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Effect of Concrete Mixing Temperatures on Performance of Superplasticizers	Final
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Supplementary Notes

Abstract

Johnston Engineering was contracted in 1992 to undertake a testing programme whereby three admixture systems were to be evaluated at four concrete temperatures: 13, 18, 23 and 28°C. The primary objective was to determine the effect of concrete mixing temperature on changes in slump and air content with time.

Controlling temperature variations in the test batches proved difficult so the prograrnme was modified to include 4 admixture systems at three temperatures: 13, 23 and 28°C.

It was concluded that the performance of the admixture system as a whole must be considered when using superplasticizers in air-entrained concrete. For optimum admixture utilization, the temperature of the concrete during and after mixing should be maintained in the range of 22±2°C.

Key Words	Distribution
Concrete Temperature Admixture Superplasticizer	Unlimited
	Project Coordinator Paul Carter, P.Eng.

ALBERTA TRANSPORTATION AND UTILITIES

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- SPECIALIST IN CEMENT, ASPHALT, CONCRETE -

EFFECT OF CONCRETE MIXING TEMPERATURE ON PERFORMANCE OF SUPERPLASTICIZERS

The frame of reference for this testing program was identified in a letter from Paul D. Carter of Bridge Branch dated February 21, 1992. Three admixture systems were to be evaluated at four concrete temperatures of 13, 18, 23 and 28°C. The primary objective was to determine the effect of concrete mixing temperature on changes in slump and air content with time.

Following attempts to fulfil the mandate as specified, it became clear that achieving a specific mixture temperature initially is quite difficult for small (0.08 m^3) batches in a pan type mixer with the drum initially at ambient temperature. The tendency of the steel mixing drum to extract or inject heat also became apparent when successive batches were prepared, the first with a clean dry mixing drum at ambient (22°C) temperature and the second with a washed drum cooled by mains wash water. Maintaining the initial mixture temperature constant over a 60-90 minute period was also found impossible for small batches without special facilities to cover and insulate the mixer.

As a consequence of the inability to precisely control mixture temperature, the number of target temperatures was reduced from four to three, coded as 13, 23 and 28 to imply initial concrete mixture temperatures immediately after mixing of 13, 23 and 28°C. In reality, the initial mixture temperatures achieved were 14-15.5°C, 21-24°C, and 27-30°C, and subsequently they increased or decreased to reach thermal equilibrium with the mixing drum and the 22°C ambient atmosphere.

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In view of the reduced number of temperature variables, the number of admixture systems evaluated was increased from three to four in accordance with the following table.

SUPERPLASTICIZER	AIR-ENTRAINING	CODE	SUPPLIER
Daracem-100	Daravair	G	Grace
Sikament 10ESL	Fro V5	S	Sika
Rbeobuild 1000	Microair	MR	Master Builders
Resine GT	Pavair	CR	Conchern

Mixture Proportions and Concrete Temperature

The proportions chosen for the test mixture in this program were the same as in the SP2 series of a recent more extensive investigation of the effects of superplasticizers on concrete performance. The test mixture has a cement content of 370 kg/m^3 with a water-cement ratio (w/c) of 0.40 using 14 mm coarse aggregate. It is similar to a reference concrete used in the more extensive investigation with the same aggregate and cement content at a w/c of 0.50 that meets the specified 30 MPa strength for Alberta Transportation Class D without using a superplasticizer. The difference is that the superplasticizer has been used to reduce water content and w/c by 20%.

The aggregates and cement were preconditioned in an oven at 30-35°C (oven capacity was quite limited) or by overnight cold storage at 0-10°C. The dry materials were batched into the mixer drum and allowed to cool or warm to within a few degrees of the target 13 and 28°C temperatures. Water conditioned to approximately the target temperature was added with airentraining admixture (AEA) and mixing continued for 3 minutes. Superplasticizer (SP) was added during the fourth minute of mixing in the amount needed to produce a slump of about 150 mm. After a I minute rest period to allow for any tendency to false set, mixing was continued for a further minute and additional SP was added if necessary to achieve the desired slump. Starting immediately thereafter, concrete temperature, slump, mid air content were repeatedly monitored at intervals over the following 80-90 minutes.

Actual Concrete Temperatures

The initial concrete temperatures and the change in temperature with time over a 60-minute period following the initial measurement are shown in Table 1. Generally, the initial temperature was within ±°C of the target 13, 23 or 28°C temperatures. The change over 60 minutes amounts to an increase of about 3°C for the below-ambient temperature condition and a decrease of about 6°C for the above-ambient temperature condition. Clearly, the effect of temperature on concrete behavior has been investigated for three temperature ranges rather than for three precisely controlled constant temperatures because of the limitations associated with batch size, conditioning facilities, and mixing equipment.

Slump Retention

The raw data obtained from the primary data sheets is depicted graphically to show change of slump with time for the four admixture systems (Figure 1). However, because initial slump can never be the same for all mixtures, slump retention at specific times after the initial slump measurement is more useful for comparing the performance of different admixture systems at different temperatures. This is an extension of the concept introduced in CAN3 A266.6-M85. The standard specifies 50% retention of the initial slump after 20 minutes during which the mixture remains undisturbed prior to remixing (for an unspecified time) and the final slump test.

In this program the concrete was remixed for approximately 30 seconds prior to each slump test, and the time interval between successive tests was about 15 minutes. Such remixing simulates to some extent the intermittent mixing or agitation that occurs on the job. Under these circumstances, all four admixture systems exceed the 20-minute slump retention requirement of 50% at all temperatures, but the G and S admixture systems do so by a greater margin than the MR and CR systems (Figure 2).

For the SP's of today, which are promoted as superior to those prevalent in the early 1980's when the 50% requirement was first considered, a 60-minute slump retention is a more discriminating measure for comparison (Figure 2). Generally, the G and S systems are superior and could meet a 60-minute slump retention requirement of 25% while the MR and CR systems could not generally do so.

Interestingly, the effect of mixture temperature over the ranges studied is somewhat unexpected but fairly consistent. For all four admixture systems, 60-minute slump retention is highest for the intermediate (ambient) temperature range (Figure 2). It is on average 9% less for the higher temperature range which is not surprising, but it is also slightly less, about 3% on average, for the lower temperature range (Table 2). Apparently, cooling the concrete below 20°C does not improve slump retention with these admixture systems.

When SP doses and the associated costs are considered, the lowest dose required to achieve the target slump of 150 mm is in most cases associated with the intermediate temperature range (Figure 2, right). Generally, the doses are higher for the low temperature range and the same or slightly higher for the high temperature range. Accordingly, the most economical temperature range for use of these SP's is around 22 ± 2°C, and cooling the concrete is not advantageous either in terms of cost or performance.

Air Retention

Again, the raw data is depicted graphically to show the comparative rates of change of air content with time for the four admixture systems (Figure 3). Regardless of differences in the initial air content, the rates of air loss (average slope of the relationships) are very different with respect to admixture system and very similar with respect to concrete temperature for the same admixture system. The clear implication is that there are major differences between admixture systems, attributable primarily to the AEA's, and that concrete temperature is relatively unimportant.

Because of differences in the initial values of air content between mixtures, air retention at specific times after the initial measurement is a useful basis of comparison (Figure 4). On this basis, the 60-minute retention is again more discriminating than the 20-minute retention, and shows the superiority of the S and MR systems and the inferiority of the G system. Generally, the S, MR and CR systems could meet a 60-minute air retention requirement of 70%, while the G system could not.

The effect of mixture temperature on air retention is really quite insignificant (Table 3), so it is clear that the choice of admixture system is much more important than concrete temperature in meeting any specified minimum air content requirement over the duration of the placement period.

When AEA doses are considered in relative terms (Table 3), concrete temperature has some effect (Figure 4, right). Doses tend to be higher for the higher temperature range and are about the same for the low and intermediate temperature ranges. The increase in AEA requirement at higher temperatures is expected, but has only very minor cost implications, unlike an increase in SP requirement where the amounts are higher and the products often more expensive.

Strength Development

Mixing temperature within the ranges evaluated appears to have a negligible effect on 28-day strength, as evidenced by the averages for all four admixture systems of 51.5, 50.8, and 50.0 MPa for the low, intermediate and high temperature ranges respectively (Table 4). Differences by admixture system can amount to more than differences due mixing temperature. In this case the G system produces the highest average strength at 55.3 MPa, compared with averages of 50.8, 48.7 and 48.2 MPa for the CR, S and MR systems respectively (Table 4).

Conclusions

1. The performance of the admixture system as a whole must be considered when using superplasticizers in air-entrained concrete. What is optimal from the point of view of slump retention may not be optimal in terms of air retention, which is much more important for long-term durability than slump retention. Admixture system performance could be controlled by specifying slump and air retention requirements for trial mixtures in specifications. Slump and air content during job placements could be controlled by specifying appropriate minima for both that would govern how long placement could continue regardless of ambient conditions.

2. From the point of view of optimal admixture utilization, the temperature of the concrete during and after mixing should be maintained in the intermediate range 22±2°C, since there are apparently no advantages from the point of view of slump retention, air retention, or cost of admixtures in specifying a substantially lower temperature. However, it is acknowledged that warm weather placement conditions may favor more stringent limits on concrete temperature such as the 20°C maximum currently specified for bridge deck placement.

3. The temperature of the concrete during mixing has very little effect on 28-day compressive strength for the three temperature conditions evaluated.

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President

TABLE 1. Concrete Temperature Changes with Time

Mixture Code	Temperature °C		Mixture Code	Temperature °C		Mixture Code	Temperature °C	
	Initial	60 min.[a]		Initial	60 min.[a]		Initial	60 min.[a]
G13	14.0	17.0	G23	21.0	18.5	G28	28.0	22.0
S13	15.0	18.0	S23	21.5	20.0	S28	30.0	23.0
MR13	15.5	18.0	MR23	23.0	21.0	MR28	28.5	22.5
CRI3	14.0	17.5	MR28	24.0	21.5	CR28	27.0	22.5

[a] - 60 minutes after initial temperature measurement

TABLE 2. Slump Retention and SP Doses

Mixture Code	Initial Slump - mm	Slum Retention		SP Dose/100 kg of Cement	
		20 min.	60 min.	ml	gm solids[a]
G13	125	74%	32%	1199	576
G23	155	71%	35%	980	470
G28	157	66%	24%	1013	486
S13	158	69%	35%	997	235
S23	153	64%	39%	794	187
S28	150	62%	28%	912	215
MR13	138	52%	25%	1149	552
MR23	153	67%	27%	895	430
MR28	157	59%	18%	946	454
CRI3	117	59%	17%	1250	431
CR23	151	54%	21%	1014	350
CR28	138	53%	14%	878	303

[a] - Based on values of specific gravity and solids concentration in solution supplied by manufacturer.

TABLE 3. Air Retention and Relative AEA Doses

Mixture Code	Initial Air %	Air Retention		AEA Dos/100 kg cem.	
		20 min.	60 min.	ml	Relative[a]
G13	11.7	83%	60%	101	8.63 (+8.6%)
G23	10.2	83%	66%	81	7.95
G28	9.7	82%	61%	101	10.4 (+30.9%)
S13	6.3	100%	92%	709	112.5 (+5.8%)
S23	6.1	98%	90%	650	106.3
S28	5.5	96%	91%	845	153.6 (+44.5%)
MR13	6.2	97%	85%	95	15.3 (+4.8%)
MR23	6.5	95%	86%	95	14.6
MR28	5.2	94%	87%	95	18.2 (+24.7%)
CRI3	7.5	88%	73%	30	4.05 (-7.5%)
CR23	6.8	99%	76%	24	4.38
CR28	8.0	96%	75%	37	4.64 (+5.9%)

[a] - Dose divided by initial air content with percent difference from value at 23°C in parenthesis.

TABLE 4. 28-Day Compressive Strengths

Mixture Code	Air[a] %	Strength Mpa	SP Dose gm per 100 kg cem.[b]
G13	6.2	56.8	576
G23	6.4	53.4	470
G28	5.6	55.6	486
S13	5.6	48.4	235
S23	5.6	48.6	187
S28	4.9	49.2	215
MR13	5.3	47.0	552
MR23	5.5	50.0	430
MR28	4.5	47.6	454
CRI3	5.4	53.7	431
CR23	5.6	51.3	350
CR28	5.9	47.4	303

[a] - Final value at time of molding cylinders
[b] - Based on values of specific gravity and solids concentration

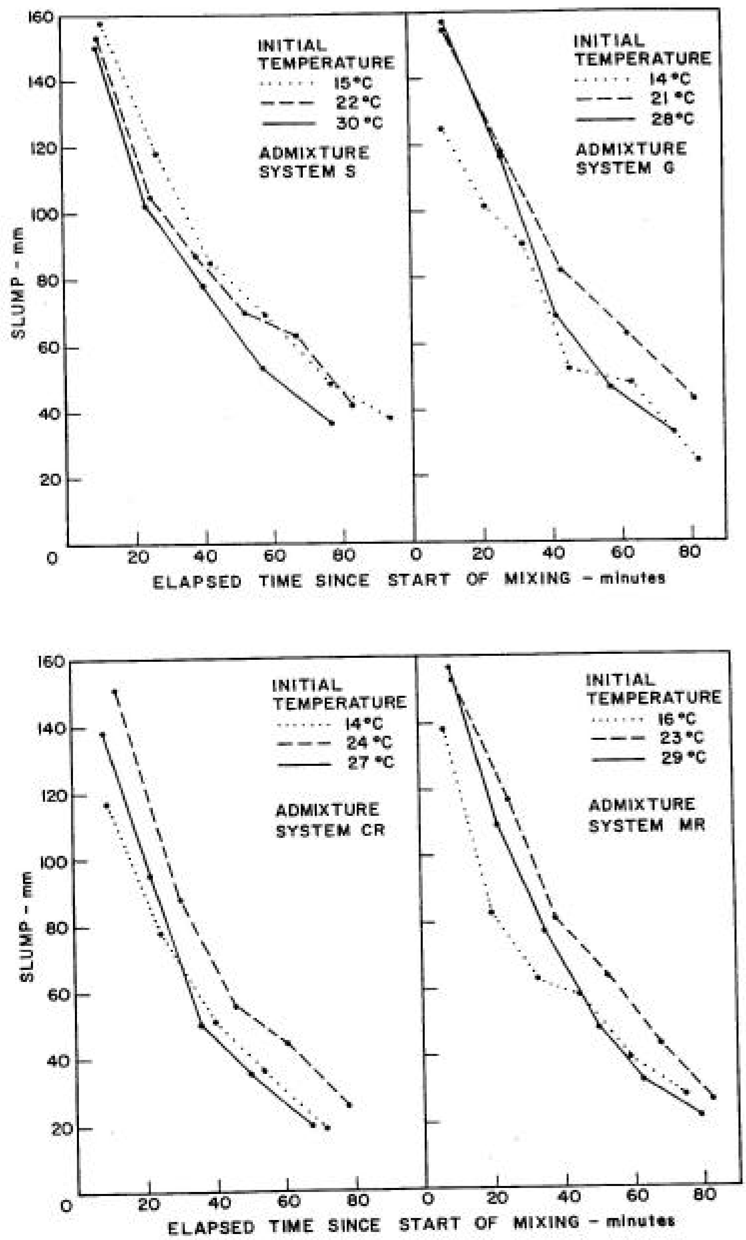

Fig. 1. Change of Slump with Time After Mixing at Various Concrete Temperatures

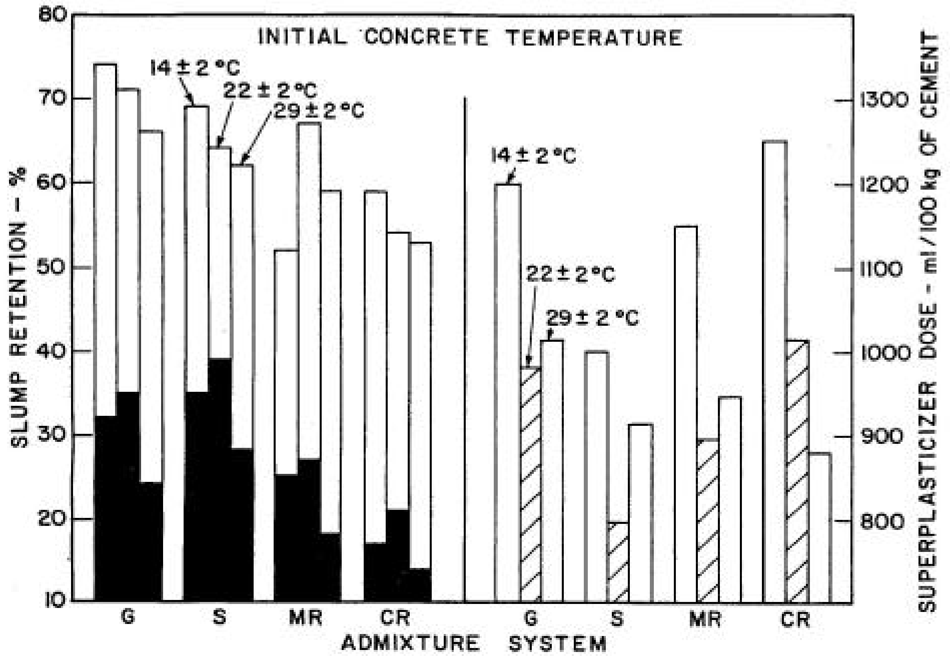

Fig. 2. Slump Retention After 20 and 60 Minutes (left) and Comparative SP Doses (right)

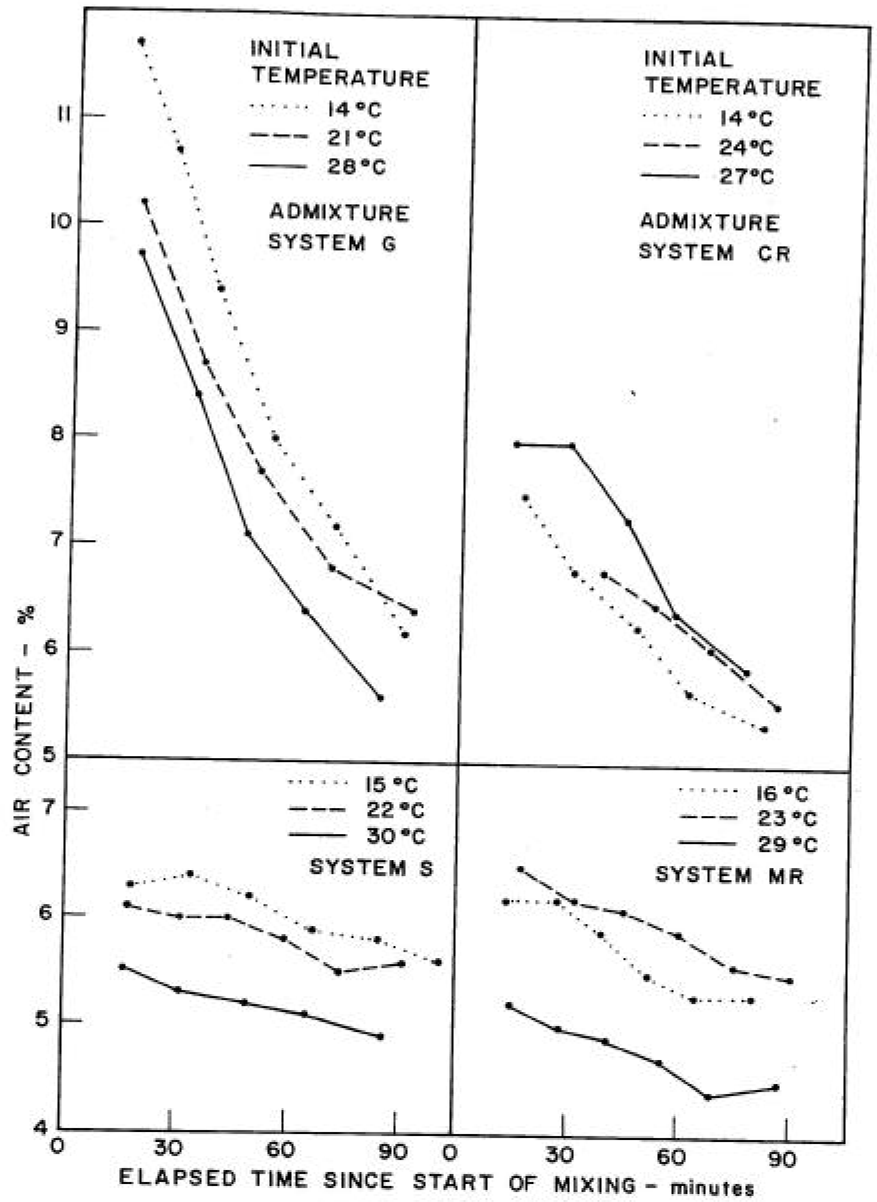

Fig. 3. Change of Air Content with Time After Mixing at Various Temperatures

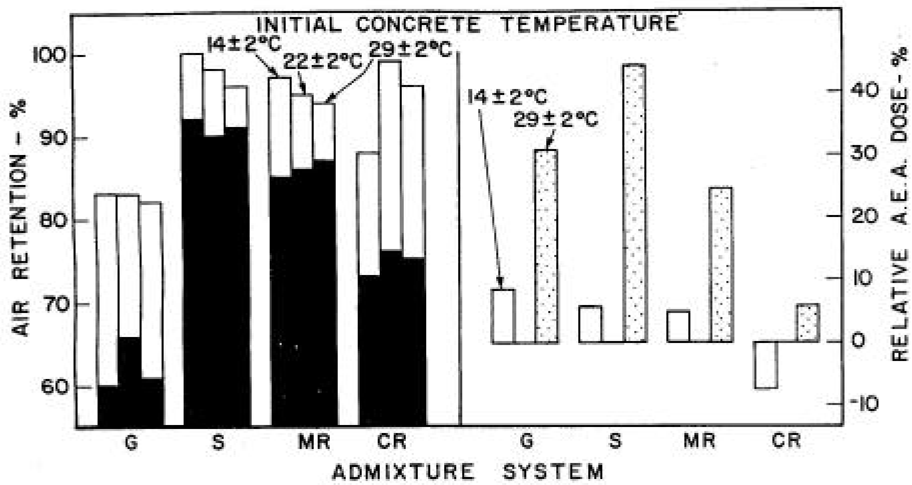

Fig. 4. Air Retention After 20 and 60 Minutes (left) and Relatives AEA Doses (right)

PRIMARY CONCRETE DATA

Mixture Designation G-13C

Date Mixed 24/03/92

Time mixing started 8-44
Time SP added 8-47
Mixture temperature

Dry materials 10°C
Water 8°C

Mixture Proportions

Ingredients	Cubic Metre	Batch 0.08 m³	Source
14 mm aggregate	980 kg	78.4 kg	
__ mm aggregate	kg	kg	
Sand	751 kg	60.1 kg	
Cement Type 10	370 kg	29.6 kg	
Fly Ash	kg	kg	
Silica Fume	kg	kg	
Water Initial	149 kg	11.9 kg	
Supp.	kg	kg	
Total	kg	kg	
Admixture Type WN Initial	ml	ml	
Supp.	ml	ml	
Total	ml	ml	
Admixture Type SP Initial	ml	355 ml	Daracem 1199 ml/100 kg.
Supp.	ml	ml	
Total	ml	ml	
Admixture Type AEA Initial	ml	30 ml	* Daravair 101 ml/100 kg cem. 8.63 ‡
Supp.	ml	ml	
Total	ml	ml	

* Very stiff. Didn't blend easily with +8.55% cool water. However, air content same initially as SP2/02

Workability v. Time

Slump -mm	Time	E.T.* -min.	Flow -s	Temp.	E.T.* -min.	
125	8-53	9		14.0	5	8-49
101	9-05	21		15.0	16	9-00
90	9-16	32	1.2	16.0	31	9-15
52	9-29	45	2.1	16.5	45	9-29
48	9-47	63	2.3	17.0	66	9-50
24	10-06	82	3.9	17.0	83	10-07
93	9-13	74%				
40	9-53	32%				

‡ AEA Dose / Initial Air

Air Content v. Time

Sample wt.-kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
15.30	2167	11.7	8-59	15
15.50	2195	10.7	9-10	26
15.70	2223	9.4	9-22	38
16.00	2266	8.0	9-38	54
16.20	2294	7.2	9-55	71
16.40	2322	6.2	10-14	90
		9.7	9-19	83%
		7.0	9-59	60%

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
21/04	28	1018	1028	1060	1035.3	56.8	

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm⁻¹	L-mm

‡Container volume 0.007062 m³
*Elapsed time from start of mixing

PRIMARY CONCRETE DATA

Mixture Designation SK 13C Date Mixed 19/03/92

Time mixing started 8-26
Time SP added 8-29
Mixture temperature See below

Water 40°C
Mixture Proportions Dry ingred. init: 10°C

Ingredients	Cubic Metre	Batch 0.08m³	Source
14 mm aggregate	980 kg	78.4 kg	
__ mm aggregate	kg	kg	
Sand	751 kg	60.1 kg	
Cement Type 10	370 kg	29.6 kg	
Fly Ash	kg	kg	
Silica Fume	kg	kg	
Water Initial	149 kg	11.9 kg	
Supp.	kg	kg	
Total	kg	kg	
Admixture Type WN Initial	ml	ml	
Supp.	ml	ml	
Total	ml	ml	
Admixture Type SP Initial	ml	295 ml	Sikament 10 ESL
Supp.	ml	ml	497 ml/
Total	ml	ml	100kg cem.
Admixture Type AEA Initial	ml	210 ml	Fro V5
Supp.	ml	ml	709 ml/
Total	ml	ml	100 kg cem. 112.5

+5.43%

Workability v. Time ↓

Slump -mm	Time	E.T.* -min.	Flow -s	~~Time~~ Temp	E.T.* -min.	ET
158	8-37	11		15	8-31	5
118	8-53	27		17	8-47	21
85	9-08	42	1.3	17	8-55	29
69	9-24	58	1.7	18	9-10	44
48	9-43	77	2.0	18	9-26	60
38	10-00	94	2.5	18	9-45	79
109	9-57	69%				
55	9-37	35%				

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
16/04	28	890	872	887	883	48.4	

Air Content v. Time

Sample wt.-kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
16.40	2322	6.3	8-44	18
16.35	2315	6.4	9-00	34
16.40	2322	6.2	9-16	50
16.45	2329	5.9	9-33	67
16.45	2329	5.8	9-50	84
16.45	2329	5.6	10-07	101
		6.3	9-04	100%
		5.8	9-44	92%

Casting completed 10-15

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm⁻¹	L̄-mm

‡Container volume 0.007062 m³
*Elapsed time from start of mixing

PRIMARY CONCRETE DATA

Mixture Designation G23C   Date Mixed 26/03/92   Time mixing started 10-12
Time SP added 10-15
Mixture temperature ____
Dry materials 20°C
Water 29°C

Mixture Proportions

Ingredients	Cubic Metre	Batch 0.08 m³	Source
14 mm aggregate	980 kg	78.4 kg	
__ mm aggregate	kg	kg	
Sand	751 kg	60.1 kg	
Cement Type 10	370 kg	29.6 kg	
Fly Ash	kg	kg	
Silica Fume	kg	kg	
Water Initial	149 kg	11.9 kg	
Supp.	kg	kg	
Total	kg	kg	
Admixture Type WN Initial	ml	ml	
Supp.	ml	ml	
Total	ml	ml	
Admixture Type SP Initial	ml	290 ml	Daracem 980 ml/100 kg cem.
Supp.	ml	ml	
Total	ml	ml	
Admixture Type AEA Initial	ml	24 ml	Daravair 84 ml/100 kg cem.
Supp.	ml	ml	
Total	ml	ml	7.95

Workability v. Time

Slump -mm	Time	E.T.* -min.	Flow -s	~~Time~~ Temp	E.T.* -min.	
155	10-22	10		21.0	5	10-17
118	10-38	26		20.5	11	10-23
82	10-55	43	1.3	19.5	28	10-40
63	11-14	62	2.1	19.0	45	10-57
43	11-33	81	2.5	18.5	63	11-15
110	10-42	71%		18.5	85	11-37
55	11-22	35%				

Drop in concrete temperature can only be attributed to a cooled down after washout from the previous batch since ambient temperature is 21-22°C.

Air Content v. Time

Sample wt. -kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
15.6	2209	10.2	10-29	17
15.9	2251	8.7	10-46	34
16.05	2273	7.7	11-02	50
16.20	2294	6.8	11-22	70
16.35	2315	6.4	11-44	92
		8.5	10-49	83%
		6.7	11-29	66%

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
23/04	28	1000	950	974	974.7	53.4	

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm⁻¹	$\bar{L}$-mm

‡Container volume 0.007062 m³
*Elapsed time from start of mixing

PRIMARY CONCRETE DATA

Mixture Designation MR 28C   Date Mixed 17/03/92

Dry ingredients 30°C
Water 29°C

Time mixing started 11-17
Time SP added 11-20
Mixture temperature 28.5 27.0 26.0 24.5 23.5 22.5 22.0
(11-21) (11-25) (11-37) (11-51) (12-08) (12-19) (12-34)

Mixture Proportions

Ingredients	Cubic Metre	Batch 0.08m³	Source
14 mm aggregate	980 kg	78.4 kg	
__ mm aggregate	kg	kg	
Sand	751 kg	60.1 kg	
Cement Type 10	370 kg	29.6 kg	
Fly Ash	kg	kg	
Silica Fume	kg	kg	
Water Initial	149 kg	11.9 kg	
Supp.	kg	kg	
Total	kg	kg	
Admixture Type WN Initial	ml	ml	
Supp.	ml	ml	
Total	ml	ml	
Admixture Type SP Initial	ml	280 ml	Rheobuild 1000
Supp.	ml	ml	946ml/100kg cem.
Total	ml	ml	
Admixture Type AEA Initial	ml	28 ml	Microair 95ml/100kg cem.
Supp.	ml	ml	
Total	ml	ml	18.2

+24.7%

Workability v. Time

Slump -mm	Time	E.T.* -min.	Flow -s	~~Time~~ Temp.	E.T.* -min.
157	11-26	9		28.5	4
109	11-39	22		27.0	8
77	11-52	35	1.7	26.0	20
48	12-07	50	2.6	24.5	34
32	12-20	63	3.6	23.5	48
22	12-36	79	4.3	22.5	62
				22.0	79
92	11-46	59%			
28	12-26	18%			

Air Content v. Time

Sample wt.-kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
16.55	2343	5.2	11-32	15
16.70	2365	5.0	11-45	28
16.70	2365	4.9	11-58	41
16.70	2365	4.7	12-13	56
16.80	2379	4.4	12-26	69
16.75	2371	4.5	12-44	87
		4.9	11-52	94%
		4.5	12-32	87%

Casting completed 13-00

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
14/04	28	886	845	876	869	47.6	

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm⁻¹	$\bar{L}$-mm

‡Container volume 0.007062 m³
*Elapsed time from start of mixing

PRIMARY CONCRETE DATA

Mixture Designation CR/23C Date Mixed 12/03/92

Time mixing started 8-27
Time SP added 8-30
Mixture temperature ~~24.0~~ 22.5 22.0 21.5
(8-40) (8-56) (9-12) (9-43)
MIXING WATER 28°C

Mixture Proportions

Ingredients	Cubic Metre	Batch 0.08 m³	Source
14 mm aggregate	980 kg	78.4 kg	
__ mm aggregate	kg	kg	
Sand	751 kg	60.1 kg	
Cement Type 10	370 kg	29.6 kg	
Fly Ash	kg	kg	
Silica Fume	kg	kg	
Water Initial / Supp.	149 kg / kg	11.9 kg / kg	
Water Total	kg	kg	
Admixture Type WN Initial / Supp.	ml / ml	ml / ml	
Admixture Type WN Total	ml	ml	
Admixture Type SP Initial / Supp.	ml / ml	300 ml / ml	Rossine GT 1014 ml/100 kg
Admixture Type SP Total	ml	ml	
Admixture Type AEA Initial / Supp.	ml / ml	7 ml / 3* ml	Pavair 24 ml/100 kg 4.38 [illegible]
Admixture Type AEA Total	ml	10 ml	34 ml/100 kg 4.9 h

Workability v. Time

Slump -mm	Time	E.T.* -min.	Flow -s	~~Time~~ Temp	E.T.* -min.
151	8-40	13		24.0	13
*Added AEA Remixed 1 minute					
88	8-57	30	1.0	22.5	29
56	9-13	46	1.9	22.0	45
45	9-28	61	2.7	21.5	76
26	9-45	78	3.3		
82	9-00	54%			
32	9-40	21%			

21.5°C 9-43

Air Content v. Time

Sample wt.-kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
–		5.4	8-47	20
*Added AEA				
16.25		6.8	9-05	38
16.40		6.5	9-19	52
16.45		6.1	9-34	67
16.57		5.6	9-52	85
		6.7	9-25	99%
		5.2	10-05	Extrapolation 76%

Casting completed 9-55

‡Container volume 0.007062 m³
*Elapsed time from start of mixing

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
9/04	28	947	920	940	935.7	51.3	

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm⁻¹	L̄-mm

PRIMARY CONCRETE DATA

Mixture Designation CR/28C   Date Mixed 12/03/92

Dry ingredients 28.5°C

Time mixing started 11-10
Time SP added 11-13
Mixture temperature 27.0 (11-16) 25.0 (11-32) 24.0 (11-48) 23.0 (12-01) 22.5 (12-14)

Mixture Proportions

Ingredients		Cubic Metre	Batch 0.08 m³	Source
14 mm aggregate		980 kg	78.4 kg	
__ mm aggregate		kg	kg	
Sand		751 kg	60.1 kg	
Cement Type 10		370 kg	29.6 kg	
Fly Ash		kg	kg	
Silica Fume		kg	kg	
Water	Initial	149 kg	11.9 kg	
	Supp.	kg	kg	
	Total	kg	kg	
Admixture Type WN	Initial	ml	ml	
	Supp.	ml	ml	
	Total	ml	ml	
Admixture Type SP	Initial	ml	260 ml	RessinGT 878 ml/100 kg cem.
	Supp.	ml	ml	
	Total	ml	ml	
Admixture Type AEA	Initial	ml	11 ml	Pavair 37 ml/100 kg cem.
	Supp.	ml	ml	
	Total	ml	ml	4.64

+59%

Workability v. Time

Slump -mm	Time	E.T.* -min.	Flow -s	~~Time~~ Temp.	E.T.* -min.
138	11-19	9	–	27.0	5
45	11-32	22	1.0	25.0	22
50	11-46	36	1.9	24.0	38
35	12-00	50	2.9	23.0	51
20	12-18	68	4.0	22.5	69
73	11-39	53			
19	12-19	14%			

Air Content v. Time

Sample wt.-kg‡	Density -kg/m³	Air -%	Time	E.T.* -min.
16.00	2266	8.0	11-24	14
16.00	2266	8.0	11-38	28
16.20	2234	7.3	11-54	44
16.40	2322	6.4	12-07	57
16.50	2336	5.9	12-27	77
		7.7	11-44	96%
		6.0	12-24	75%

Compressive Strength Data

Test Date	Age -days	Specimen loads #1	#2	#3	Mean	Strength -MPa	C of V -%
9/04	28	876	866	854	865.3	47.4	

Air Void Data

Test Date	Age -days	Air -%	Air Void Parameters P/A	α-mm^{-1}	$\bar{L}$-mm

‡Container volume 0.007062 m³
*Elapsed time from start of mixing