MECHANICAL PROPERTIES OF CONCRETE WITH RECYCLED AGGREGATES AND WASTE GLASS

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Abstract
The present investigation analyses the mechanical behaviour of concrete with recycled aggregates and waste glass. The recycled aggregates are obtained from debris of prefabricated concrete pipes with a compressive strength of 20 MPa. The waste glass has been obtained from glass disposal facilities. Four variables are considered: the percentage of recycled course aggregates, the amount of mortar adhered to their surface, the amount of cement replaced by recycled glass powder and the maximum size of its particles. The final goal is to determine which of the variables has a more significant effect in the final product and which combination is the most efficient to optimize the performance of the concrete maximizing its environmental value. Significant results have been obtained that show that the calibration of the parameters may not be trivial, and the importance of combining different recycled materials.

Keywords: Recycled aggregates; Recycled concrete; Concrete mechanical properties; Compressive strength.

1. INTRODUCTION
Waste management has become a serious social concern in modern societies. In particular 25% of solid waste disposals is provided by building sector. This concern has led researchers to focus on these environmental issues by considering the manufacture of construction Materials as a new way of recycling certain wastes. Nowadays, many different residues have already been tested and incorporated, at certain percentages, as construction Materials, such as fired clay brick and concrete. Moreover, mechanical and physical properties of such construction Materials have been proven to satisfy some regulatory requirements and, therefore, its use has been included in certain technical building regulations.

The manufacture of traditional concrete is one of the most pollutants industries. 70% of GHG emissions and energy used in the fabrication of concretes derives from the high temperatures required for cement production and the decomposition of the calcium carbonate. Hence, environmental impact of these procedures can be reduced by using alternative Materials to partially replace the Portland cement.

The effect of the use of recycled aggregates (RA) in concrete has been widely studied (1-4). The differences found in the mechanical properties due to the substitution of natural aggregates for recycled ones have been attributed to the old mortar adhered to the surfaces of the RA. Two
interfaces have to be considered, the old interface, between the old mortar and the RA, and the new one, between the RA and the new cement mixture (1). The quality of these interfaces, given by the quantity and quality of the old adhered mortar, is one of the main parameters influencing the mechanical behavior of recycled concrete (5-7).

A popular alternative to control the loss of strength due to RA is to limit the amount of substituted aggregates. Various authors (8-12) have proven that the use of relatively low percentages of RA doesn’t modify significantly the properties of the material and, nowadays, several European technic regulations allow the use of up to 30% of RA in structural concrete.

Other way to minimize the effect of the use of RA is to reduce the amount of adhered mortar to their surfaces. Eliminating the adhered mortar improves the quality of the contact surface between the RA and the new cementious mixture, enhancing the strength of the specimen(2,4,13).

On the other hand, due to its high silica content, the use of glass powder (GP) as a supplementary cementious material has been widely investigated. When only small particles are considered (<300μm) the GP presents pozzolanic properties which increase when the particle size decreases (14-17).

As a measure to reduce the environmental impact generated by concrete manufacturing, studies have been performed combining the use of RA and different industrial waste as cement replacement. Kou et al. (18) studied the behavior of RAC adding silica fumes, metakaolin fly ash and ground granulated blast slag. Çakir (19) studied the use of silica fume and ground granulated clast slag. Kim et al. (20) analyze the use of RA and fly ash, concluding that fly ash replacement. Beltran et al. (21) analyzed the mechanical properties of concretes with RA and biomass bottom ash. Nassarand and Soroushian (22) studied concretes with 50% of RA, using a 20% of GP as cement replacement, prove that the mechanical properties in the long term are similar to those of traditional concrete.

The goal of this investigation is to analyze the mechanical properties of concretes containing different percentages of GP (10-20-30%), modifying the particle maximum size (75-150-425μm) and using different amount of RA (20-30-40%) that have suffered different levels of abrasion to reduce the old mortar adhered to its surface (100-200-300 rev). To minimize the amount of test needed Taguchi’s statistical method is applied, combining the variables reducing the experimental tests to 9 specimens plus a control concrete elaborated with natural aggregates and no cement replacement. Compressive strengths and flexural strengths are analyzed and compared, to find the optimum combination of parameters and determine which one is the most significant.

2. MATERIALS

2.1 Cement and glass powder

Pozzolanic cement, equivalent to ASTM type P cement is used. Different percentages of this cement will be replaced by GP classified by the maximum size of its particles. The glass powder is obtained from municipal recycling containers in the region.

2.2 Natural and recycled aggregates

Natural and recycled aggregates were used to prepare the concrete mixtures. The recycled aggregates were obtained from precast concrete debris and their nominal sizes are 9.5 mm and 6.3 mm.

The Los Angeles abrasion machine is used to reduce the amount of adhered mortar to the surface of the RA. Using different revolution settings, different abrasion levels are obtained and
different degrees of mortar reduction can be used. The effect of 100 rev, 200 rev and 300 rev is analyzed.

3. EXPERIMENTAL TESTS

To reduce the number of tests needed, due to the great amount of variables and levels considered, Taguchi’s method (23) is applied. Taguchi’s method is a combination of statistical and engineering methods for variable optimization in any process reducing the amount of experimental tests needed. Combining the three levels considered for each of the four variables the minimum amount of tests needed to evaluate their influence in the results is 9 series.

- The levels of the percentage of RA considered were 20%, 30% and 40%. These values were chosen in base to several European technic regulations that nowadays allow the use of RA.
- The levels of the percentage of GP replacing cement considered were 10%, 20% and 30%.
- The abrasion levels applied to reduce the adhered mortar to the surface of the RA were 100 rev, 200 rev and 300 rev, based on previous experimental tests.
- The maximum sizes of the recycled GP particles considered were 75 μm, 150 μm and 425 μm.

These levels were combined following Taguchi’s method and 9 series were established to design the specimens needed (Table 1).

All the specimens were designed following Faury Joisel [24] method (24) dosed for a compressive strength of 30MPa after 28 day of curing with a water/cement rate of 0.42.

To calculate the final amount of water included in each sample the aggregates were pre-saturated up to 80%. This previous saturation has been proven to seal the pores, limiting water interchanges and avoiding workability issues in fresh concrete and the water/cement rate (25-26).

All the samples were elaborated under laboratory conditions and unmolded after 24±2 hours. Later, they were submerged in water with lime at 23±3°C during the appropriate curing time.

The final values used in the dosing are shown in table 1.

Table 1: Concrete sample dosing and tests

<table>
<thead>
<tr>
<th></th>
<th>NA 2,36-9,5 (mm)</th>
<th>RA 4,75-9,5 (mm)</th>
<th>Cement</th>
<th>GP</th>
<th>Sand</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>975,56</td>
<td>199,25 (20%)</td>
<td>100</td>
<td>343,80</td>
<td>38,20 (10%)</td>
<td>75</td>
</tr>
<tr>
<td>H2</td>
<td>975,56</td>
<td>199,25 (20%)</td>
<td>200</td>
<td>305,60</td>
<td>76,40 (20%)</td>
<td>150</td>
</tr>
<tr>
<td>H3</td>
<td>975,56</td>
<td>199,25 (20%)</td>
<td>300</td>
<td>343,80</td>
<td>38,20 (10%)</td>
<td>150</td>
</tr>
<tr>
<td>H4</td>
<td>822,37</td>
<td>352,44 (30%)</td>
<td>300</td>
<td>343,80</td>
<td>38,20 (10%)</td>
<td>425</td>
</tr>
<tr>
<td>H5</td>
<td>822,37</td>
<td>352,44 (30%)</td>
<td>100</td>
<td>305,60</td>
<td>76,40 (20%)</td>
<td>425</td>
</tr>
<tr>
<td>H6</td>
<td>822,37</td>
<td>352,44 (30%)</td>
<td>200</td>
<td>267,40</td>
<td>114,60 (30%)</td>
<td>75</td>
</tr>
<tr>
<td>H7</td>
<td>704,89</td>
<td>469,92 (40%)</td>
<td>200</td>
<td>343,80</td>
<td>38,20 (10%)</td>
<td>425</td>
</tr>
<tr>
<td>H8</td>
<td>704,89</td>
<td>469,92 (40%)</td>
<td>300</td>
<td>305,60</td>
<td>76,40 (20%)</td>
<td>75</td>
</tr>
<tr>
<td>H9</td>
<td>704,89</td>
<td>469,92 (40%)</td>
<td>100</td>
<td>267,40</td>
<td>114,60 (30%)</td>
<td>150</td>
</tr>
<tr>
<td>HC</td>
<td>1174,81</td>
<td>(0%)</td>
<td>-</td>
<td>382,00</td>
<td>(0%)</td>
<td>-</td>
</tr>
</tbody>
</table>
The mechanical properties of the samples were determined for each dosage by compressive and flexural tests. The compressive tests were performed following the NCh 1037 and the NCh 1017, using three cubic 15x15x15 cm test specimens after 28 and 90 days of curing. The flexural tests were performed following the NCh 1038 using three prismatic 15x15x50 cm test specimens after 28 days of curing. In each case the mean value of the three samples tested is considered.

4. RESULTS AND DISCUSSION

4.1 Effect of RA replacement

Table 2 shows the results of the Taguchi analysis, individualizing each of the variables to study their effect separately.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Levels</th>
<th>Compressive strength (MPa)</th>
<th>Flexural strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP (%)</td>
<td>10</td>
<td>28,86</td>
<td>3,30</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>28,28</td>
<td>3,00</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>27,33</td>
<td>3,04</td>
</tr>
<tr>
<td>Maximum size</td>
<td>75</td>
<td>29,69</td>
<td>3,32</td>
</tr>
<tr>
<td>GP (μm)</td>
<td>150</td>
<td>28,93</td>
<td>3,47</td>
</tr>
<tr>
<td></td>
<td>425</td>
<td>26,06</td>
<td>2,56</td>
</tr>
<tr>
<td>RA (%)</td>
<td>30</td>
<td>29,50</td>
<td>3,21</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>28,60</td>
<td>2,98</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>28,28</td>
<td>2,92</td>
</tr>
<tr>
<td>Abrasión (rev)</td>
<td>200</td>
<td>28,33</td>
<td>3,17</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>28,07</td>
<td>3,22</td>
</tr>
</tbody>
</table>

The maximum compressive strength value is obtained for a 30% replacement of RA, overpassing the value obtained for a 20% replacement in an 11%. This behavior is similar to the one obtained by Soares et al. (27) who also obtained maximum strength values for a 30% replacement. On the other hand, the mechanic abrasion shows no significant effect, lower than 1%, in the strength values.

The flexural strength is achieves its maximum value for a RA replacement of 30% with a gaining rate of a 3% from the value obtained for a 20% replacement. This behavior is similar to that of the compressive strength. Nevertheless, reducing the amount of adhered mortar through mechanical abrasion increases the flexural strength. Samples over a 10% stronger are obtained when the abrasion changes from 100 rev to 300 rev. A similar behavior is obtained by Pepe et al. (13) who uses a similar methodology to reduce the amount of adhered mortar.


4.2 Effect of GP replacement

The increase in the amount of GP doesn’t reduce the compressive strength significantly. When percentage grows from 10% to 30% the strength reduction provoked is only of a 5.3%. As expected, an increase in the particle size of the GP produces a significant decrease in the strength values, up to a 12% when the size rises from 75 μm to 425 μm. Carsana et al(14) establish that GP increases the compressive strength when very small particles are used and Federico and Chidiac (28) conclude that pozzolanic properties are only observed for GP particles under 300 μm.

Increasing the amount of GP from 10% to 30% only provokes a total decrease in the flexural strength of a 7.8%, showing a low significance in the results. On the other hand, as the size of the particles of the GP increases the flexural strength decreases as expected, presenting a global loss of 23% when the size increases from 75 μm to 425 μm.

Table 3 presents the ANOVA results of Taguchi method. After 28 days of curing the more significant parameters in the compressive strength were the maximum size of the GP and the percentage of RA. The amount of mortar, measured through the abrasion level, shows almost no significance in the final results. In the flexural strength, the most significant variable is the maximum size of the GP. On the other hand, the one that has the least influence is the percentage of RA.

Table 3: ANOVA results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Significance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compressive strenght</td>
</tr>
<tr>
<td>% RA</td>
<td>33,949</td>
</tr>
<tr>
<td>% GP</td>
<td>9,743</td>
</tr>
<tr>
<td>GP max size</td>
<td>56,003</td>
</tr>
<tr>
<td>Abrasion</td>
<td>0,304</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS

The ANOVA results show that the GP maximum size is the most relevant parameter of the four analysed here. Both, for the compressive and the flexural strength the best performance is obtained when the smallest particles are used. Either way, the amount of GP replacement has low significance in the final results.

Following these conclusions an important amount of GP can be reused in recycled structural concrete as long as the particle size is controlled.

On the other hand, the percentage of RA used in the dosage is also significant when the compressive strength is considered, finding an optimum performance when a 30% of the natural aggregates are replaced. The relevance decreases significantly when the flexural strength is considered. The abrasion level shows very low effects in the final compressive and flexural strengths results.

Comparing the performances obtained, the optimum combination of the four parameters, for the Materials and the variables tested here is RA=30%; GP max size = 75μm; GP=10% and Abrasion level=300rev. Though, the variability in the significance of the parameters may allow considerable changes in the GP percentage and the abrasion level.

ACKNOWLEDGEMENTS

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