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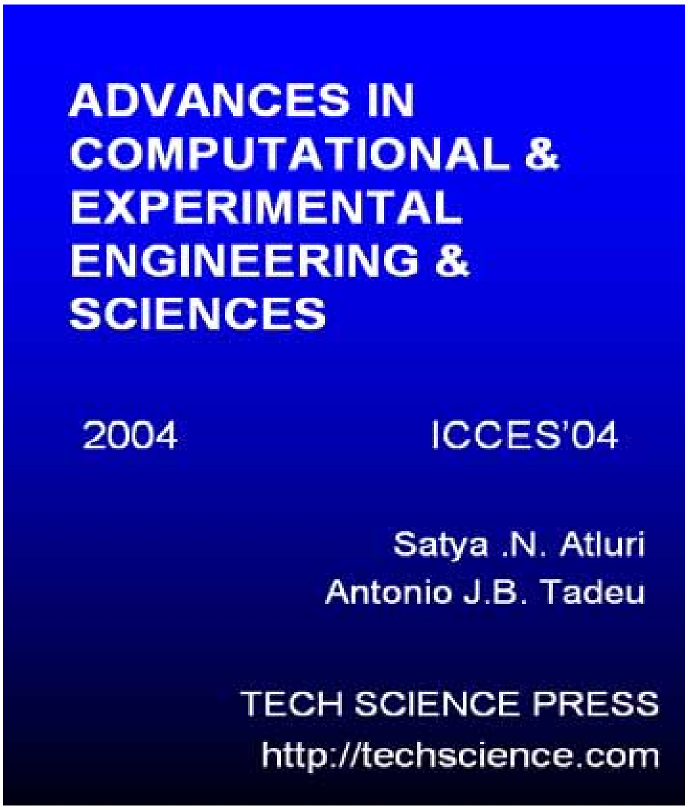

Predicting Mechanical Properties of Enhanced Performance Concrete Using Compressive Strength

A. Camões[1], B. Aguiar[1], S. Jalali[1]

Summary

Mechanical properties of concrete are usually evaluated from compressive strength test results. Extensive literature, codes and regulations recommend the prediction of mechanical properties such as splitting and flexural tensile strength using the compressive strength of cylindrical specimens. These expressions are not related with the type of concrete and, generally, are only a function of the cylindrical compressive strength. It is the objective of this research work to investigate the validity of the existing relationships for enhanced performance concrete, obtained by replacing cement with fly ash for up to 60% in weight.

The experimental program investigated the effect of replacing cement with fly ash on the mechanical properties, i.e. compressive strength, splitting-tensile strength and flexural-tensile behaviour. Results obtained show that, in most cases, a good linear correlation exists between the evaluated mechanical properties, i.e. splitting-tensile strength, flexural-tensile strength and elasticity modulus in flexure, and the square root of compressive strength. This further indicates that an increase in the compressive strength produces a less pronounced increase of the tensile strength.

Introduction

The research work was carried out with the objective of evaluating the possibility of predicting the main mechanical properties of enhanced and high-performance concrete using the compressive strength test. Concretes were produced with reduced cost using high quantities of fly ash (FA) for substitution of cement and using crushed aggregates, thus, reducing the consequences associated with high consumption of cement (C) and extraction of natural aggregates, particularly sand, from river bed, estuaries and sea coast.

The influence of the amount of binder (500 kg/m^3 and 600 kg/m^3), the percentage of cement replaced by fly ash (0, 20%, 40% and 60%), as well as the concrete age on the mechanical behaviour (compressive strength, splitting-tensile strength, flexural-tensile strength and modulus of elasticity in flexure) were assessed using laboratory experiments. Results obtained are presented and the relationship with compressive strength are analysed.

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Materials, Manufacture and Curing

The aggregates used in this research work were crushed granite of the same quarry. Two sands with maximum aggregate sizes (D_{max}) of 2.38 mm and 4.76 mm, and a coarse aggregate with D_{max} of 9.53 mm were used as received, without any treatment. The cement used was Portland cement type CEM I 42.5R. Fly ash (FA) was supplied by the Portuguese Thermoelectric Power Plant of Pego. The superplasticizer (SP) used had a chemical composition based on naphthalene sulphonate formaldehyde condensates. In previous works [1], the optimum SP solid content was estimated to be between 0.5% and 1.0% of the mass of binder. In order to keep the costs low 0.5% was adopted.

Eight different mixtures corresponding to two binder contents (B) and four levels of cement replacement were studied. Binder contents of 500 kg/m^3 and 600 kg/m^3 were adopted and the corresponding water/binder ratio (w/B) were maintained constant for each binder content and was estimated experimentally to achieve 200 mm slump when 40 % FA was used. Using this procedure, concretes with B = 500 kg/m^3 and B = 600 kg/m^3 were made with w/B = 0.3 and w/B = 0.25, respectively.

The mnemonic abbreviation used has the following meaning: the first number refers to the amount of binder and the number that follows FA represents the percentage of cement replaced by FA.

Cylindrical specimens of 150 mm diameter and 300 mm height were moulded in order to evaluate the compressive strength and the splitting-tensile strength of the concrete compositions. The flexural behaviour was assessed using 850x100x100 mm^3 beam specimens. The specimens were removed from the forms 24 hours after casting and were stored immersed in water at 21º until their preparation for testing.

Experimental Results

Table 1 presents the main results obtained in the experimental program. Each value is the average of results of three specimens. In this table $f_{cm,cyl}$ is the average compressive strength of cylindrical specimens, $f_{ctm,sp}$ is the average splitting-tensile strength, $f_{ctm,fl}$ is the average flexure tensile strength and $E_{cm,fl}$ is the average modulus of elasticity in flexure.

Splitting-tensile Strength

The $f_{ctm,sp}$ can be predicted using $f_{cm,cyl}$, by means of expressions suggested in the available references [2, 3]. Figure 1 presents the experimental results and the predictive curves using the equations referred to in available literature. It can be seen that, for lower values of strength, the suggested curves are mostly higher than the experimental values, while this tendency is inverted for higher strength concretes. This tendency is more pronounced for the lower values of $f_{ctm,sp}$ which correspond to the lower compressive strengths estimated for curing times up to 7 days and for the compositions with higher quantities of FA.

Table 1 – Experimental results

Concrete	Age	$f_{cm,cyl}$ (MPa)	$f_{ctm,sp}$ (MPa)	$f_{ctm,fl}$ (MPa)	$E_{cm,fl}$ (GPa)
500FA0	7	42.63	3.03	5.71	29.22
	28	45.41	4.12	6.08	29.57
	56	46.12	4.47	6.00	30.49
	420*	69.26	4.96	6.28	31.81
500FA20	7	33.36	2.50	4.64	26.50
	28	40.83	3.97	5.65	26.65
	56	46.22	4.39	5.24	31.45
	420*	68.07	5.09	5.29	30.01
500FA40	7	30.15	2.12	***	***
	28	35.54	3.01	***	***
	56	48.30	3.57	5.12	29.43
	420*	69.26	4.62	5.70	32.27
500FA60	7	17.83	1.69	2.58	18.97
	28	28.13	2.51	3.28	23.45
	56	34.24	2.98	3.81	24.09
	420*	55.82	4.40	4.34	25.71
600FA0	7	46.23	3.55	5.44	28.49
	28	53.16	4.54	5.69	29.21
	56	58.24	4.97	6.01	30.33
	415**	76.06	5.41	5.95	31.48
600FA20	7	39.31	2.95	4.64	28.26
	28	50.76	4.15	5.01	29.25
	56	59.70	4.73	6.03	30.35
	415**	77.29	5.38	6.13	31.29
600CV40	7	31.90	2.52	3.77	22.05
	28	45.09	3.39	4.68	26.77
	56	52.59	3.97	5.81	28.97
	415**	85.50	4.78	5.66	29.92
600FA60	7	23.01	2.04	2.61	17.76
	28	36.26	2.79	4.31	23.22
	56	50.41	3.21	5.01	25.38
	415**	65.32	4.48	5.22	25.52

* 165 days for flexural test ($f_{ctm,fl}$ and $E_{cm,fl}$);
** 157 days for flexural test ($f_{ctm,fl}$ and $E_{cm,fl}$);
*** Results not considered due to anomalies detected.

Equations (1) and (2) are suggested for prediction of the splitting tensile strength that gives the best fit of data for all the results obtained.

$$f_{ctm,sp} = 0.8062\sqrt{f_{cm,cyl}} - 1.7375 \quad (R^2 = 85.97\%) \tag{1}$$

$$f_{ctm,sp} = 35.2584 f_{cm,cyl}^{0.0608} - 40.7074 \quad (R^2 = 87.14\%) \tag{2}$$

Figure 2 indicates that the two equations have similar results for $f_{cm,cyl}$ ranging from 30 MPa to 70 MPa.

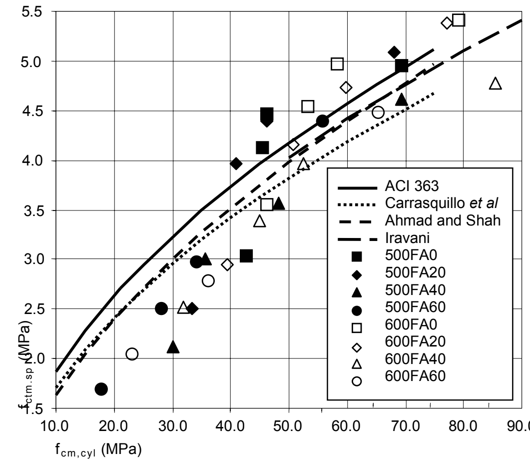

Figure 1 – Results obtained and the correlations available in the literature

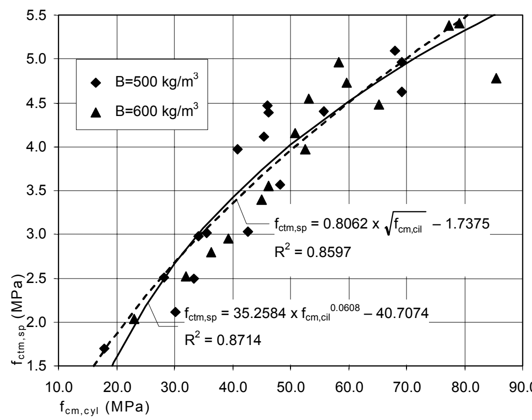

Figure 2 – Best fit of data for predicting the splitting-tensile strength using Eq.1 and 2

Flexural-tensile Strength

The flexural behaviour of the compositions studied was evaluated by three-point bending tests according to RILEM recommendations [4] using 850x100x100 mm^3 beam specimens.

Figure 3 shows the compressive strength, $f_{cm,cyl}$, versus flexural tensile strength, $f_{ctm,fl}$. It can be noted that values of $f_{ctm,fl}$ are larger than those of $f_{ctm,sp}$. This type of discrepancy between the values of $f_{ctm,sp}$ and $f_{ctm,fl}$ has already been identified by other authors [3, 5]. It is noted that the fracture mechanism apparently is not the same for the two tests. Visual observation of the fractured surface of specimens subjected to flexural tests indicates that fracture surface has occurred along the aggregate-paste interface, whereas in splitting tests, the fracture surface passes through the large aggregates. Thus, the results from the two tests are expected to be different.

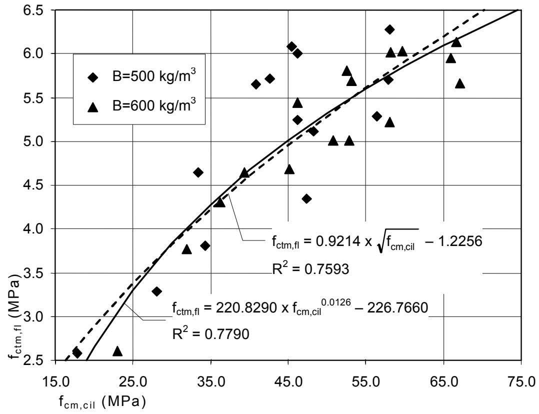

Figure 3 – Best fit of data for predicting flexural-tensile strength using compressive strength

Modulus of Elasticity

The elastic modulus of concrete is controlled by the modulus of its components: hydrated binder paste and aggregates. The concrete elastic modulus can be estimated using empirical expressions, where, in general, the compressive strength is considered as the main influencing factor.

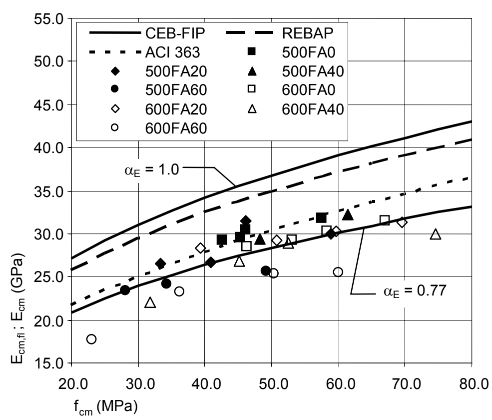

Figure 4 – Elastic modulus obtained from bending and compressive tests versus compressive strength and the best fit of data

Figure 4 present the experimental results and the correlation between $f_{cm,cyl}$, and the corresponding flexural elastic modulus, $E_{cm,fl}$. Best fit of data using equations proposed by ACI 363 [2], CEB-FIP [6] and Portuguese code (REBAP) [7] are also included in Figure 4. These curves represent the relationship between the $f_{cm,cyl}$ and the compressive elasticity modulus, E_{cm}.

Results show that $E_{cm,fl}$ are, in general, lower than the corresponding estimated values of E_{cm} obtained using proposed equations. So, for the compositions studied, the applicability of the referred expressions seems to overestimate the $E_{cm,fl}$ values. ACI 363 equation is the one that comes closest to the obtained $E_{cm,fl}$ experimental results.

CEB-FIP [6] suggests the adoption of a coefficient that takes into account the influence of the type of aggregate, α_E. For quartzite aggregates used in the present work, CEB-FIP proposes a unit value for α_E. However, the $\alpha_E = 0.77$ gives the best fit with $R^2 = 0.69$. This value of α_E is similar to the one proposed by CEB-FIP for estimating concrete's E_{cm} using sandstone aggregates ($\alpha_E = 0.7$).

Conclusions

In most cases, a good linear correlation was obtained between the evaluated mechanical properties (splitting-tensile strength, flexural-tensile strength and modulus of elasticity in flexure) and the square root of compressive strength. This indicates that to an increase of the compressive strength corresponds a less pronounced increase of the tensile strength.

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