NATIONAL BUREAU OF STANDARDS REPORT

4200

QUARTERLY REPORT
ON

EVALUATION OF REFRACTORY QUALITIES OF CONCRETES FOR JET AIRCRAFT WARM UP, POWER CHECK, AND MAINTENANCE APRONS

by

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U. S. DEPARTMENT OF COMMERCE
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Refractories Section

Mineral Products Division

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TECHNICAL REQUIREMENTS

The technical requirements for the concretes designed with dense aggregates are the same as those given in NBS Report 3012, dated December 31, 1953.

The technical requirement for the concretes designed with lightweight aggregates are: (1) they must develop a flexural strength of 600 psi after curing for 28 days in the fog-room; (2) the maximum cement content shall not exceed nine sacks per cubic yard.

1. INTRODUCTION

The objective of the investigation is the determination of the physical properties of concretes that will evaluate their suitability for use in jet aircraft warm-up, power check, and maintenance aprons.

2. MATERIALS: PREPARATION AND TESTING

2.1 Cements

The permanent length change, the water lost as indicated by the weight loss, and the decrease in strength as indicated by Young's modulus of elasticity (dynamic method) were determined on specimens fabricated from each of the three types of cement

namely portland, portland pozzolon and high-alumina. Each was mixed with water to a normal consistency [1] and the specimens fabricated from the mix were cured for 28 days in the fog-room. They were then weighted, measured, and Young's modulus determined. The specimens were then heated to apparent constant weight at 100°C, removed from the oven, cooled in a desicator, and the same properties redetermined. This operation was repeated at 100°C intervals to 500°C.

2.2. Aggregates

Coarse fractions of the lightweight aggregate, "Rocklite", are marketed in sizes not comparable to the standard sizes commonly used in concrete design[2]. The fines are furnished as passing a No. 8 mesh screen. Since this is a coated material the usual method of crushing to obtain desired sizes could not be used. It was, therefore, necessary to screen a comparatively large amount of this aggregate to recover the needed percentages of the various sizes. The screening has been completed and the aggregate was recombined to the finness moduli that would develop the maximum strength in the trial mixes of concrete.

The rate of absorption, saturated surface dry, was determined on the aggregate at 5-minute intervals up to one-half hour. This information was necessary in order that the amount of free water available for mixing be known when the aggregate is charged into the mixer in a dry condition. Having this information is important,

especially when concretes containing high-alumina hydraulic cement are mixed. In such mixes it is necessary to add the required water at one time due to the rapid initial set of the cement.

The method used in saturating the aggregate for the concrete mix was as follows: It was placed in burlap sacks, and immersed in water for 8 hours, the sacks and contents were then removed from the water and drained for 18 hours and weighed. This method was found to be the most convenient for the size of batches used.

2.3. Concretes

Five one-cubic foot trial batches, one five-cubic foot and three 15-cubic foot final batch of concretes were designed and mixed. The properties of the fresh concretes were determined, and specimens were fabricated, cured, and those tested which had completed the curing period.

Two of the five trial mixes were designed with the lightweight aggregate, "Kenlite", and portland cement in one and portland pozzolan in the other.

The other three trial mixes were designed with the lightweight aggregate, "Rocklite". Portland cement was used in one of the mixes portland pozzolan in the second and the high-alumina hydraulic cement, "Lumnite", in the third.

Three final 15-cubic foot batches were designed with the "Rocklite" aggregate and contained either portland, portland pozzolan, or Lumnite cement.

One final five-cubic foot batch of concrete was designed with portland cement and olivine as the aggregate. White Marsh sand, -30 to -100, was substituted for 50 percent of the fines of the parent aggregate. The reduction in volume (from 15 to 5 cubic ft.) of this batch was due to a shortage of the aggregate.

In the March 31, 1955, quarterly report information was given on concretes containing sintered slag. The properties of three of these concretes containing either portland, portland pozzolan, or the high-alumina cements were determined after curing and after heat treatments at 250°, 500° and 1000°C respectively.

The properties of the three concretesdesigned with portland cement and containing either crushed building brick, olivine, or calcined Kentucky flint clay as part of the aggregate were determined after two curing periods and the same three heat exposures. White Marsh sand was substituted for 50 percent of the fines, -30 to -100, in these concretes as detailed also in the preceding quarterly report.

3. Results and Discussion

3.1. Cements

Subjecting the neat cement specimens to increasing heat treatments resulted in a continual linear shrinkage. The linear shrinkage for all three cements based on the length of the specimen as removed from the fog-room after a 28 day curing period, was uniform to 300°C. The shrinkage up to that temperature of portland pozzolan cement was 1.49 percent, that of portland 1.08 and that of

Lumnite 0.86 percent. From 300° to 500°C the portland cement continued to shrink at a uniform rate to a total of 1.9%. From 300? to 400°C the pozzolanic portland cement continued to shrink uniformly to a total of 2.12 percent, but from 400° to 500°C there was a decided decrease resulting in a final shrinkage of 2.14 percent. The high-alumina hydraulic cement changed very little from 300° to 500°C, and the total for the entire range was 0.87 percent.

The percent water lost, as indicated by weight loss, was based on the weight of the specimens after the 28 day fog-room curing. It was assumed that the original proportion of mixing water had not changed. The lumnite cement had lost all the mixing water at 300°C; the portland pozzolan at 400°C and the portland at 500°C.

The method, although it indicates the weight lost after heating at the various temperature, and a greater part of this loss is probably water, is not considered too accurate. Some of the errors that maybe introduced are for example: the mixing water may not be equally distributed from one specimen to another; bleeding may occur during or after fabrication; the cements may gain or lose a small percentage of the water during curing; repeated handling of the specimens even with utmost care may cause some loss.

Young's modulus of elasticity was determined, of each specimen after each treatment. The modulus for all cements after the 28 day fog-room curing was above 5,000,000 psi. Increasing the heat treatments to 500°C reduced this value to slightly above 1,000,000 psi for the Lumnite, and portland pozzolan and 2,000,000 psi for the portland. This decrease in modulus of elasticity would indicate a corresponding decrease in strength.

3.2. Aggregate

The rate of absorption, saturated surface dry[3/] for the coarse aggregate sized to the gradation used in the concretes was as follows:

5 Min. Immersion	2.4 Percent
10 " "	2.6 "
15 " "	3.2 "
30 " "	3.4 "

The absorption[4/] for the fine aggregate was as follows:

5 Min. Immersion	11.7 Percent
10 " "	13.7 "
15 " "	16.3 "
30 " "	17.3 "

The method used in wetting the aggregate resulted in somewhat higher absorption values because the surface water was not completely removed especially from the fines. The producers of this aggregate recommend that it be used at 75 percent of its total absorption and claim to obtain this condition by spraying.

3.3. Concretes

Table 1 gives the composition and some properties of the fresh concretes, together with the flexural strengths after 28 days of fog-room curing. The trial mixes P-K-G[3] and Z-K-E[3] contained the +3/4" top-size of the aggregate "Kenlite". The flexural strengths given, when compared with those appearing in table 3 of NBS Report 3855, December 31, 1954 indicate that this coarse size of aggregate did not tend to increase the flexural strength of the concrete. Apparently the strength of the aggregate decreased with increase in size.

Table 1 also gives the composition and some of the properties of the fresh concretes designed with, "Rocklite" aggregate. The trial batches identified as P-R-E[3], P-R-F[3], and P-R-G[3] contained increased amounts of the +1" to +1/2" aggregate. Trial batches P-R-H[4], Z-R-E[4], and L-R-E[4] contained increased amounts of the intermediate sizes + 3/8" and +No4. Such variation of the finness moduli resulted in only one concrete (Z-R-E[4]), that met the technical requirement for flexural strength of 600 psi.

The last column of this table gives the flexural strengths of prisms measuring 3 x 4 x 16 inches. The values for flexural strength when determined on smaller specimens have been consistently higher than when determined by the ASTM method[5]. Most of the available data on the flexural strengths of lightweight aggregate concrete was determined on specimens similar in cross sectional area to the 3 x 4 x 16 inch prisms.

Table 1. Properties of Fresh Concretes,[a] Trial Batches.

Identification[b]	Proportion by Weight of Cement to Coarse and to Fine Aggregate	Cement Content	Vinsol Resin by Weight of Cement	Water Content[c]	Air Content[d] Gravimetric Method	Slump	Weight of Fresh Concrete	Water Cement Ratio	Remarks: Fresh Concrete	Flexural[e] Strength 6x6x20" Beams	Remarks: Cured Concrete	Flexural[e] Strength 3x4x16" Prisms
		sacks/yd^3 of concrete	percent	gals/yd^3 of concrete	percent	inches	lbs/ft^3			psi		psi
P-K-F^1	1 : 1.06 : 0.70	8.71	0.005	37.8	5.50	2.25	100.00	0.39	very good	605	mostly aggregate fracture	740
P-K-G^3	1 : 1.03 : 0.68	8.97	.005	42.6	3.02	4.25	102.05	.42	easily placed; too wet	560	large air voids; aggregate fractured along cleavage lines	715
Z-K-E^3	1 : 0.98 : 0.65	9.56	none[f]	42.2	1.79	0.50	104.70	.39	fair; sticky	550	large air voids; aggregate fractured along cleavage lines	770
P-R-E^3	1 : 0.92 : 0.76	8.93	.005	38.7	3.04	6.00	100.00	.38	good placeability	505	all aggregate fractured	575
P-R-F^3	1 : 1.01 : 0.67	8.98	.005	35.7	2.95	2.50	99.40	.35	good placeability	500	all aggregate fractured	550
P-R-G^3	1 : 1.09 : 0.59	8.65	.005	34.1	5.49	2.50	95.60	.35	slightly harsh but placeable	560	all aggregate fractured	700
P-R-H^4	1 : 0.99 : 0.73	9.06	.005	34.4	2.03	0.50	101.20	.34	fair placeability	460	several large pull-outs; air voids	590
Z-R-E^4	1 : 1.05 : 0.66	8.53	none[f]	38.9	4.10	2.50	96.90	.40	very good	620	few air voids; 100% aggregate fracture	690
L-R-E^4	1 : 0.97 : 0.75	9.07	.005	36.3[g]	8.72	1.50	97.20	.35	very good	475	25% pull-outs	575

a/ For convenience the flexural strength of specimens, fabricated from trial batches and cured for 28 days in fog-room, are included.
b/ The first letters: P = portland cement; Z = portland pozzolan cement; L = Lumnite, a high-alumina hydraulic cement.
The second letters: K = Kenlite, a lightweight, expanded shale, crushed aggregate; R = Rocklite, a lightweight expanded shale, coated aggregate.
The third letters are batch identification, with superscript 1, 3, and 4 indicating a change in gradation of the aggregate (see text for details).
c/ The mixer was charged with the aggregate in a saturated-surface dry condition.
d/ The use of the pressure method in determining the air content in concretes, designed with this type aggregate (lightweight aggregate with high absorption) is not recommended.
e/ The flexural strength as determined, after 28-day fog-room curing, on 6 x 6 x 20 inch beams (A.S.T.M. Method C78-44) and 3 x 4 x 16 inch prisms; (using an 18 inch and 13 1/2 inch span respectively).
f/ This type cement, Green-bag portland pozzolan, was purchased with an air-entraining agent.
g/ The mixer was charged with dry aggregate.

Table 2 gives the properties of the fresh concretes as determined on the three final 15-cubic foot mixes. "Rocklite" was the aggregate in these concretes and the bond either portland, portland pozzolan, or the high-alumina hydraulic cement. The results indicate the probable variation in the properties of concrete of the same design that may be expected in laboratory controlled mixing. Flexural strength determinations on beams fabricated from the many trial mixes previously reprted indicated that the maximum strength to be expected would not be greater than 600 psi. The low average value of 585 psi for the flexural strength of the concrete designed with portland pozzolan cement was caused by the results of a beam fabricated from mix Z-R-1. This particular mix was too plastic, because of low water content, to fabricate sound beams for testing.

Table 3 gives the composition and some properties of the fresh concretes, together with the flexural strength of the final batches designed with portland cement and either crushed building brick, calcined Kentucky flint clay, or olivine. In designing three of these concretes, namely P-B-WM, P-C-WM and P-O-WM, white marsh sand was substituted for 50 percent of the fine parent aggregate. The properties of the concretes that do not contain the white marsh sand have appeared in previous reports but are again given to illustrate how the sand effects the properties. Flexural strength determinations on beams fabricated from trial mixes of the

Table 2. Properties of Fresh Concretes,[a] Final Mixes, with Lightweight Aggregate.

Identification[b]	Proportion by Weight of Cement to Coarse and to Fine Aggregate	Cement Content	Vinsol Resin by Weight of Cement	Water Content	Air Content[c] Gravimetric Method	Slump	Weight of Fresh Concrete	Water Cement Ratio	Remarks Fresh Concrete	Flexural[d] Strength	Remarks Cured Concrete
		sacks/yd^3 of concrete	percent	gals/yd^3 of concrete	percent	inches	lbs/ft^3			psi	
P-R-1	1 : 1.01 : 0.73	8.77	0.005	35.9	2.83	1.75	99.57	0.36	slightly sticky but placed well		
P-R-2	do	8.81	.005	37.3	1.73	2.25	100.43	.37	placed well	605[d]	all aggregate fractured
P-R-3	do	8.78	.005	35.5	1.50	1.50	99.57	.36	slightly sticky but placed well		
Z-R-1	1 : 1.00 : 0.64	9.06	none[e]	35.3	3.77	1.25	98.70	0.35	sticky but placeable		
Z-R-2	do	9.00	do	41.8	1.19	2.37	100.00	.41	very good	585[d]	all aggregate fractured
Z-R-3	do	9.01	do	41.2	1.33	2.50	100.00	.41	do		
L-R-1	1 : 0.97 : 0.72	9.17	0.005	25.2	6.80	0.50	98.27	0.24	poor placeability, too stiff		
L-R-2	do	9.27	.005	25.2	4.78	0.50	100.40	.24	do	-[f]	-[f]
L-R-3	do	9.04	.005	30.7	3.93	1.00	98.70	.30	fair placeability		

a/ For convenience the flexural strength of specimens fabricated from final mixes and cured for 28 days in fog-room are included if tested.

b/ The first letters: P = portland cement; Z = portland pozzolan cement; L = Lumnite, a high-alumina hydraulic cement.
The second letter: R = Rocklite, a lightweight aggregate.
Numerals 1, 2 and 3 indicate the number of the mix, same design but different charges.

c/ The use of the pressure method in determining the air content in concrete with this type aggregate (lightweight aggregate of high absorption) is not recommended.

d/ The value for flexural strength is an average value for specimens fabricated from individual mixes 1, 2 and 3.

e/ This type cement is furnished the trade with an air entraining agent added.

f/ Dash indicates tests have not been completed.

Table 3. Properties of Fresh Concretes,[a] with Sand Substituted for Portion of Fines.

Identification[b]	Proportion by Weight of Cement to Coarse and to Fine Aggregate	Cement Content	Vinsol Resin by Weight of Cement	Water Content	Air Content		Slump	Weight of Fresh Concrete	Water Cement Ratio	Remarks Fresh Concrete	Flexural Strength[c] 28-day Fog-Room Curing
					Gravimetric Method	Pressure Method					
		sacks/yd^3 of concrete	percent	gals/yd^3 of concrete	percent	percent	inches	lbs/ft^3			psi
P-B	1 : 3.12 : 1.47	6.02	0.010	33.3	5.38	6.04	2.75	136.46	0.46	harsh but placeable	685
P-B-WM	1 : 2.72 : 1.28[d]	7.21	.005	37.4	3.43	3.62	2.00	138.55	.46	harsh but placeable slight bleeding	790
P-C	1 : 3.02 : 1.42	7.12	.015	35.4	2.38	4.46	2.00	147.12	.44	very easily placed	705
P-C-WM	1 : 2.84 : 1.33[d]	7.68	.015	35.3	4.45	5.78	1.00	150.22	.41	harsh but placeable	800
P-O	1 : 3.50 : 1.50	7.17	.030	33.8	2.25	3.27	2.00	170.00	.39	plastic but easily placed	665
P-O-WM	1 : 3.50 : 1.50[d]	7.23	.005	31.5	5.55	6.01	1.00	161.27	.39	plastic but easily placed	700

a/ The properties of three of these concretes identified as P-B, P-C, and P-O appeared in N.B.S. Reports 3201 and 3399 respectively.

b/ The first letter: P = portland cement.
The second letters: B = crushed building brick; C = calcined Kentucky flint clay; O = olivine.
The third set of letters: WM indicates the substitution of White Marsh sand for 50 percent of the fine parent aggregate.

c/ The flexural strength was included for comparative purposes.

d/ The third term of the ratio describing the design of the concrete includes 50 percent of the parent aggregate, as identified, and 50 percent White Marsh sand.

concretes, containing some sand, indicated that an increase in cement would be necessary to maintain the specified strength.

The substitution of sand in concretes P-C-WM, and P-O-WM resulted in a higher air content.

The sand, when introduced in the design of concretes P-B and P-C, reduced the lubricating effect of the fine parent aggregate. This produced a harsher mix and necessitated reducing the ratio of coarse to fine aggregate to obtain workable concretes.

In general the properties of the fresh concretes indicated that sand might be substituted for all the fines without adversely effecting their properties.

Table 4 gives the properties of the cured and heat-treated concretes. The results indicate that sand may be substituted for part of the fines of the parent aggregate. The use of sand did not seriously affect the strength, resistance to abrasion, Young's modulus of elasticity or the shrinkage of these concretes when tested after two different curing treatments or the heating at 250°C. When, however, specimens were tested either after the 500°C or 1000°C heat treatment, the results indicate that the sand was the cause of a reduction, in the strength of the concrete, its resistence to abrasion, and an increase in the expansion.

Table 5 gives the properties of three cured and heat-treated concretes designed with sintered slag aggregate and either portland,

Table 4. Properties of Cured and Heat-Treated Concrete;[a] with Sand Substituted for Portion of Fines.

Identification[b]	Proportions by Weight of Cement to Coarse and to Fine Aggregate	Treatments[c] Preceding Tests	Compressive Strength	Flexural Strength	Type of Failure	Abrasion Loss: Weight of Dust	Abrasion Loss: Depth of Wear[d]	Young's Modulus of Elasticity Dynamic: Longitudinal	Total[e] Linear Change	Total[f] Weight Change
			psi	psi		grams	inches	lbs/inch^2 x 10^6		
P-B	1 : 3.12 : 1.47	1						3.218		
		2						4.750	+0.01	+0.42
		3		435	mostly pull-outs	21.05	0.0075	4.619	-0.01	-2.13
		4	4430[g]	685	few pull-outs	16.05	.0056	5.280	+0.01	+0.51
		5						3.788	-0.02	-5.49
		6		580	few pull-outs	65.15[h]	.0186	3.305	-0.03	-5.76
		7		395	90% pull-outs	93.70[h]	.0233	2.763	-0.08	-6.54
		8		125	all pull-outs	501.00[h]	.1159	1.610	-0.08	-7.73
P-B-WM	1 : 2.72 : 1.28	1						3.464		
		2						5.287	+0.01	+0.40
		3		535	50% pull-outs	43.35	0.0141	5.338	-0.01	-1.48
		4	4640[g]	790	25% pull-outs	15.60	.0074	5.520	+0.00	+0.78
		5						4.475	-0.01	-5.15
		6		555	75% pull-outs, 25% fracture aggregate	53.50	.0162	3.640	-0.04	-5.76
		7		360	50% pull-outs, 50% fracture aggregate	61.00[h]	.0158	2.032	-0.03	-6.94
		8		80	all pull-outs	441.00[h]	.0913	1.083	+0.05	-8.45
P-C	1 : 3.02 : 1.42	1						3.714		
		2						5.619	+0.00	+0.20
		3		520	few pull-outs; mostly aggregate fracture	34.35	0.0094	5.309	-0.02	-1.65
		4	4420[g]	705	few pull-outs; mostly aggregate fracture	19.75	.0069	6.535	+0.03	+0.39
		5						4.634	-0.02	-4.79
		6		590	few pull-outs; mostly aggregate fracture	47.20	.0103	3.555	-0.05	-5.33
		7		425	few fractures; mostly pull-outs	41.45[h]	.0091	2.012	-0.04	-6.73
		8		95	all pull-outs	1198.80[h]	.2360	1.152	-0.24	-7.56
P-C-WM	1 : 2.84 : 1.33	1						4.226		
		2						6.186	+0.01	+0.39
		3		620	all aggregate fractured	9.60	0.0043	5.947	-0.01	-0.68
		4	5810	800	all aggregate fractured	8.55	.0040	6.298	+0.02	+0.50
		5						4.481	-0.03	-3.99
		6		680	75% fracture, 25% pull-outs	23.55	.0072	3.409	-0.02	-4.43
		7		360	50% pull-outs	34.70[h]	.0083	1.576	-0.02	-5.44
		8		60	all pull-outs	1361.00[h]	.2610	.784	-0.03	-7.00
P-O	1 : 3.50 : 1.50	1						3.803		
		2						6.142	+0.01	+0.41
		3		530	few pull-outs	19.75	0.0045	6.545	-0.01	-0.99
		4	4740	665	very few pull-outs	18.15	.0051	7.195	+0.02	+0.61
		5						5.363	-0.03	-3.84
		6		675	few pull-outs	66.50[h]	.0155	4.873	-0.06	-4.25
		7		500	mostly fractured aggregate	96.80[h]	.0219	3.686	-0.13	-4.69
		8		70	all pull-outs	616.00[h]	.1138	1.063	-0.13	-6.90
P-O-WM	1 : 3.50 : 1.50	1						5.480		
		2						6.654	+0.03	+0.34
		3		535	few pull-outs	-	-	7.515	-0.04	-0.87
		4	-[i]	700	some aggregate fracture	-	-	-	-	-
		5						-	-	-
		6				-	-	-	-	-
		7		415	mostly aggregate fracture	-	-	2.254	-0.75	-4.75
		8				-	-	-	-	-

a/ The properties of three of these concretes identified as P-B, P-C, and P-O appeared in N.B.S. Reports 3201 and 3705 respectively.

b/ The first letter: P = portland cement.
The second letters: B = crushed building brick; C = calcined Kentucky flint clay; O = olivine.
The third set of letters: WM = White Marsh sand substituted for 50 percent of the parent aggregate.

c/ The results in line 1 were obtained after 20 to 24 hours in mold; line 2 after 7 days in fog-room; line 3 after line 2 treatment plus 21 days at ordinary laboratory conditions; line 4 after 28 days in fog-room; line 5 after line 3 treatment plus drying at 110°C; line 6 after line 3 treatment plus heating at 250°C for 5 hours; line 7 after line 3 treatment plus heating at 500°C for 5 hours; line 8 after line 3 treatment plus heating at 1000°C for 5 hours.

d/ A description of the apparatus and method used in determining depth of wear was given in N.B.S. Report 3201.

e/ Based on length after 24 hours in mold.

f/ Based on weight after 24 hours in mold.

g/ Low compressive strength, compared to the relatively high flexural strength may be attributed to the smooth surface, shape, and alignment of aggregate in cylinders.

h/ Coarse aggregate exposed.

i/ Dash indicates that due to shortage of aggregate no test specimens were fabricated, consequently no test results obtained.

Table 5. Properties of Cured and Heat-Treated Concretes,[a] with Lightweight Aggregate.

Identification[b]	Proportion by Weight of Cement to Coarse and to Fine Aggregate	Treatment Preceding Test[c]	Compressive Strength	Flexural Strength	Type of Failure	Abrasion Loss: Weight of Dust	Abrasion Loss: Depth of Wear[d]	Young's Modulus of Elasticity Dynamic; Longitudinal	Total[e] Linear Change	Total[f] Weight Change
			psi	psi		grams	inches	$lbs/inch^2 \times 10^6$	percent	percent
L-SS	1 : 1.31 : 1.31	1						4.207		
		2						4.596	-0.000	+ 0.51
		3		505	50% pull-outs; 50% aggregate fracture	40.50	0.0114	4.259	-0.020	- 1.63
		4	7720	670	few pull-outs; mostly aggregate fracture	58.85	0.0171	4.750	+0.020	+ 1.63
		5						2.706	-0.031	- 6.63
		6		435	90% pull-outs	75.25	0.0214	1.857	-0.052	- 8.13
		7		345	90% pull-outs	80.65	0.0227	1.546	-0.090	-10.89
		8		145	all pull-outs	382.00	0.0753	1.534	+0.462	-13.06
P-SS	1 : 1.38 : 1.57	1						2.756		
		2						4.428	+0.025	+ 0.36
		3		485	mostly pull-outs	44.75	0.0148	4.260	no change	- 2.34
		4	5595	795	50% pull-outs; 50% aggregate fracture	35.40	0.0113	4.697	+0.051	+ 0.53
		5						3.373	-0.043	- 7.62
		6		615	75% pull-outs	63.45	0.0170	2.806	-0.053	- 8.32
		7		520	85% pull-outs	91.30	0.0238	2.183	-0.134	- 9.57
		8		130	all pull-outs	572.00	0.1166	1.194	-0.424	-13.01
Z-SS	1 : 1.58 : 1.52	1						1.465		
		2						3.829	+0.003	+ 0.43
		3		470	50% pull-outs	26.20	0.0089	3.971	-0.031	- 3.03
		4	6445	725	25% pull-outs	20.80	0.0067	4.536	+0.150	+ 0.35
		5						2.895	-0.060	- 8.89
		6		600	75% pull-outs; 25% aggregate fracture	66.40	0.0204	2.205	-0.128	- 9.61
		7		465	50% pull-outs; 50% aggregate fracture	69.25	0.0188	1.809	-0.143	-10.43
		8		80	all pull-outs	678.00	0.1509	.576	-0.240	-13.56

a/ Some of the data included in this table appeared in Table 4 of N.B.S. Report 4055 and is reported here for comparative purposes.

b/ The first letters: L = Lumnite, a high-alumina hydraulic cement; P = portland cement; Z = portland pozzolan cement.
The second letters: SS = sintered slag aggregate, second shipment.

c/ The results in line 1 were obtained after 20 to 24 hours in mold; line 2 after 7 days in fog-room; line 3 after line 2 curing treatment plus 21 days at ordinary laboratory conditions; line 4 after 28-day fog-room curing; line 5 after line 3 treatment plus drying at 110°C; line 6 after line 3 treatment plus heating at 250°C for five hours; line 7 after line 3 treatment plus heating at 500°C for five hours; line 8 after line 3 treatment plus heating at 1000°C for five hours.

d/ A description of the apparatus and method used in determining depth of wear was given in NBS Report 3201.

e/ Based on length after 24 hours in mold.

f/ Based on weight after 24 hours in mold.

portland pozzolan, or high-alumina hydraulic cement, as the bond. The results indicate that this type of aggregate may be used in the design of concretes that will meet the specified technical requirements. It was, however, necessary to use from eight-and-one-half to nine sacks of cement to develop the specified strength. After curing for 28 days in the fog-room these concretes developed a flexural strength of well over 650 psi. After the seven day fog-room curing plus the 21-day laboratory storage, these concretes developed equally as much strength as any of those designed in this investigation.

After heat treatments at 250°C and 500°C, the concretes retained a considerable percentage of their original strength. After the treatment at 1000°C, however, the strength and resistance to abrasion were reduced materially and nodules of lime were noted in the concrete. These nodules were up to one-half inch in diameter and occured most frequently at the surface of the specimens causing some cracks to develop. Although the source and method of preparation of this aggregate was traced, no apparent reason for the lime has been uncovered.

REFERENCES

1/ ASTM C187-49

2/ ASTM C136-46

3/ ASTM C127-42

4/ A modification of the ASTM method C128-42, suggested by the laboratories of the Public Roads Administration, and described in detail in NBS Report, "Investigation of Lightweight Aggregate Concrete", by Kluge, Sparks, Tuma, Clevenger, and Robinson - December 2, 1949.

5/ ASTM C78-49

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