CONCRETE PRODUCTION PROCESS CONTROL

Matti Alasalmi
Tecnical Research Centre of Finland
Concrete and Silicate Laboratory
M.Sc. (Eng.) Research Scientist

The exact control of the rheological properties of fresh concrete and knowledge of early age strength of concrete is extremely important for mechanization and automation of the manufacturing processes of the concrete industry. In the research project automatic early age strength determination using ultrasonic pulse velocity measurement was studied. A real time consistency measurement using pressure transducer installed in a pan mixer was tested preliminarily. A microwave moisture analyzer was tested for measuring the water content of aggregate.

Keywords: Fresh concrete, process control, early age strength, consistency, moisture measurement

1 INTRODUCTION

Measuring techniques form the bottle-neck in developing a process control system. This is true also in concrete industry.

The increased use of new admixtures and new constituents of concrete such as fuel ash and blast furnace slag has made predicting the early age strength and controling the rheological properties more difficult. Usually the stripping strength is secured by an extra amount of cement. This can be avoided by developing a control system based on non destructive strength determination. The proportioning is controlled by determining the strength of concrete on the basis of ultrasonic pulse velocity (abbreviation UPV) measurement at the age of 10...24 h.

Variations in the moisture of aggregate make the water control more difficult. For this reason the workability of fresh concrete is not always under control.

2 THE OBJECTIVES OF THE RESEARCH

The objective of the research project was to develop the fresh concrete production process in two areas:

I early age strength determination using ultrasonic pulse velocity measurement and

II better workability control by
- measuring the moisture of aggregate by microwave

method,
- replacing the Proctor-test by the UPV-method and
- real time determination of the consistency of fresh concrete by measuring the pressure in mixer.

Literature was studied and numerous experiments were performed to correlate ultrasonic pulse velocity to compressive strength values especially at the age of 15 - 48 h. Possibilities of replacing the Proctor-test by the UPV-method were clarified according to literature and laboratory tests.

3 BACKGROUND TO THE EXPERIMENTS

3.1 The early age strength determination using ultrasonic pulse velocity measurement

It has been stated, that two concretes with the same compressive strength may have dynamic elastic modules differing as much as ± 35 % from each other as the dynamic elastic modules of aggregates varies /1/. Also the maximum aggregate size and the amount of entrained air have an affect on the correlation between ultrasonic pulse velocity and compressive strength. The fact that so many factors affect the UPV has made the method unsatisfactory in the cases of unknown composition of concrete. In ready-mix concrete plants and precast concrete factories the composition is known. Thus the UPV method can be applied much more succesfully.

Moreover, the UPV-method has been found especially suitable for determining the early age strength. The method has been proposed even for determining the final set value (Proctor test). According to Casson & Domone UPV is 2 km/s at the age of final set /2/.

3.2 Workability control

Workability is a subjective term indicating properties of fresh conctrete connected to a specific manufacturing method. The rheological properties of fresh concrete are affected by many factors. One of the most important ones is the moisture variation in the aggregate.

A direct measurement of the rheological properties of fresh concrete in the manufacturing process (mixing) is the goal of a process engineer developing a control system. Many methods have been proposed but none of them has so far proven satisfactory.

4 EXPERIMENTS

4.1 Determination of the early age strength using the ultrasonic method

4.1.1 Test arrangement

The UPV-test arrangement consists of an ultrasonic tester (Pundit) and an analog output unit, a data logger and a microcomputer (Fig. 1).

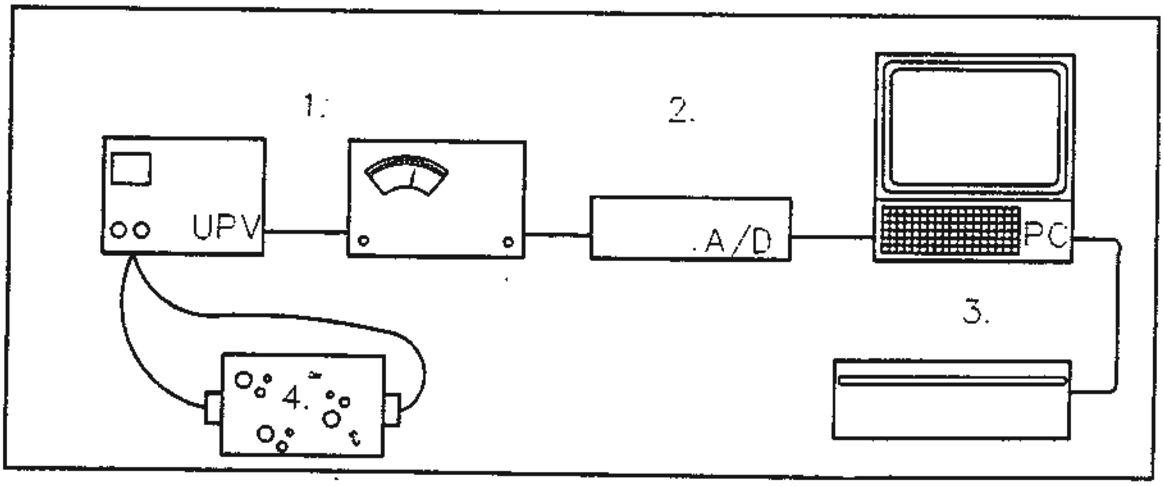

Fig. 1. Test arrangement
1. Ultrasonic tester and an analog output unit.
2. Data logger.
3. Microcomputer + printer.
4. Test specimen.

4.1.2 Fundamental UPV-tests

The tests were carried out using the mixes presented in table 1. Using each mix as raw material 150*150*150 cm^3 standard cubes were manufactured to be tested with the UPV-method at the ages (three cubes/age) presented in table 2.

Table 1. Concrete mixes in tests 0 - 8.

Test n:o	Concrete quality * (MPa)	Temperature °C	Percentage cement replaced by p.f.a.
0	30	20	0
1	20	20	0
2	20	60	0
3	20	20	40
4	20	60	30
5	40	20	0
6	40	60	0
7	40	20	20
8	40	60	20

*) compressive strength

Table 2. Testing ages.

Test n:o	Testing age							
0	21 h	24 h	29 h	2 d	3 d	7 d	28 d	
1	18 h	24 h	30 h	2 d	3 d	7 d	28 d	
2	18 h	24 h	28 h	2 d	3 d	7 d	28 d	
3	12 h	24 h	30 h	2 d	3 d	7 d	28 d	
4	12 h	22 h	24 h	29 d	2 d	3 d	7 d	28 d
5	18 h	24 h	28 h	2 d	3 d	7 d	28 d	
6	10 h	24 h	30 h	2 d	54 h	3 d	7 d	28 d
7	12 h	24 h	30 h	2 d	54 h	3 d	7 d	28 d
8	12 h	22 h	24 h	30 h	2 d	3 d	7 d	28 d

The nine measurement points on the surface of each cube are shown in fig. 2. An arithmetic mean of the nine measurements was calculated. The mean value of the three cubes/age represents the ultrasonic pulse velocity at each age in the following presentation.

Immediately after the UPV-measurement of each cube the compressive strength R was determined by crushing the cube.

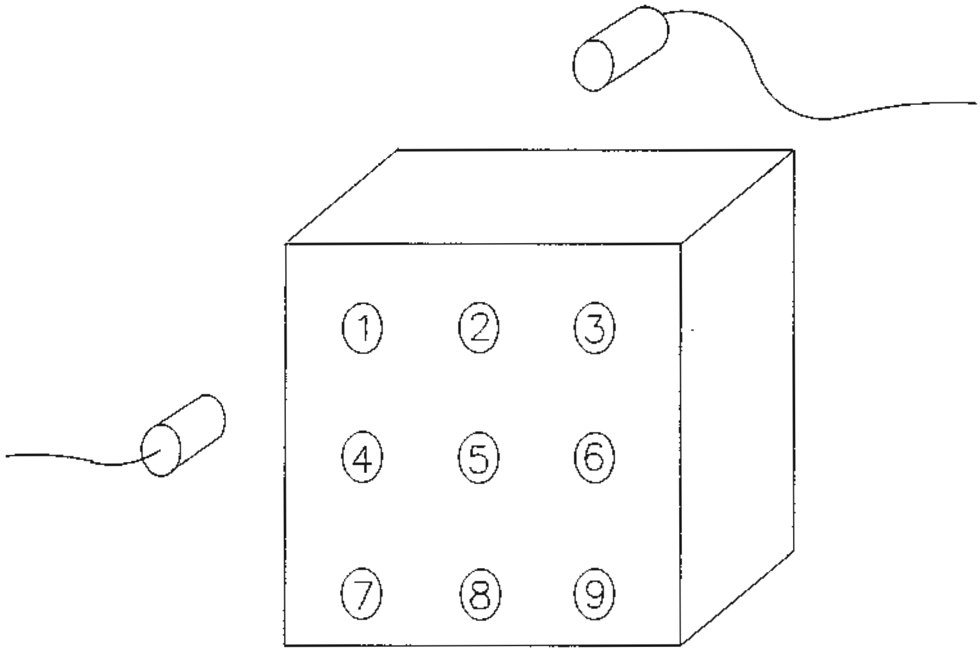

Fig. 2. The nine measurement points on the cube surface.

In addition to the standard cube samples, so-called plastic bag samples were manufactured for continuous UPV-measurement. The concrete was compacted with a poker vibrator into a plastic bag to form a cylindrical sample about 10 cm in diameter. The UPV-sensors were assembled on the opposite sides of the cylinder immediately after compaction.

4.1.3 Test results

The following symbols will be used in the forthcoming presentation:

R is	compressive strength determined by compressing a cube (MPa),
V_k	ultrasonic pulse velocity measured in a cube (km/s),
V_p	ultrasonic pulse velocity measured in a plastic bag sample (km/s),
R_k	compressive strength of a cube calculated using formula (1) (MPa) and
R_p	compressive strength of a plastic bag sample calculated using formula (1), (MPa).

Using FID-curve fitting program function (1) was fitted to compressive strength development with age /3/. FID applies the least squares method /4/.

$$R_k = \exp\left(\frac{A}{1 - BV_k}\right) - C \qquad (1)$$

where R_k is the calculated compressives strength (MPa), V_k the ultrasonic pulse velocity (km/s) and A, B and C are parameters

The curve was fitted to the compressive strength R and velocity V_k values using the following parameter combinations:

1) A = constant = 1.12, B ja C calculated
2) B = constant = 0.15, A ja C calculated
3) C = constant = 3.00, A ja B calculated
4) A = constant = 1.12 and B = constant = 0.15, C calculated
5) A = constant = 1.12 and C = constant = 3.00, B calculated
6) B = constant = 0.15 and C = constant = 3.00, A calculated

The best correlation between the compressive strength R and the calculated compressive strength R_k was obtained when C was constant (C = 3.0). The values of parameters A and B for each mix are presented in table 3.

Table 3. Values of parameters A and B for tests 0 - 8 when C = 3.0.

Test n:o	A	B	C constant
0	1.1677870	.14873885	3.0
1	.90253794	.16098636	3.0
2	1.1066958	.14937146	3.0
3	.92438102	.15725081	3.0
4	.83865857	.16844951	3.0
5	1.2513810	.14632821	3.0
6	1.3733238	.14015026	3.0
7	1.1150948	.15433961	3.0
8	1.2494686	.14795268	3.0

In fig. 3 the compressive strength R and calculated compressive strength R_k developments with age are presented for test n:o 4. None of the parameters A, B and C was constant in this curve fitting.

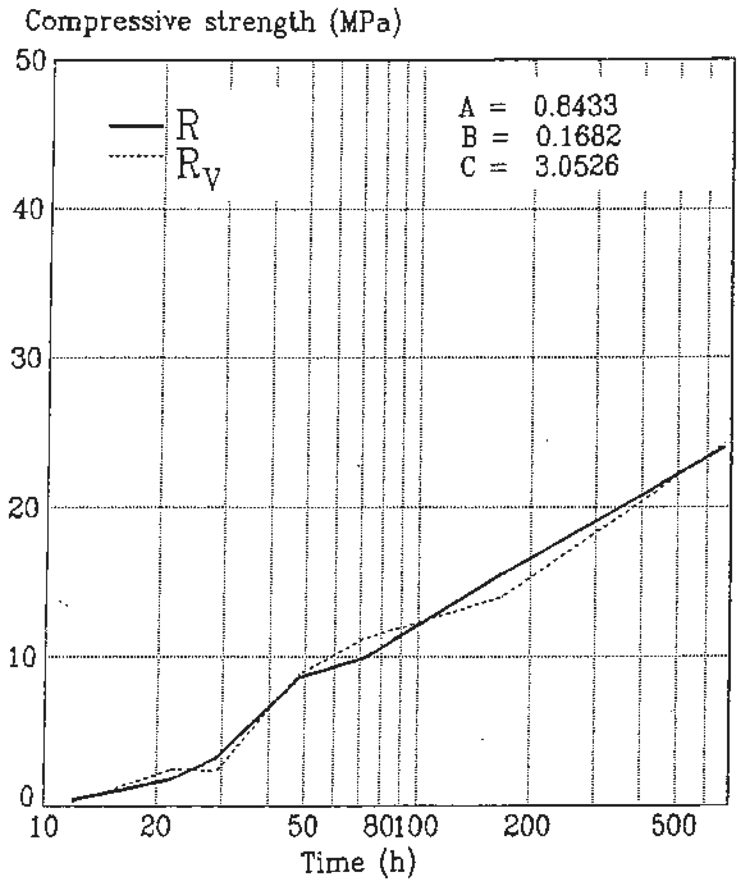

Fig. 3. Compressive strength R and calculated compressive strength R_k developments with age in test 4.

To get an idea of the accuracy of the UPV-method in repetitive tests parallel tests 10 -19 were performed. In these tests also the possibility of estimating the pulverized fuel ash content of cement was clarified. In parallel tests 10, 11, 12 and 13 no p.f.a. was added. In parallel tests 14, 15 and 16 five percent and in tests 17, 18 and 19 respectively ten percent of the cement was replaced by p.f.a. The temperature in tests 10 - 19 was 20°C.

In each test (10 - 19) three test cubes (I, II and III) were tested to determine R and calculate R_k at the age of one, two and 28 days. Two or three plastic bag samples were used simultaneously for continuous UPV-measurement and corresponding compressive strength values R_p were calculated. The results are presented in table 4.

The correlation between UPV and compressive strength was clarified by analysing the test results using SPSS-statistical program. The correlation coefficient between R and R_k was found to be 0.99.

Table 4. The accuracy of the UPV-method in repetitive tests and the sensitivity to p.f.a. - substitution of cement. R is compressive strength. R_k is the calculated compressive strength (cubes) and R_p is the calculated compressive strength (plastic bag samples). Values for parametres are: A = 1.1, B = 0.15 and C = 3.0.

		Cubes						Plastic bag samples		
Test n:o	Cube n:o	1 d		2 d		28 d		Sample n:o	1 d	2 d
		R	R_k	R	R_k	R	R_k		R_p	R_p
10	I	9,1	9,1	17,6	18,9	37,6	36,0	I	8,1	10,0
	II	9,6	9,1	17,3	16,3	38,9	37,6	II	8,5	10,5
	III	9,4	9,6	17,7	19,3	37,8	36,5			
	mean	9,4	9,3	17,5	18,2	38,1	36,7		8,3	10,2
11	I	6,3	7,9	15,4	17,7	37,2	29,2	I	10,0	13,3
	II	6,2	7,3	15,2	17,2	34,5	33,7	II	10,2	13,9
	III	6,5	7,1	16,2	16,2	37,4	36,5			
	mean	6,3	7,5	15,6	17,0	36,4	33,1		10,1	13,6
12	I	6,0	7,7	15,8	16,6	40,4	33,2	I	12,2	16,1
	II	5,9	7,4	16,0	15,1	40,3	34,8	II	10,3	
	III	5,5	8,0	15,7	14,9	39,6	36,5			
	mean	5,8	7,7	15,8	15,7	40,1	34,8		11,2	16,1
13	I	8,2	8,8	15,6	15,8	35,4	37,2	I	10,1	13,1
	II	7,8	9,5	15,4	15,2	33,8	33,2	II	10,0	12,8
	III	8,3	9,6	15,6	17,2	36,5	36,5	III	8,8	11,4
	mean	8,1	9,3	15,5	16,0	35,2	34,7		9,7	12,4
14	I	6,0	7,1	14,9	16,5	41,2	33,3	I	6,6	
	II	5,6	7,2	14,9	19,0	40,0	33,8	II	9,8	10,9
	III	6,0	7,5	14,6	19,5	39,2	34,6	III	8,5	9,2
	mean	5,9	7,3	14,8	18,3	40,1	33,7		8,3	10,1
15	I	4,6	5,9	13,7	15,9	36,0	34,7	I	9,2	11,5*
	II	5,3	5,8	13,4	15,0	36,5	33,4	II	7,8	9,9*
	III	5,7	6,5	13,4	15,7	37,4	34,3			
	mean	5,2	6,1	13,5	15,5	36,6	34,1		8,5	10,7*
16	I	5,3	7,1	13,5	14,7	37,3	28,2	I	9,1**	12,5***
	II	4,9	6,6	13,2	14,4	33,3	29,4	II	8,7**	12,1***
	III	5,2	6,7	12,8	14,9	35,6	30,3			
	mean	5,1	6,8	13,2	14,6	35,4	29,3		8,9**	12,3***
17	I	3,2	5,0	11,1	10,6	29,9	31,8	I	9,6**	13,3
	II	3,5	5,3	11,3	11,1	27,3	31,1	II	7,7**	10,6
	III	3,4	5,5	11,5	10,9	28,2	26,3	III	8,4**	11,1
	mean	3,4	5,3	11,3	10,9	28,5	29,7		8,5**	11,7
18	I	5,4	6,3	11,7	13,4	30,9	29,5	I	9,2	12,3
	II	5,2	5,9	11,6	13,5	30,7	30,5	II	6,4	8,6
	III	5,2	5,9	11,9	12,7	32,0	32,5	III	9,3	12,9
	mean	5,3	6,0	11,7	13,2	31,2	30,8		8,3	11,3
19	I	6,0	7,2	12,3	13,6	33,6	32,0	I	7,9	10,6
	II	5,8	7,0	12,6	12,4	32,9	32,7	II	10,2	13,7
	III	5,8	6,5	12,4	12,4	33,3	30,3	III	10,9	15,4
	mean	5,9	6,9	12,4	12,8	33,3	31,7		9,7	13,2

* 47 h ** 25 h *** 49 h

4.2 Workability control

The control of workability was developed in three ways:

- using the UPV-method for final set determination (replacing Proctor-test),
- measuring moisture of aggregate by the microwave absorption method and
- real-time measurement of the consistency of fresh concrete in the mixer.

4.2.1 Final set determination by UPV-method

Proctor-tests were performed simultaneously with tests 0 - 8 during the first ten hours with half an hour intervals. The values of UPV at the age of final set in tests 0 - 8 are presented in table 5.

Table 5. Values for UPV at the age of final set. Samples a and b are samples taken from same test mix.

Test n:o	Final set (h.min)	UPV (km/s)
3	8.50	2.4
4	5.30	1.2
7	5.00	1.6
8	5.30	1.8
13a	6.05	1.3
13b	6.05	1.6
14a	7.05	1.5
14b	7.05	1.4
15a	6.40	1.6
15b	6.40	1.8
17a	7.20	1.0
17b	7.20	1.2
18a	6.55	1.6
18b	6.55	1.7

4.2.2 Moisture determination of aggregate by microwave method

Based on the literature study the microwave absorption method was chosen for the tests /5/.

Five 0 - 4 mm sand samples containing 0, 1, 2, 3 and 4 % water were prepared. A 40*120*1200 mm^3 material bed was transported continuosly through Finnmoist-moisture analyser. Radiation readings are presented in fig. 4.

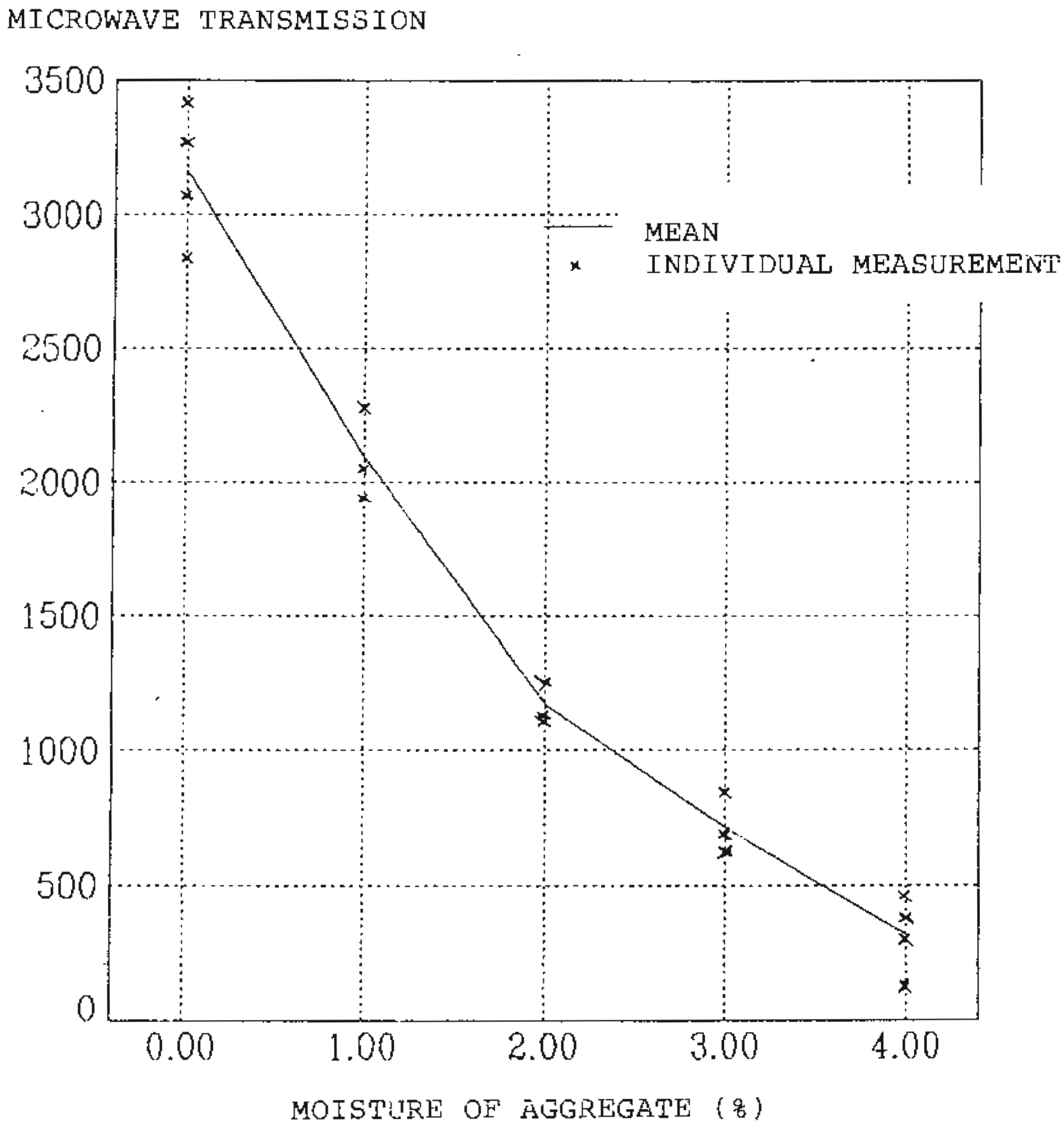

Fig. 4. Relationship between microwave radiation transmission and moisture of aggregate.

4.2.3 Consistency measurement of fresh concrete

A soil pressure transducer was installed into the fresh concrete flow in an Eirich-pan mixer (Fig 5.). In this type of mixer the pan rotates and thus it was easy to install the transducer stationary to the surroundings.

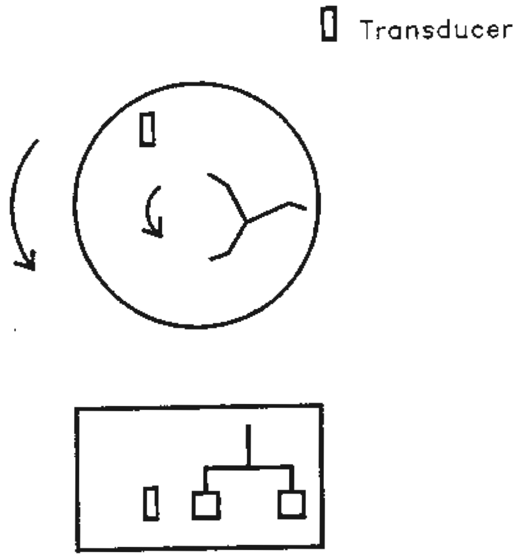

Fig 5. Soil pressure transducer installed into the fresh concrete flow in an Eirich-pan mixer.

The pressure during mixing was measured. The relationship between pressure and water/cement ratio together with the corresponding Vebe- consistometer test results are presented in fig. 6.

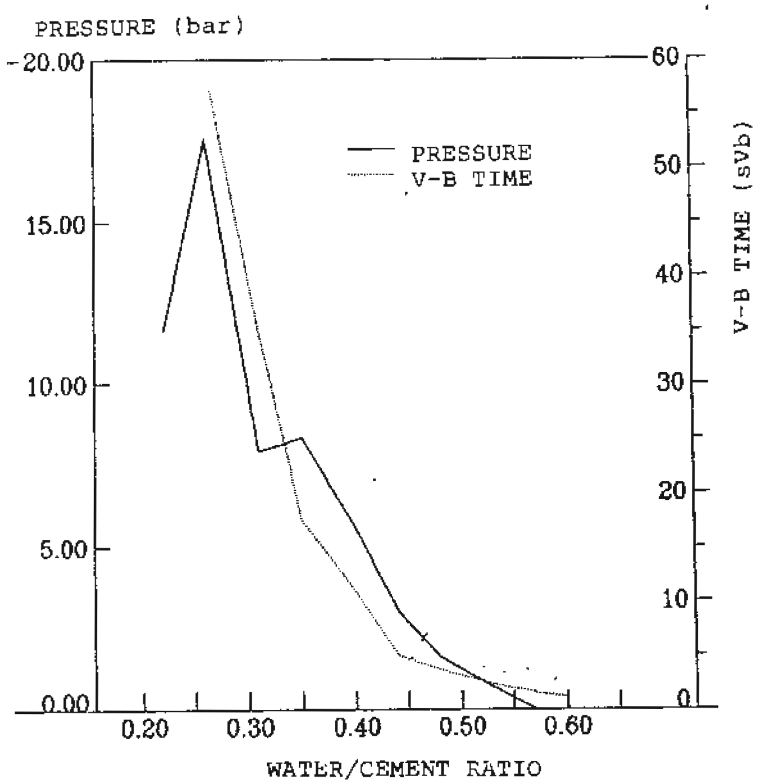

Fig. 6. Pressure and V-B-time for concretes with different water/cement ratios.

5 DISCUSSION AND CONCLUSIONS

The contact between UPV-tester transducers and concrete is critical. Imperfect contact can cause remarkable errors. Vaseline, wallpaper paste and snug-plastics have been tested as contact material. None of them gives a perfect contact between transducer and concrete.

5.1 Correlation between UPV and compressive strength

The individual pulse velocities measured in test cubes varied typically ± 10 % at the age of one day in each test. The variation diminishes clearly during the next two days and is about 1 - 2 % at the age of 28 d. It is impossible to say whether this is due to the applied method or the real strength variation at this early age of cement hydration. The compressive strength values R obtained by pressing the cubes varied typically ± 5 %, but variations of as much as ten percent were observed.

In fitting the results in formula (1) rather good correlation between R and R_k was obtained; standard deviation being 1.42 - 2.59 MPa. The minimum standard deviation (1.42 MPa) was obtained when parameter C was 3.0.

The results in table 4 show that compressive strength values R in parallel test e.g. 10 - 13 vary considerably. So do also the calculated values of R_k. The parallel tests (table 4) show that UPV-measurement is reproducable i.e. it is accurate in repetitive tests.

5.2 Plastic bag samples

The two columns on the right side of table 4 show that the compressive strength values calculated using UPV:s measured in plastic bag samples R_p (continuous mesurement) have considerably larger deviations than corresponding ones measured in cubes (R_k). The most probable reason for this is the poorer contact of the transducer through the plastic film to a cylinder than the one formed with vaseline to a cube.

5.3 Workability control

The UPV-method does not seem to be suitable for determining the final set of concrete. In many tests the final set was reached before the first readings could be obtained out of the plastic bag samples. Also the UPV-values at final set vary considerably; thus this method cannot be recommended for determining the final set. The path length should be considerably shorter than 10 cm to get readings at this early stage of hardening. A shorter path presupposes sieving the coarser aggregate out of the sample.

In the microwave measurements a good correlation between transmissed radiation and moisture of aggregate was obtained. The method is fast (one measurement/sec) and almost continuous measurement is possible. The bulk density of the material has an effect on the results. This was not taken into account in the tests. A gamma-ray density compensation will be made in a forthcoming research project.

In the preliminary tests using pressure transducer installed in a pan mixer promising results were obtained. The correlation between the pressure caused by fresh concrete to a soil pressure transducer during mixing and the Vebe-consistometer values was evident.

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