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# Application of low grade recycled aggregates for non-structural concrete production in the city of Barcelona

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## ABSTRACT

In this research work the applicability of low grade recycled coarse aggregates (RA) on non-structural concrete production was evaluated. Two types of RA were used, produced by recycling plants located in Barcelona. The properties of RA and limestone aggregates were determined. Conventional concrete as well as concretes made with 50% and 100% of RA were produced. Three types of cements, CEM II/A-L 42,5 N, CEM I 52,5 R and CEM I 42,5 N-SR were used in each type of concrete production. The physical, mechanical and durability (sorptivity and resistance to sulfate attack) properties of all the concretes were determined. According to the results, the concretes produced with 100% of RA obtained the lowest quality properties when cement with limestone additions was used. CEM I cement would be adequate using as maximum 50% of RA for concrete production. Finally, a pilot test was conducted to verify the large scale behavior.

**Keywords.** Low grade recycled aggregates, non-structural concrete.

## 1. INTRODUCTION

The generation of huge volumes of Construction and Demolition Waste (CDW), together with the production of low-grade recycled aggregate requires the analysis of the use of those aggregates in the production of non-structural concretes. The approach to the European Community objective with respect to reused and recycling of CDW (70%) for 2020 (Delgado et al. 2009) is also necessary. Many European countries have established rules and procedures according to EU guidelines to encourage the reuse of CDW materials in new applications. With respect to Spain, according to CDW management, the Spanish Environment Ministry defined the objective for 2015 as that of recycling 35% of the waste (Spain. Ministerio de Medio Ambiente. 2007).
In 2007, the Catalan regional government reinforced that objective defining (Catalonia, Departament de Medi Ambient. 2010) for 2012 with a reduction of 10% of generated CDW as well as a recycling target of 50% of its use. Due to the economic crisis the CDW generation was reduced by 60-70% with respect to values obtained on 2007. We must remember that this is a growing problem which will become greater in the future.
Although the Spanish government have made an effort to use recycling aggregate in new constructions: 1) Specifications of Road Works (PG-3) (Spain. Ministerio de Fomento. 2004). 2) The Spanish Structural Concrete Instruction (EHE-08) which allows the use of recycled coarse concrete aggregates on substitution of raw aggregates for structural concrete production (Grupo de trabajo "Hormigón reciclado" 2002). With respect to production of Non-structural concrete, the use of other kinds of recycled aggregates, low grade aggregates

like mixed or ceramic aggregates are excluded for their use in any kind of concrete production.
Mostly low grade recycled aggregates are produced in the Barcelona area. High percentages of the components of those aggregates do not come from concrete, such as brick, ceramic tile, asphalt etc. (González & Etxeberria 2011). Although the use of CDW recycled products has become more frequent in Spain in the past few years, the CDW recycled aggregates were only employed in low required applications (Jimenez et al. 2010, Vegas et al. 2008). Many precast elements are not subject to high mechanical demands (Poon et al. 2009, Vegas et al. 2010) and it is possible to use non-structural concrete.
Little research works have been carried out to study the properties of concrete produced with low graded recycled aggregate. It is known that they have much lower density and much higher absorption capacity than raw aggregates. A decrease in the concrete's compressive and tensile strength properties takes place when the proportion of the mixed recycled aggregates increase in concrete production (Mas et al. 2012a, 2012b, Martinez-Lage et al. 2012). However, the durability properties of concretes produced with low graded (mixed) recycled aggregates are unknown.
In this study the recycled aggregates produced in the two recycling plants located closed to Barcelona city were analyzed and used for concrete production. An experimental phase was carried out in the laboratory. The two recycled coarse aggregates were used in substitution of raw coarse aggregates 50% and 100%. Three type of cements (CEM II/A-L 42.5 N, CEM I 52,5 R and CEM I 42,5 N-SR) were used for the concrete production in order to evaluate their influence on the physical (Density and absorption capacity), mechanical (compressive, splitting tensile and modulus of elasticity) and durability (capillary absorption capacity and resistance to sulfate attack) properties. After which a pilot test was made on site in Barcelona.

## 2. LABORATORY EXPERIMENTAL PHASE

### 2.1 Materials and testing procedure

#### 2.1.1 Materials

*Cement*

Three types of cements were used for concrete production. CEM II/A-L 42.5 N, normal strength Portland cement with 20% of limestone filler; CEM I 52,5 R, Rapid hardened and high strength Portland cement; and CEM I 42,5 N-SR, Portland Cement and sulfate resistance normal strength. Chemical composition of three cements are shown in Table 1.

Table 1. Chemical composition of three cements

| | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|
| CEM II/A-L 42,5N | 20.2 | 4.4 | 4.2 | 63.3 | 1.8 | 0.6 | 0.1 | 2.9 |
| CEM I 52,5 R | 20. | 3.4 | 5.3 | 62.5 | 2.1 | 0.9 | 0.1 | 3.3 |
| CEM I 42,5 N-SR | 19.0 | 3.7 | 5.6 | 64.5 | 2.0 | 0.9 | 0.1 | 3.2 |

*Raw aggregates*

Limestone fine and coarse aggregates were used for concrete production. Physical properties of aggregates were determined according to UNE-EN 1097-6:2001 (see Table 2). The grading size distribution of all raw aggregates was adequate with respect to Spanish concrete regulations.

Table 2: Propiedades físicas de los áridos naturales utilizados

| Properties | Fine aggregates (0/4mm) | Coarse aggregate (4/10mm) | Coarse aggregates (10-20mm) |
|---|---|---|---|
| Dry density ($g/cm^3$) | 2.53 | 2.63 | 2.61 |
| Absorption capacity (%) | 1.70 | 1.30 | 0.45 |

*Recycled aggregates*

Two types of recycled coarse aggregates were used in the substitution of raw coarse aggregates for concrete production. One of the recycled coarse aggregates, named PB with a nominal size of 20 mm was obtained from a recycling plant located on the Port of Barcelona. The second one, named LF with a nominal size of 16 mm was produced in the Les Franqueses recycling plant. Both recycling plants are managed by the company Gestora de Runes de la Construcció S.A.

The constituents of the recycled aggregates were determined according to prEN 933-11 standard. The constituents of the PB recycled aggregates were: 3% of Asphalt, 23% of ceramic, 44% of Cement and cementituous materials, 28% of clean aggregates, 1% of X1 (clays and soils), 0% of X2 (mixed components such as wood, glass, metals, plastic etc) and 1 % of X3 (gypsum, plaster). LF recycled aggregates, 13% of Asphalt, 37% of ceramic, 32% of Cement and cementituous materials, 14% of clean aggregates, 1% of X1 (clays and soils), 0% of X2 (mixed components such as wood, glass, metals, plastic etc) and 2 % of X3 (gypsum, plaster).

The sulfates soluble in acid were determined according to UNE-EN 1744-1 standards. The PB and LF recycled aggregates had 0.60 and 1.10%, respectively. According to Agrela et al (2011), the gypsum content should be limited to 1.5% in order to avoid durability problems in concrete.

In table 3, the physical and mechanical properties of recycled aggregates are described. All the properties were determined according to EN specifications.

Table 3: Physical and Mechanical properties of recycled aggregate

| | Dry Density ($g/cm^3$) | Saturated Density ($g/cm^3$) | Water absorption (%) | Fine material quantity (<0.063mm) (%) | Resist. to fragmentation (%) | Flakiness Index |
|---|---|---|---|---|---|---|
| PB | 2.07 | 2.27 | 9.79 | 2.25 | 25.30 | 11.90 |
| LF | 2.10 | 2.29 | 8.88 | 2.10 | 33.60 | 18.36 |

Due to the high amount of ceramic aggregates, the absorption capacity of the aggregates was elevated (much higher than obtained by raw aggregates). All the other properties of the recycled aggregates were acceptable according to the technical specifications for aggregates to be used in concrete production.

*Admixture*

Superplasticer was used in all concretes in order to obtain adequate fresh state properties.

**2.1.2 Concrete mix proportions and productions**

Concrete mix proportions were defined according to their maximum volumetric compaction. In order to produce 1 m3 of conventional concrete and also concrete with 50% coarse aggregates in substitution of raw coarse aggregates, 240 kg of cement and an effective water-cement ratio of 0.6 were used. 265 kg of cement was used in concrete produced with 100% recycled coarse aggregates, effective water –cement ratio being 0.60 when employing LF recycled aggregates. This effective water rate was changed to 0.55 with 100% PB aggregates. The reason for this change was the low strength in those concrete produced previously (González & Etxeberria 2011). The concrete mix proportions used are defined in table 4. The effective water, defined in the table, was the water which had reacted with the cement. At concrete production the water added in the mixer was the effective water plus the water absorbed by the aggregates at mixing time. Recycled coarse aggregates were used with high humidity (aprox. 80-85% of their absorption capacity) in order to reduce their water absorption capacity at the moment of concrete production. The total water-cement ratio of conventional concrete, concrete made with 50% of recycled aggregate and concrete made with 100% of recycled aggregate were approximately 0.67, 0.81 and 0.90, respectively. All the concretes were made maintaining the same production process as previous tests (González & Etxeberria 2011).

Table 4. Mix proportions of produced concretes. Aggregates, cement and water are given in mass (kg).

| Concrete | Cement | Effective water | Sand (0-4mm) | Coarse aggregate (4-10mm) | Coarse aggregate (10-20mm) | Recycled aggregate |
|---|---|---|---|---|---|---|
| CC | 240 | 144 | 1018 | 305 | 713 | - |
| C-PB50% | 240 | 144 | 1018 | 153 | 356 | 435 |
| C-PB100% | 265 | 144 | 982 | - | - | 803 |
| C-LF50% | 240 | 144 | 1018 | 153 | 356 | 438 |
| C-LF100% | 265 | 159 | 979 | - | - | 801 |

The fifth concretes were produced using CEM II/A-L 42.5N (42.5AL), CEM I 52.5R (52.5R) and CEM I 42.5 N-SR (42.5SR), Each concrete was named according to the cement used was, for example, CC-42.5AL (conventional concrete made with CEM II/A-L 42.5N) C-LF50%-42.5SR (concrete made with 50% of recycled aggregates from Les Franqueses using CEM I 42.5 N-SR).

**2.1.3 Specimens casting and curing**

All the specimens were cast in steel molds and compacted manually. The concrete specimens were kept for 24 hours in the molds covered with wet burlap and a plastic covering to ensure that the temperature and wet conditions were stable between 19º C and 24º C and high moisture. Specimens were demolded 24 hours after casting and they were cured in humidity room at 23ºC and 95% humidity until the age of testing.

**2.1.4 Tests of hardened properties of concrete**

Physical properties as density, absorption capacity and porosity of concretes at 28 days of curing were determined according to UNE-EN 12390-7:2009**.**

According to the mechanical properties, the compressive strength of concrete was determined using a compression machine with a loading capacity of 3000 kN. It was measured at 7 days, 28 days and 6 months following the UNE-EN 12390-3. The compressive strength variability (dispersion) of different concretes produced with CEM II/A-L 42.5 N was also evaluated. The splitting tensile strength and the elastic modulus were tested at 28 days also following the UNE-EN 12390-5, UNE-EN 12390-6 and UNE 83-316-96 specifications, respectively. Three specimens were tested for each type of concrete produced. With respect to the durability properties, the concrete's capillary water absorption was assessed at 28 days after mixing, using 100 x 100 x 100 mm cubic specimens according to ISO 15148:2002(E) and the concrete resistance to sulfate attack was carried out according to ASTM C1012-95 which although more applicable in mortars can also be used for concretes (XU et al. 1998).

## 2. 2. Results and discussion

### 2.2.1 Physical properties

Table 5 shows the results. Concretes made with recycled aggregates obtained lower density and higher porosity than conventional concrete. A higher difference was appreciated when more recycled aggregates were used. The density of the concrete did not depend on the type of cement used, however, the absorption was lower when CEM I 52.5 R was applied and concretes produced with LF recycled aggregates achieved lower absorption capacity than concrete made with PB recycled coarse aggregates.

Table 5. density and water absorption capacity of concretes

| Notation | Dry-density (kg/dm$^3$) | | | Absorption (%) | | |
|---|---|---|---|---|---|---|
| | 42.5AL | 42.5SR | 52.5R | 42.5AL | 42.5SR | 52.5R |
| CC | 2.36 | 2.39 | 2.37 | 2.20 | 2.01 | 1.66 |
| C-PB50% | 2.27 | 2.29 | 2.31 | 2.92 | 2.77 | 2.07 |
| C-PB100% | 2.19 | 2.21 | 2.18 | 3.13 | 2.93 | 2.92 |
| C-LF50% | 2.30 | 2.29 | 2.26 | 2.20 | 2.55 | 2.18 |
| C-LF100% | 2.16 | 2.10 | 2.18 | 2.84 | 3.06 | 2.84 |

Concrete C-LF100% made with 42.5SR achieved the lowest density and the highest absorption capacity. However concretes produced with PB and natural aggregates using 42.5AL cement obtained the highest absorption capacity. The increase in porosity with the replacement of the Portland cement for limestone has be noted previously (Irassar et al. 2003) and corresponds to decrease in the amount of the reactive clinker capable of filling the space with hydrates.

### 2.2.2. Mechanical properties

The compressive strength at different time stages, splitting tensile and modulus of elasticity at 28 days of curing are shown in table 6.

Compressive strength of concretes made with a higher amount of recycled aggregates achieved lower strength. At 6 months, the recycled aggregate concrete produced with LF aggregates and CEM II/A-L 42.5 N achieved a similar compressive strength to that of the conventional concrete made with same type of cement. Conventional concretes made with CEM I obtained higher compressive strength than any recycled aggregate concrete.

The concretes produced with 100% of PB recycled aggregates produced, with any type of cement, obtained the lowest compressive strengths at all ages. They suffered a decrease of more than 20% compressive strength with respect to the compressive strength of conventional concrete.

According to the evolution in time of the compressive strength, there was no appreciable difference between concrete made with same cement and different types of aggregates. The concrete, which obtained lowest compressive strength at 7 days suffered the highest strength development from 7 to 28 days. From 28 days to 6 months, the concretes made with 100% of LF recycled aggregates obtained the highest increase in strength .

Table 6. Mechanical properties of all concretes

| Notation | Compressive strength (MPa) | | | Splitting Tensile Strength (MPa) | Modulus of elasticity (MPa) |
|---|---|---|---|---|---|
| | 7 days | 28 days* | 6 months** | | |
| CC 42,5 AL | 26.0 | 29.5 (12) | 32.8 (10) | 2.76 | 33288 |
| CC 42,5 SR | 29.0 | 32.04 (9) | 39.7 (19) | 2.67 | 34099 |
| CC 52,5 R | 34.8 | 38.9 (11) | 43.2 (10) | 3.39 | 35010 |
| PB 50% 42,5 AL | 18.7 | 23.3 (20) | 26.5 (12) | 2.16 | 21891 |
| PB 50% 42,5 SR | 22.9 | 28.1 (19) | 34.2 (18) | 2.62 | 28006 |
| PB 50% 52,5 R | 25.8 | 28.7 (10) | 33.1 (13) | 3.40 | 26586 |
| PB 100% 42,5 AL | 16.4 | 21.8 (25) | 25.2 (13) | 2.16 | 20008 |
| PB 100% 42,5 SR | 17.8 | 21.7 (18) | 28.1 (23) | 2.16 | 20564 |
| PB 100% 52,5 R | 24.6 | 28.7 (14) | 33.7 (15) | 2.58 | 21576 |
| LF 50% 42,5 AL | 21.4 | 26.4 (19) | 32.9 (20) | 2.65 | 27936 |
| LF 50% 42,5 SR | 22.05 | 27.7 (20) | 33.4 (17) | 2.61 | 27823 |
| LF 50% 52,5 R | 33.4 | 35.6 (6) | 40.9 (13) | 3.64 | 30170 |
| LF 100% 42,5 AL | 17.9 | 25.7 (30) | 33.0 (22) | 2.91 | 19835 |
| LF 100% 42,5 SR | 15.3 | 22.6 (32) | 30.9 (27) | 2.47 | 19731 |
| LF100% 52,5 R | 27.9 | 32.6 (14) | 38.8 (16) | 3.33 | 23847 |

* (number) means increase in strength from 7 to 28 days ** (number) increase in strength from 28 days to 6 months

The variability of compressive strength was determined in order to determine the influence of different percentages and type of recycled coarse aggregates on compressive strength of concrete made with CEM II/A-L 42.5 N cement. 19 test specimens were tested in each type of concrete. Table 7 shows the results of the analysis.

Table 7. Standard deviation of different type of concretes

| Notation | Mean (Mpa) | Standard Deviation | Variation Coef. | Minimum (Mpa) | Maximum (Mpa) |
|---|---|---|---|---|---|
| CC42,5 AL | 39.94 | 1.67 | 0.042 | 36.12 | 44.16 |
| PB 50% 42,5 AL | 28.94 | 1.45 | 0.04 | 26.44 | 31.13 |
| PB100% 42,5 AL | 22.73 | 0.73 | 0.032 | 21.01 | 23.89 |
| LF 50% 42,5 AL | 29.13 | 1.01 | 0.035 | 27.49 | 31.53 |
| LF100% 42,5 AL | 24.61 | 0.91 | 0.037 | 22.84 | 26.27 |

The compressive strength of conventional concrete suffered the highest dispersion; it obtained the highest standard deviation value. The studied concretes were low strength concretes, produced with high water-cement ratio. The concrete with the highest compressive strength at 28 days had a higher standard deviation. Concretes produced with

100% of recycled aggregates obtained low compressive strength, and its however the obtained standard deviation of compressive strength was also very low.
As was expected the conventional concrete obtained the highest modulus elasticity (see table 6). It is known that the modulus of elasticity of concrete is influenced by the modulus of elasticity of the coarse aggregate (Neville, 2000) and according to Lydon and Balendran the modulus of elasticity of aggregate is proportional to the square of its density (Lydon & Balendran 1986). Consequently, recycled aggregate concrete produced with higher percentages of recycled aggregates obtained lower modulus elasticity.
According to splitting tensile strength, the recycled aggregate concrete produced with LF aggregates obtained similar results to those of the conventional concrete, due to an adequate bond between those aggregates and the cement paste. The 20 mm of nominal size of PB recycled aggregates as well as their flat shape influenced in the obtaining of lower splitting tensile strength.

**2.2.3 Durability properties**
Table 8 shows the Sorptivity coefficient of each concrete. The capillary absorption capacity of concretes made with CEM II/A-L 42.5N was higher than concretes made with CEM I 42.5 SR. According to Schmidt et al. (2009), the replacement of a higher fraction of cement content than 5% by limestone led to an increase in its capillary porosity. Concretes made with CEM I 52.5R obtained the lowest sorptivity coefficient.
Figure 1 shows the capillary absorption process in the different time stages of the concretes. All concretes made with 100% of recycled aggregates suffered the highest capillary absorption. In general, except in CEM II, the concrete produced with 50% of recycled aggregates suffered a little more absorption capacity than CC concrete.

Table 8. Sorptivity coefficient of produced concretes

| | Sorptivity Coefficient (mm/min0.5) | | | | |
|---|---|---|---|---|---|
| | CC | C-PB50% | C-PB100% | C-LF50% | C-LF100% |
| 42.5AL | 0.043 | 0.071 | 0.120 | 0.079 | 0.079 |
| 42.5SR | 0.036 | 0.045 | 0.080 | 0.063 | 0.071 |
| 52.5R | 0.025 | 0.030 | 0.055 | 0.042 | 0.061 |

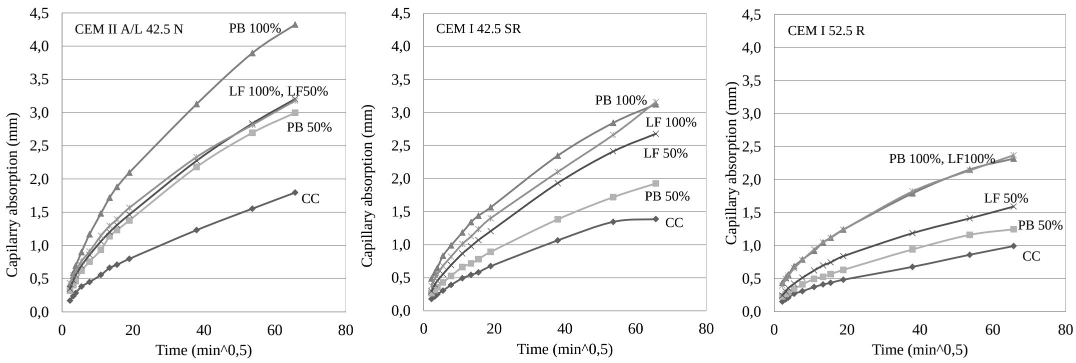

Figure 1. Capillary absorption capacity of concretes

According to the results concerning resistance to sulfate attack, the results are shown in figure 2. The concrete was exposed to very severe environmental conditions. Firstly the concretes specimens were submerged in a water solution- water plus 50 gr $Na_2SO_4$/l. Secondly the concrete was made with PB and LF recycled aggregates which had 0.60% and

1.10% (respect to its weight) soluble sulfates in acid respectively. The concretes made with 100% of recycled aggregates suffered a higher expansion than 0.1% when they were produced with CEM II/A-L 42.5N and CEM I 52.5R. As Schimdt et al. (2009) mentioned with respect to cement with limestone additions (CEM II/A-L 42.5N), the impact of limestone additions on the degradation in sulfate solutions are dominated by their impact on the cement paste porosity and on the rate of sulfate ingress. And the CEM I 52.5R due to the high availability of $Ca(OH)_2$ increased its expansion (Lea 1949). Consequently, due to the presence of some soluble sulfates in recycled aggregates CEM I 42.5 SR cement should be used in order to avoid expansion higher than 0.1% in concrete produced with 100% of recycled aggregates. However, Concretes made with 50% of recycled aggregate concretes suffered lower expansion than 0.1% and consequently they have no risk of failure due to expansion.

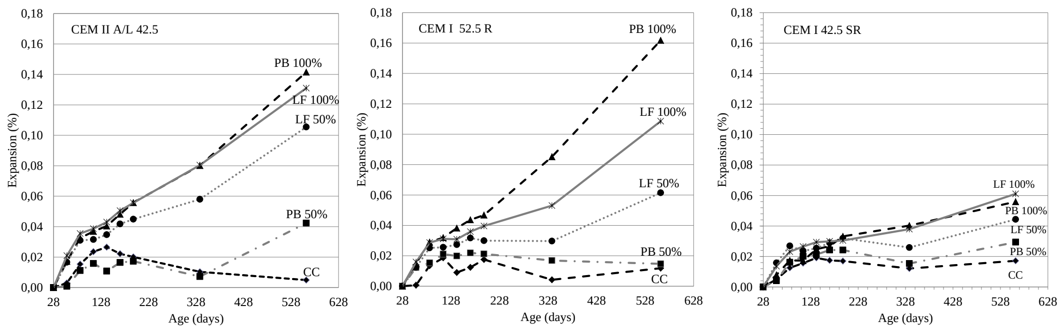


Figure 2. Expansion of concrete submitted to sulfate attack

The conventional concretes produced with three types of cements suffered similar expansion. All the recycled aggregate concretes made with CEM I 42.5 SR suffered low expansion. According to the criteria of Monteiro & Kurtis (2003) concretes with lower expansion than 0.1% had low risk of failure. An expansion in the concrete of 0.5% is necessary in order to produce failure from cracking.

## 3. PILOT TEST

Two pilot tests of sidewalks base construction produced with recycled aggregate concrete were carried out in Barcelona city by Vias y Constructions S.A and Lafarge enterprises. In order to validate the recycled aggregates use in non-structural concretes.

### 3.1 Materials and concrete production

Cement type CEM II A/V 42.5R Portland cement with fly ash as additive was used in two pilot tests. The PB recycled aggregates were used, the grading of 8/16 mm, dry density and absorption capacity of 2.17 $kg/dm^3$ and 7.50% respectively. The constituents were similar to those showed in table 3. Limestone raw aggregates were used for concrete production. Fine aggregates (0/4 mm) had a density of 2.59 $kg/dm^3$ and an absorption of 1.50%, the coarse aggregate (11/22mm) had a density of 2.63 $kg/dm^3$ and an absorption of 0.75%.
According to the laboratory test, the concretes produced with 50% of recycled aggregates obtained adequate physical, mechanical and durability properties for their use in non-structural concrete production. Consequently, concrete were produced with 50% of recycled coarse aggregates in substitution of raw coarse aggregates. For 1 m3 of concrete production, 260 kg of cement was used, total water of 195 kg (the water –cement ratio of 0.75), 990 kg of fine aggregates, 425 kg of raw and recycled coarse aggregates were used and two types of superplasticizer. The mixing process of the materials was carried out in a truck mixer.

### 3.2 Properties of concretes

All the series of concretes obtained a slump of 9-10 cm and the entrained –air was of 2.6%. The density of the hardened concrete was 2.25kg/dm$^3$, and the compressive strength of the concretes was 30 MPa at 28 days. It was 34 MPa and 38 MPa at 90 days and 6 months, respectively. The sorptivity, capillary absorption capacity and resistance to sulfate attack were also evaluated in the concretes produced. The sorptivity of concretes was 0.096 mm/min^0.5. A little higher than the values obtained in the laboratory tests, however a discontinuous grading distribution of aggregates combination could produce that effect. The concrete expansion after 560 days was lower than 0.02%. Similar to conventional concrete analyzed in laboratory test.

## 4. CONCLUSIONS

The following conclusions may be derived from the results obtained in this study:

-Low grade (mixed) recycled aggregates produced in recycling plants had high percentages of ceramic and some contaminants such as asphalts and gypsum.

- The higher the quantity of recycled aggregates used in the concrete resulted in lower density, higher absorption capacity and lower mechanical properties obtained. The concretes produced with CEM II A/L 42.5N obtained the lowest quality due to the decrease in the amount of reactive clinker capable of filling space with hydrates.
- Concrete produced with 100% of recycled aggregates from Barcelona Port (PB) due to its nominal size of 20mm (bigger than 16 mm of LF recycled aggregates) obtained the lowest mechanical properties. However, the mechanical properties of that concrete were sufficiently adequate for its use in non-structural concrete regardless of the cement used in its manufacture.
- Concrete with higher compressive strength suffered higher dispersion in values of compressive strength. The variation coefficient of compressive strength of concretes made with 100% of recycled aggregates was low and consequently its application is easily controllable.
- Concrete made with 50% of Recycled aggregates and CEM I, obtained adequate properties, similar to that of conventional concrete.
- Due to the presence of gypsum in recycled aggregates and sulfate soluble in acid, the concrete made with 100% of recycled aggregates must be produced with sulfate resistance cement. Concretes produced with 50% of recycled aggregates and all of the three types of cement, achieved lower expansion than 0.1% after 560 days.
- The results obtained in the laboratory are easily repeatable on site.

When considering the use of low grade recycled aggregate for concrete production where possible environmental exposure to sulfate attack has, Cement with pozzolanic additions or sulfate resistance cement must be used.

## REFERENCES

AGRELA, F.; SÁNCHEZ DE JUAN, M.; AYUSO, J. et al. (2011) Limiting properties in the characterization of mixed recycled aggregates for use in the manufacture of concrete. *Construction and Building Materials*. 25 (10). p.3950-3955.

CATALONIA. Departament de medi ambient i habitatge. *Programa de Gestió de Residus de la Construcció (PROGROC*). Barcelona: Agència de Residus de Catalunya.

DELGADO L.; CATARINO A. S.; EDER P. ET AL. (2009) JRC European Commission, End of Waste Criteria, Final report EUR 23990 EN – 2009.

GONZALEZ, A. (directora ETXEBERRIA, M.) (2011) *Clasificación y análisis de la aplicabilidad de áridos reciclados (Recycled aggregates classification and applicability* *analysis)*. A Thesis Submitted in partial fulfilment of the Requirements of Polytechnic University of Catalonia (UPC) for the Degree of Engineer. http://upcommons.upc.edu/handle/2099.1/12438 (In Spanish).

Grupo de trabajo “Hormigón reciclado” (2002) *Utilización de árido reciclado para la fabricación de hormigón estructural*. Universitat Politècnica de Catalunya. Barcelona: UPC.

IRASSAR, E.F.; BONAVETTI, V.L. & GONZALEZ, M. (2003) Microstructural study of sulfate attack on ordinary and limestone Portland cements at ambient temperature. *Cement and Concrete Research*. 33. p.31-41.

JIMÉNEZ, J.R.; AGRELA, F.; AYUSO, J. & LÓPEZ, M. (2010) Estudio comparativo de los áridos reciclados de hormigón y mixtos como material para subbases de carreteras. *Materiales de construcción*. ISSN: 0465-2746.

LEA, F.M. (1949) The mechanism of sulphate attack on Portland cement. *Canadian Journal of Research*. 27. p.297-302.

LYDON, F.D. & BALENDRAN, R.V. (1986) Some observations on elastic properties of plain concrete. *Cement and Concrete Research*, 16 (3). p.314-24.

MARTÍNEZ-LAGE, I.; MARTÍNEZ-ABELLA, F.; VÁZQUEZ-HERRERO, C. & PÉREZ-ORDÓÑEZ, J.L. (2012) Properties of plain concrete made with mixed recycled coarse aggregate. *Construction and Building Materials*. 37. p. 171-176.

MAS, B.; CLADERA, A.; del OLMO, T.; PITARCH, F. (2012b) Influence of the amount of mixed recycled aggregates on the properties of concrete for non-structural use. *Construction and Building Materials*. 27 (1). p.612-622.

MAS B.; CLADERA, A.; BESTARD, J. et al. (2012a) Concrete with mixed recycled aggregates: Influence of the type of cement. *Construction and Building Materials*. 34. p.430-441.

MONTEIRO, J.M.,. KURTIS, P. & E K (2003) Time to failure for concrete exposed to severe sulfate attack. *Cement and Concrete research*. 33. p.987-993.

NEVILLE A.M. (2000) *Properties of Concrete*, Essex England: Longman.

POON, C.S.; KOU, S.; WAN, H. & ETXEBERRIA, M. (2009) Properties of concrete blocks prepared with low grade recycled aggregates. *Waste Management.* 29. p.2369-2377.

SCHMIDT, T.; LOTHENBACH, B.; ROMER, M. et al. (2009) Physical and microstructural aspects of sulfate attack on ordinary and limestone blended Portland cement, *Cement and Concrete Research*. 39. p.1111-1121.

SPAIN. MINISTERIO DE FOMENTO (2004) *Orden/FOM/891 por la que se actualizan determinados artículos del Pliego de Prescripciones Técnicas Generales para Obras de Carreteras y Puentes, relativos a firmes y pavimentos*. BOE 83. p.14446-14509. Madrid: Ministerio de Fomento.

SPAIN. MINISTERIO DE MEDIO AMBIENTE. (2007) *Plan Nacional Integrado de Residuos (PNIR) 2008 – 2015. Informe de Sostenibilidad Ambiental (ISA).* Madrid: Ministerio de Medio Ambiente.

VEGAS, I.; IBAÑEZ, J.A.; SAN JOSÉ, J.T. & URZELAI, A. (2008) Construction demolition wastes, Waelz slag and MSWI bottom ash: A comparative technical analysis as material for road construction. *Waste Management*. 28. p.565-574.

VEGAS, I.; LISBONA, A.; SÁNCHEZ DE JUAN, M. & CARVAJAL, M.D. (2010) Characterization of mixed recycled aggregates for use in non-estructural concrete: influence of the treatment process. In *International Rilem Conference on Progress of Recycling in the Built Environment*. Sao Paulo - Brasil, December 2010. Bagneux-France: RILEM.

XU, A.; SHAYAN, A. & BABURAMANI P. (1998) Test methods for sulfate resistance of concrete and mechanim of sulfate attack. *ARRB Transport Research Ltd*. Review Report 5.