METAKAOLIN IN CONCRETE – BENEFICIAL IMPACT ON PERFORMANCE PARAMETERS

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Abstract
Both extensive literature and practical experience have shown that a partial replacement of Portland cement with pozzolanic additions may substantially improve the general durability properties of concrete, while simultaneously contribute to the sustainability of construction industry.

The possibility of producing concrete with enhanced durability performance, including locally produced materials such as metakaolin is studied. The effect that metakaolin has is assessed by comparing the mechanical and durability performance of a concrete with metakaolin additions with without.

The total binder used (300 kg/m³) is composed of metakaolin and fly ash in percentages up to 30%, resulting in concrete with significant compressive strength and enhanced durability performance.

The durability of the studied compositions was evaluated by the absorption of water into concrete under capillary and under immersion action, the non steady state chloride migration tests and four-point electrode resistivity measurements.

Based on the test results obtained, of the various concretes tested, the results demonstrate the beneficial effect of metakaolin addition to improve the concrete durability, namely the resistance against chloride penetration. Test results demonstrate that the use of metakaolin does not seem to affect long term strength gain when compared to ordinary Portland cement.

1. INTRODUCTION
It is known that the use of pozzolans may contribute to improve the performance of concrete. The use of pozzolans is considered efficient as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. To obtain an adequate thermal activation, the temperature range should be established between 600 to 750°C.

The hydration of normal Portland cement produces calcium hydroxide. Metakaolin will react with the calcium hydroxide, decreasing the amount of this product in the microstructure.
and, in addition, producing more calcium silicate hydrates and calcium aluminosilicate hydrate via pozzolanic reaction. Thus, the partial replacement of cement with metakaolin will increase the performance of the concrete.

To study the effect of the metakaolin in the concrete, several compositions were prepared. These contain partial replacement of the cement with 15% metakaolin, 30% fly ash, and 15% metakaolin + 15% fly ash.

The present study aims to evaluate the mechanical and durability properties of the metakaolin in the concrete. The mechanical properties were studied with the compressive strength test. The durability parameters measured were the non steady state chloride migration coefficient, the electricity resistivity and the capillary absorption coefficient.

2. EXPERIMENTAL PROGRAM

The effect of the pozzolanic additions such as metakaolin and fly ash on concrete durability is studied by means of mechanical strength tests (reference test), chloride migration coefficients, electrical resistivity (Werner electrode) measurements and capillary absorption on concrete specimens at the ages 7, 14, 28, 56 and 90 days.

2.1 Materials and mixes

For the concrete used in this research, an ordinary Portland-composite cement (CEM II 42.5 R) was used as requested by the industrial partner. This cement type is the most commonly used in Portugal. Therefore, the effect of the additions on the compositions used daily is studied. Table 1 shows the chemical composition and physical characteristics of the cement.

The kaolin used to produce the metakaolin was extracted near Leiria. Metakaolin is normally obtained by calcination of kaolin at a temperature of ≈ 600 °C - 750 °C [1]. Figure 1 shows the results of the thermal gravimetric analysis. As can be observed, the kaolin used looses its chemically bound water at approximately 600 °C. The chemical composition of this material is present in table 1. The course aggregates used are of limestone, and are also commonly used in concrete production. For fine aggregates a natural river sands was used. A plasticizer was used in order to increase the workability of the concrete.

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>CEM II 42.5 R</th>
<th>Fly Ash</th>
<th>Metakaolin</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>10,26</td>
<td>61,26</td>
<td>37,83</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1,66</td>
<td>27,00</td>
<td>21,85</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>4,00</td>
<td>3,08</td>
<td>10,48</td>
</tr>
<tr>
<td>CaO</td>
<td>76,93</td>
<td>0,16</td>
<td>18,61</td>
</tr>
<tr>
<td>MgO</td>
<td>0,88</td>
<td>0,16</td>
<td>0,74</td>
</tr>
<tr>
<td>SO₃</td>
<td>4,24</td>
<td>0,05</td>
<td>1,46</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0,00</td>
<td>0,10</td>
<td>0,12</td>
</tr>
<tr>
<td>K₂O</td>
<td>1,05</td>
<td>6,62</td>
<td>2,24</td>
</tr>
</tbody>
</table>

In addition to the reference composition, three different compositions were studied. The first contained a partial replacement of the cement with 15% metakaolin (MK15); the second
a partial replacement of the cement with 30% fly ash (FA30); and the third a partial replacement of the cement with 15% metakaolin and 15% fly ash (MK15CV15).

Figure 1 – Thermal gravimetric analysis of the kaolin.

The concrete proportions are summarised in table 2. The production of the concrete mixes was based on the NP EN 206-1 [2]. After mixing, a series of cubical (100mm³) and cylindrical (Ø100x200mm) specimens were filled with concrete, compacted and stored in a vapour chamber (20°C/95 % r.h.) for a day, after which they were demoulded and stored in water at 21 ºC until testing.

Table 2 – Concrete mixes (/m³)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Standard</th>
<th>MC15</th>
<th>CV30</th>
<th>MC15CV15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg)</td>
<td>300.0</td>
<td>255.0</td>
<td>210.0</td>
<td>210.0</td>
</tr>
<tr>
<td>Fine agg. 1 (kg)</td>
<td>305.5</td>
<td>305.5</td>
<td>305.5</td>
<td>305.5</td>
</tr>
<tr>
<td>Fine agg. 2 (kg)</td>
<td>699.0</td>
<td>699.0</td>
<td>699.0</td>
<td>699.0</td>
</tr>
<tr>
<td>Course agg. 1 (kg)</td>
<td>404.7</td>
<td>404.7</td>
<td>404.7</td>
<td>404.7</td>
</tr>
<tr>
<td>Course agg. 2 (kg)</td>
<td>580.4</td>
<td>580.4</td>
<td>580.4</td>
<td>580.4</td>
</tr>
<tr>
<td>Water (l)</td>
<td>148.9</td>
<td>148.9</td>
<td>148.9</td>
<td>148.9</td>
</tr>
<tr>
<td>Metakaolín (kg)</td>
<td>-</td>
<td>45.0</td>
<td>-</td>
<td>45.0</td>
</tr>
<tr>
<td>Fly ash (kg)</td>
<td>-</td>
<td>-</td>
<td>90.0</td>
<td>45.0</td>
</tr>
<tr>
<td>Plasticizer (kg)</td>
<td>1%</td>
<td>1%</td>
<td>0,17%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Tests were performed at different ages ranging from 3 days to 90 days, depending on the test in question.
3. TEST RESULTS AND DISCUSSION

3.1 Compressive strength tests

The compressive strength was determined according to LNEC E-226 [3]. The specimens used were 100mm³ cubes.

The results of compressive strength development are shown in figure 2. For early ages (up to 7 days), the portland composite cement shows the best performance, as can be expected due to the higher portland cement content.

![Figure 2 - Compressive strength development with time.](image)

However, from 14 days onward, the MK15 reveal compressive strengths greater than the portland composite cement and the other compositions. At 90 days age, the compressive strength exceeds 50 MPa. For the MK15FA15 and the FA30 compositions, due to the large cement replacement, the chemical reaction of these pozzolans with the hydration products is much slower. However, as time passes, the gap between the reference composition and these two diminishes. At 90 days, the difference is less than 5 MPa.

3.2 Electrical resistivity test

The electrical resistivity was determined according to LMC P02 [4] procedure using the four point Werner electrode. The electrical resistivity is measured on the surface of the concrete specimens (100mm³ cubes). The electrical resistivity is an important durability parameter as it quantifies the quality of the surface concrete. Correlations exist between the electrical resistivity and the compressive strength and the diffusion coefficient of concrete [5,6]. The test is appropriate for establishing reference curves for concrete quality control and durability performance assessment.

All the compositions with partial replacement of Portland-composite cement displayed expected development of the electrical resistivity values with time. The composition with the best performance after 90 days was MK15FA15, however, this performance only surpassed MK15 after 28 days. This delay might be related to the delayed reaction of fly ash. The composition with only Portland-composite cement has the poorest performance, with electrical resistivity value well below the others, as can be seen from figure 3.

These performances are in accordance to published literature with regards to the
performance of concrete with pozzolanic additions [7,8,9].

Figure 3 – Variation of electrical resistivity with time.

3.3 Chloride Migration test

The chloride migration coefficient was determined according to LNEC E-465 [10]. Specimens for the test were 50 mm disks obtained from cutting $\varnothing$100x200mm concrete cylinders. Tests were performed on 28 days and 90 days old specimens.

As shown in figure 4, the migration coefficient at 28 days of age for both compositions with metakaolin has better performances than those without. However, after 90 days, only the Portland composite-cement has not shown signs of improvement. The fly ash composition has improved significantly. From a durability point of view, and keeping in mind the type of cement, the cement content and the water/binder ratio, these values indicate a significant improvement in performance.

Figure 4 – Variation of diffusion coefficient with time.

3.4 Capillary absorption test

The capillary absorption coefficient was determined according to LNEC E-393 [10]. Concrete specimens used were 100mm$^3$ cubes. Tests were performed on 28 days and 90 days
As shown in figure 5, the capillary absorption coefficients at 28 days of age for both compositions with metakaolin have better performances than those without. However, after 90 days, only the Portland composite-cement has not shown signs of improvement. The fly ash composition has improved significantly. From a durability point of view, and keeping in mind the type of cement, the cement content and the water/binder ratio, these values indicate a significant improvement in performance.

4. CONCLUSION

This research program was developed with three main purposes: evaluate the behaviour of the pozzolan metakaolin and fly ash in concrete; observe the interaction of two distinctive pozzolans in the concrete; and establish a reference for durability parameters with MK additions. The conclusions derived from the experimental investigation and regression analysis are presented below.

1. The behaviour of the concrete with partial replacement of portland composite cement by pozzolans, principally metakaolin, is significantly superior to concrete that use only portland composite cement as binder. Analysing the results, whether resistance to compression or durability tests, the incorporation of metakaolin in concrete has significant benefits in the concrete.

2. The composition with 15% metakaolin has had the best results in almost every test. Even in resistance to compression this composition, with 15% cement had better performance than the composition that used only portland composite cement has binder. This clearly shows the benefits of using this additive in the concrete.

3. The combination of two different pozzolans also had impressive results. In this composition the percentage of substitution was 30%. The compressive resistance was similar to the composition with only portland composite cement, but the performance of this concrete in terms of durability is far better.

4. Analysing all the results it is possible to state that the introduction of these additives in the concrete as several advantages. These advantages reflect in terms of mechanical and
durability behaviour, economical and environmental behaviour.

REFERENCES

[10] LNEC E-465 - Concrete - Methodology for estimating the performance properties of the concrete allowing to comply with the design working life of the reinforced or prestressed concrete structures under the environmental exposures XC and XS. Laboratório Nacional de Engenharia Civil, Lisboa. 2005.