Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Web only Papers. http://www.claisse.info/Proceedings.htm

HIGH STRENGTH CONCRETE WITH HIGH VOLUME OF CALCAREOUS FLY ASH

I. PAPAYIANNI

Aristotle University of Thessaloniki, Laboratory of Building Materials

ABSTRACT: Calcareous fly ashes are not widely used in replacing high volume of cement in concrete production mainly because of problems often associated with free lime and sulfate content. However, if this material has been processed by grinding and prehydrating, it is transformed to an excellent cementitious material that contributes to strength of concrete. In the paper the development of a commercial high strength concrete of the range 55-65MPa with high content of fly ash is presented. Fly ash replaced cement from 25 up to 50% by mass of the total cementitious material. Mechanical and elastic characteristics of the different mixtures were measured. River sand and crushed limestone coarse aggregate were used as well as superplastisizer for modifying the slump values that ranged from 60 to 80mm. The w/c+f ratio ranged from 0.28 to 0.32. The strength values at 3, 7, 28 and 90 days were measured. The desired level of the 28-d strength was achieved but the rate of strength development depended on the fly ash content in the mixtures. The statistically estimated values of compressive, flexural and splitting tensile strength as well as the modulus of elasticity were compared with those given in the European codes for this category of concrete strength. The semi-empirical expressions known from literature, which are used for the estimation of flexural strength or modulus of elasticity, were applied and compared with the statistical experimental values.

Keywords: High strength concrete, calcareous fly ash

1 INTRODUCTION

High strength concrete (HSC), nowadays, is defined as concrete with ordinary aggregates, w/c ratio below 0.40 and 28 day compressive strength between 60 and 130 MPa [1], although higher strength levels, up to 200 MPa, are also mentioned in the literature [2]. By 1960, concrete with compressive strength levels of 40 to 50 MPa was considered as high strength concrete and by 1970 this level was increased to 60 MPa. Today, concrete of more than 100 MPa designed strength is used in bridge construction. The interest on high strength concrete has grown over the last decades of the 20th century, when concrete technology made significant progress with the introduction of advanced chemical admixtures and new transportation and placement methods. High-rise buildings and constructions close to sea water require thin section concrete elements of good durability and guaranteed service life.

The use of HSC permits significant reduction in columns' dimensions, which gives 30% more free space in high-rise building parking areas and, furthermore, by using HSC the number of beams in bridge construction is reduced [3]. Regarding waterfront construction, the use of HSC can ensure more than 100 years of service life.

It must be noted that the production of high strength concrete does not require other than conventional building materials, but it involves better quality control of the materials and also control of all the production stages. In Canada, USA and Europe these concretes are produced with the use of supplementary cementitious materials of pozzolanic character, such as fly ash, slag, silica fume and their combinations [4]. During the 80's, a high strength concrete using more than 50% siliceous fly ash as replacement of cement was developed in the CANMET Recearch Center [5].

The first standards on HSC were established in Norway (NS 3473-1989). Today, the production of HSC is controlled by standards and manuals such as the CSA Standard A23.3-1994 and the ACI Committee Report 363.2R-98 [1].

The aim of this laboratory work was to develop a high strength concrete, which could be commercially produced by the ready-mix concrete industry with conventional building materials, using a high volume of processed Greek calcareous fly ash. The desired workability was selected equal to S2 category (7-9 cm slump) according to EN 206-1, in order for the concrete mixtures to be suitable for precast concrete elements production.

The first part of this research is a study of the mechanical and elastic properties of the proposed high strength concrete (150 MPa) with high volume of fly ash.

2 EXPERIMENTAL PROGRAM

Six different concrete mixtures were produced, each one with a total binder content of 600 to 700 kg/m^3. Ten 15x30 cm cylinders, five 15x15x15 cm cubes and five 10x10x40 cm prisms were cast from each mixture, in order to determine compressive strength at different ages, splitting tensile and flexural strength, as well as elastic and dynamic modulus of elasticity. The parameters studied were total binder content, percentage of fly ash in the total binder content and the water to binder ratio for the desired level of workability.

Natural river sand and crushed limestone coarse aggregates were used for all of the mixtures, and their grading is shown in Table 1. The aggregate mix for the concrete mixtures resulted from three separate fragments sized 0-4mm, 4-8mm and 4-12.5mm.

Table 1. Aggregate gradation

Aggregates	Sieve opening (mm)					
Retained (%)	0.25	1.0	2.0	4.0	8.0	16
River sand	8.61	62.82	84.60	97.77	100	100
Crushed limestone (4-8mm)	2.25	2.50	3.00	25.75	100	100
Crushed limestone (4-12.5mm)	1.61	1.81	2.47	3.46	32.08	100
Aggregate mix						
40% river sand	3.444	25.128	33.84	39.108	40.00	40.00
20% cr. limestone (4-8mm)	0.450	0.500	0.600	5.150	20.00	20.00
40% cr. limestone (4-12.5mm)	0.660	0.724	0.988	1.384	12.832	40.00
Actual aggregate mix gradation	4.55	26.352	35.42	45.642	72.83	100.00
Target aggregate mix gradation	7.00	20.00	30.00	45.00	70.00	100.00

Some properties of the aggregates are shown in Table 2. The moisture of the aggregates was measured before casting in order to correct water content of the concrete mixtures to the assumed saturated-surface dry condition of the aggregates.

Table 2. Some properties of the aggregates used

Aggregate	App. specific density (kg/dm^3)	Water absorption (%)	Water content (%)
River sand	2,564	0,80	8-11
Crushed limestone (4-8mm)	2,675	0,50	1,4-3,6
Crushed limestone (4-12.5mm)	2,680	0,33	1,05-2,6

The type of cement used was CEM I42.5 N (ordinary Portland cement) according to EN 197-1. The fly ash used was characterized as type 2 according to the Greek National Specification for Fly Ash. Its main characteristics and the respective requirements of the specification were free CaO = 2.8% (<3.0%), SO_3 = 3.5% (< 5.0%), apparent specific density = 2.42 g/cm^3, fineness 328 m^2/kg, $R_{45\mu m}$ ~ 20% (<30%). A polycarboxylate-based plasticizer was used at rates of 1-2% by weight of the total binder.

The proportions and fresh mixture properties of the concrete mixtures produced are shown in Table 3, while their mechanical and elastic properties are shown in Table 4. A comparison of the mechanical characteristics to the rate of compressive strength development is shown in Figs. 1 and 2.

Table 3. Concrete mixture proportioning

Mixture No.	1	2	3	4	5	6
CEM I42.5 (kg/m^3)	450	450	300	350	350	350
Fly ash (kg/m^3)	150	150	300	350	350	350
(percentage of the total binder)	(33%)	(33%)	(50%)	(50%)	(50%)	(50%)
River sand (kg/m^3)	683.90	676.50	689.83	598.14	565.20	565.24
Cr. limestone (4-8mm) (kg/m^3)	324.38	323.10	319.67	283.92	274.44	274.21
Cr. limestone (4-12.5mm) (kg/m^3)	635.85	637.10	632.08	561.3	549.60	549.63
Water (kg/m^3)	182.2	145.8	132.78	167.02	213.40	214.00
Plasticizer (kg/m^3)	4.0	6.0	12.0	14.0	14.5	7.00
Water to binder ratio	0.30	0.25	0.22	0.238	0.30	0.30
Slump (cm)	6.9	6.8	8.0	8.5	7.0	7.2
Plasticizer percentage of the total binder (%)	0.5	0.65	1.2	1.4	1.0	1.0

The fresh mixtures were compacted on a vibrating table. The degree of compaction for each mixture was determined by dividing the density of the compacted fresh concrete with the theoretical density of the concrete based on the weight of its constituents per m^3. The above ratio was found equal to 0.88-0.93 for all the mixtures and was considered to be sufficient. All the produced specimens were cured at 20˚C and 95% RH for 28 days and then remained at outdoor ambient conditions.

The measurements of the concretes' mechanical properties were carried out according to the ASTM Standards. More specifically, ASTM C469-04 was used for measuring the splitting tensile strength; ASTM C293-02 was used for flexural strength; and ASTM C496-02 was used for the static modulus of elasticity. The measurement of the dynamic modulus of elasticity was based on ASTM C215-02 and was carried out on cubic specimens.

Table 4. Mechanical and elastic properties of the produced concrete mixtures

Mixture No.	1	2	3	4	5	6
7-day cubic compressive strength, $f_{c,cube7}$ (MPa)	-	-	-	-	45.1	40.8
28-day cylindrical compressive strength, $f_{c,cyl28}$ (MPa)	49.5	56.8	65.9	59.9	55.3	50.9
28-day cubic compressive strength, $f_{c,cube28}$ (MPa)	59.4	64.5	73.9	69.5	68.2	60.1
150-day cubic compressive strength, $f_{c,cube150}$ (MPa)	63.5	78.6	71.3	75.2	69.3	64.4
28-day splitting tensile strength, $f_{c,s28}$ (MPa)	4.71	4.45	4.88	4.52	4.30	2.67
28-day flexural strength, $f_{c,b28}$ (MPa)	9.05	9.84	8.16	7.10	7.69	7.54
28-day static modulus of elasticity, E_{st} (GPa)	27.2	32.5	33.6	29.2	27.8	29.2
28-day dynamic modulus of elasticity, E_d (GPa)	42.9	47.5	47.85	40.9	45.3	44.34
$f_{c,cube28}/f_{c,cyl28}$	1.20	1.13	1.12	1.17	1.23	1.18
$f_{c,s28}/f_{c,cyl28}$ (%)	9.51	7.84	7.40	7.62	7.79	5.21
$f_{c,b28}/f_{c,cube28}$ (%)	15.2	15.2	11.02	10.2	11.2	12.5
E_d/E_{st}	1.576	1.462	1.422	1.401	1.631	1.516

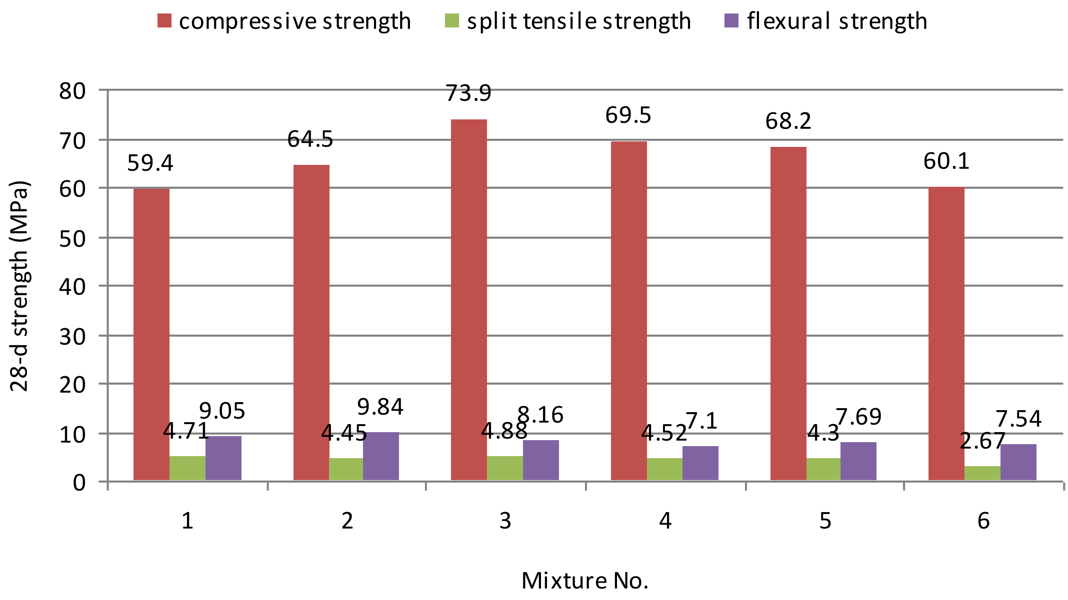

Fig. 1 Mechanical and elastic properties of concrete mixtures

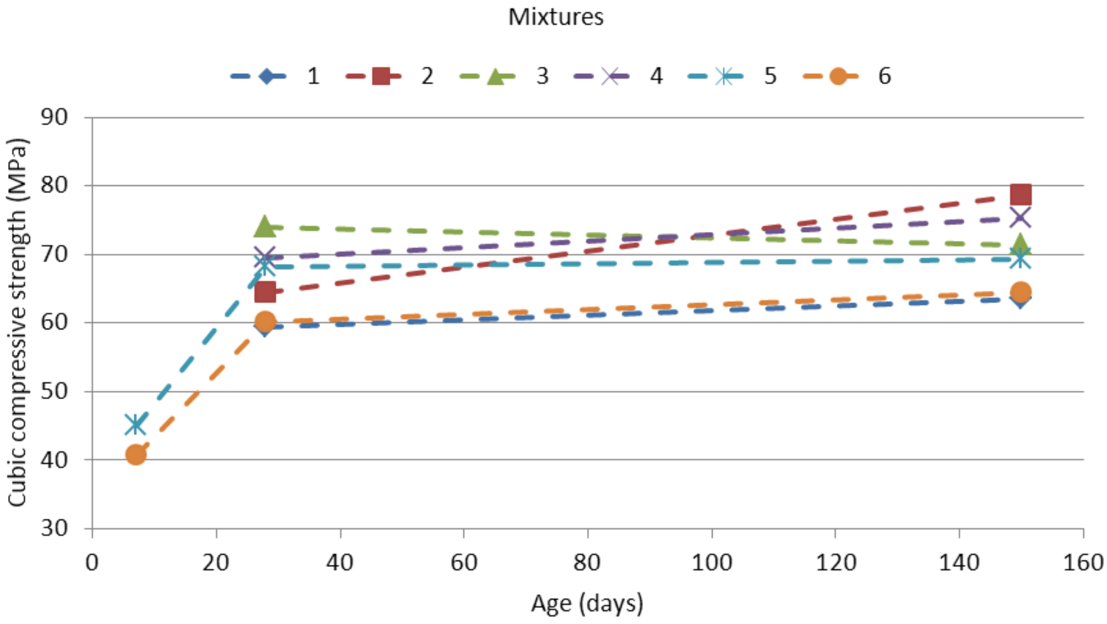

Fig. 2 Rate of strength development for different concrete mixtures

3 RESULTS AND DISCUSSION

First of all, a 28 day cubic compressive strength level of more than 60 MPa was achieved with a total binder content of 600 to 700 kg/m^3, By comparing mixtures 1-3 to mixtures 4-6, there is no clear differentiation due to the greater binder content (700 kg/m^3) of mixtures 4-6. There is a trend of lower flexural strengths and lower elastic moduli in those mixtures, which implies that the mixtures of 600 kg/m^3 binder content show better mechanical characteristics. The parameter that seems to influence strength is the water to binder ratio (w/b); at w/b below 0.30 the values achieved were higher. It seems also that increased percentage of fly ash in the mixture require larger amount of plasticizer in order to achieve the desired workability. There is a good rate of strength development and it seems that a 7-day compressive strength of 40 to 50MPa is possible.

Splitting tensile strength ranges from 2.6% to 4.8% of the compressive strength, while flexural strength ranges 7% to 9% of the compressive strength. The static modulus of elasticity ranges from 27.0 to 33.5 GPa. When comparing these values with the respective calculated values from the CEB-FIP Formula ($E_{cm} = 9.5 \times (f_{ck} + 8)^{1/3}$) for conventional concrete, it seems that the static modulus of elasticity in the concrete mixtures with large amounts of fly ash are slightly lower (for example 33.5 GPa instead of 37 GPa).

Regarding the rate of strength development (Fig.2), it could be said that the contribution of calcareous fly ash to compressive strength is, generally, lower after the age of 28 days compared to that of the first days.

It must also be pointed out that although the mechanical and elastic properties give a hint for the behavior of concrete over time, further testing on durability of high strength concrete with high volume of fly ash is required.

4 CONLUSIONS

It is possible to produce a commercial high strength concrete using processed fly ash at 30%-50% replacement rates of the total binder.

It is suggested that the lowest possible amount of binder should be used, which in the present research was 600 kg/m^3. Some further investigation could lower this amount even more. The most important parameter for strength development seems to be the water to binder (water/cement+fly ash) content. The high-fly-ash-volume and high-strength concrete shows lower static modulus of elasticity compared to that of conventional concrete.

REFERENCES

1 ACI Committee, ACI 363 2R-98. Guide to Quality Control and Testing of High-Strength Concrete.

2. S.I Keda et al, Innovative Design and Construction of a 50m Span Footbridge using Reactive Powder Concrete, in Proc. of G. C. Hoff, Symp. on High Performance Concrete and Concrete for Mar Environment", Las Vegas, May 2004 Editor T.C. Lin, pp 93-107.

3. H.G. Russel, Applications of High Performance Concrete and Concrete for Marine Environment, Editor T.C Lin, pp 1-17, Las Vegas USA, 2004.

4. J.A.Bickley, North American Trends in the Development of High Strength Concrete, 5th Int. Symp.on Utilization of High Strength and High Performance Concrete, Proc.Vol.1, pp 1-14 Editor I Holand and E.Sellevold, Sandefjord, Norway, 1999.

5. V.M. Malhotra and P.K Mehta, High Performance, High Volume Fly Ash Concrete, pp.33-35, Canada 2002.

6. T.R Naik and B.W Ramme, High-Strength Concrete Containing Large Quantities of Fly Ash, ACI Materials Journal, 86 (2), pp 111-116, 1989.