Pergamon

Cement and Concrete Research, Vol. 28, No. 12, pp. 1783–1796, 1998

0008-8846/98 $–see front matter

PII S0008-8846(98)00154-9

SUPERPLASTICIZED PORTLAND CEMENT: PRODUCTION AND COMPRESSIVE STRENGTH OF MORTARS AND CONCRETE

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(Received June 29, 1998; in final form September 8, 1998)

ABSTRACT

This paper deals with the effect of intergrinding different percentages of a naphthalene-based superplasticizer with Portland cement clinker and gypsum on the fineness of the product, and on the water requirement and the compressive strength of the mortars made with the superplasticized cement. The properties of the fresh and hardened concrete made with the superplasticized cements were also investigated. The results showed that the intergrinding of a given amount of a naphthalene-based superplasticizer with Portland clinker and gypsum reduced the grinding time required for obtaining the same Blaine fineness as that of the control Portland cement without the superplasticizer. The water requirement of the mortars made with the superplasticized cements was similar to that of the mortars made with the control Portland cements when the same amount of the superplasticizer was added at the mortar mixer; for a given grinding time and a Blaine fineness of $\sim$4500 cm^2/g, the mortars made with the superplasticized cement had higher compressive strength than those made with the control Portland cement. For a given grinding time or Blaine fineness of cement $\geq$5000 cm^2/g, the slump loss, air content stability, bleeding, autogenous temperature rise, setting times, and compressive strength of the concrete made with the superplasticized cements were generally comparable to those of the concrete made with the control Portland cements when the superplasticizer was added at the concrete mixer. *Crown Copyright © 1998 Published by Elsevier Science Ltd*

Introduction

In 1995, CANMET undertook a project to develop a blended cement incorporating high volumes of ASTM Class F fly ash. It was found that the intergrinding of 0.9% naphthalene-based superplasticizer (SP) with the Portland cement clinker, fly ash, and gypsum was the most effective mode of grinding to produce the blended fly ash cement and to obtain higher strength of the product (1). This was attributed to the fact that the SP was acting as a grinding aid with the clinker and fly ash. However, it was not clear whether the SP had acted as a

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TABLE 1
Chemical composition and specific gravity of the clinker.

Chemical composition	%
Silicon dioxide (SiO_2)	22.3
Aluminum oxide (Al_2O_3)	4.5
Ferric oxide (Fe_2O_3)	3.4
Calcium oxide (CaO)	65.5
Magnesium oxide (MgO)	2.9
Sodium oxide (Na_2O)	0.4
Potassium oxide (K_2O)	0.8
Specific gravity	3.23

grinding aid with the cement clinker or fly ash, or both, and if there was an optimum content of SP in terms of the grinding time, fineness of the product, water requirement, and the compressive strength of the mortars made with the cement so produced.

This paper presents the results of an investigation on the effect of intergrinding different percentages of a naphthalene-based SP with the Portland cement clinker and gypsum on the fineness of the product, and on the water requirement and the compressive strength of the mortars made with the superplasticized cement. The properties of the fresh and hardened concrete made with the superplasticized cements also were investigated. The above properties were compared with that of the laboratory produced control Portland cement without the SP.

Phase I—Superplasticized Cements: Production and Compressive Strength of Mortars

Materials used

Portland cement clinker. A Portland cement clinker for the production of ASTM type III cement was obtained from a cement producer, and its chemical composition is given in Table 1.

Gypsum. The chemical composition of gypsum is given in Table 2.

Superplasticizer. An SP of sulfonated, naphthalene formaldehyde condensate in a dry powder form was used.

Production of the superplasticized and control Portland cements

The superplasticized Portland cements were produced at CANMET by intergrinding the powder SP with the cement clinker and gypsum, and the control Portland cements were produced by grinding only the cement clinker and gypsum. The percentage of the gypsum used in the investigation was approximately 3% by weight of the clinker. Before grinding, the cement clinker was crushed and sieved so that all the particles were $<$0.6 mm.

TABLE 2
Chemical composition of the gypsum.

Chemical composition	%
Free water (T $<$45°C)	0.03
Combined water (T $<$230°C)	16.4
Carbon dioxide (CO_2)	4.7
SiO_2 and insoluble matter	2.7
Iron and aluminum oxide ($Fe_2O_3 + Al_2O_3$)	0.9
Lime (CaO)	33.4
Magnesium oxide (MgO)	1.5
Sulphur trioxide (SO_3)	41.0
Chloride	0.01
$CaSO_4 \cdot 2H_2O$ (calculated from the above)	78.3

A ceramic grinding mill with a capacity of 1.5 kg (180 mm in length and 280 mm in diameter) was used for producing the cements. Different sizes of steel balls were used in the grinding mill, and the weight ratio of the material to be ground to the grinding balls was 1:15.

For all the cements produced, the fineness of the cements was determined according to ASTM C 204, and the compressive strength of mortars was determined according to ASTM C 109 with the flow ranging from 105 to 115.

The effect of intergrinding the SP with the clinker and gypsum on the Blaine fineness of the cement produced was investigated by intergrinding 0%, 0.1%, 0.3%, 0.5%, 0.7%, and 0.9% of the SP (by weight of the clinker and gypsum) with the clinker and gypsum for 1.0, 1.5, 2.0, 2.5, and 3.0 h.

To determine the effect of intergrinding the SP with the clinker and gypsum on the water requirement and compressive strength of mortars, superplasticized Portland cements incorporating 0.3%, 0.5%, 0.7%, and 0.9% of the SP and three control Portland cements were produced. The designation, the percentage of the SP incorporated, grinding time, and Blaine fineness of these cements are given in Table 3. For each percentage of the SP, two cements were produced, one with a controlled grinding time of 180 min and the other with a controlled Blaine fineness of 5400 $\pm$ 200 cm^2/g. A third cement incorporating 0.9% of the SP was produced after 90 min of grinding with a Blaine fineness of 4500 cm^2/g. The water requirement and compressive strengths of the mortars made with the superplasticized Portland cements were determined and compared with those of the mortars made with the corresponding control Portland cements with the SP added at the mortar mixer.

For comparison, the control Portland cement designated C180 was produced eight times corresponding to each of the superplasticized Portland cements except for the cement designated C9S90. Before producing each superplasticized cement and its corresponding control Portland cement, the clinker used was split into two parts by using a sample splitter, one part for producing the superplasticized cement and the other for producing the control Portland cement to ensure that the clinker used for both cements had similar initial fineness.

TABLE 3
Designation of the laboratory-produced cements for mortar testings.

Designation	Description	Superplasticizer (%)	Grinding time (min)	Blaine fineness (cm^2/g)
C180	Control Portland cement	0.0	180	5380 ± 140
C125		0.0	125	4850
C90		0.0	90	3990
C3S150	Superplasticized cement	0.3	150	5300
C5S150		0.5	150	5600
C7S135		0.7	135	5320
C9S125		0.9	125	5200
C3S180	Superplasticized cement	0.3	180	5890
C5S180		0.5	180	5760
C7S180		0.7	180	5950
C9S180		0.9	180	5990
C9S90	Superplasticized cement	0.9	90	4500

Results and discussion

Effect of intergrinding the SP with the cement clinker and gypsum on the Blaine fineness of the cements produced. The intergrinding of a certain amount of the naphthalene-based SP with the clinker and gypsum reduced the grinding time required to obtain the same Blaine fineness as that of the control Portland cement without the SP (Fig. 1). It seems that for up to 0.9% SP, the increased dosage of the SP resulted in decreased grinding time for obtaining

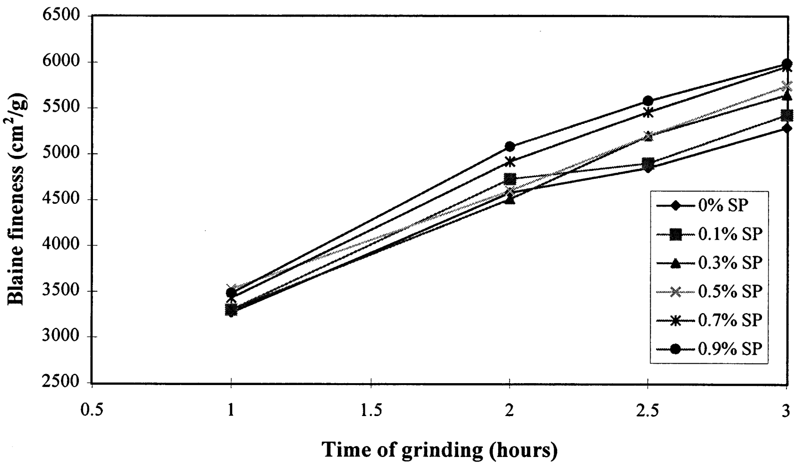

FIG. 1.
Effect of intergrinding the superplasticizer with Portland cement clinker and gypsum on the Blaine fineness of the cement produced.

TABLE 4
Effect of intergrinding the superplasticizer with the clinker and gypsum on the compressive strengths of the mortars made with the cements ground to a Blaine fineness of 5400 ± 200 cm^2/g.

Mix no.	Cement type	Grinding time (min)	Blaine fineness (cm^2/g)	SP* added in grinding mill (%)	SP added in mortar mixer (%)	W/C	Compressive strength at 7 days (MPa)	Relative strength ratio† at 7 days (%)	Compressive strength at 28 days (MPa)	Relative strength ratio at 28 days (%)
1	C180	180	5400	0.0	0.3	0.45	37.4	100	45.9	100
2	C3S150	150	5300	0.3	0.0	0.45	39.1	105	49.0	107
3	C180	180	5440	0.0	0.5	0.44	39.9	100	47.9	100
4	C5S150	150	5600	0.5	0.0	0.44	43.5	109	50.8	106
5	C180	180	5340	0.0	0.7	0.41	47.7	100	56.6	100
6	C7S135	135	5320	0.7	0.0	0.41	48.3	101	56.9	101
7	C180	180	5240	0.0	0.9	0.39	46.4	100	58.3	100
8	C9S125	125	5200	0.9	0.0	0.39	51.5	111	62.4	107

* Superplasticizer.
† The compressive strength of the mortar divided by that of the mortar made with the control Portland cement.

fineness similar to that of the control Portland cement. No optimum percentage of the SP was observed in term of its effect on the Blaine fineness of the cements produced as reported by Popescu et al. (2). For the cement incorporating 0.1% of the SP, no significant improvement in the fineness was observed; for the cements incorporating 0.3% and 0.5% of the SP, the improvement in the fineness was more noticeable when grinding time was 2.5 h or more; and for the cements incorporating 0.7% and 0.9% of the SP, the improvement in the fineness was more noticeable when grinding was performed for 2 h or more.

The control Portland cements without the SP required 3 h of grinding to obtain a Blaine fineness of 5400 ± 200 cm^2/g. To obtain the same fineness, the intergrinding of 0.3% or 0.5%, 0.7%, and 0.9% of the SP with the clinker and gypsum reduced the grinding time by 30, 45, and 55 min, respectively.

Effect of superplasticized cements on the compressive strength of mortars. Superplasticized and control Portland cements with similar Blaine fineness. The compressive strengths of the mortars made with the superplasticized Portland cements (mixtures 2, 4, 6, and 8), and those of the mortars made with the corresponding control Portland cements where the same amount of the SP was added at the mortar mixer (mixtures 1, 3, 5, and 7) are given in Table 4.

At each percentage of the SP, the mortar mixture made with the superplasticized Portland cement required the same amount of water to reach a flow of 110 ± 5 as that of the mortar made with the control Portland cement with the SP added at the mortar mixer. The 7- and 28-day compressive strengths of the mortars made with the superplasticized cements were similar to, or somewhat higher than, those of the mortars made with the control Portland

TABLE 5
Effect of intergrinding the superplasticizer with the cement clinker and gypsum on the compressive strengths of mortars made with the cements ground for 180 min.

Mix no.	Cement type	Blaine fineness (cm^2/g)	SP added in grinding mill (%)	SP added in mortar mixer (%)	W/C	Compressive strength at 7 days (MPa)	Relative strength ratio at 7 days (%)	Compressive strength at 28 days (MPa)	Relative strength ratio at 28 days (%)
9	C180	5520	0.0	0.3	0.46	38.5	100	45.7	100
10	C3S180	5890	0.3	0.0	0.46	40.8	106	47.8	105
11	C180	5300	0.0	0.5	0.43	39.3	100	47.5	100
12	C5S180	5760	0.5	0.0	0.45	41.5	106	48.3	102
13	C180	5280	0.0	0.7	0.41	47.1	100	57.5	100
14	C7S180	5950	0.7	0.0	0.41	53.5	114	59.3	103
15	C180	5290	0.0	0.9	0.40	51.0	100	58.5	100
16	C9S180	5990	0.9	0.0	0.40	53.0	104	63.6	109

cements. This indicated that the SP had acted as a grinding aid when interground with the cement clinker and gypsum as the superplasticized cements required less grinding times than the corresponding control Portland cements.

Superplasticized and control Portland cements (grinding time = 180 min). The compressive strengths of mortars made with the superplasticized Portland cements (mixtures 10, 12, 14, and 16) and those of the mortars made with the control Portland cements where the same amount of the SP was added at the mortar mixer (mixtures 9, 11, 13, and 15) are given in Table 5.

The Blaine fineness of the superplasticized cements ranged from 5760 to 5990 cm^2/g, and these were greater than those of the control Portland cements, which ranged from 5280 to 5520 cm^2/g. The water requirement of the mortars made with the superplasticized cements were the same as that of the mortars made with the control Portland cements when the SP was added at the mortar mixer except for the mixture that contained 0.5% of the SP. In spite of the greater finenesses of the superplasticized cements, the mortars made with these cements did not achieve appreciably higher compressive strengths than those made with the control Portland cements. This indicated that the advantage of intergrinding SP with the clinker and gypsum might not be significant when the Blaine fineness value of the cement was $ge;5200 cm^2/g.

Effect of the level of the Blaine fineness of the cement on the compressive strength of mortars. To evaluate the effect of the Blaine fineness on the compressive strength of the mortars, one additional Portland cement incorporating 0.9% SP was produced with a Blaine fineness of 4500 cm^2/g. This cement together with the superplasticized cements C9S125 and C9S180 used in the above tests were employed for this part of the investigation. The Blaine fineness of the three cements ranged from 4500 to 5990 cm^2/g. The corresponding control

TABLE 6
Effect of the level of the Blaine fineness of the cements on the improvement of the compressive strength of mortars.

Mix no.	Cement type	Grinding time (min)	Blaine fineness (cm^2/g)	SP added in grinding mill (%)	SP added in mortar mixer (%)	W/C	Compressive strength at 7 days (MPa)	Relative strength ratio at 7 days (%)	Compressive strength at 28 days (MPa)	Relative strength ratio at 28 days (%)
17	C90	90	3990	0.0	0.9	0.39	41.1	100	50.2	100
18	C9S90	90	4500	0.9	0.0	0.39	51.5	125	57.0	114
19	C125	125	4850	0.0	0.9	0.39	49.0	100	61.5	100
8	C9S125	125	5200	0.9	0.0	0.39	51.5	105	62.4	101
15	C180	180	5290	0.0	0.9	0.40	51.0	100	58.5	100
16	C9S180	180	5990	0.9	0.0	0.40	53.0	104	63.6	109

Portland cements with the same grinding time as each of the above superplasticized cements were also produced for comparison (Table 6).

The test results showed that even though the superplasticized cements were much finer than the corresponding control Portland cements, the mortar mixtures made with the superplasticized cements required the same amounts of water as those made with the control Portland cements (Table 6).

The 7- and 28-day compressive strengths of the mortar made with the superplasticized cement with a Blaine fineness of 4500 cm^2/g (mixture 18) were 25% and 14% higher than those of the mortar made with the control Portland cement (mixture 17). However, when the Blaine fineness of the cements was greater than approximately 5000 cm^2/g, the improvement in the compressive strengths of the mortars made with the superplasticized cements instead of the control Portland cements was not significant.

Phase II—Properties of Fresh and Hardened Concrete Using the Laboratory Produced Superplasticized Cement

Materials used

Portland cement clinker, gypsum, and superplasticizer. The Portland cement clinker, gypsum, and SP used in Phase I of the present study also were used in this part of the investigation. The characteristics of the clinker and gypsum are given in Tables 1 and 2, respectively.

Air-entraining admixture. A synthetic resin type of air-entraining admixture (AEA) was used in all the concrete mixtures.

Aggregates. A crushed granite with a maximum nominal size of 19 mm was used as the coarse aggregate, and a local natural sand was used as the fine aggregate. Both the coarse and

TABLE 7
Grading of coarse and fine aggregate.

Coarse aggregate		Fine aggregate	
Sieve size (mm)	Percentages passing	Sieve size (mm)	Percentages passing
19.0	100	4.75	100
12.7	70	2.36	90.0
9.5	32	1.18	67.5
4.75	0	0.600	42.5
		0.300	20.0
		0.150	6.0

fine aggregates were separated into different size fractions and recombined to a specific grading given in Table 7. The coarse and fine aggregates each had specific gravity of 2.70, and the water absorption of 0.5% and 0.8%, respectively.

Production of the superplasticized and control Portland cements

For this part of the investigation, two superplasticized Portland cements and two control Portland cements were produced at CANMET. Three percent of the gypsum by weight of the clinker was used for all the cements produced, and the superplasticized cements contained 0.3% of the SP by weight of the clinker and gypsum. Before grinding, the clinker was crushed and sieved to obtain particles $<$0.6 mm.

A ceramic grinding mill, 420 mm in length and 500 mm in diameter with a grinding capacity of approximately 10 kg of material, was used for the production of the cements. According to previous results (3), a combination of 35 kg of large ceramic cylinders (30-mm thickness and 30-mm diameter) and 35 kg of medium ceramic cylinders (20-mm thickness and 20-mm diameter) was used for grinding. The weight ratio of the materials to be ground to the grinding ball was 1:7.

Table 8 gives the SP dosage, grinding time, and the Blaine fineness of the cements

TABLE 8
Designation of the laboratory-produced superplasticized and control Portland cements for concrete testing.

Designation	Superplasticizer (%)	Grinding time (h:min)	Blaine fineness (cm^2/g)
LPCS5	0.3	5:00	5400
LPC5	0.0	5:00	5270
LPCS	0.3	4:20	5320
LPC	0.0	4:20	4990

produced. The superplasticized cement LPCS5 and the control Portland cement LPC5 were ground for 5 h each, and the cements LPCS and LPC were ground for 4 h 20 min each (Table 8). The physical properties and chemical composition of the cements produced were determined and are given in Table 9.

Proportions of concrete mixtures, preparation, curing, and testing of the concrete

Four concrete mixtures were made with the cements produced. The proportions of the concrete mixtures are summarized in Table 10.

The coarse and fine aggregates were weighed in a room dry condition. The coarse aggregate was then immersed in water for approximately 24 h, the excess water was decanted, and the water retained by the aggregates was determined by the weight difference. A predetermined amount of water was added to the fine aggregate, which then was allowed to stand for 24 h.

All the concrete mixtures were mixed in a laboratory counter-current mixer for a total of 5 min. After the mixing, the slump, unit weight, air content, and bleeding of the concrete were determined following ASTM Standards. The setting times of the concrete were determined using the mortar obtained by sieving the fresh concrete.

The autogenous temperature rise of the concrete mixtures was measured using a 152 $\times$ 305-mm cylinder in an adiabatic chamber. The temperature of the concrete was recorded every 2 h for up to 7 days.

Twelve 102 $\times$ 203-mm cylinders were cast from each mixture for the determination of the compressive strength at various ages. The cylinders were cast in two layers, with each layer being consolidated on a vibrating table. After casting, all the molded specimens were covered with plastic sheets and water-saturated burlap, and left in the casting room for 24 h. They then were demolded and transferred to a moist-curing room at 23 $\pm$ 2°C and 100% relative humidity until required for testing. At the age of 1, 7, 14, and 28 days, three cylinders from each mixture were tested according to ASTM Standard C 39.

Results and discussion

Characteristics of superplasticized and control Portland cements. Table 9 presents the physical properties and chemical composition of the superplasticized and control Portland cements. All of the cements meet the general requirements of ASTM C 150 type I and type III cements. The initial and final setting times of the superplasticized and the control Portland cements ranged from 50 to 85 min, and from 75 to 120 min, respectively; the compressive strengths of the mortars made with the above cements ranged from 15.8 to 19.8 MPa at 1 day, and from 27.3 to 31.2 MPa at 3 days.

From the results shown in Table 9, it seems that mortars made with the superplasticized cements (LPCS5 and LPCS) had shorter setting times and higher compressive strengths than those made with the control Portland cements (LPC5 and LPC). This was primarily due to the lower water-to-cement ratio of the mortars made with the superplasticized cements.

Properties of fresh concrete. The unit weight, slump loss and air content stability of the fresh concrete are given in Table 11, and the results on the bleeding, setting times, and

TABLE 9
Physical properties and chemical composition of the cements produced for concrete testing.

	LPCS5	LPC5	LPCS	LPC	ASTM C 150 Type I	ASTM C 150 Type III
Physical tests						
Specific gravity	3.17	3.17	3.17	3.17	—	—
Fineness						
Passing 45 μm (%)	94.0	93.9	92.9	90.1	—	—
Specific surface, Blaine (cm^2/g)	5400	5270	5320	4990	2800 (min)*	—
Compressive strength of						
51-mm cubes (MPa)						
1-day						
3-day	19.8	19.0	19.1	15.8	—	12.4 (min)
7-day	31.2	28.1	28.5	27.3	12.0 (min)	24.1 (min)
w/c of the mortar for the cube	—	—	—	—	19.0 (min)	—
Time of setting (min; Vicat)	0.45	0.48	0.45	0.48	—	—
Initial setting						
Final setting	50	70	75	85	45 (min)	45 (min)
Air content of mortar	75	95	105	120	375 (max)†	375 (max)
(volume %)						
	8.4	6.5	7.3	5.6	12 (max)	12 (max)
Chemical analyses (%)						
Silicon dioxide (SiO_2)						
Aluminium oxide (Al_2O_3)	21.6	21.8	21.7	21.6	—	—
Ferric oxide (Fe_2O_3)	4.0	4.0	4.0	3.9	—	—
Calcium oxide (CaO)	3.0	3.0	3.0	3.1	—	—
Magnesium oxide (MgO)	66.2	66.2	66.2	66.2	—	—
Sodium oxide (Na_2O)	2.5	2.5	2.4	2.4	6.0 (max)	6.0 (max)
Potassium oxide (K_2O)	0.4	0.4	0.4	0.5	—	—
Equivalent alkali ($Na_2O + 0.658K_2O$)	0.5	0.5	0.5	0.5	—	—
Phosphorous oxide (P_2O_5)	0.7	0.7	0.7	0.9	—	—
Titanium oxide (TiO_2)	0.3	0.3	0.2	0.3	—	—
Sulphur trioxide (SO_3)	0.2	0.2	0.2	0.2	—	—
Loss on ignition	2.5	2.6	2.5	2.4	3.0 (max)	3.5 (max)
	0.3	0.1	0.2	0.1	3.0 (max)	3.0 (max)
Bogue potential compound composition						
Tricalcium silicate C_3S						
Dicalcium silicate C_2S	67	65	66	68	—	—
Tricalcium aluminate C_3A	12	13	12	11	—	—
Tetracalcium aluminoferrite C_4AF	6	6	5	5	—	15 (max)
	9	9	9	9	—	—

* Minimum.
† Maximum.

TABLE 10
Proportions of the concrete mixtures.

Mixture no.	W/C*	Water (kg/m^3)	Cement Type	Cement kg/m^3	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	AEA† (mL/m^3)	SP‡ (L/m^3, added in the mixture)	SP (L/m^3, added in the grinding mill)§	Total SP (L/m^3)
1	0.43	167	LPCS5	390	726	1090	126	0	2.4	2.4
2	0.43	163	LPC5	380	709	1064	126	2.4	0	2.4
3	0.44	166	LPCS	380	722	1084	78	0	2.4	2.4
4	0.44	166	LPC	380	722	1084	63	2.4	0	2.4

* Water-to-cement ratio.
† Air-entraining admixture.
‡ Superplasticizer.
§ The superplasticizer was used in a dry form in the grinding mill. The value reported in this table is the corresponding volume of liquid superplasticizer calculated based on 1) the density of the liquid SP is 1.21 kg/cm^3 and 2) the liquid SP contained 40% solids by mass.

maximum autogenous temperature rise of the concrete are given in Table 12. The autogenous temperature rise of the concrete for up to 7 days is shown in Figure 2.

Dosage of the SP and slump loss. A dosage of 2.4 L/m^3 of the SP was used for the concrete mixtures made with the control Portland cement to reach a slump of approximately 80 $\pm$ 10 mm that had been achieved for the concrete made with the superplasticized cements. The slump loss after 75 min was 30 to 50 mm. As to the dosage of the SP and slump loss, there was no significant difference between the concrete made with the superplasticized cements and those made with the control Portland cements.

TABLE 11
Unit weight, slump loss, and air content stability of fresh concrete.

Mixture no.	W/C	Cement type	Unit weight (kg/m^3)	Right after mixing: Slump (mm)	Right after mixing: Air content (%)	75 min after the mixing was completed: Slump (mm)	75 min after the mixing was completed: Air content (%)
1	0.43	LPCS5	2370	70	4.8	30	3.6
2	0.43	LPC5	2320	90	6.8	40	5.3
3	0.44	LPCS	2360	80	5.4	50	3.9
4	0.44	LPC	2360	90	5.4	45	3.6

TABLE 12
Bleeding, maximum autogenous temperature rise, and setting times of concrete.

Mixture no.	W/C	Cement type	Total bleeding water (mL/cm^2)	Setting time (h:min) Initial	Setting time (h:min) Final	Maximum autogenous temperature rise (°C)
1	0.43	LPCS5	0.0064	4:05	5:15	28.8
2	0.43	LPC5	0.0080	4:00	5:05	27.2
3	0.44	LPCS	0.0080	4:08	5:25	28.1
4	0.44	LPC	0.0160	4:45	6:20	27.3

Dosage of the AEA and air content stability. The dosage of the AEA required for obtaining an air content in the range of 5% to 7% was influenced by the fineness and type of the cement used in the concrete. It appears that the concrete made with the finer cements required more AEA. A comparison of mixtures 1 and 2, and 3 and 4 showed that, for given grinding times of the cements, the type of the cement used did not have significant effect on the dosage of the AEA. However, comparing mixtures 2 and 3, for a given fineness, the concrete made with the superplasticized cement required less AEA to obtain the same air content than the concrete made with the control Portland cements.

The concrete lost 1.2% to 1.8% air content after 75 minutes. It appears that the concrete made with the superplasticized cements lost less air than the corresponding concrete made with the control Portland cements Also, the concrete made with the finer cements showed less loss in air content; however, the difference were not significant.

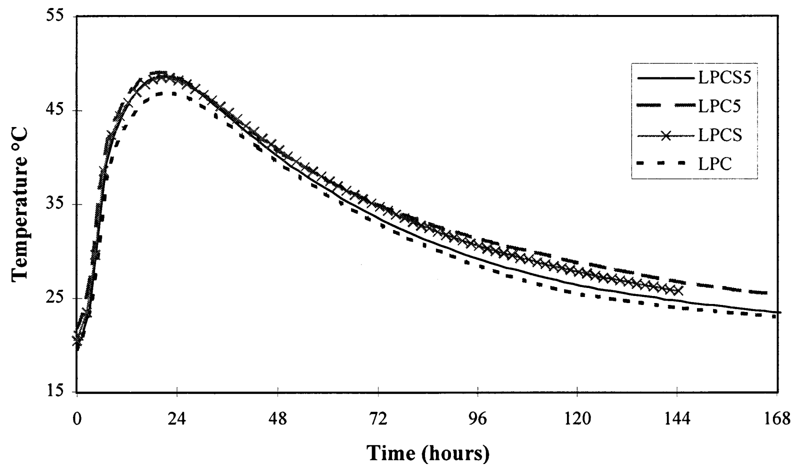

FIG. 2.
Autogenous temperature rise in 152 × 305-mm concrete cylinder.

TABLE 13
Compressive strength of concrete.

Mixture no.	W/C	Cement type	Unit weight of hardened concrete at 1 day (kg/m^3)	Compressive strength (MPa) 1 day	7 days	14 days	28 days
1	0.43	LPCS5	2387	19.8	37.8	42.4	45.7
2	0.43	LPC5	2344	19.0	34.2	39.2	42.5
3	0.44	LPCS	2368	18.8	38.5	39.7	44.3
4	0.44	LPC	2385	18.6	34.5	38.9	43.9

Bleeding, autogenous temperature rise, and setting times of concrete. The concrete made with the superplasticized cements appear to show less bleeding and higher maximum autogenous temperature rise than the corresponding concrete made with the control Portland cements; however, these differences were not significant. The total amount of the bleeding water ranged from 0.0064 to 0.0160 mL/cm^2, and the maximum autogenous temperature rise ranged from 27.2 to 28.8 °C for the concrete tested.

The initial and final setting times of the concrete made with the superplasticized cement were similar to those of the concrete made with the control Portland cements when the cements were ground for 5 h. However, when the cements had been ground for 4 h 20 min, the concrete made with the control Portland cement had longer setting times (37 min longer for initial and 55 min longer for the final setting times) than those of the concrete made with the superplasticized cement.

Compressive strength of concrete. The unit weight and compressive strength of the concrete are given in Table 13. The compressive strengths of the concrete did not appear to have been affected significantly by the type of cement used or whether the SP had been used in the grinding process or added at the mixer. The lower 7-day compressive strength of concrete mixture 2 might be attributed primarily to its higher air content.

The test results confirmed the finding of phase I that at Blaine fineness level $\geq$5000 cm^2/g, the advantage of intergrinding the SP with the clinker and gypsum to produce superplasticized cements was not significant.

Summary and Conclusions

1. The intergrinding of a given amount of a naphthalene-based SP with Portland clinker and gypsum reduced the grinding time required for obtaining the same Blaine fineness as that of the control Portland cement without the SP. If the grinding time was kept the same, the superplasticized cements had higher Blaine fineness than the control Portland cements.
2. The water requirement of the mortars made with the superplasticized cements was similar to that of the mortars made with the control Portland cements when the same amount of the SP was added at the mortar mixer.

3. For a given grinding time and a Blaine fineness of ~4500 cm^2/g, the mortars made with the superplasticized cement had higher compressive strength than those made with the control Portland cement when the SP had been added at the mortar mixer; however, for given grinding time or Blaine fineness of cement ≥5000 cm^2/g, the compressive strength of the mortars made with the superplasticized cements were not significantly different from those made with the control Portland cements.
4. Superplasticized cements produced by intergrinding 0.3% of SP (by weight of the clinker and gypsum) with the clinker and gypsum meet the requirements of ASTM C 150 for type I and type III cements.
5. For a given grinding time or Blaine fineness of cement ≥5000 cm^2/g, the slump loss, air content stability, bleeding, autogenous temperature rise, setting times, and compressive strength of the concrete made with the superplasticized cements generally were comparable to those of the concrete made with the control Portland cements when the SP was added at the concrete mixer.

Acknowledgments

This investigation was jointly funded by Environment Canada and CANMET, Natural Resources Canada. Grateful acknowledgement is made to Mr. Donald Rose, Project Engineer, Environment Canada, for his helpful comments during the investigation.

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