HIGH STRENGTH CONCRETE

First International Conference

Edited by
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HIGH STRENGTH CONCRETE

First International Conference

PROCEEDINGS

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Abstract: This proceedings, *High Strength Concrete*, consists of papers presented at the first Engineering Foundation Conference on High Strength Concrete, held July 13-18, 1997, in Kona, Hawaii. The conference brought together a group of individuals known for their contributions to high strength concrete (HSC), from material aspects to applications in the field. Since the 1980s, intense research activities have been conducted to resolve design issues related to the use of HSC. These papers explore such issues as the behavior of interior beam-and column subassemblages in a reinforced concrete frame, ductility and strength of HSC columns, shear strength of HSC beams, seismic behavior of prestressed concrete beam-column joints, crack growth and cyclic loads, and thermal performance of HSC.

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PENETRATION RESISTANCE TESTS ON HIGH STRENGTH CONCRETE

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ABSTRACT

The aim of the investigation described here is to verify the applicability of penetration resistance tests on high strength concrete as a way of estimating its compressive strength "in situ". A relationship between compressive strength of a given concrete and its resistance to penetration by a steel probe fired into the concrete surface is presented to a compressive strength range varying from 50 MPa to 90 MPa using an alternative firing apparatus to the standard apparatus Windsor Probe Test System.

INTRODUCTION

The interest of high strength concrete has increased considerably in the last few years. Several research works on this subject have contributed to a better understanding of the material properties and mechanical behavior in structural elements of high strength concrete.

One subject, which needs some investigation as far as the use of high strength concrete in building construction is concerned, is the prediction of "in situ" concrete strength. It is known that the strength measured on standard specimens, at 28 days and cured in standard conditions, only gives the potential value of the concrete strength, which is useful for quality control purposes and for checking the acceptability of the concrete as it is produced (1, 2). However, this reference strength is normally achieved by the real structure at ages much higher than 28 days, depending on various parameters, mostly associated with curing conditions. On the other hand it is often necessary to know the strength of concrete before 28 days to determine when the forms can be disassembled or to know the structure performance at certain age.

As a way of estimating the "in situ" strength for high strength concrete, some techniques, previously used in normal strength concrete, have been adapted and used. One of those techniques consists on calibrating a relationship between the compressive strength of a given concrete and its resistance to penetration by a steel probe fired into the concrete surface. This test, generally known as Windsor Probe Test System, has only shown its applicability in concretes in which strengths are no more than 50 MPa (measured in cubes of 150 mm).

In an attempt to use Windsor Probe Test System in high strength concrete, performed by the authors, it was found that the available probes and/or the power level are unsuitable; probes didn't penetrate the concrete surface. It means that probably a new probe and/or a new power level has to be provided by manufacturer in order to be possible its use in high strength concrete.

On the present investigation the possibility of using an alternative firing apparatus to the traditional Windsor Probe Test System was evaluated for the range of concrete compressive strength varying from 50 MPa to 90 MPa. A previous study, comparing the reliability of both apparatus, is also presented for the range of concrete compressive strength up to 50 MPa.

TEST EQUIPMENT

Windsor Probe Test System

A test apparatus, designed for penetration resistance measurements, using a special probe and standardized powder charge, was developed in the USA during the 1960s' and is known as Windsor Probe Test System and covered by the ASTM Standards (ASTM-C803-90) (3). In Europe, similar standards are the British Standards (BS 1881: Part 207: 1992) (4). This system allows the use of two kinds of probes: the silver colored probe, to use in concrete with natural aggregate; and the gold colored probe, to use with lightweight concrete. Two different power levels are also possible, using the same power load, by an adjustment in the instrument: the standard power and low power. For the purpose of this study, it was decided to use the silver colored probe (of hardened steel alloy with 6.35 mm diameter, 79.5 mm length, a blunt conical end and a plastic guide) associated with the standard power.

Probes were fired into concrete, using the driver unit, and the exposed length was measured individually, by using a rectangular plate, placed over probe and pressured against the concrete by a knurled spring-nut, and a measuring cap threaded on top of probe. The distance was measured from top of cap to plate with the micrometer depth gauge.

Alternative Firing Apparatus

The way of delivering the energy to the probe by the Alternative Firing Apparatus has little difference from the WPT System previously mentioned. Both systems use a powder cartridge and probes, but while in the first apparatus (WPT System) detonation resultant energy of the powder cartridge is transmitted directly to the probe, which is accelerated and projected into the concrete surface, in the Alternative Firing Apparatus this energy is transmitted to a piston, which is projected in high velocity against the probe, like a hammer, thrust in the probe by the impact.

The Alternative Firing Apparatus enables the control of the energy level, delivered to the probe by the driver, as well as different dimensions and geometries for the probe.

The probe used for normal strength concrete was made of steel alloy with 4.5 mm diameter and 52.0 mm length, a conical end and a plastic guide. The powder charge was level 6.

For high strength concrete, the probe was made of steel alloy with 4.5 mm diameter and 42.0 mm length, a conical end and a plastic guide. The powder charge was level 7.

In both cases the exposed length was directly measured, by using a depth gauge, relatively to the original surface of the concrete.

PROCEDURE

Previous Studies on Normal Strength Concrete

In a previous study on normal strength concrete, performed by the authors (5), the possibility of using an alternative firing apparatus to the traditional Windsor Probe Test System was evaluated.

Five different mix proportions, corresponding to five different classes of compression strength, were produced in order to obtain five sets of specimens, each one comprising a 750x550x170 mm slab and 4 cubes of 150 mm, all obtained by using metallic moulds. Each slab was constructed to withstand 6 tests of WPT System and, at least, 12 tests by the Alternative Firing Apparatus. The dimensions were determined in order to obtain, for standard power, the recommended edge distances, member thickness and minimum distances between tests, given by ASTM standards (3), to prevent splitting of the member under test, structural cracking and also to avoid overlapping of zones of influence.

The mix proportions were established in order to fix the maximum number of parameters. Therefore, the Faury modules of fineness remained exactly the same and the workability of fresh concrete, measured by slump test, was fixed between 80 mm and 120 mm. Also the operations of mixing and compacting (type and frequency) were kept constant in all the cast specimens.

The coarse aggregates were crushed rock from granite with the maximum dimension of 25.4 mm and a Mohs' hardness scale level 7. The fine aggregate was a natural sand from the river.

The specimens were cured together at approximately 12ºC and relative humidity of 65%. All the tests were performed at 28 days age for each group of specimens and, at the time of testing, the specimen condition was dry.

Studies on High Strength Concrete

The Alternative Firing Apparatus was studied in order to find out its suitability and reliability for normal strength concretes and good results were obtained. Therefore the same study was applied to high strength concrete which is explained in this paper.

Five different mix proportions were produced with constituent materials of the same characteristics, which allows five different classes of compression strength between 50 MPa and 90 MPa. From each batch 3 standard cubes of 150 mm were produced as well as one prismatic slab with dimensions 550x500x170 mm.

As for normal strength concrete, mix proportions were determined in order to keep constant the maximum number of parameters, such as, Faury modules of fineness, workability and the operations of mixing and compacting.

Among the types of cement available in Portugal, a normal portland cement, type I, class 42.5R, classified according to the Portuguese Norms NP2064, was chosen.

Considering the desirable level of strength and concrete producing conditions, a superplasticizer was selected which was highly concentrated and based on synthetic resins without air-entraining agents. This superplasticizer enabled a water reduction of about 22%, keeping the same workability.

The fine aggregate is natural sand from the river with a fineness modulus about 3.5 and the coarse aggregates is a crushed rock from granite supplied with two gradations, classified as coarse aggregate 1 and coarse aggregate 2, with a maximum dimension of 25.4 mm and a Mohs' hardness scale level 7.

For concrete mix proportions a water/cement relationship based on weight varying from 0.36 to 0.26 was considered in order to obtain the compressive strength between 50 MPa and 90 MPa. The cement quantity varied from 400 kg to 600 kg per cubic meter and the workability, measured by slump test, remained between 60 and 100 mm. The five basic mix proportions are presented on Table 1.

Table 1 - Basic mix proportions per cubic meter

	f	g	h	i	j
Sand (kg)	802	755	660	549	422
Coarse agg.1(kg)	241	306	399	401	503
Coarse agg.2(kg)	730	708	670	732	716
Cement (kg)	400	425	485	535	600
Admixture (l)	10.0	10.6	12.1	13.4	15.0
Water (l)	142	140	145	145	157
W/C	0.36	0.33	0.30	0.27	0.26

All specimens (slab and cubes) were cured in water at controlled temperature of 20ºC ± 2ºC and all the tests were performed at 28 days. For each batch, 3 cubes were tested for compression strength and penetration resistance tests applied on concrete slab surface by using the "Alternative Firing Apparatus". All specimens were wet at the time of testing.

ANALYSIS OF RESULTS

Previous Studies on Normal Strength Concrete

Both apparatus were simultaneously used on the same concrete and the obtained experimental results are shown in Table 2.

Table 2 - Results obtained for normal strength concrete
(Number in parenthesis shows the number of measurements).
E is the mean value of the exposure length.
f_{cm} is the mean value of compressive strength on standard cubes.

		a	b	c	d	e
Cubes of 150 mm cured at 12 ºC, R.H. 65%, tested dry, at 28 days	f_{cm} [MPa]	17.70 (4)	23.80 (3)	37.43 (4)	42.33 (4)	53.18 (4)
	SDX [MPa]	0.47	2.62	0.87	1.74	1.94
	CV [%]	2.66	11.00	2.32	4.11	3.65
Penetration Test Resistance by WPT System	E [mm]	39.14 (6)	43.59 (6)	51.52 (6)	52.97 (6)	54.70 (5)
	SDX [mm]	3.34	1.54	1.65	1.64	2.34
	CV [%]	8.53	3.53	3.20	3.10	4.27
Penetration Test Resistance by the Alternative Firing Apparatus	E [mm]	16.40 (17)	19.82 (13)	24.53 (12)	25.08 (13)	26.92 (17)
	SDX [mm]	1.40	0.85	1.65	0.80	1.13
	CV [%]	8.54	4.29	6.73	3.19	4.20

The results presented on the above Table 2 were analyzed and plotted individually for both apparatus used, as shown in Fig. 1 and Fig. 2.

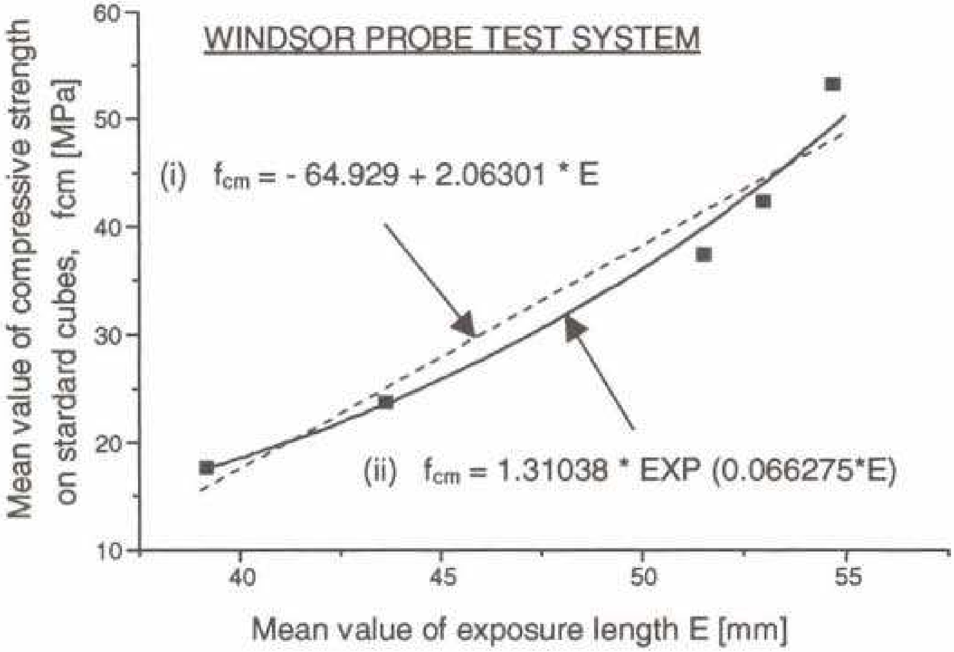

Fig. 1- Results obtained from the Windsor Probe Test for normal strength concrete.

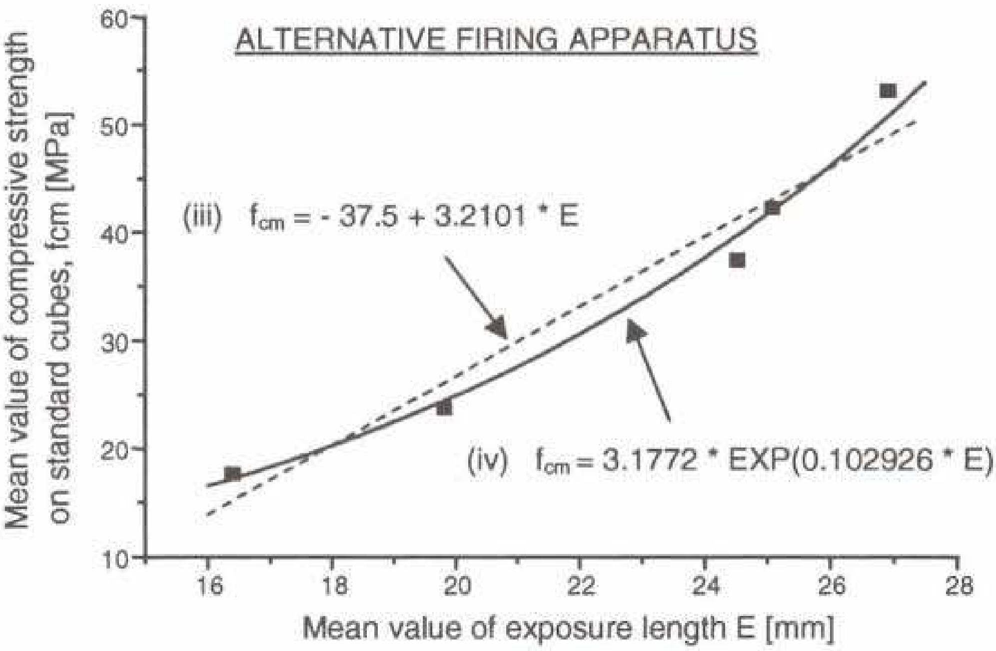

Fig. 2 - Results obtained from the Alternative Firing Apparatus for normal strength concrete.

Studies on High Strength Concrete

The experimental study on high strength concrete lead to the folowing results presented on Table 3.

Table 3 - Results obtained for high strength concrete.
(Number in parenthesis shows the number of measurements).
E is the mean value of the exposure length.
f_{cm} is the mean value of compressive strength on standard cubes.

		f	g	h	i	j
Cubes of 150 mm cured in water at 20 ºC, tested wet, at 28 days	f_{cm} [MPa]	49.12 (3)	58.27 (3)	67.77 (3)	78.35 (3)	81.94 (3)
	SDX [MPa]	1.02	0.82	1.56	2.17	1.12
	CV [%]	2.08	1.41	2.30	2.77	1.37
Penetration Test Resistance by the Alternative Firing Apparatus	E [mm]	16.32 (10)	17.48 (9)	18.49 (10)	20.31 (7)	20.00 (8)
	SDX [mm]	0.92	0.97	1.64	0.56	0.87
	CV [%]	5.64	5.50	8.87	2.76	4.35

The obtained results (Table 3) were analyzed and plotted as shown in Fig. 3.

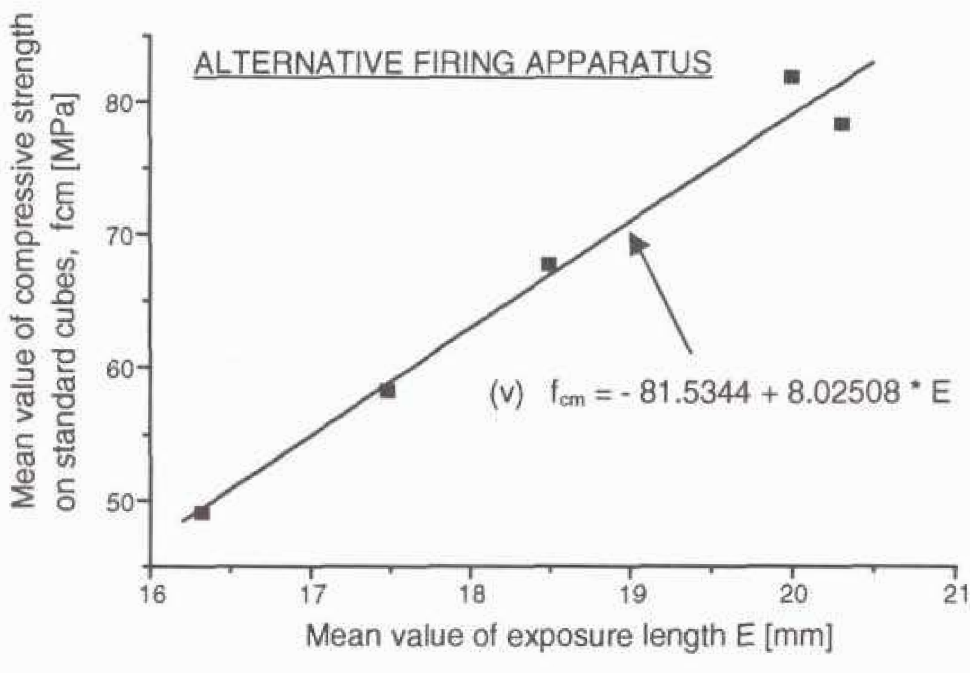

Fig. 3 - Results obtained from the Alternative Firing Apparatus for high strength Concrete.

CONCLUSIONS

The results obtained for the range of normal strength concrete, Fig. 1 and Fig. 2, showed that the Alternative Firing Apparatus could be a suitable mean for the assessment of "in-situ" strength, and gives a good agreement when compared to Windsor Probe Test System (5). When testing high strength concrete (Fig. 3), the Alternative Firing Apparatus appears to be particularly useful since the results obtained so far are very consistent.

Penetration resistance tests applied to high strength concrete, using the Alternative Firing Apparatus has shown a linear correlation, Fig. 3, which probably can be impute to more closeness between cement paste and aggregate strength.

It is clear and mentioned by different authors (6, 7) that, as most other non-destructive tests, aggregate characteristics and other factors may have a considerable influence on the results and, therefore, the validity of calibration tables has to be carefully analyzed for each situation. So, the results presented on Fig. 1, Fig. 2 and Fig. 3 are valid for the established conditions of this investigation.

The main physical limitation of penetration resistance tests is the surface damage and the danger of splitting of members, which limits the zones of testing. However, it was found that the Alternative Firing Apparatus causes less damage than WPT System. Consequently, minor distances between probes are possible.

Other aspect that cannot be ignored is the higher cost of WPT System equipment and probes in Europe when compared with the Alternative Firing Apparatus.

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NOTATION

E - is the mean value of the exposure length.
f_{cm} - is the mean value of compressive strength on standard cubes.
SDX - is the Standard deviation.
CV - is the Coefficient of variation.
R.H. - is the relative humidity.

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This book contains the proceedings from the First Engineering Foundation Conference on High Strength Concrete, held in July 1997 in Kona, Hawaii. This conference represents a milestone in bringing together experts known for their contributions to High Strength Concrete, from material aspects to applications in the field.

Rapid transfer of High Strength Concrete to the marketplace in the 1980s and the simultaneous lack of research data led to severe code limitations imposed on the use of this material. This followed in the late 1980s and early 1990s with intense activity to resolve design issues related to High Strength Concrete and the replacement of code limitations with more rational provisions. The papers in this book reflect this historical trend in the development of High Strength Concrete and its utilization in construction.

With the increased use of High Strength Concrete, owners and designers also became more interested in the long term performance of certain types of High Strength Concrete, and the term High Performance Concrete began to appear in the literature. The papers in this volume focus specifically on High Strength Concrete as opposed to High Performance Concrete, and bring together the most current thinking and state-of-the-art information on this topic.

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