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ESTIMATING COMPRESSIVE STRENGTH OF CONCRETE BY MORTAR TESTING

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ABSTRACT

Concrete mix design laboratory tests which time consuming and entails considerable effort. This study presents a method of reducing mix design testing costs by testing mortar instead of concrete specimens. The experimental programme consisted of defining mortar mixes equivalent to concrete mixes, moulding specimens of both mortar and concrete mixes studied and finally evaluating the compressive strength of specimens cured at different curing time. Results obtained indicate that a good linear correlation between the compressive strength of mortar and the corresponding concrete exist. It is concluded that trial laboratory testing of mortar mixes may be used for prediction of corresponding concrete mixes.

1. INTRODUCTION

The concrete mix design in most cases is still an experimental process. A great deal of research work has been performed for the development of rational methods for conventional or high performance concrete mix designs in the last few decades. However, they do not dispense trial mixes to confirm concrete’s behaviour in fresh and hardening state. Generally, compressive strength must be performed on a sufficient number of relatively large specimens (150 mm cube edge or 150 mm diameter and 300 mm high cylindrical specimens) for each concrete trial mix. Hence, development of adequate mix design for a given concrete requires considerable time and effort. The development of methods to reduce these testing costs is an area where additional improvement is needed.

This research work presents a method of reducing these testing costs. It is suggested that testing mortars instead of corresponding concrete specimens can provide the information
needed with much less time and effort. In this research work the compressive strength of mortars incorporating various percentages of cement replacement by fly ash was evaluated. The mix design of mortars used similar materials and proportions to the corresponding concrete.

It is well known that concrete, as a composite material, consists essentially of a binding medium within which are embedded particles of aggregates [1]. Concrete can be considered as a two phasic composite: the matrix (binder paste) and the granular skeleton (coarse aggregate). The matrix contains cement, mineral additions, chemical admixtures, water and the finer part of the sand used in concrete. Hence, it is reasonable to expect that the compressive strength of the matrix is correlated with the compressive strength of the corresponding concrete, i.e. concrete using the same matrix.

The strength of an aggregate generally does not influence the strength of conventional concrete as much as paste strength and paste aggregate bond, while aggregate strength does become important in high-strength concrete [1]. Generally, it is accepted that the weaker component of a conventional concrete is the past aggregate bond, while, in an enhanced-strength concrete the paste-aggregate interface is sufficiently ameliorated and thus its strength is similar to the strength of the binder paste.

The research work carried out intended to evaluate the possibility of predicting fly ash enhanced-concrete compressive strength by testing corresponding mortar specimens.

The mortar and concrete mixes used the same amount of binder (500 kg/m$^3$). The effect of the percentage of cement replacement by fly ash (0, 20% and 60%) on compressive strength was evaluated at different curing times. The results obtained are presented and analysed.

2. MATERIALS AND MIX DESIGN USED

The aggregates used in this research work were obtained from crushed granite of the same quarry. In the concrete mixtures, two sands of maximum particle sizes ($D_{\text{max}}$) of 2.38 mm and 4.76 mm, and a coarse aggregate of $D_{\text{max}}$ of 9.53 mm were used as received. The cement (CEM) used was Portland cement type CEM I 42.5R. The fly ash (FA) was supplied by Pego Power Plant, Portugal. The superplasticizer (SP) used had a chemical composition based on naphthalene sulphonate formaldehyde condensates. The percentage of SP used was 0.5% (solid content) of binder mass ($B = \text{CEM} + \text{FA}$).

Three different concrete mixtures with three percentage of cement replacement were studied. Binder content of 500 kg/m$^3$ was adopted and the corresponding water/binder ratio (w/B) was maintained constant and equal to 0.3.

The corresponding mortar mixes were prepared with the same materials considering only the finer particles, i.e. particles with $\phi < 2$ mm of the concrete. For preparing the mortars the coarse aggregate was not used and the coarse particles of the sand ($\phi > 2$ mm) were also removed by sieving.
The different concrete mixes used are presented in Table 1, as well as the results of Slump Test.

**Table 1 – Concrete mix designs used**

<table>
<thead>
<tr>
<th>Concrete Mix</th>
<th>w/B</th>
<th>CEM (kg/m³)</th>
<th>FA (kg/m³)</th>
<th>Fine Sand (kg/m³)</th>
<th>Course Sand (kg/m³)</th>
<th>Course Aggregate (kg/m³)</th>
<th>Slump (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>0.30</td>
<td>500</td>
<td>0</td>
<td>502.9</td>
<td>308.4</td>
<td>865.6</td>
<td>25</td>
</tr>
<tr>
<td>C20</td>
<td></td>
<td>400</td>
<td>100</td>
<td>461.8</td>
<td>334.0</td>
<td>869.8</td>
<td>105</td>
</tr>
<tr>
<td>C60</td>
<td></td>
<td>200</td>
<td>300</td>
<td>364.2</td>
<td>373.7</td>
<td>848.7</td>
<td>205</td>
</tr>
</tbody>
</table>

The corresponding mortar mix designs are presented in Table 2.

**Table 2 – Mortar mix designs used**

<table>
<thead>
<tr>
<th>Mortar Mix</th>
<th>w/B</th>
<th>CEM (kg/m³)</th>
<th>FA (kg)</th>
<th>Fine Sand (ϕ &lt; 2 mm) (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>0.30</td>
<td>1105.4</td>
<td>0</td>
<td>909.0</td>
</tr>
<tr>
<td>M20</td>
<td></td>
<td>884.3</td>
<td>221.1</td>
<td>909.0</td>
</tr>
<tr>
<td>M60</td>
<td></td>
<td>442.2</td>
<td>663.2</td>
<td>909.0</td>
</tr>
</tbody>
</table>

Cubic specimens with 100 mm edge and cylindrical specimens of 150 mm diameter and 300 mm high were moulded in order to evaluate the compressive strength of the concrete mixes studied. The mortar specimens moulded were prismatic with 40x40x160 mm³.

The specimens were cured at 21°C and at a constant relative humidity of 80% for the first 24 hours and after demoulding were cured in water at 21°C until testing. The top ends of the cylindrical specimens were prepared with a sulphur-capping compound before compressive strength tests.

### 3. EXPERIMENTAL RESULTS

The compressive strength tests of the concrete specimens were evaluated using a closed-loop servo controlled compression-testing machine. A linear voltage displacement transducer (LVDT) of 5 mm linear measuring length and 0.09% of accuracy was used to control the test, at a displacement rate of 0.12 mm/min (cylindrical specimens) or 0.36 mm/min (cubic specimens).

Figures 1 and 2 show the average values obtained in three cubic ($f_{\text{cm,cube}}$) and cylindrical specimens ($f_{\text{cm,cyl}}$) as well as the best fit of results using the hyperbolic equation (1), proposed by Carino [2] and Knudsen [3].
In equation (1) $f_c$ represents the compressive strength predicted at a given time $t$; $t_0$ is the time needed before the strength gain begins ($t_0 = 0$ was considered); $f_{\text{max}}$ is the final strength when $t$ tends to infinity; and $k$ is a rate constant for strength gain, expressed in days$^{-1}$.

$$f_c = f_{\text{max}} \frac{k(t - t_0)}{1 + k(t - t_0)} \quad (1)$$
Figure 3 represents the average values obtained in mortar specimens ($f_{cm,mortar}$). These average values were obtained in six half specimens after being subjected to flexural tests (three specimens).

![Figure 3: Mortar compressive strength](image)

4. CORRELATIONS BETWEEN CONCRETE AND MORTAR COMPRESSIVE STRENGTH

The relations between compressive strength results obtained in concrete cubic and cylindrical specimens with the corresponding mortar values were determined for the same curing time.

Figures 4 and 5 present the observed relations between concrete cubic and cylindrical specimens and mortar compressive strength, respectively.

Figures 4 and 5 indicate that a good linear correlation exists for the results obtained with a high correlation coefficients.

\[
 f_{cm,cube} = 1.0269 \times f_{cm,mortar} \quad ; \quad R^2 = 96.38\% 
\]

\[
 f_{cm,cyl} = 0.7638 \times f_{cm,mortar} \quad ; \quad R^2 = 95.04\% 
\]
The relation between compressive strength of cubic specimens of concrete and mortar specimens can be expressed by equation (2), with a linear regression coefficient of 96.38%. With cylindrical concrete specimens the linear regression coefficient is similar (95.04%).

For the mixes tested, the results obtained demonstrate that: the compressive strength of cubic specimens of concrete are approximately equal to the one obtained in mortar specimens.
(around 3% higher); while the cylindrical compressive strength are about 76% of the corresponding mortar specimens.

5. CONCLUSIONS

A good linear correlation was obtained between the evaluated compressive strength of concrete specimens (cubic and cylindrical) and corresponding mortar specimens. This evidence can be of great importance as it demonstrates that mortar specimens can be used for estimating the compressive strength of corresponding concrete. It is noted that the mortar mixes should be made using the smaller particles (less than 2 mm) present in concrete.

The advantages of using mortar instead of concrete specimens are obvious: mortar requires much less quantities of material, hence, reducing the time needed for the preparation and moulding of specimens as well as reducing the space needed for curing of the specimens. The reduction in man-hours needed for mixing and testing is estimated to be halved when mortar is used.

The trial mixes of mortars can be made in a sufficient amount to effectively select the finer raw materials, their basic proportions and the admixtures dosages. After having done this, the coarse aggregate to be used is selected for concrete trial mix. It is suggested that mortar specimens can be seen as the first step in concrete mix-design process. With this methodology the number of concrete trial mixes can be minimized.

6. REFERENCES