DOE/CS/40419-4

ENERGY CONSERVATION POTENTIAL
OF PORTLAND CEMENT
PARTICLE SIZE DISTRIBUTION CONTROL
PHASE II

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CTL Contract CR 7728/2405

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PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY

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QUARTERLY PROGRESS REPORT
FOR THE PERIOD
1 NOVEMBER 1982 - 31 JANUARY 1983

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TECHNICAL PROGRESS REPORT

1 November 1982 - 31 January 1983

PHASE II

THE MANUFACTURE AND USE OF CONTROLLED PARTICLE SIZE DISTRIBUTION CEMENTS

I. OBJECTIVES AND SCOPE

The main objectives of Phase II are to determine the feasibility of using cements with controlled particle size distributions (CPSD cements) in practical concrete applications, and to refine our estimates of the potential energy savings that may ensue from such use.

The work in Phase II is divided into two main tasks, some parts of which will be carried out simultaneously:

Task I will continue cement paste studies to optimize cement performance similar to those of Phase I, but with particular emphasis on gypsum requirements, blended cements, and water-reducing admixtures. This task will also include preparation of sufficient CPSD cements for use in all Phase II work.

Task II will be a comprehensive examination of the properties of concretes made with CPSD cements. This will include optimization of concrete mix designs to obtain the best possible performance for practical applications of both portland and blended cements. The effects of chemical admixtures and curing temperature variations will also be determined.

II. SUMMARY OF PROGRESS

Sub-Task IF: Materials Preparation

Twenty-three blended cements for Sub-Task IC(a) were prepared from two CPSD portland cements blended with 30 percent (by volume) of various mineral admixtures, in binary, ternary, and quaternary blends. Variations of the three best blended cements were prepared for use in Sub-Task IC(b). In these 15 cements the mineral admixture content was varied from 0 to 40 percent. This series included one normally ground and two CPSD cements (less than 31 microns and less than 23 microns) blended with Class F fly ash, and blends with granulated blast furnace slag. Some blends also included 5 percent ground limestone, which have previously been found to improve strength development and volume stability.

Sub-Task IC: Blended Cements

Blended cement pastes were prepared at water contents equal to that of the control portland cements at 0.5 water/cement ratio. Paste flow, compressive strengths up to 28 days, and drying shrinkage after 7 and 28 days of moist curing were used to evaluate the blended cements. The major mineral admixtures (fly ashes and granulated slags) improved the fresh paste flow properties of both CPSD cements. As expected, strengths of the blended cements were less than that of the portland cements at equal water contents, but this effect varied with curing time and the type of mineral admixture. Five percent ground limestone improved strengths at all ages in all of the blends

and reduced drying shrinkage. Two percent silica fume reduced the paste flow substantially, showed no consistent effects on strength, and increased the drying shrinkage significantly. Class C fly ash and granulated slag yielded the best strengths, but also increased drying shrinkage. Class F fly ash showed lower early strengths, but improvement with curing time. Use of 10 percent of a coarse fraction (greater than 15 microns) of ground granulated slag improved flow and 28-day strengths, and reduced drying shrinkage.

The three best blends selected for Sub-Task IC(b) were two containing Class F fly ash and ground limestone with both CPSD cements, and one containing granulated slag with the finer (less than 23 micron) CPSD cement. Testing of these cements has begun. The results obtained will be used to determine the compositions of three blended cements selected for use in Task II.

Sub-Task IE: Soundness Tests

Cements RB2119, 2128, and 2137 prepared for use in Task II were tested for potential unsoundness using ASTM standard tests for strength development (or retrogression), autoclave expansion, and expansion during long term wet curing. There is no evidence to date of unsoundness of any of these cements.

Sub-Task IIA: Concrete Mix Proportioning

Compressive strength results through 90 days showed little consistent difference between cements prepared at equal w/c ratio. The one CPSD cement (2128) prepared at higher w/c ratio

showed the expected strength decrease. Flexural strengths for all cements were nearly identical at 28 days age. CPSD cements exhibited somewhat higher elastic moduli.

Shrinkage of concretes prepared with the CPSD cement 2137 appeared to correlate with reduced water content; however, cement 2128 exhibited reduced shrinkage in spite of increased water content. Results of creep testing after 50 days under load showed that CPSD cements exhibit lower normalized creep than does the normal grind.

Sub-Task IIB: Effects of Chemical Admixtures

Bleeding and setting time tests on all cements were completed. Concretes prepared with Mighty-150 bled excessively, most likely due to extremely low paste contents. Retardation of CPSD cements was very low for concretes containing Mighty-150. In one case a slight acceleration effect was noted.

Cement 2128, in combination with WRDA-79, exhibited compressive strength equivalent to the other two cements, even though w/c ratio was higher. With Mighty-150, however, no such effect was seen. Flexural strengths of CPSD cements with WRDA-79 were somewhat higher than for the normal grind. With Mighty-150 no consistent pattern was evident.

Sub-Task IIC: Air Entrainment

Air-entrained concretes were prepared using CPSD cements and normal grind. Trends for compressive and flexural strength were similar to those for non-air entrained concretes. Durability testing will be initiated shortly.

Sub-Task IIF: Miscellaneous Testing

Workability loss testing was carried out using spread and "V-B" test apparatus. Behavior of cements 2119 and 2137 was similar with respect to spread loss. Cement 2128 showed a somewhat higher rate of spread loss with WRDA-79 and lower rate with Mighty-150. Cement 2128 showed best response to vibration and less tendency toward rapid stiffening than did the other two cements.

III. PROGRESS FROM 1 NOVEMBER 1982 through 31 JANUARY 1983

Sub-Task IF

1. Materials Preparation for Sub-Task IC Blended Cements

Blended cements for Sub-Task IC(a) were prepared using major amounts of two fly ashes (ASTM Class F and C), one ground granulated blast furnace slag, a coarse fraction (greater than 15 microns) of this same slag, lesser amounts of one finely ground limestone, and one silica fume. Physical data on these mineral admixtures were given in Table 2C in the August-October 1982 Quarterly Report. Binary, ternary, and quaternary mixtures were prepared to explore the effects of composition on performance of these blended cements. The compositions of the 23 blended cements made by blending these materials with CPSD cements RB2128 and RB2137 are given in Table 3E. These blends were prepared using 70 percent portland cement and 30 percent (by volume) mineral admixtures.

Based on the results obtained in Task IC(a), three blended cements selected for further study in Task IC(b) were 2204, 2212, and 2213. Fifteen additional blended cements, including controls made using normally ground cement RB2119, were prepared in which the percentage of portland cement in the blends was varied from 60 to 80 percent, by volume. The compositions of these cements are given in Table 3F.

2. Materials Preparation for Task II

The preparation of the first three batches of cements (RB2119, 2128, and 2137) for use in Task II was described in

TABLE 3E. BLENDED CEMENTS PREPARED FOR SUB-TASK IC(a)
WITH CEMENT 2128 (LESS THAN 23 MICRONS)
AND CEMENT 2137 (LESS THAN 31 MICRONS)

Blended Cement	Volume Percentages in Blended Cement						
	CPSD Cement RB2128 <23 microns	Class F Fly Ash PDG388	Class C Fly Ash 21834	GBF Slag PDG468	GBF Slag PDG468 >15 microns	Limestone A-140	Silica Fume PDG383
2128	100						
2196	70	30					
2197	70		30				
2198	70			30			
2199					30		
2200	70	15		15			
2201	70		15	15			
2202	70	15			15		
2203	70		15		15		
2204	70	25				5	
2205	70		25			5	
2206	70				25	5	
2207	70	28					2
2208	70		28				2
2209	70				28		2
2210	70	15			10	5	
2211	70		15		10	5	
2212	70			15	10	5	
<hr/>							
	RB2137 <31 microns						
2137	100						
2213	70	25				5	
2214	70		25			5	
2215	70				25	5	
2216	70	15			10	5	
2217	70		15		10	5	
2218	70			15	10	5	

TABLE 3F. BLENDED CEMENTS PREPARED FOR SUB-TASK IC(b)
WITH CPSD CEMENTS 2128 and 2137 AND NORMALLY GROUND CEMENT 2119 AS A CONTROL

Mix No.	Blended Cement Compositions (volume percentages)			Mix No.	Blended Cement Compositions (volume percentages)		
	Cement	(%)	Mineral Admix.		Cement	(%)	Mineral Admix.
2221	2119	80	F L	2230	2119	80	S Sc L
2222	2119	70	F L	2231	2119	70	S Sc L
2223	2119	60	F L	2232	2119	60	S Sc L
2224	2128	80	F L	2233	2128	80	S Sc L
2225	2128	70	F L	2234	2128	70	S Sc L
2226	2128	60	F L	2235	2128	60	S Sc L
2227	2137	80	F L				
2228	2137	70	F L				
2229	2137	60	F L				

F = Class F fly ash PDG 388
S = ground granulated blast furnace slag PDG468
Sc = ground granulated blast furnace slag PDG468 (>15 microns)
L = ground A-140 limestone

the August-October 1982 Quarterly Report. During the current reporting quarter, the last three batches of these same cements were prepared. In an attempt to speed the Vortec milling, two variations of the original closed-circuit milling of 16-mesh feed were tried. In the first variation, the 16-mesh feed was premilled with a single pass through the Vortec impact mill. When this product was used as feed for closed-circuit milling to yield less than 30 micron and less than 22 micron products, the B.S.S. (Blaine specific surface) values were found to be excessively high. To achieve the required B.S.S. values, fines were removed by an additional classification step. Not only did this waste some material, but also required additional tests to maintain control of the preparation of the cements.

In the second variation, the one-pass Vortec milled material was first classified at the desired cut point (30 or 22 microns) to obtain the fine fraction. The coarse fraction was then close-circuit milled at the same cut point. This procedure permitted more rapid milling without wasting material or requiring additional testing.

Despite these variations, the cements were found to have B.S.S. values, particle size distributions and performance essentially equal to those of the first three batches.

Sub-Task IC(a): Blended Cements

The blended cements listed in Table 3E were used to prepare blended cement paste mixes. The volume of 70 percent cement + 30 percent mineral admixture mixes was equal to the cement

volume in the portland cement control mixes; the water contents were also constant at the value for $w/c = 0.5$ in the control mixes so that the volumes of the paste were equal to those of the controls. Since the densities of the mineral admixtures were slightly less than those of the portland cements, the weights and water/solids ratios varied slightly, as indicated in Tables 18 and 19.

The test results obtained with these blended cements are given in Tables 18 and 19, where they are arranged in different order from Table 3E to make it easier to compare effects of each major admixture and smaller increments of other admixtures (some entries are duplicated).

Table 18 shows data obtained with the less than 23 micron cement RB2128. All four major mineral admixtures improved the flow properties of fresh pastes made with this cement. Strength results are expressed as the percentage of the strength of the control at the same age. As expected, replacement of 30 percent of the cement with any of the major mineral admixtures resulted in considerable reduction of strength. This effect was greatest with the Class F fly ash and the coarse fraction of the ground slag, and was least with the Class C fly ash. Class C fly ashes are known to be cementitious because of their relatively high CaO contents. The slowly reacting Class F fly ash blend showed lower early strengths but improvement with longer curing time. The granulated slag blend showed strength development between the Class C and Class F fly ash blended cements.

TABLE 18. EFFECTS OF SEVERAL MINERAL ADMIXTURES IN
BLENDED CEMENTS (70% 2128 AND 30% ADMIXTURES)

Mix No.	Blended Cement Compositions (volume percentages)			Fresh Paste Properties		Compressive Strength (percent of control)		Drying Shrinkage (percent)	
	Major Admix.	Other Admix.	(%)	Water/ Solids (g/g)	Pat Area ₂ (in. ²)	1-day (2350 psi)	7-day (6575 psi)	7-day cure	28-day cure
2128 (control)	None	0	None	0.50	13.6	(2350 psi)	(6575 psi)	0.31	0.33
2196	F	30	None	0.53	19.5	53.2	54.7	0.28	0.32
2207	F	28	s.f.	0.54	11.2	48.9	60.8	0.30	0.38
2204 IC(b)	F	25	L	0.53	17.0	59.6	63.1	0.30	0.34
2200	F	15	S	0.52	20.3	54.2	54.7	0.30	0.38
2202	F	15	Sc	0.52	22.5	50.0	55.9	0.28	0.34
2210	F	15	{Sc &L 5}	0.52	19.8	66.0	67.3	0.27	0.33
2197	C	30	None	0.52	24.3	80.8	66.9	0.34	0.44
2208	C	28	s.f.	0.53	14.9	81.9	76.8	0.39	0.50
2205	C	25	L	0.52	21.9	84.0	83.6	0.36	0.39
2201	C	15	S	0.52	20.1	54.3	72.6	0.34	0.43
2203	C	15	Sc	0.52	24.4	71.3	66.2	0.29	0.41
2211	C	15	{Sc &L 5}	0.52	21.5	65.5	63.9	0.34	0.36
2198	S	30	None	0.51	18.7	61.7	70.7	0.33	0.41
2200	S	15	F	0.52	20.3	54.3	54.8	0.30	0.38
2201	S	15	C	0.52	20.1	54.3	72.6	0.34	0.43
2212	S	15	{Sc &L 5}	0.51	20.5	62.8	63.1	0.29	0.33
2199	Sc	30	None	0.51	24.8	51.1	63.1	0.27	0.31
2209	Sc	28	s.f.	0.51	13.5	54.3	65.4	0.31	0.37
2206	Sc	25	L	0.51	21.9	64.9	73.8	0.29	0.31
2202	Sc	15	F	0.52	22.5	50.0	55.9	0.28	0.34
2203	Sc	15	C	0.52	24.4	71.3	66.2	0.29	0.41

F = Class F fly ash PDG388

C = Class C fly ash 21834

s.f. = silica fume PDG383

S = granulated blast furnace slag PDG468

Sc = granulated blast furnace slag PDG468 (>15 microns)

L = ground A-140 limestone

Two percent silica fume in these blends reduced the flow, or increased the water requirement for flow, of all of these cements. The effects on strength were not consistent, both positive and negative effects occurring at different ages in the same blends.

Five percent ground limestone only slightly reduced the flow, but improved strengths at all ages in all of these blends.

Fifteen percent slag substituted for fly ash had little effect on strength of the fly ash blends except for reductions of the 1-day strengths of the Class C fly ash blends. Quaternary blends with coarse slag and limestone significantly increased the strength of the Class F fly ash blend, but not of the others.

Drying shrinkage of the blends increased with curing time and the amount of silica fume or Class C fly ash. The fine granulated slag increased the drying shrinkage of the Class F fly ash blend, but not that of the Class C fly ash blend. Coarse slag and limestone tended to reduce drying shrinkage.

Results obtained with the less than 31 micron cement RB2137 given in Table 19 are less complete but show some similar trends. Since the data in Table 18 always showed beneficial effects with 5 percent ground limestone, all of these blends were made with limestone.

Five percent limestone with the Class F fly ash blend yielded higher relative strengths than with the RB2128 cement. Comparable Class C fly ash and slag blends usually showed lower relative strengths than with cement RB2128.

TABLE 19. EFFECTS OF SEVERAL MINERAL ADMIXTURES IN
BLENDED CEMENTS (70% 2137 AND 30% ADMIXTURES)

Mix No.	Blended Cement Compositions (volume percentages)				Fresh Paste Properties		Compressive Strength (percent of control)			Drying Shrinkage (percent)	
	Major Admix.	(%)	Other Admix.	(%)	Water/ Solids (g/g)	Pat Area ₂ (in. ²)	1-day (1975 psi)	7-day (6225 psi)	28-day (9325 psi)	7-day cure	28-day cure
2137	None	0	None	0	0.50	21.4				0.30	0.33
2213 IC(b)	F	25	L	5	0.53	25.5	61.5	63.8	67.0	0.32	0.32
2216	F	15	{ Sc εL	{ 10 5	0.52	27.1	59.5	56.6	64.9	0.26	0.29
2214	C	25	L	5	0.52	25.8	78.2	73.9	75.3	0.36	0.37
2217	C	15	{ Sc εL	{ 10 5	0.52	23.5	74.7	74.7	62.2	0.27	0.32
2215	Sc	25	L	5	0.51	25.4	56.2	58.6	63.2	0.28	0.30
2218	S	15	{ Sc εL	{ 10 5	0.51	22.5	64.6	62.2	71.8	0.26	0.30

IC(b) = Selected for Sub-Task IC(b)

F = Class F fly ash PDG388

C = Class C fly ash 21834

s.f. = silica fume PDG383

S = granulated blast furnace slag PDG468

Sc = granulated blast furnace slag PDG468 (>15 microns)

L = ground A-140 limestone

Criteria in addition to strength were used to select the three best blended cements to be used in Sub-Task IC(b). It was originally intended to prepare blended cements similar to the recognized ASTM Types IP and IS blended cements made with a Class F fly ash and a granulated slag. Provision was also made for a third, multicomponent, blend. The Class C fly ash was included in Sub-Task IC(a) because such ashes are coming into more common use and will be of increasing interest as more Western coals are used for power generation. The particular Class C ash used here yielded blended cements with very good strength development. However, drying shrinkage of the hardened cements was substantially greater than the controls, even with 5 percent limestone. Shrinkage of concrete causes cracking and reduces the useful life of concrete structures. Since the main objective of Sub Task IC is to determine the efficacy of using CPSD cements in blended cements, rather than characterization of fly ashes, it was decided to use the more conventional and widely used Class F fly ash.

Blend 2204 with 5 percent limestone was selected because of its improved earlier strengths. The granulated slag was selected as the second generic type of mineral admixture. Blend 2212 with 5 percent limestone and 10 percent coarse granulated slag was selected because both the paste flow and 28-day strengths were greatest and the drying shrinkage was substantially less than with the fine slag alone. It was originally supposed that the less than 23 micron cement RB2128 would be the cement that would benefit most from the improved

flow and compensate for the reduced early strengths of blended cements. The results in Tables 18 and 19 showed that this was not always true. The data show that the relative strengths of the blends of Class F fly ash, 5 percent limestone, and the less than 31 micron cement RB2137 were higher than those made with the less than 25 micron cement RB2128. Blended cement 2218 was selected, therefore, as the third blended cement for use in Sub-Task IC(b).

Sub-Task IC(b): Blended Cements

The 15 blended cements listed in Table 3F were used to prepare blended cement paste mixes. Results available to date are given in Table 20. These show progressive reduction of 1-day strengths as the mineral admixture contents increase from 0 to 40 percent, for all of the blended cements. As expected, this reduction is not as pronounced for the two CPSD cements as for the normally ground cement RB2119 in the blended cements containing fly ash. For the blended cements containing granulated slag, this advantage of the CPSD cements is not apparent over the normally ground cements at 20 percent mineral admixture, but becomes apparent at higher admixture contents.

Sub-Task IE: Soundness Tests

The first three cements selected for soundness tests were the cements prepared for Task II: RB2119, 2128, and 2137. Soundness testing included 1) compressive strengths of mortars by ASTM C109 at ages up to 1 year, 2) autoclave expansion of cement paste bars by ASTM C151, and 3) expansion of mortar bars

TABLE 20. EFFECTS OF MINERAL ADMIXTURE CONTENT ON PERFORMANCE
OF BLENDED CEMENTS MADE WITH RB2110, 2128, AND 2137

Mix No.	Cement	Mineral Admix. (%)	Water/ Solids (g/g)	Pat Area ² (in. ²)	Compressive Strength ASTM C109 (psi)			
					1-day	7-day	21-day	28-day 91-day
2119	2119	100	0	25.5	2375	5750		8900
2221	2119	80	20	27.9	1470	5100		
2222	2119	70	30	30.6	1115	4750		
2223	2119	60	40	30.0	730	2900		
2128	2128	100	0	13.6	2350	6575		9150
2224	2128	80	20	20.2	1900	4800		
2225	2128	70	30	22.0	1387	3700		
2226	2128	60	40	24.3	1125	3100		
2137	2137	100	0	21.4	1975	6225		9325
2227	2137	80	20	26.8	1525	4950		
2228	2137	70	30	28.5	1187	3850		
2229	2137	60	40	27.5	875	3200		
2230	2119	80	S+Sc+L	30.2	1625	5700		
2231	2119	70	S+Sc+L	31.1	1177	4700		
2232	2119	60	S+Sc+L	31.2	850	4100		
2233	2128	80	S+Sc+L	16.7	1600	5300		
2234	2128	70	S+Sc+L	21.5	1395	4900		
2235	2128	60	S+Sc+L	23.6	1067	3900		

F = Class F fly ash PDG 388

S = ground granulated blast furnace slag PDG468

Sc = ground granulated blast furnace slag PDG468 (>15 microns)

L = ground A-140 limestone

during moist curing by ASTM C157 for ages up to 1 year. The latter calls for flow table tests to determine the water content required for standard plastic consistency (flow of 110 ± 5 percent).

Results obtained to date for the Task II portland cements are given in Table 21. These compressive strength results at 0.475 water/cement ratio are consistent with the neat cement paste results of 0.4 and 0.5 water/cement ratio given in Table 17 of the August-October 1982 Quarterly Report. The paste results are higher mainly because ASTM C109 mortars contain entrapped air and the cement pastes are almost free of air voids.

The autoclave expansion test is an accelerated test designed to reveal potential unsoundness of portland cements due to delayed expansion caused by the hydration of CaO or MgO or both. None of these cements exceeded the 0.8 percent maximum expansion allowed by ASTM C150: Standard Specification for Portland Cements; in fact, they contracted instead of expanded. None of these cements indicated any tendency toward unsoundness by this test.

The mortar flow table tests indicated that the water requirement of the less than 31 micron cement 2137 was less, and that of the less than 23 micron cement 2128 was about the same, as that for the normally ground cement 2119. These mortar flow results disagree with cement paste mini-slump pat areas and concrete slump tests which both indicated that cement 2128 had a higher water requirement than the other cements. Mortar bar expansions do not indicate excessive expansion up to 8 weeks.

TABLE 21. SOUNDNESS TEST RESULTS

Cement	Compressive Strength ASTM C109 (psi)					Autoclave Expansion ASTM C151	Flow Table Test	Mortar Bar Expansion ASTM C157 (percent)					
	1d	7d	28d	91d	364d	(%)	(%)	1d	28d	8 wks	16 wks	32 wks	64 wks
RB2119	1808	4333	5702			-0.015	109	0.47	0	0.008	0.008		
RB2128	2233	5150	6408			-0.014	106	0.46	0	0.009	0.009		
RB2137	1542	4692	6083			-0.012	110	0.46	0	0.008	0.009		

Sub-Task IIA: Concrete Mix Proportions

Testing continued on concrete specimens cast during the previous quarter. Compressive and flexural strength data are given in Tables II-1 and II-2, respectively.

Table II-1. Compressive Strength
(psi)

Cement	Age at Test					
	1d	3d	7d	28d	90d	365d
2119	1320	2940	4150	6210	6970	
2137	1070	3050	4620	6000	7330	
2128	1080	2810	4230	5400	5720	

Each value represents the average of three 3x6-in. cylinders.

Table II-2. Flexural Strength
(psi)

Cement	Age at Test		
	3d	7d	28d
2119	525	755	790
2137	480	690	810
2128	480	710	790

Each value represents the average of three 3x3x11-1/4 inch prisms tested under third-point loading.

Compressive strengths for concretes prepared with cements 2119 and 2137 are roughly equivalent at 28 and 90 days. Cement 2128 shows lower strength, but most of this may be attributable to the higher w/c ratio used in this concrete. Flexural strengths for all concretes are nearly identical at 28 days age.

Results of shrinkage measurements through 2 months of drying are presented in Table II-3. These specimens were cured seven days in a fog room, then placed in laboratory air maintained at $73 \pm 2^\circ\text{F}$ and approximately 50 percent relative humidity.

Table II-3. Drying Shrinkage
(%)

Cement	Drying Time		
	1 wk	4 wk	2 mo
2119	0.019	0.039	0.048
2137	0.014	0.032	0.040
2123	0.016	0.035	0.043

Concrete cast with cement 2137 exhibits less shrinkage than does that cast with normal grind cement (2119). While this may be attributable to particle-size effects, the lower water content of the 2137 mix also would tend to produce less shrinkage. On the other hand, the concrete cast with cement 2128 has a higher water content, but somewhat less shrinkage; thus, particle size appears to be a major factor in this case.

Elastic moduli were determined after 28 days of moist curing. Values were 4.3×10^6 psi, 5.0×10^6 psi, and 4.7×10^6 psi for cements 2119 (normal grind), 2137, and 2128, respectively. The particle size cements apparently exhibit somewhat higher moduli than does the normal grind.

Creep tests were initiated after 28 days of moist curing. Specimens were placed in a room maintained at $73 \pm 2^\circ\text{F}$ and approximately 50 percent relative humidity. Test specimens were loaded to a uniform value of 2500 psi. Companion specimens were left unloaded in the same environment to provide a

correction for drying shrinkage. Raw data (in microstrain/psi) were multiplied by 28-day compressive strength in order to obtain a normalized creep coefficient. Results through 50 days of test are shown in Figure II-1. Particle size cement concretes exhibit lower creep than do normal grind cement concretes.

Tests for resistance of concrete to accelerated sulfate attack were initiated after 28 days of moist curing. Specimens are stored in 10 percent sodium sulfate solution at 70-80°F for 16 hours, then placed in a room maintained at 130±3°F for 8 hours. This cycle is repeated daily. Weight change through 2 months of test is shown in Table II-4.

TABLE II-4. Sulfate Resistance
(Weight Change in %)

Cement	Age		
	1 mo	2 mo	3 mo
2119	+0.002	-.098	+0.190
2137	-.087	-.060	+0.064
2128	-.370	-.320	

This is a long-term test and results are not sufficiently advanced for any conclusions to be reached at this time.

Sub-Task IIB: Effects of Chemical Admixtures

Tests of properties of fresh concretes containing water-reducing admixtures were concluded. Summary results for bleeding and setting time are presented in Tables II-5 and II-6, respectively.

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10 X 10 TO 10 1/2 X 10 1/2 IN. 2 1/2 X 10 1/2 IN. KEUFEL & LORICO, MADE IN U.S.A.

Figure II-1. Normalized Creep vs. Time under Load

TABLE II-5. Bleeding Test Results
(% of Net Water)

<u>Cement</u>	<u>Control</u>	<u>WRDA-79</u>	<u>Mighty-150</u>
2119	1.79	4.79	10.83
2137	3.25	3.45	10.38
2128	2.22	3.36	12.08

TABLE II-6. Setting Time of Concrete Mixtures

<u>Cement</u>	<u>Admixture</u>	<u>Time-of-Set</u>		<u>Retardation</u>	
		<u>Initial hr:min</u>	<u>Final hr:min</u>	<u>Initial hr:min</u>	<u>Final hr:min</u>
2119	None	4:30	6:00	-	-
	WRDA-79	6:40	8:25	2:10	2:25
	Mighty-150	5:05	7:32	0:35	1:32
2137	None	5:00	7:03	-	-
	WRDA-79	6:50	8:05	1:50	1:02
	Mighty-150	5:00	7:17	0:00	0:14
2128	None	4:51	6:42	-	-
	WRDA-79	6:30	8:28	1:39	1:46
	Mighty-150	4:45	7:18	-0:06	0:36

- signifies acceleration of set

Mixtures prepared with Mighty-150 exhibit high amounts of bleeding. This may be partially attributed to the very low cement content in these mixtures. Setting times of normally ground mixes containing Mighty-150 are slightly retarded. There is much less of a retardation effect for controlled particle size cements, and in one instance an acceleration of set was noted.

Compressive and flexural strengths of mixtures containing water reducers through 28 days are presented in Tables II-7 and II-8, respectively.

TABLE II-7. Compressive Strength of Concretes
Containing Admixtures (psi)

Cement	Admixture	Age at Test			
		3d	3d	7d	28d
2119	WRDA-79	670	2760	4370	5590
	Mighty-150	1190	3070	4240	5960
2137	WRDA-79	560	3290	4420	5270
	Mighty-150	1035	3010	4160	5650
2128	WRDA-79	610	3270	4440	5890
	Mighty-150	900	2670	3740	5190

TABLE II-8. Flexural Strength of Concretes
Containing Admixtures (psi)

Cement	Admixture	3d	7d	28d
2119	WRDA-79	560	735	820
	Mighty-150	500	700	855
2137	WRDA-79	650	790	945
	Mighty-150	535	710	765
2138	WRDA-79	600	765	955
	Mighty-150	565	645	730

With respect to compressive strength, differences in strength development between cements 2119 and 2137 are relatively minor with both admixtures. With cement 2128 and WRDA-79, however, strengths are roughly equivalent (or slightly higher) than normal grind (2119) strengths at 3 days and beyond, even though w/c ratio is higher.

Flexural strengths of CPSD cements with WRDA-79 are somewhat higher at all ages than those for normal grind (2119). Strength of CPSD cements with Mighty-150 show no consistent pattern when compared to normal grind.

Elastic moduli for admixed concretes measured at 28 days, are shown in Table II-9. Moduli for cement 2137 are lower than normal grind for both admixtures, moduli for 2128 are higher for WRDA-79 and slightly lower for Mighty-150.

TABLE II-9. Elastic Moduli
(psi x 10⁶)

<u>Cement</u>	<u>Admixture</u>	<u>28 days</u>
2119	WRDA-79	5.0
	Mighty-150	5.0
2137	WRDA-79	4.5
	Mighty-150	4.3
2128	WRDA-79	5.5
	Mighty-150	4.8

Other tests on specimens cast during this Sub-Task are not sufficiently advanced for any significant data to be reported at this time.

Sub Task IIC: Air Entrainment

Air-entrained concrete mixtures were prepared using cements 2119, 2137, and 2128. A 2 percent solution of neutralized Vinsol resin was used as air-entraining agent (AEA). Mix properties are given in Table II-10.

TABLE II-10. Air-Entrained Concrete Mix Characteristics

<u>Cement</u>	<u>w/c</u>	<u>Cement</u>	<u>Water</u>	<u>Aggregate</u> (lb/yd ³)		<u>AEA</u>	<u>Slump</u>	<u>Air</u>
		(lb/yd ³)	(lb/yd ³)	<u>Fine</u>	<u>Coarse</u>	(ml/lb)	(in.)	(%)
2119	0.50	468	234	1213	1976	2.0	3.5	6.5
2137	0.50	450	225	1181	2085	2.0	2.0	5.7
2128	0.53	466	247	1038	2151	2.0	3.5	5.8

Specimens were cast for determination of compressive strength, flexural strength, resistance to freeze-thaw cycling, resistance to deicer scaling, and determination of air void parameters.

Results of compressive and flexural strength tests to-date are given in Tables II-11 and II-12, respectively.

TABLE II-11. Compressive Strength (psi) of Air-Entrained Concretes

Cement	Age at Test			
	1d	3d	7d	28d
2119	1305	2970	3890	
2137	1370	3100	3910	
2128	1250	2640	3420	

TABLE II-12. Flexural Strength (psi) of Air-Entrained Concretes

Cement	Age at Test		
	3d	7d	28d
2119	425	630	
2137	495	620	
2128	565	590	

With respect to compressive strength, CPSD cement 2137 shows just slightly higher strengths than normal grind, and 2128 shows lower strengths, most likely reflecting the higher w/c ratio. With respect to flexural strengths, there are only small differences among the various cements.

Sub-Task II-F: Miscellaneous Tests

Work was carried out on loss of workability with time for concretes containing water-reducing admixtures. Two techniques were used. In the first, termed the "spread test," the diameter over which a cone of concrete spreads, after being subjected to mechanical impact on a flat surface, is measured. In the second, termed the "V-B" test, the time for a cone of concrete to re-form into a cylindrical vessel under a vibratory force is measured.

Spread tests were carried out immediately after mixing, and at 15-minute intervals thereafter. Concrete was remixed for 1 minute prior to each spread determination. When spread approached a value of 13 in.², "V-B" testing was initiated, and continued on the same 15-minute intervals until concretes had entered the "very stiff" range (see Table II-13).

TABLE II-13. Interpretation of "V-B" Readings

<u>"V-B" Reading</u> (sec)	<u>Range of Consistency</u>
0-3	Plastic
3-5	Stiff Plastic
5-10	Stiff
10-18	Very Stiff
18-32	Extremely Dry

Results are shown in Figures II-2 and II-3 for concretes containing WRDA-79 and Mighty-150, respectively. For WRDA-79, behavior of cements 2119 and 2137 for spread loss was nearly equivalent. Cement 2128 initially exhibited a higher spread, but rate of loss was somewhat greater. For "V-B" time, normally

Figure II-2. Workability loss for concrete prepared with WRDA-79.

ground cement showed the highest initial time, followed by 2137 and 2128. Cement 2128 was able to maintain its "V-B" time below the "very stiff" range for a longer period than the other two cements. With Mighty-150, results for 2119 and 2137 with respect to spread loss were again similar. In this case, cement 2128 showed a somewhat lower rate of spread loss, and was able to maintain spread above 13 inches for a greater time period than the other two cements. With respect to "V-B" time, cement 2137 showed the most rapid rise, followed by 2119 and 2128. The rate of rise of "V-B" time for all cements with Mighty-150 was much greater than with WRDA-79. Much of this can be attributed to the greater paste reductions in concrete prepared with Mighty-150.

PLANS FOR FUTURE WORK

Task I

The blended cements being prepared in Sub-Task IF for use in Task II will be completed in February. Long term tests of the blended cements in Sub-Task IC will continue on schedule until the end of April. Testing of the blended cements to be used in Task II will also be tested in Sub-Task IB(b) beginning in March.

Cement clinkers with high free CaO and MgO are being acquired for use in Sub-Task IE; these clinkers will be made into ordinary and CPSD portland cements in Sub-Task IF as they arrive.

Task II

Work on Sub-Task IIA using blended cements has been postponed until blended cements become available, now scheduled for March 1, 1983. Casting of all Sub-Task IIB specimens is complete; testing will continue throughout 1983. All casting of Sub-Task IIC specimens is complete; testing will continue throughout 1983. Sub-Task IID will commence in mid-February 1983. Sub-Task IIF will enter a hiatus until Sub-Task IIA casting is completed, then additional work will be initiated.

END

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