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Editors

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Author Index
Concrete rehabilitation using epoxy resins

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ABSTRACT: The use of polymeric materials in civil construction makes possible original bonding processes because they have good adhesion. In this paper the bond between fresh/hardened concrete was made using epoxy resins in aqueous solution. Also the incorporation of one filler in the epoxy resin was analyzed. This study had two phases. In the first were conducted two shear tests - slant and direct. In the second phase were produced concrete with different strength classes by varying the ratio W/C - 0.6, 0.55 and 0.3. The results for the first phase showed that the direct shear test was the most appropriate. It was found in both phases mixed failures (type II). The use of mineral fillers also proved beneficial This study also demonstrated the importance of water in the adhesion. The best water-cement ratio was 0.55, revealing the best balance between the porosity and the amount of water.

1 INTRODUCTION

Concrete is currently the most widely used construction material in the world. This is due to its ease of application, ability to shape, high resistance to compression, durability and low cost. The concrete buildings that have been made, are, many of them deteriorated, needing work of rehabilitation. Even some new ones justify now, interventions in this direction, due in large part to the action of air pollution on the acceleration of the degradation. The appearance of polymeric materials in the construction industry has developed procedures for the original connection and can provide interesting works, since these materials present good performance in repair and bonding works, due to their high adhesion, which makes possible connection between hardened concrete-hardened concrete, fresh concrete-hardened concrete and hardened concrete-metallic materials by collage (Aguiar and Van Gemert 2007). Among the polymers that can be used in bond and rehabilitation, the epoxies are those with more advantages in these applications. Rehabilitation may be external (reconstitution of deteriorated concrete, increasing the strength capacity of concrete elements and fulfilling the voids of the concrete) or internal (fulfilling of cracks by injection). Also, when it concerns with bond of concrete elements or fresh concrete to hardened concrete the use of epoxy has been advised and their use has increased. The study of adhesive strength is extremely important for materials used in repair and bonding works in construction. Usually, it is determined by tensile, flexure or shear tests (Ozkul et al 2003, Nsambu and Gomes 2006, and Slopková 1999).
2 EXPERIMENT

2.1 1st Phase

2.1.1 Materials

The concretes were made with Portland cement (CEM I 42.5 R), gravel with maximum size of 8 mm and density of about 2551 kg/m³, sand with maximum size of 4 mm and density of about 2504 kg/m³, fine sand with maximum size of 1 mm and density of about 2357 kg/m³. The epoxy was in an aqueous solution. The sieve analysis of the aggregates is shown in Fig. 1. The main characteristics of the epoxy resin are presented in Table 1. Calcareous filler was incorporated in the epoxy resin.

![Figure 1: Sieve analyzes of aggregates](image)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Component A</th>
<th>Component B</th>
<th>Modified epoxy resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (A + B)</td>
<td>1.1 kg/dm³</td>
<td>Aqueous solution of a modified aliphatic amine</td>
<td></td>
</tr>
<tr>
<td>Pot-life</td>
<td>60 min (at +20 °C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum temperature of application</td>
<td>+10 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportions of mixture</td>
<td>Component A</td>
<td>47 P. W.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Component B</td>
<td>55 P. W.</td>
<td></td>
</tr>
</tbody>
</table>
2.1.2 Description of experimental work and testing

The study of the composition of the concretes was made using the method of Faury. For the study of the composition of the conventional concrete a cement content of 300 kg/m$^3$ and a water-cement ratio of 0.6, were assumed (Table 2).

<table>
<thead>
<tr>
<th>Materials</th>
<th>Composition (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>300 kg</td>
</tr>
<tr>
<td>Gravel</td>
<td>897.80 kg</td>
</tr>
<tr>
<td>Sand</td>
<td>348.83 kg</td>
</tr>
<tr>
<td>Fine sand</td>
<td>483.14 kg</td>
</tr>
<tr>
<td>Water</td>
<td>193.49 l</td>
</tr>
</tbody>
</table>

According to the standard EN 12350-2 (CEN 1999) the slump of the conventional concrete was about 9 cm. The tests performed were: compressive test, direct shear test and slant shear test. The compressive tests were made with three cubes with 150x150x150 mm$^3$ in order to determine the strength class of the concrete. The average of the compressive strength of the conventional concrete was 24.3 MPa. So, according the standard EN 206-1 (CEN 2000) this concrete belongs to strength class C16/20. For the direct shear tests, the specimens were obtained by bonding the 3 parallelepiped of concrete. The hardened concrete has dimensions of 8 * 10 * 10 cm$^3$ as illustrated in Fig. 2a, since it was sawn (thus leaving to be a cube), while the fresh concrete is a cube with 10 cm of edge. The final specimen stayed with dimensions of 28x10x10 cm$^3$. The extremes are of hardened concrete (28 days), while the middle is composed of fresh concrete. The tests were performed at 14 days in a hydraulic press at a speed of 15 kN/min. The readings were taken by a digital system.

For the slant shear tests, the cylindrical specimens were sawn. The cutting section was defined by measurement of 5 cm from the base and subsequent application of the cut with an angle of 45°, leaving the dimensions of 10 cm in diameter of the base and two sides with different heights, one 15 cm and another 5cm. Then the sawed specimen stayed in the mold. The final specimen, illustrated in Fig 2b, is a result of fill the mold with fresh concrete. The dimensions are 10 cm in diameter at the base and 20 cm in height. Due to surface contact in cylindrical specimens to be quite irregular, which could cause dispersion in experimental results, it was necessary to smooth by rectifying.

Figure 2: a) cubic samples; b) cylindrical samples
2.1.3 Results

The test results of the direct and the slant shear tests are presented in Fig. 3 and Fig. 4. The comparison of the results of the two tests is showed in Fig. 5.

Figure 3: Influence of the quantity of filler in adherence (direct shear test)

Figure 4: Influence of the quantity of filler in the adherence (slant shear test)

Figure 5: Comparison of both shear tests
2.1.4 Conclusions

The main objective of this phase was to evaluate the adhesion between hardened concrete and fresh concrete using two shear tests: direct and slant. For the slant shear test, as all the failures occurred in the concrete little can be concluded regarding the phenomenon of adhesion. On the direct shear tests failures were mixed adhesive-concrete and it was possible to draw some conclusions. The incorporation of calcareous filler in epoxy resin influences the adhesive strength. There is an increase in the adherence until a maximum, 23 % filler incorporation. After, with the incorporation of more filler the adherence decreased.

2.2 2nd Phase

2.2.1 Materials

The materials used are the same on 2.1.2 except the sand, with maximum size of 16 mm and density of about 2549 kg/m$^3$, fine sand with maximum size of 4 mm and density of about 2226 kg/m$^3$. And we used also a superplasticizer based in polycarboxylates. The sieve analysis of the aggregates is showed in Fig. 6.

![Figure 6: Sieve analyzes of aggregates](image)

2.2.2 Description of experimental work and testing

The study of the composition of the concretes was made based on the method of Faury. In this phase, we produced concrete with different classes of resistance by varying the ratio W/C - 0.6, 0.55 and 0.3 (Tables 3 to 5). For 0.6 and 0.55 were assumed a cement content of 300 kg/m$^3$ and for 0.3 it was 500 kg/m$^3$.

<table>
<thead>
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<th>Table 3 - Composition of concrete 0.3</th>
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</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
</tr>
<tr>
<td>Cement</td>
</tr>
<tr>
<td>Gravel</td>
</tr>
<tr>
<td>Sand</td>
</tr>
<tr>
<td>Fine sand</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td>Superplasticizer</td>
</tr>
</tbody>
</table>
According to the standard EN 12350-2 (CEN 1999) the slump was 16 cm, 4 cm and 20 cm, respectively for concretes 0.6, 0.55 and 0.3. The tests performed were: compressive and direct shear. We did not use the slant shear test in this phase because on the previous the direct shear test obtained better results. The compressive tests were made as in the previous phase (see 2.1.3) and the results are showed in table 6.

Table 4 - Composition of concrete 0.55

<table>
<thead>
<tr>
<th>Materials</th>
<th>Composition (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>300.00 kg</td>
</tr>
<tr>
<td>Gravel</td>
<td>906.38 kg</td>
</tr>
<tr>
<td>Sand</td>
<td>351.74 kg</td>
</tr>
<tr>
<td>Fine sand</td>
<td>478.44 kg</td>
</tr>
<tr>
<td>Water</td>
<td>191.50 l</td>
</tr>
</tbody>
</table>

Table 5 - Composition of concrete 0.6

<table>
<thead>
<tr>
<th>Materials</th>
<th>Composition (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>300.00 kg</td>
</tr>
<tr>
<td>Gravel</td>
<td>887.18 kg</td>
</tr>
<tr>
<td>Sand</td>
<td>344.29 kg</td>
</tr>
<tr>
<td>Fine sand</td>
<td>468.31 kg</td>
</tr>
<tr>
<td>Water</td>
<td>205.94 l</td>
</tr>
</tbody>
</table>

Table 6: Results for the compressive test

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Average strength (MPa)</th>
<th>Strength class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>31.8</td>
<td>C25/30</td>
</tr>
<tr>
<td>0.55</td>
<td>34.1</td>
<td>C25/30</td>
</tr>
<tr>
<td>0.3</td>
<td>86.5</td>
<td>C60/75</td>
</tr>
</tbody>
</table>

For the direct shear tests, the specimens were obtained by bonding 3 cubes of concrete with dimensions of 10x10x10 cm³. The final specimen stayed with dimensions of 30x10x10 cm³. The extremes are of hardened concrete (28 days), while the middle is composed of fresh concrete.

The tests were performed at 14 days in a hydraulic press at a speed of 15 kN/min. The readings were taken by a digital system.

2.2.3 Results

The test results of the direct shear test are presented in Fig. 7 to Fig. 9. The comparison of the three different concretes is showed in Fig. 10.

![Figure 7: Influence of the quantity of filler in the adherence (concrete 0.6)](image-url)
2.2.4 Conclusions

As mentioned, the main objective of this phase was to understand the influence in adhesion of the composition of the concrete and the content of filler incorporated in the epoxy. All the failures were mixed (type II). For all of them the adherence maximum occurred at 50%, so the incorporation of mineral filler was beneficial. Another conclusion is that water has a great influence on adherence. We expected a greater adherence for the concrete 0.6, because it was the most porous. This did not occur due to excess of water. Concrete 0.3 showed the worst
adherence, showing that it is not advantageous the use of high strength concrete. The concrete 0.55 showed the best adherence. This water-cement ratio proved to be the most suitable, because it revealed a good balance between the porosity and the amount of water.

3 GENERAL CONCLUSIONS

With this research we obtained some conclusions. One objective of the first phase was to compare two shear tests: slant and direct. The latter being the more appropriate because it is more demanding for the bonding, since in the slant shear test did not occur adhesive failures. The use of epoxies is advisable because they were obtained adherences quite satisfactory. Besides that it was found in both phases mixed failures (type II). Also the use of mineral fillers proved beneficial for the second phase the maximum stresses in all the concrete occurred for the addition of 50%. In the first phase curiously, for this incorporation the adherence was minimal. One possible explanation was the difference in aggregate used. This study also demonstrated the importance of water in the adherence, requiring a careful study of its quantity, because in excess clearly decreases this property. The best ratio W/C was 0.55, revealing the best balance between the porosity and the amount of water. This work contributed to better insight into the feasibility of using epoxy resins in the rehabilitation of concrete, noting that these products represent a clear added value in rehabilitation.

4 REFERENCES


