ANALYSIS OF ZERO-SLUMP CONCRETE MADE RECYCLED AGGREGATE FROM CONCRETE DEMOLITION WASTE

Serna, P. (1), Ulloa, V. A. (1), Pelufo, M. J. (1) and Jacquin, C. (1)
(1) Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería Civil. UPV. Camino de Vera S/N 46022.

ABSTRACT

The use of recycled aggregates in zero slump concrete constitutes an important option to the management of construction and deconstruction waste; This concrete can be used like Roller Compacted Concrete (RCC) the required amount of recycled aggregates on pavements may be significant and its quality does not need to be very high. The objective of this paper is to evaluate the methodology to obtain good quality pavements using recycled aggregates. Factors such as optimal humidity, compaction level and minimum requirements of quality of recycled aggregate are being evaluated in order to study their final effect on the pavement produced. As a quality parameter, the effect of the recycled aggregates impurities in the final product will be also analyzed. The goal is to establish a selection and classification criteria of recycled aggregates that will be useful to found dosages to make roller compacted pavements according with the needs established in the design stage.

Keywords: Non-structural concrete, recycled aggregates, Mechanical properties.

1. INTRODUCTION

At the moment, there is a great interest in the use of recycled aggregates. In order to an appropriate Construction and Demolition (C&D) waste management appropriate, the Union of Organizations of the Recycling of Demolitions (GERD), with the support of the ministry of Environment and in equipment with Spanish institutions and companies, among which the Polytechnic University of Valencia (UPV) participates, are developing the Spanish Guide of Recycled Aggregates (GEAR). This guide tries to characterize and to classify the products that are at the moment in the market of recycled aggregate (RA) to promote his use in pavements, prefabricated elements, structural concrete, etc.

With the aim to implement recycled aggregates as raw material, the use of this material in Roller Compacted Concrete (RCC) manufacturing is evaluated. The term “Roller Compacted Concrete” describes the concrete used in the construction process that combines fast and economic techniques of positioning, with the resistance and durability of the concrete [1]. This concrete is characterized by the use of vibratory rollers for its compaction and by properties that make it viable for this constructive process. The extensive use of RCC has been use in construction of dams and other great similar constructions, fast works of repairs and pavements.

RCC is functionally and structurally similar to vibrated concrete [2]. Their difference is the moisture content and the construction process. RCC, practically dry, is transported and
extended by means of equipment normally used to move grounds and is then soon compacted with vibratory rollers. The simplicity of design and the construction methodology can add to its high productivity and low production costs, the possibility of the use of recycled aggregate coming from Construction and Demolition waste. Hence it must be analyzed the recycled aggregate quality levels to be demanded, the dosage criteria and the conditions of execution of the pavements.

2. OBJECTIVE

In this work an experience oriented to the use of recycled aggregate of C&D waste in the manufacture of zero slump Concrete to be used like RCC is presented. It is tried in this way to contribute to the suitable management of the C&D. The goal is to validate the use of recycled aggregates present in the market without a specific treatment.

The practical objective was to obtain a zero slump Concrete with different substitutions percentages of natural aggregates by recycled aggregates, with splitting tensile strength greater than or equal to 3.3MPa at 28 days. For this specimens were made with a vibratory compactor in agreement with technical specifications exposed in [4].

3. EXPERIMENTAL PROGRAM AND METHODOLOGY

The experimental program includes the following sections:

Analysis and characterization of recycled aggregate produced usually in a plant of Construction and Deconstruction waste management, and selection of one of them which will be appropriate for the proposed application.

Due to the difficulty in determining the real water/cement (w/c) ratio because of the high variation of absorption in the recycled concrete aggregate, it was decided to use basic ACI 211.1. The establishment of a reference dosage made with natural aggregate was in agreement with the proposals of the bibliography for Roller Compacted Concrete [2] and following Spanish recommendations.

The required water content to obtain the optimal level of compaction was analysed. For this, the reference dosage and another one made with a 50% substitution of natural aggregate by recycled aggregate were analysed. With these two dosages, three mixtures with different effective water/cement ratio were performed and the influence of the effective water/cement ratio on their density and splitting tensile strength to 7 days, was tested. This way the water content to be used in remaining work was determined.

Finally the influence of the substitution percentage (0%, 20%, 50%, 75% and 100%) of natural aggregates by recycled aggregate in the quality of the reference concrete is studied. At this stage effective water/cement ratio was fixed. At this phase the specimen density and the concrete splitting tensile strength were also determined at 7 and 28 days according with UNE 7240 and UNE 7396 Spanish standards.

The procedure used in the specimens manufacture was the indicated in the EN 12697-32: 2003 standard “Compaction in Laboratory of Bituminous Mixtures by Means of Vibratory Compactor” [3]. A vibratory hammer was used for the compaction (model Kango 900 K®). The dimensions of the specimens were 152.45±0.5 mm of diameter and 170±0.5 mm in length. An image of the equipment used can be seen in figure 1.

4. CHARACTERIZATION AND SELECTION OF MATERIALS

The natural aggregates used to produce the concrete were crushed of limestone origin, three aggregate size (7/12, 12/20, sand 0/4) and two types of recycled aggregate of different size (5/20 fraction and 0/40 fraction) produced in the Belcaire recycling plant were used. The
cement was CEM II/B-M (42.5 S-LL) R. To obtain the wished workability of the concrete a plasticiser was also used.

The process necessary to obtain the recycled aggregate from C&D wastes consists of a crushing whit jaw crusher, then through magnetic separators, transporting sieves to obtain the classified material.

In order to characterize the aggregates the following test methods were applied: UNE EN 1097-6 Determination of the density of particles and the water absorption. UNE EN 933-1 Determination of the particles size distribution. UNE EN 1097-2 Methods for the determination of the resistance to the fragmentation. Los Angeles test method.

The natural and recycled aggregates properties are shown in Table 1 and Figure 2.

![Figure 1. Kango 900 compactor for production of cylindrical specimens of RCC.](image)

Some tests, such as the impurities content or the adhered mortar content exist only for recycled aggregate characterization. The values of the contents of impurities of recycled aggregates characterized are shown in Table 2.

The recycled aggregates studied can be observed in Figures 3 and 4. Some of the characteristics such as the size and the content of impurities are reflected.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Aggregates</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Naturals</td>
<td>Recycled</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0/4</td>
<td>7/12</td>
<td>12/20</td>
<td>5/20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>2,61</td>
<td>2,57</td>
<td>2,58</td>
<td>2,20</td>
</tr>
<tr>
<td>Absorption (%)</td>
<td>0,47</td>
<td>2,23</td>
<td>2,19</td>
<td>7,13</td>
</tr>
<tr>
<td>Los Angeles (%)</td>
<td>-</td>
<td>-</td>
<td>20,05</td>
<td>31,75</td>
</tr>
</tbody>
</table>
Figure 2. Grading curve of aggregates.

Table 2. Impurity content of recycled aggregates tested

<table>
<thead>
<tr>
<th>Recycled Aggregate</th>
<th>Classification of impurities of coarse recycled aggregate UNE-EN 933-11:2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ra (%)</td>
</tr>
<tr>
<td>Recycled 0/40.</td>
<td>4,5</td>
</tr>
<tr>
<td>Recycled 5/20.</td>
<td>0,02</td>
</tr>
</tbody>
</table>

Ra: bituminous material  
Rb: Masonry Elements  
Rc: Concrete and concrete products, mortars  
Ru: Aggregates not attached  
X: Others.

Figure 3. Recycled aggregate 5 / 20.  
Figure 4. Recycled aggregate 0 / 40.
The recycled aggregates are composed with products from diverse origin, dominated by stone, concrete and ceramic origins.

Taking into account the initial classification proposal of the recycled aggregates Spanish Guide GEAR [5], these aggregates can be classified according to their composition as ArM-c Type II for recycled aggregate 0/40 and ArM-p type II for the recycled aggregate 5/20.

After this preliminary study it was decided to select as recycled aggregate only 5/20 fraction. This selection was found on the appropriate maximum size and the aggregate grading, easier to be adapted to the adopted reference grading curve.

5. REFERENCE DOSAGE

The reference dosage for RCC manufacturing has been established from data found in the bibliography [2]. Different proportions of natural coarse aggregates / sand were analyzed trying to be adapted into the grain size limits proposed in the Spanish recommendations for gravel-cement (Figure 5). The aim was to find a good workability.

Table 3 shows the tested dosages made with natural aggregates. The cement and water contents were set to have a dry consistency, but it was also considered that when using recycled aggregate more water will be need, due to the greater absorption of recycled aggregates [6].

Table 3. Natural aggregate mix proportioning analysed to define the reference dosage.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dosage 1</th>
<th>Dosage 2</th>
<th>Dosage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Sand 0/4</td>
<td>950</td>
<td>750</td>
<td>600</td>
</tr>
<tr>
<td>Aggregate 7/12 Soinval</td>
<td>425</td>
<td>575</td>
<td>650</td>
</tr>
<tr>
<td>Aggregate 12/20 Soinval</td>
<td>425</td>
<td>575</td>
<td>650</td>
</tr>
<tr>
<td>Cement</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

Figure 5. Grading curves of the dosages studied as reference.
After the production of these three dosages, it was choose the number 2 as reference dosage due to its better workability and its good adjustment into the recommended size gradation limits.

6. DOSAGES WITH RECYCLED AGGREGATES

Figure 6 shows the grading curves for different percentages of recycled aggregate replacement (20%, 50%, 75% and 100%). These percentages refer to the total aggregate, so a 100% substitution of recycled aggregate concrete would be to be manufactured exclusively with recycled coarse aggregate which evidently moves away of the reference curve and finally is discarded. This level of substitution was not therefore used.

The criterion of substitution was initially to replace the natural coarse aggregate for recycled aggregate (20% and 50% substitution) with only slight adjustments in the sand content. When replacing the 75% was also necessary to reduce substantially the natural sand content.

7. RESULTS AND DISCUSSION

7.1 Properties of recycled aggregates

It can be observed that the absorption of recycled aggregates is always greater than the natural aggregates (Table 1) as literature establishes [7]. That is probably due to the presence of adhered mortar and other absorbent materials such as ceramics [8]. Therefore, when designing dosages this phenomenon was considered, and the quantity of effective water was keep constant and the consistency of concrete was not influenced. Consequently in mixtures with recycled aggregate the total water / cement ratio will be higher than in conventional concrete. The value of the coefficient of Los Angeles, should also be greater than for natural aggregates [9], which is a parameter that plays an important role when analyzing the strength of concrete.

7.2 Density of concrete

In order to determine the density of the concrete UNE-EN 12390-7:2001 standards was followed. The density values of RCC for different percentages of substitution oscillate
between (table 4) 2.25 and 2.41 g/cm³. Variation in the density for low percentage of substitution of recycled aggregate is not perceptible (figure 7). Only for a substitution of 75% of recycled aggregate, the density at 28 days attains a maximum difference to the reference concrete up to 6.22%.

Table 4. Density values RCC with recycled aggregate at 7 and 28 days

<table>
<thead>
<tr>
<th>% substitution</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.35</td>
<td>0.00%</td>
</tr>
<tr>
<td>20</td>
<td>2.37</td>
<td>-0.85%</td>
</tr>
<tr>
<td>50</td>
<td>2.31</td>
<td>1.70%</td>
</tr>
<tr>
<td>75</td>
<td>2.25</td>
<td>4.26%</td>
</tr>
</tbody>
</table>

7.3 Density versus effective water/cement ratio.

Concretes with a 0% and 50% substitution were analyzed with 4 different effective water/cement ratios 0.40; 0.45; 0.50 and 0.55 looking to evaluate the influence of water content on the density of the specimens. Figure 8 shows that, for both concretes, maximum density is obtained with a 0.5 effective water/cement ratio. This value has been considered therefore the reference one for the development of the subsequent studies.
7.4 Tensile strength of concrete

Test were performed according to the UNE-EN 12390-6:2001 Splitting Tensile Strength test (Figure 9). The results of recycled concrete made with a 0.5 effective water / cement ratio, with different substitution levels are presented in Table 5 and figure 10.

![Figure 9. Test Splitting Tensile Strength. Specimen with 75% of recycled aggregate.](image)

<table>
<thead>
<tr>
<th>% substitution</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2,79</td>
<td>0,00%</td>
</tr>
<tr>
<td>20</td>
<td>2,67</td>
<td>4,30%</td>
</tr>
<tr>
<td>50</td>
<td>2,5</td>
<td>10,39%</td>
</tr>
<tr>
<td>75</td>
<td>2,17</td>
<td>22,22%</td>
</tr>
</tbody>
</table>

![Table 5. Splitting Tensile Strength vs. recycled aggregate percentage substitution.](image)

From Figure 10, it can be conclude that the tensile strength at 7 days is greatly affected by the replacement percentage of recycled aggregate for the same effective water/cement ratio. A decrease over 20% when the substitution of recycled aggregate is 75% is reported. At 28
days differences are minor, imperceptible to replacement levels of 20 to 50% and only 6.12% when the concrete contains 75% recycled aggregate.

The reductions in strength, especially in the short term, can be influenced by the humidity state of the aggregates when introduced in the mix. The recycled aggregates absorb water from the mix to complete its absorption. The time spent and the water balance achieved in different areas may be affected by the initial moisture content. Although some studies use pre-saturated recycled aggregate [10] to avoid this effect, this is not a possible procedure in construction site.

It should be noted that the splitting tensile strength achieved at 28 days exceeds the value required by the recommendations for RCC (3.3 MPa) even with 50% substitution. Although 75% of concrete with recycled aggregate only reaches 3.22 MPa this value can also be considered very optimistic given that the dosages used are susceptible of improvement. Consequently, the higher strength of natural aggregates has scarcely affected the results of concrete strength.

It is important to indicate that the present work is only one first experience and that it is needed to continue studying and investigating to obtain optimized mixtures and analyzing other aspects, particularly those related to durability.

8. CONCLUSIONS AND PERSPECTIVE

Based on the results of the tests, it can be reported that the use of recycled aggregates normally produced in a waste management plant may be acceptable for the use of concrete up to a 50% substitution, without any significant influence on the RCC.

The densities obtained in these concretes are similar than the reference concrete values, without influence of recycled aggregates. The difference in tensile strength for different percentages of replacement is more evident to 7 days that at 28 days. At 7 days values differ from 4 to 25% respect to reference concrete, whereas at 28 days the greater difference does not surpass a 6.5%.

The increase of the coefficient of Los Angeles of recycled aggregates, which could mean their lower resistance, does not influence in the splitting tensile strength for substitutions of recycled aggregate over 50%.

However, considering that recycled aggregates available in the market can have very different characteristics (absorption, coefficient of Los Angeles, density and composition, among others), it is important to have a recycled aggregates classification criteria useful to indentify the adequate material each application.

To control the water / cement ratio strictly in the mixture, considering the effects of absorption of recycled aggregates will be essential to ensure a adequate workability and to reach the wished concrete strength.

The research must be continued to obtain optimized mixtures adapted for every material characteristics, and analyzing other aspects, particularly those related to durability. Real size experiences must be also be developed.

ACKNOWLEDGEMENTS

This experimental work has been supported by the General Direction of Quality and Environmental Evaluation of the Ministry of Environment in Spain.

Recycled aggregate samples have been collected, thanks to the collaboration of the company Gestion de Residuos Belcaire
REFERENCES


