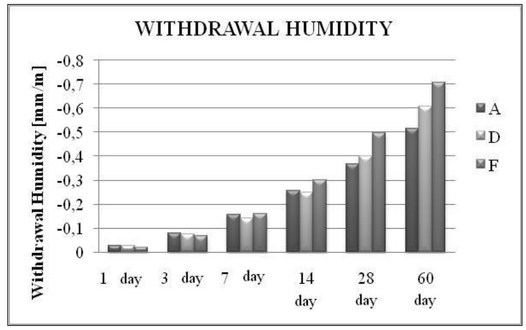

Figure 8- Igrometric Shrinkage variation during the time.

As for the igrometric shrinkage (Figure 8) data for the range 1 day - 60 days, the mixes prepared using recycled materials (D and F) showed higher values. These data are directly related with the water absorption of the concrete. In fact higher value of water absorption in concrete lead to higher igroscopic water release during time, consequently higher values of shrinkage.

Considering all the data obtained from the characterisation of recycled aggregates and concrete produced with them, substituting part of the natural aggregate, it can be asserted that it is possible to create concrete mixes with good performance using higher quantity of recycled fraction than permitted by law. The concrete produced could be used for the preparation of concrete elements such as elements to control traffic velocity. It is important to highlight that the aggregates have an important role in the concrete performance, but also the cement is an important part. In this study it has been decided to use a standard cement, but for improving the performance of the concrete, one could use some additives or cements with peculiar features.

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