# Concrete Demolition Waste: Sustainable Source for Structural Concrete

S. Manzi [1], C. Mazzotti [2] and M.C. Bignozzi [3]

**ABSTRACT**: An increasing trend towards the use of sustainable processes has led to recycle materials of different nature into concrete. Recycling contributes to waste valorization and environmental impact reduction, thus avoiding waste landfill disposal and preserving natural raw materials. Construction and demolition waste (C&DW) constitutes a major portion of solid waste production in the world. Research on the possibility of treating and reusing such waste as aggregate in new concrete has largely increased in the last years. Although it is generally recognized that crushed recycled aggregates derived from C&DW produce concrete with a low compressive strength when used as natural aggregate replacement, many features still need to be studied to properly assess the use of C&DW for building construction purposes, in particular for structural concrete. This paper investigates a suitable treatment of C&DW prior to batching and the set up of structural concrete mix design with the aim to optimize physical and mechanical properties of the new concrete. Fresh- and hardened-state properties of the studied formulations are compared with that of traditional concrete with natural aggregates. Moreover, the effects of C&DW on concrete time-dependent properties such as shrinkage and viscoelasticity, etc. are also investigated.

## 1 INTRODUCTION

Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development. Concrete is one of the most widely used building material in the construction industry, mainly due to its features such as versatility, high compressive strength, cost effectiveness, etc.. However, the use of conventional concrete has been claimed to be not environmentally friendly, manifested by frequently voiced negative concerns such as the depletion of natural resources reserve, high energy consumption and disposal issues (Marinkovic et al., 2010; Meyer, 2009; Rao et al., 2007). As a matter of fact, consumption of natural aggregates (NA) as the largest concrete component is constantly and rapidly increasing with the production and utilization of concrete. Then a question arises concerning the availability of natural aggregate's sources. On the other hand, waste deriving from construction sector (C&DW) is also an important concern for the environment. The most common method of managing C&DW is through landfill disposal, thus creating huge deposits of waste. Recycling C&DW has the potential to both reduce its amount disposed to landfill and preserve natural resources. Accordingly, the use of C&DW as recycled aggregates (RA) in concrete production has attracted much attention in recent years (Etxeberria et al., 2007; Evangelista and Brito, 2010; González-Fonteboa and

[1] *Researcher, Department of Civil, Environmental and Materials Engineering – Engineering Faculty - University of Bologna – viale Risorgimento, 2 – I-40136 Bologna - Italy, tel. +39 051 2090329, stefania.manzi4@unibo.it*
[2] *Associate Professor, Department of Civil, Environmental and Materials Engineering – Engineering Faculty - University of Bologna – viale Risorgimento, 2 – I-40136 Bologna - Italy, tel. +39 051 2093251, claudio.mazzotti@unibo.it*
[3] *Associate Professor, Department of Civil, Environmental and Materials Engineering – Engineering Faculty - University of Bologna – viale Risorgimento, 2 – I-40136 Bologna - Italy, tel. +39 051 2090342, maria.bignozzi@unibo.it*

Martínez-Abella, 2008; Khatib, 2005; Kou and Poon, 2009; Kovler and Roussel, 2011; Martín-Morales et al., 2011; Rao et al., 2007; Tabsh and Abdelfatah, 2009). However a fruitful recycling approach can be achieved if C&DW is used not only in lower quality product applications, but also for structural concrete (Domingo-Cabo et al., 2009; González-Fonteboa and Martínez-Abella, 2008). The quality of aggregates is a crucial issue for structural concrete applications: C&DW based aggregates usually exhibit lower mechanical properties than those of natural aggregates (Khatib, 2005; Kou and Poon, 2009; Kovler and Roussel, 2011; Marinkovic et al., 2010; Meyer, 2009; Rao et al., 2007; Tabsh and Abdelfatah, 2009). When demolished concrete is crushed, a certain amount of mortar and cement paste from original concrete remains attached to stone particles in recycled aggregates. It is well known that attached mortar is the main reason for the lower quality of C&DW (low density, high water absorption, etc.) compared to natural aggregates (Etxeberria et al., 2007; Martín-Morales et al., 2011; Sánchez de Juan and Alaejos Gutiérrez, 2009). Attached mortar can be diminished increasing the number of crushing processes in the production plants, thus improving coarse aggregate quality, but also growing the production costs.

In this paper C&DW deriving from the demolition of concrete buildings located in Punta Perotti (Bari, Italy) have been crushed and assorted to create grain size distributions suitable to produce high quality concrete for structural applications. Exploiting previous researches in this field (Sandrolini et al., 2009), optimized concrete mixes have been designed modifying the content and grain size distribution of C&DW. The concrete performances, in terms of fresh and hardened properties, are reported and discussed for concrete with natural and recycled aggregates, with special focus on time-dependent features that have not been so far largely investigated for C&DW based concrete.

## 2 EXPERIMENTAL PART

### 2.1 Materials

Cement type II-A/LL 42.5 R, according to UNI EN 196-1, was used as binder in samples preparation.

Sand ($S_{0\text{-}6}$, 0-6 mm), fine gravel ($FG_{8\text{-}16}$, 8-16 mm) and gravel ($G_{16\text{-}25}$, 16-25 mm) (Cave Pederzoli, Bologna, Italy) were used as natural aggregates (NA) in concrete mixes. Two cumulative grain size distributions were prepared following Fuller distribution, with maximum diameter of 16 and 25 mm respectively: $NA_{0\text{-}16}$ ($S_{0\text{-}6}$ 60 wt.% and $FG_{8\text{-}16}$ 40 wt.%) and $NA_{0\text{-}25}$ ($S_{0\text{-}6}$ 48 wt.%, $FG_{8\text{-}16}$ 25 wt.% and $G_{16\text{-}25}$ 27 wt.%).

Concrete waste coming from Punta Perotti building (Bari, Italy, 2006), demolished eleven years after its construction and located near the shoreline (Sandrolini et al., 2009), was used as recycled aggregates. Punta Perotti demolition constitutes an unrepeatable C&DW study case as the building was not finished yet. Thus it was made only of concrete, without any interior partitions, technological apparatus, etc.. Compressive test made on concrete cores of the original buildings showed a good quality of the material (Rck ≈ 39 MPa), making the relevant demolition waste very attractive for the production of new structural concrete. The demolished concrete underwent crushing in two different stages. The first crushing treatment, able to separate concrete from steel, was made with clamp mechanical excavators and jackhammers immediately after building demolition. Then, C&DW were suitably treated on site with a mobile crusher (secondary crushing treatment) and with jaw crusher (maximum sieve open: 9 cm) to obtain a nearly homogeneous material. Furthermore, two crushing treatments were made with laboratory jaw crushers (maximum sieve open: 29 mm and 20 mm respectively) to obtain chunks with size comparable to that one of natural aggregates. In particular, after the first laboratory crusher, C&DW aggregates were divided in two groups on the basis of the dimension of 25 mm.

C&DW with an average size > 25 mm were subjected to a second jam crusher, thus obtaining a cumulative grain size distribution curve (named as $RA_{0\text{-}16}$) similar to that one prepared with the natural aggregates $NA_{0\text{-}16}$ ($D_{max}$ =16 mm), according to Fuller distribution (Figure 1). C&DW with an average size ≤ 25 mm were further sieved to select only the fraction 16-25 mm. This fraction, named as $RA_{16-25}$ shows a grain size distribution similar to that one of natural aggregate fraction $G_{16-25}$.

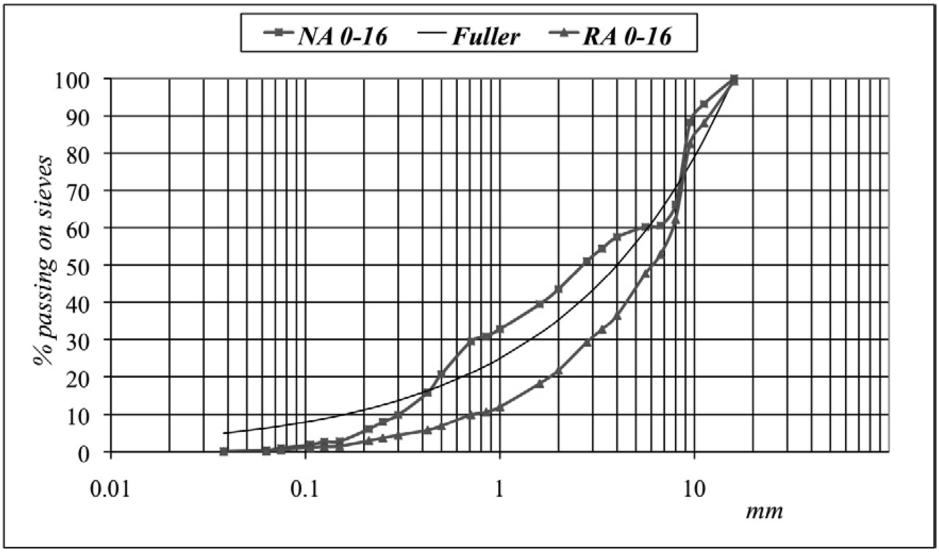



Figure 1 - Grain size distribution of recycled aggregates ($RA_{0-16}$) and natural aggregates ($NA_{0-16}$), compared with Fuller distribution ($D_{max}$ =16 mm).

The main physical properties (dry bulk density $\rho_{rd}$, saturated surface-dried density $\rho_{ssd}$ and water absorption WA) of natural and recycled aggregates are reported in Table 1. An acrylic based superplasticizer (SP) was used as admixture in all concrete mixes.

Table 1 - Physical properties of natural and recycled aggregates.

| | **Natural aggregates (NA)** | | | **Recycled aggregates (RA)** | |
|---|---|---|---|---|---|
| | **$S_{0-6}$** | **$FG_{8-16}$** | **$G_{16-25}$** | **$R_{0-16}$** | **$RA_{16-25}$** |
| **$\rho_{rd}$ (Mg/m$^3$)** | 2.63 | 2.54 | 2.54 | [a] | 2.10 |
| **$\rho_{ssd}$ (Mg/m$^3$)** | 2.68 | 2.57 | 2.57 | [b] | 2.25 |
| **WA (%)** | 2.2 | 1.4 | 1.2 | 9.0[c] | 7.0 |

[a] For 0-4 mm $\rho_{rd}$ = 2.10 Mg/m$^3$ and 4-16 mm $\rho_{rd}$ = 2.26 Mg/m$^3$, according to UNI EN 1097-6
[b] For 0-4 mm $\rho_{ssd}$ = 2.32 Mg/m$^3$ and 4-16 mm $\rho_{ssd}$ = 2.43 Mg/m$^3$, according to UNI EN 1097-6
[c] For 0-4 mm WA = 10.0 % and 4-16 mm WA = 7.7 %, according to UNI EN 1097-6

## 2.2 Samples preparation

Concrete mixes investigated are reported in Table 2. Cement content (350 kg/m$^3$), water/cement ratio (0.48) and $D_{max}$ (25 mm) were constant for all the formulations. Reference mix, named $NA_{mix}$, was prepared with 100 wt.% of natural aggregates ($NA_{0-25}$). In order to investigate the effects of coarse aggregate substitution on the concrete properties, C-$RA_{mix}$ was prepared replacing all the natural gravel ($G_{16-25}$) with the recycled fraction $R_{16-25}$. A further concrete mix, named F-$RA_{mix}$, was prepared partially replacing the natural fraction $NA_{0-16}$ with the recycled fraction $R_{0-16}$. In particular, half amount of sand and fine gravel were replaced with recycled aggregates, exploiting the similarity of $NA_{0-16}$ and $R_{0-16}$ grain size distribution (Table 3).

For all the investigated mixes, superplasticizer was dosed to ensure a slump test result between 10-20 cm (S3 or S4). C-RA$_{mix}$ and F-RA$_{mix}$ required a slighty higher amount of superplasticizer than NA$_{mix}$.

Table 2 - Mix proportions of concrete mixes.

| **Mixes** | **NA$_{mix}$** | **C-RA$_{mix}$** | **F-RA$_{mix}$** |
|---|---|---|---|
| *Water/cement ratio* | *0.48* | *0.48* | *0.48* |
| Cement (kg/m$^3$) | 350 | 350 | 350 |
| Water (kg/m$^3$) | 168 | 168 | 168 |
| NA (kg/m$^3$)$^{(a)}$ | 1800 | 1314 | 1143 |
| RA (kg/m$^3$)$^{(a)}$ | 0 | 486 | 657 |
| Total amount of aggregate (kg/m$^3$)$^{(a)}$ | 1800 | 1800 | 1800 |
| Superplasticizer (%)$^{(b)}$ | 1.0 | 1.2 | 1.2 |

$^{(a)}$ in satured surface-dried (ssd) conditions
$^{(b)}$ wt.% on cement amount

Table 3 - Natural and recycled aggregates amount (wt.%) in concrete mixes.

| Mixes | Natural aggregates (**NA**) | | | | Recycled aggregates (**RA**) | | |
|---|---|---|---|---|---|---|---|
| | **S$_{0-6}$** (%) | **FG$_{8-16}$** (%) | **G$_{16-25}$** (%) | *Total* *(%)* | **RA$_{0-16}$** (%) | **RA$_{16-25}$** (%) | *Total* *(%)* |
| **NA$_{mix}$** | 48.0 | 25.0 | 27.0 | *100.0* | 0.0 | 0.0 | *0.0* |
| **C-RA$_{mix}$** | 48.0 | 25.0 | 0.0 | *73.0* | 0.0 | 27.0 | *27.0* |
| **F-RA$_{mix}$** | 24.0 | 12.5 | 27.0 | *63.5* | 36.5 | 0.0 | *36.5* |

### 2.3 Samples characterization

Slump test was performed to measure concrete workability, according to UNI EN 12350-2. For each formulation at least 10 cylindrical concrete samples (diameter: 12 cm, height: 24 cm) as well as 2 cubic samples (15x15x15 cm) were prepared and cured for 28 days at room temperature (≈ 22°C) and relative humidity (RH) > 95%, for physical and mechanical tests. Water absorption (WA) test at atmospheric pressure was performed on 2 cubic concrete samples, according to UNI 7699. Concrete compressive strength ($f_{cm}$) was determined using a universal testing machine (4000 kN), according to UNI EN 12390-3. Four concrete cylindrical samples were tested for each mix. Secant elastic modulus ($E$), according to UNI 6556, was also measured by compression tests on cylindrical samples (2 samples for every mix were considered).

Finally, long-term behaviour of recycled concretes was investigated by performing creep and shrinkage tests. In more details, two cylinders for every mix were subject to creep test, according to ASTM C512/C512M-10 standard, and two cylinders were subjected to shrinkage test (starting at two days from casting). All the tests were performed in a climate room at 20°C and 60% RH for a time duration of more than 90 days. The longitudinal strain variation with time of each cylinder was measured by using electrical strain gauges connected to a digital acquisition system. As for the creep tests, a compression stress of about 30 percent of the strength at the time of loading (i.e. within stress limit of linear viscoelasticity) was applied at 28 days age of loading.

## 3 RESULTS AND DISCUSSION

As expected, the mixes with recycled aggregates show a considerable reduction of workability (Slump) at the fresh state, compared to the reference mix (Figure 2). Workability reduction was observed in C-RA$_{mix}$ and F-RA$_{mix}$ even if higher amount of superplasticizer was used (the upper limit suggested by the producer has been met). This behaviour is probably due to the shape and morphology of recycled aggregates, mainly covered by hardened cement mortar or paste.

At the hardened state, an increase in WA measurements was only detected for F-$RA_{mix}$ where a WA=7.8% has been determined (Figure 2). This increase is due to the high content of fine recycled aggregates which have the highest open porosity, as reported in Table 1.

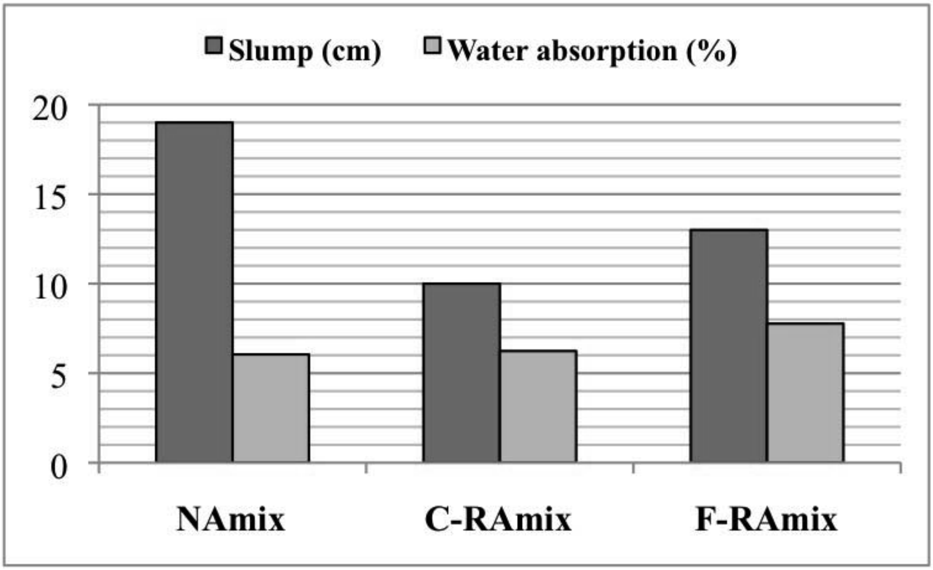



Figure 2 - Physical properties of concrete mixes.

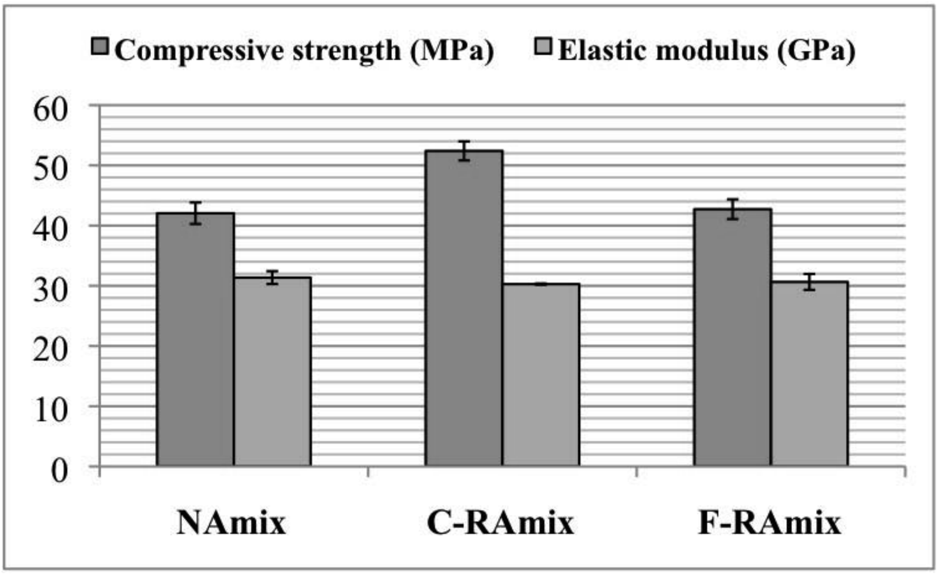
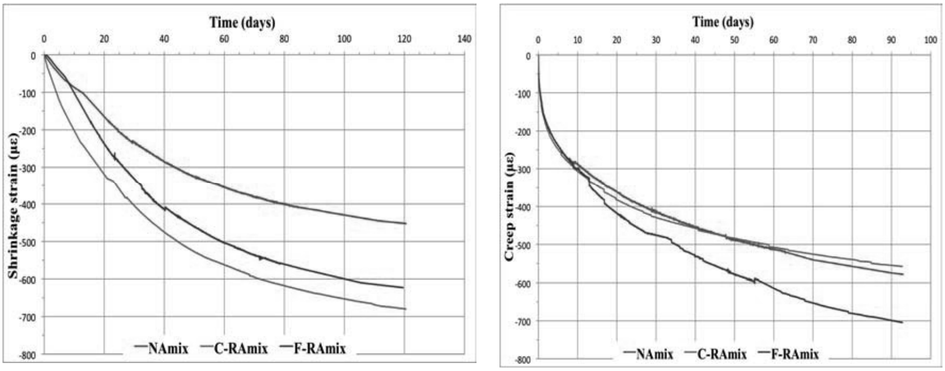



Figure 3 - Mechanical properties of the concrete mixes.

The mechanical properties ($f_{cm}$ and $E$) of the investigated concrete samples are reported in Figure 3. $NA_{mix}$ and $F\text{-}RA_{mix}$ show similar $f_{cm}$ values after 28 curing days. Moreover, $C\text{-}RA_{mix}$ shows the highest compressive strength value (about 52 MPa), confirming the good mechanical strength of the coarse recycled aggregates used in the mix-design as well as their optimized grain size distribution. Elastic modulus for the investigated mixes is about 30 GPa (Figure 3) in all cases, which means that the stiffness characteristics of the RA are completely comparable with the ones from NA. These results prove that the considered C&DW, if properly assorted, may be used in the production of concrete with outstanding mechanical properties, even suitable for structural applications.




(*a*) (*b*)

Figure 4 - Shrinkage strains (*a*) and creep strains (*b*) of the investigated concrete mixes.

Figure 4 shows the long-term behaviour of the considered mixes. In Figure 4*a*, in particular, shrinkage strains (autogenous and drying contributions together) have been reported, where the effect of the amount of recycled aggregates can be observed: $C\text{-}RA_{mix}$ shows the largest shrinkage between the considered mixes, in agreement with literature data, where is reported that an increase of the content of coarse recycled aggregate generally leads to larger values of shrinkage (Rao, 2007). Correspondingly, replacing an even larger amount of natural aggregates (36.5 in place of 27 percent) but with RA of finer dimensions ($F\text{-}RA_{mix}$), a shrinkage curve intermediate between those of $NA_{mix}$ and $C\text{-}RA_{mix}$ is obtained. Creep curves (basic and drying contributions together) are reported in Figure 4*b*: $C\text{-}RA_{mix}$ and $NA_{mix}$ have very similar long-term behaviour, whereas $F\text{-}RA_{mix}$ shows larger creep strain values. This is due to the larger content of recycled aggregate introduced in the mix and to the use of the most porous fraction ($RA_{0\text{-}16}$) between the recycled aggregates. Further investigations are in progress to better correlate microstructure, mechanical properties and time dependent behaviour of the investigated mixes.

## 4 CONCLUSIONS

Use of C&DW based aggregates in concrete provides for a promising solution to the problem of their management. With tailored investigations (choice of the most suitable treatment of recycled aggregates before batching as well as proper mix design), C&DW can be used in the production of structural concrete. Correlations between microstructure, mechanical and long-term rheological properties are an important issue to move towards real applications in the construction field.

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