Durability properties of structural concrete incorporating fine aggregates from the waste marble industry

Filipe João Ferreira Gameiro

Extended abstract

Civil Engineering

Supervisor:

Prof. Dr. Jorge Manuel Caliço Lopes de Brito

January 2013
1. Introduction

In order to meet their needs, humans have been consuming natural resources available in nature. However, its importance as part of the environmental sustainability has only recently been noticed. In this matter, it is nowadays consensual that the waste of the ornamental stones quarrying industry has reached intolerable proportions in terms of environmental sustainability, requiring new solutions for its reuse, giving back its economic value.

In fact, the economic value of the stone quarrying industry in Portugal is one of the most important for the country. However, it is evaluated that 80% of the total extracted rock in the Estremoz, Borba and Vila-Viçosa counties (known as a rich marble area) is considered waste. Thus, this dissertation aims at evaluating the performance in terms of durability and the viability of structural concrete incorporating fine aggregates of recycled marble in order to increase the environmental protection and sustainability of natural resources. Therefore, it is essential to ensure all safety and quality parameters, as well as accurately define the performance of the concrete produced with waste fine aggregate of the marble industry, allowing its introduction in the construction industry.

For this purpose, ten concrete mixes were produced: three standard concrete mixes (containing fine basalt, river sand and granite aggregates), three with 20% substitution of primary fine aggregates by secondary fine aggregates from the marble quarrying industry waste, three with 50% substitution and a concrete with 100% substitution. All the substitutions were made by volume. The workability and bulk density tests were carried out in fresh concrete. The tests in the hardened state were compressive strength, water absorption by capillarity and immersion, carbonation, chloride penetration and drying shrinkage. To characterize aggregates, water absorption and particle density, sieve analysis, loose bulk density, Los Angeles and shape index tests were made.

The literature suggests that marble waste can be used as aggregate in concrete. André (2012) refers that the incorporation of coarse marble aggregates in concrete induces several changes in its durability properties, i.e. it is slightly beneficial and harmful in different aspects. Other authors such as Hebhoub et al. (2011), Shelke et al. (2012) and Pereira et al. (2007) point the workability reduction due to the marble incorporation as one of the most affected concrete properties. Binici et al. (2007) also proved that marble aggregates in concrete substantially reduced its chloride penetration.
2. Experimental program

2.1. Materials

The materials used to produce the ten concrete mixes were:

- Limestone gravel, supplied by José Marques Galo S.A.;
- Basalt sand supplied by Grupo Lena;
- Granite sand supplied by Grupo Motaengil;
- River sand supplied by Grupo Soarvamil;
- Fine aggregates from marble quarrying industry waste supplied by Solubema;
- CEM II 42.5R A-L cement supplied by SECIL cement works in Outão, Setúbal;
- Tap water supplied by Instituto Superior Técnico.

2.2. Concrete mixes design

Based on NP EN 206-1 (2007) requirements, concrete mixes were designed in order to be compatible with a significant number of structural applications regarding its compression strength of approximately 44 MPa (C 30/37) and a workability range of 125 ± 15 mm in the slump test in the fresh state. To reach these parameters the following characteristics were established:

- Exposure class: several;
- Maximum aggregate size: 22.4 mm;
- Mixing water: tap water, from the public supply network;
- Manufacturing site: laboratory;
- Production control type: good;
- Compression method: normal mechanical vibration (vibrating needle).

The three standard concrete mixes were designed using the Faury reference curves. For the other mixes, the ratios of incorporation of fine marble of 20%, 50% and 100% refer to the total fine aggregates volume. Therefore, these volume ratios were applied in each grading size of the three reference concrete mixes given in Table 1. According to its general purpose, fine aggregates represent particles that pass through a 4 mm mesh sieve, “rice grain” represents
particles that pass through a 6 mm mesh sieve, gravel 1 represent particles that pass through a
12 mm mesh sieve and gravel 2 represent particles that pass through a 16 mm mesh sieve.

As expected, some differences in workability were noticed. These resulted from the volumetric
replacement procedure of fine aggregates. More precisely, the fine marble aggregates addition
trended to reduce the mixes workability. This behaviour was mainly reported due to the
different geometric properties of aggregates. To obtain the same workability levels on all mixes
a further calibration on water / cement ratio was necessary, as represented in Table 2.

Table 1 - Percentage in volume of the reference concrete mixes components in total concrete volume

<table>
<thead>
<tr>
<th>Sieve grading</th>
<th>BRB</th>
<th>BRC</th>
<th>BRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.063</td>
<td>3.68</td>
<td>2.40</td>
<td>3.02</td>
</tr>
<tr>
<td>0.063 - 0.125</td>
<td>4.62</td>
<td>3.01</td>
<td>3.79</td>
</tr>
<tr>
<td>0.125 - 0.25</td>
<td>6.43</td>
<td>4.19</td>
<td>5.27</td>
</tr>
<tr>
<td>0.25 - 0.5</td>
<td>3.18</td>
<td>2.07</td>
<td>2.61</td>
</tr>
<tr>
<td>0.5 - 1</td>
<td>4.37</td>
<td>2.85</td>
<td>3.58</td>
</tr>
<tr>
<td>1 - 2</td>
<td>5.18</td>
<td>3.37</td>
<td>4.25</td>
</tr>
<tr>
<td>&gt; 4</td>
<td>3.12</td>
<td>2.03</td>
<td>2.56</td>
</tr>
<tr>
<td>&quot;Rice grain&quot;</td>
<td>9.55</td>
<td>8.09</td>
<td>16.08</td>
</tr>
<tr>
<td>Gravel 1</td>
<td>6.07</td>
<td>10.68</td>
<td>3.57</td>
</tr>
<tr>
<td>Gravel 2</td>
<td>23.43</td>
<td>31.15</td>
<td>25.01</td>
</tr>
<tr>
<td>Cement (%)</td>
<td>17.88</td>
<td>18.34</td>
<td>18.41</td>
</tr>
<tr>
<td>Water (%)</td>
<td>7.69</td>
<td>7.89</td>
<td>7.92</td>
</tr>
<tr>
<td>TOTAL (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2 - Water/cement ratio of all concrete mixes

<table>
<thead>
<tr>
<th>Type of concrete</th>
<th>Water / cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard basalt concrete - BRB</td>
<td>0.55</td>
</tr>
<tr>
<td>Basalt concrete with 20% substitution - BB/M20</td>
<td>0.55</td>
</tr>
<tr>
<td>Basalt concrete with 50% substitution - BB/M50</td>
<td>0.56</td>
</tr>
<tr>
<td>Concrete with 100% substitution - BRM</td>
<td>0.54</td>
</tr>
<tr>
<td>Standard river sand concrete - BRC</td>
<td>0.49</td>
</tr>
<tr>
<td>River sand concrete with 20% substitution - BC/M20</td>
<td>0.50</td>
</tr>
<tr>
<td>River sand concrete with 50% substitution - BC/M50</td>
<td>0.50</td>
</tr>
<tr>
<td>Standard granite concrete - BRG</td>
<td>0.54</td>
</tr>
<tr>
<td>Granite concrete with 20% substitution - BG/M20</td>
<td>0.55</td>
</tr>
<tr>
<td>Granite concrete with 50% substitution - BG/M50</td>
<td>0.56</td>
</tr>
</tbody>
</table>
2.3. Aggregates tests

The aggregates characterization tests were conducted according to the following standards and specifications:

- Particle density and water absorption: NP EN 1097-6 (2003)
- Grading size analysis: NP EN 933-1 (2000) and NP EN 933-2 (1999);
- Loose bulk density and voids: NP EN 1097-3 (2003);
- Los Angeles abrasion test: LNEC E-237 (1970);
- Shape index: NP EN 933-4 (2002).

2.4. Fresh concrete tests

The tests carried out in fresh concrete were conducted according to the following standards and specifications:

- Slump test by Abrams cone: NP EN 12350-2 (2002);
- Bulk density: NP EN 12350-6 (2002).

2.5. Hardened concrete testing

The tests performed to characterize concrete in its hardened state were conducted according to the following standards and specifications:

- Compressive strength: NP EN 12390-3 (2003);
- Water absorption by capillary action: LNEC E-393 (1993);
- Water absorption by immersion: LNEC E-394 (1993);
- Carbonation: LNEC E-391 (1993);
- Chloride penetration: LNEC E-463 (2004);
3. Experimental results and discussions

3.1. Aggregates properties

The results of the performed tests on aggregates are assembled in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Bulk density (kg/m³)</th>
<th>Water absorption (%)</th>
<th>Apparent bulk density (kg/m³)</th>
<th>Voids (%)</th>
<th>Los Angeles abrasion test (%)</th>
<th>Shape index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel 2</td>
<td>2606</td>
<td>1.5</td>
<td>1363</td>
<td>47.7</td>
<td>26.52</td>
<td>15.3</td>
</tr>
<tr>
<td>Gravel 1</td>
<td>2620</td>
<td>1.3</td>
<td>1356</td>
<td>48.3</td>
<td>25.45</td>
<td>16.8</td>
</tr>
<tr>
<td>&quot;Rice grain&quot;</td>
<td>2489</td>
<td>2.84</td>
<td>1354</td>
<td>45.6</td>
<td>22.45</td>
<td>18.4</td>
</tr>
<tr>
<td>Coarse river sand</td>
<td>2600</td>
<td>0.75</td>
<td>1542</td>
<td>40.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fine river sand</td>
<td>2523</td>
<td>0.75</td>
<td>1526</td>
<td>39.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Basalt sand</td>
<td>2820</td>
<td>1.05</td>
<td>1838</td>
<td>34.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Granite sand</td>
<td>2467</td>
<td>0.59</td>
<td>1560</td>
<td>36.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Marble sand</td>
<td>2684</td>
<td>0.14</td>
<td>1784</td>
<td>33.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3 shows that the aggregates differ in several physical properties. Concerning bulk density, basalt sand is found to have the highest value of all the aggregates analysed, contrarily to “rice grain” and granite sand which have the lowest. The same trend was observed in the apparent bulk density results, except for granite sand. In terms of water absorption and voids, it was noticed that these properties are strictly related. Therefore, for lower aggregates voids values, their water absorption tends to decrease. Regarding the Los Angeles abrasion test and shape index the results show that they increase and decrease, respectively as the particle dimensions increase. Nevertheless, the Los Angeles abrasion test revealed satisfactory resistance values for use in structural concrete. The shape index revealed a similar geometry for the coarse aggregates.

3.2. Fresh concrete properties

3.2.1. Workability

The workability of fresh concrete was measured using the slump test by Abrams cone. Figure 1 shows the results of the ten concrete mixes.
Durability properties of structural concrete incorporating fine aggregates from the waste marble industry

Figure 1 shows that the established range of 125 ± 15 mm was achieved and all the mixes were within the NP EN 206-1 S3 consistence class. Furthermore, despite the expected reduced workability caused by the incorporation of fine marble waste aggregates, the increase of the water/cement ratio proved to be an effective solution to calibrate workability. More precisely, it was necessary to slightly increase the water/cement ratio when using secondary aggregates in order to maintain a similar workability.

3.2.2. Density

The density of concrete in the fresh state was measured after the mixes production. Figure 2 shows the results.

Figure 1 - Slump test by Abrams cone

Figure 2 - Density of all fresh concrete mixes
3.3. Hardened concrete properties

3.2.1. Compressive strength

In this test, the concrete specimens were subjected to a uniform compression stress. Even though the concrete durability cannot be directly characterized by the compressive strength, this mechanical property is seen as a reliable indirect way of estimating its range. Figure 3 shows the compressive strength at 28 days for all mixes.

As Figure 3.3 shows, the overall effect of adding fine waste marble aggregates is the reduction of the compressive strength of concrete. A compression strength decrease was observed with the increase of the substitution ratio. This trend is a result of the increase of water/cement ratio. Therefore, the water contents in the mix increases and as result the compressive strength tends to decrease. The three reference concrete mixes, BRB, BRC and BRG, registered an average value of 50.4 MPa, 56.9 MPa and 49.2 MPa, respectively, while the BRM concrete mix had a compressive strength of 45.3 MPa. These variations were also verified on tests at the ages of 7 days and 56 days.

3.2.2. Absorption by capillary action

The results obtained for the water absorption and height by capillary action at 72 hours are shown in Figures 4 and 5. Concerning the water absorption, Figure 4 reveals that the addition of fine waste marble aggregates induces a general decrease in capillary action. In fact, the water absorption by capillary action is more pronounced for a 20% substitution rate due to the high
workability. For higher substitution rates, the concrete average pore size increases due to the bigger specific surface area of fines affecting the water absorption.

Figure 4 shows a different behaviour occurring in the water height capillary action due to the geometric characteristics of the aggregates. This property is mainly related to the spatial arrangement of particles, influenced by its geometric shape and texture. In this case, a significant decrease in water height capillary action can be noticed in basalt sand concrete mixes, contrarily to river sand concrete mixes. Nevertheless, granite sand concrete mixes results shown a constant trend, due to the physical similarities between granite and marble grains.

Figure 5 - Water height capillary action at 72 hours of all concrete mixes
3.2.3. Water absorption by immersion

Figure 6 shows the results of the water absorption by immersion test.

Some slight decreases can be seen in this concrete property in the granite and basalt sand concrete mixes. However, in the river sand concrete mix an incremental trend is noticed. These variations are related with the trapped air from the mixing procedure due to physical properties differences between the aggregates used. Therefore, it is concluded that fine marble aggregates increase the compactness of the BRG and BRB standard mixes reducing their water absorption by immersion. A general small variation is also perceptible, which was expected, due to the identical production and curing conditions of all concrete mixes.

3.2.4. Carbonation

Figure 7 shows the evolution of carbonation depth at 91 days for all concrete mixes. The results express an improvement in the carbonation resistance of granite sand concrete mixes with the substitution of primary aggregates by secondary fine waste marble aggregates. The river sand concrete mixes revealed a contrary trend. Regarding the basalt sand concrete mixes a residual variation in carbonation development is observed. In fact, the results for carbonation depth at previous ages revealed to be relevant. Along this test, carbonation depth was also measured at 7 days, 28 days and 56 days, as shown in Figure 8, resulting in similar patterns which give consistency to the results. These trends are mainly caused by the variations in concrete permeability, which conditions its exposure to the surrounding air.
Durability properties of structural concrete incorporating fine aggregates from the waste marble industry

3.2.5. Chloride penetration

The results for the chloride penetration test at 91 days are summarized in Figure 9. The results follow the water absorption by immersion pattern showing a strict relation between these two hardened concrete properties. In fact, Figure 10 represents its linear model correlation and its correlation coefficient. Thus, the incorporation of fine waste marble aggregates has several benefits in granite and basalt sand concrete mixes oppositely to the river sand mixes.
3.2.6. Drying shrinkage

Analysing Figures 11, 12 and 13, it is concluded that the incorporation of fine waste marble aggregates causes a decrease in concrete shrinkage. This trend is related with the cement paste porous structure as result of the combined used aggregates. Therefore, the marble incorporation led to an increase in concrete compactness with remarkable consequences in the water releasing process. In general, this fact led to lower internal compression stresses in concrete specimens with slower drying shrinkage. The most pronounced concrete shrinkage occurs during the first 20 days after its production.
Figure 11 - Drying shrinkage of basalt sand mixes

Figure 12 - Drying shrinkage of river sand mixes

Figure 13 - Drying shrinkage of granite mixes
4. Conclusions

The aim of this study was to evaluate the durability performance of structural concrete containing fine waste marble aggregates from the marble quarrying industry. After all the experimental procedure, the following conclusions were established:

- In its fresh state, the concrete workability tends to decrease with the increase of the substitution rates (0%, 20%, 50% and 100%);
- The concrete density is directly proportional to its aggregates density and imbrication; the registered concrete density variations proved to be residual with the highest value of 1.3%;
- The mechanical properties, assessed by the compressive strength, revealed a performance decrease with the addition of fine waste marble aggregates;
- In terms of water absorption by capillary action, the marble incorporation proved to be positive especially at a substitution rate of 20%;
- Regarding the water absorption by immersion it can be concluded that marble incorporation improved the permeability of granite and basalt concrete specimens which reveals a beneficial effect in terms of durability;
- For carbonation resistance, granite sand mixes showed an improvement with the incorporation of fine marble aggregates contrarily to the river sand concrete mixes; basalt sand concrete mixes had some residual changes in its results for carbonation resistance; the changes in this property were mainly caused by the variation in concrete permeability;
- There is a solid relation between the chloride penetration results and the water absorption by immersion values; the chloride migration coefficient decreased in the BRG and BRB concrete mixes as the fine waste marble aggregates substitution rate increased in opposition to BRC;
- The effect of fine marble aggregates in all mixes drying shrinkage showed to be beneficial due to the increase of compactness and reduction of internal compressive stress; the drying shrinkage test revealed a more pronounced effect in the first 20 days.

Accordingly to the analysis performed, the general conclusion of this study is that the incorporation of fine waste marble aggregates from the marble quarrying industry revealed a beneficial effect in some characteristics. Furthermore, it was found that for those characteristics where the use of marble showed worse results, they do not compromise the intended durability properties of a sound structural concrete. Therefore, these aggregates are viable to be used in concrete production.
5. References

André, A. P. (2012) - Performance in durability terms of concrete incorporating waste coarse aggregates from the marble industry. Master's Dissertation at Civil Engineering, Instituto Superior Técnico, Lisbon;


