Featured at the XVIII Symposium on Nordic Concrete Research, Helsingør, June 2002

Mechanical Properties for Green Concrete

Claus V. Nielsen
Ph.D., Senior Consultant
Concrete Centre, Danish Technological Institute
Gregersensvej, P.O. Box 141, DK-2630 Taastrup, Denmark
E-mail: claus.nielsen@teknologisk.dk

ABSTRACT

The main results of about 25 compressive tests, comprising green environmentally friendly concrete, are presented. The compressive stress – strain curve is modelled by means of the analytical expression in CEB-FIP MC 1990. A total of 5 different concrete types are tested with strengths spanning from 30 to 60 MPa. The relationship between compressive strength and elastic modulus is found to be in good agreement with the codes.

Key words: compressive stress – strain curves, elastic modulus, compressive strengths.

1. INTRODUCTION

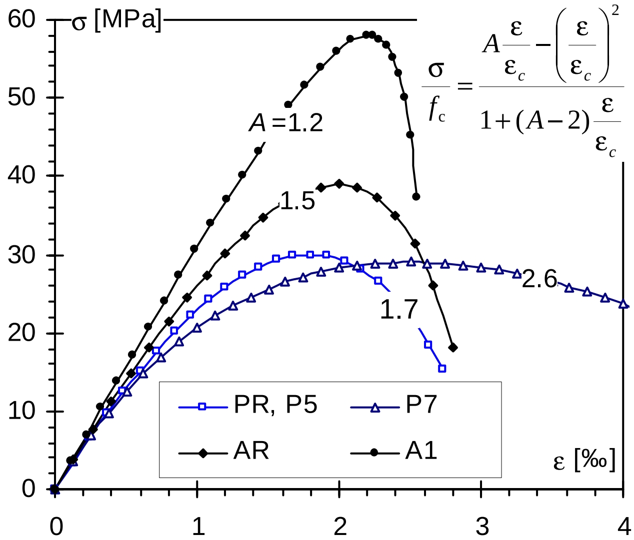
As a part of the Danish research project Green Concrete, running from 1998 to 2002, the mechanical properties of various green concretes have been tested at the structural laboratory on the Danish Technological Institute. The tests are performed in order to investigate the material properties such as the compressive strength, the tensile strength, the modulus of elasticity, the fatigue strength, the anchorage strength and the behaviour of reinforced beams. Furthermore, the behaviour is investigated through creep and shrinkage tests and under temperature variations. Only the compressive test results are presented here, including stress – strain relationships.

The Green Concrete project and the concrete mixes involved are explained in details elsewhere in the present proceedings [1,2]. The following Green Concrete mixes are presented:

- Concrete for aggressive environmental exposure class: AR and A1, with an equivalent water to binder ratio of about 0.42.
- Concrete for passive environmental exposure class (indoor, dry): PR, P5 and P7 with an equivalent water to binder ratio of about 0.7.

The two concrete types AR and PR are conventional Danish structural concrete, included for reference purposes. Concrete A1 contains an extra large amount of pfa compared with AR. The binder composition (c/ms/pfa) is about 86/5/9 and 57/5/38 % by weight for AR and A1, respectively. Concrete P5 reuses concrete slurry and P7 contains fly ash from biofuels.

The compression tests are conducted as deformation controlled tests on cast cylinders (diameter 100 mm and height 200 mm). For each concrete mix 5 test specimens are tested at 28 days. The test method is a modified version of the Danish Standard DS 423.25 [3]. The strains are recorded by means of 3 LVDT's per test specimen, mounted with a base length of 100 mm. The E-modulus is obtained from the stress – strain measurements up to 40 % of the strength.



$$\frac{\sigma}{f_c} = \frac{A\dfrac{\varepsilon}{\varepsilon_c} - \left(\dfrac{\varepsilon}{\varepsilon_c}\right)^2}{1 + (A-2)\dfrac{\varepsilon}{\varepsilon_c}}$$

Table 1 – Average test results with coefficient of variation in per cent in parentheses.

Concrete mix	f_c [MPa]	ε_c [‰]	E_c [GPa]
AR	38 (7.0)	2.0	28.4 (6.2)
A1	58 (3.4)	2.2	32.6 (3.3)
PR	35 (4.3)	1.8	32.9 (7.8)
P5	32 (4.9)	1.8	29.7 (4.7)
P7	29 (7.1)	2.5	30.5 (4.9)

Figure 1 – Analytical σ–ε curves. Parameter $A = \varepsilon_c E_c / f_c$ with (ε_c, f_c) = peak values [4].

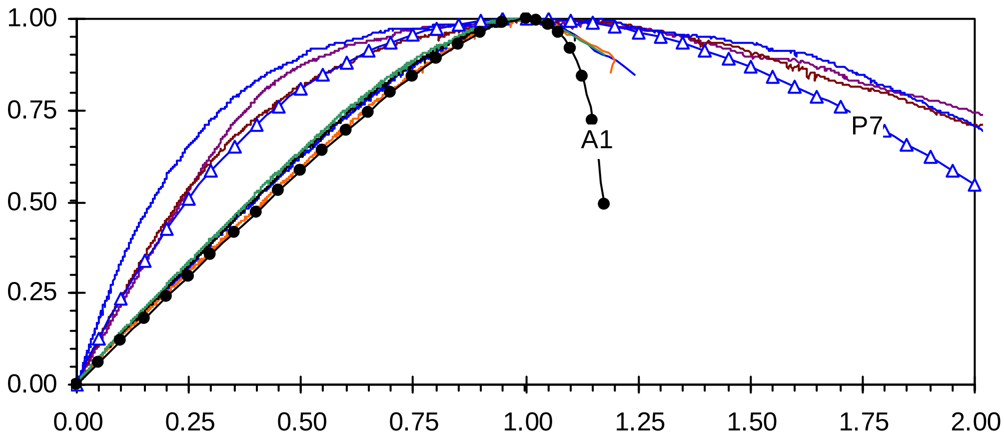


Figure 2 – Examples of normalised stress – strain curves for A1 and P7. Measured values of σ/f_c and $\varepsilon/\varepsilon_c$ compared with analytical model.

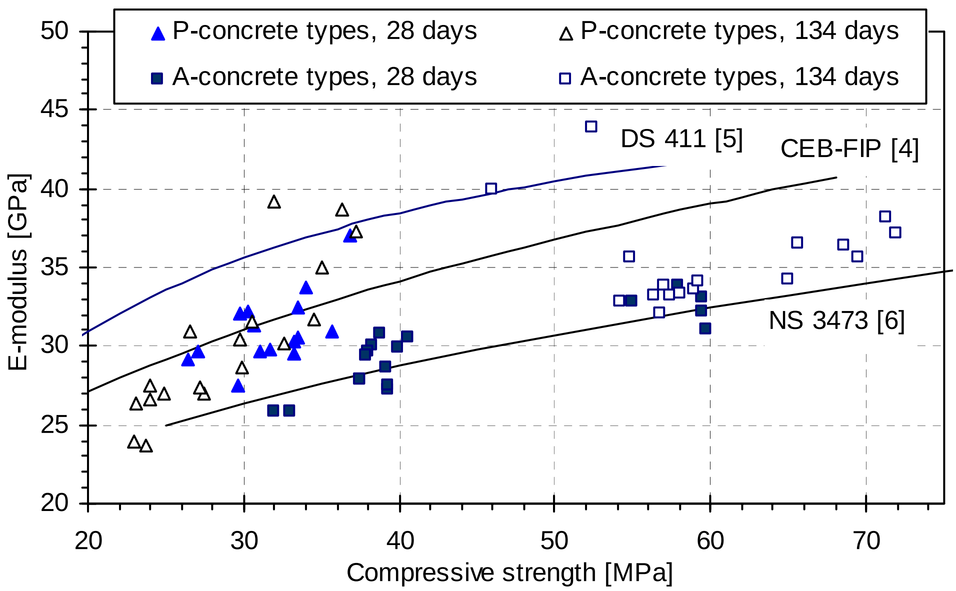


Figure 3 – Individual measurements of E_c vs. f_c together with analytical code expressions.

2. TEST RESULTS

In Fig. 1 the average σ–ε curves are depicted by means of the analytical expression recommended by CEB-FIP [4]. The parameter *A* is found to decrease with increasing strength, which is in agreement with [4]. However, the analytical expression is found to underestimate the behaviour slightly, especially for the descending branch (Fig. 2).

It is obvious that A1 represents a high-performance-concrete with almost linear-elastic behaviour until failure followed by a steep descending branch. Opposite to this we find P7 with a very ductile behaviour, while the two intermediate curves represents conventional normal-strength-concrete. Table 1 contains the main test results.

In Fig. 3 the elastic modulus is depicted as a function of the strength, including test results at 28 and 134 days. Furthermore, 3 analytical expressions taken from [4,5,6] are depicted:

$$E_c = 21.5\,\mathrm{GPa}\left(\frac{f_c}{10\,\mathrm{MPa}}\right)^{1/3}, \quad E_c = 51\,\mathrm{GPa}\,\frac{f_c}{f_c + 13\,\mathrm{MPa}}, \quad E_c = 19\,\mathrm{GPa}\left(\frac{f_c}{10\,\mathrm{MPa}}\right)^{0.3}$$

corresponding to CEB-FIP, DS 411 and NS 3473, respectively. It should be noted that the Danish code [5] states that only 70-75 % of the value obtained from its analytical expression should be used in the serviceability limit state, i.e. when calculating deflections, crack widths, etc. Thus, when multiplying the DS 411 curve in Fig. 3 with 0.7 a curve close to the Norwegian one is obtained, being a plausible lower bound of the experimental findings.

3. CONCLUSIONS

Based on compressive test results on various concrete types tested in the Danish project “Green Concrete” the following conclusions are obtained: (i) Good agreement is obtained, applying the compressive stress – strain relationship in accordance with the CEB-FIP Model Code; (ii) The relationship between the elastic modulus and the strength is found to be in fair agreement with the code expressions even though large experimental scatter exists. Hence, there is no reason to assume that the compressive mechanical properties of “green concrete” differ significantly from those of conventional concrete.

REFERENCES

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