NATIONAL BUREAU OF STANDARDS REPORT

4055

QUARTERLY REPORT
ON

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

by

W. L. Pendergast, E. C. Tuma, R. A. Clevenger
and S. F. Holley

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

QUARTERLY REPORT
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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 650 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 lack of storage facilities has made it necessary to procure additional lots of cement, at intervals, during the course of this investigation, to replenish the stock of the three types of cement used in this project. During this quarter an additional 16 sacks of portland cement were

purchased. This lot, as well as preceding ones of the same brand, came from the same plant, and each shipment was tested* in accordance with the Federal Specification applicable to the particular type of cement. Because there is no Federal Specification for high-alumina hydraulic cement, this material was subjected to the same physical and chemical tests as those applying to Type I portland cement.

Observations of the thermal length changes from room temperature to approximately 1200°C were made on the three neat cements. The specimens, which measured 7.25 x 1.25 x 1.25 inches, were cured for 28 days in the fog-room and dried for 18 hours at 105°C before testing. Observations of thermal length changes were made also on the same specimens after two preheatings at approximately 1200°C. The specimens were weighed and measured after the 28-day fog-room curing and again after the first and third preheatings. The specimens were stored in a desiccator between successive heat treatments to prevent possible changes in the cement.

2.2 Aggregates

A second shipment of 2500 pounds of the lightweight aggregate, "Rocklite," was received. A screen analysis was made of a combined sample taken from the coarse, medium, and fine grades of this material.

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* By the Concreting Materials Section, Mineral Products Division, National Bureau of Standards.

A second shipment of 50 pounds of the lightweight aggregate, "Kenlite," having a top size of +3/4 in. has been received. The top size ordinarily furnished by the manufacturers is +1/2 in. The larger aggregate was requested because the trial concretes designed with this aggregate failed to develop the required flexural strength and the results indicated that an increase in the top size might bring the strength up to the specified minimum.

The sintered slag furnished by the Armour Research Foundation of Illinois Institute of Technology is a product resulting from coal burning. It is that part of the ash that fuses and drips to the bottom of the ash pit. It is crushed, agglomerated, and sintered. The sintering temperature affects the properties of the resulting product materially. The first, a small shipment was sintered at approximately 2200°F at the Institute laboratory. The second, a 10-ton shipment, was processed by contract, the sintering temperature used was approximately 2500°F.

2.3 Concretes

Nine one-cubic foot trial batches and five 15-cubic foot final batches of concrete were designed and mixed. Specimens fabricated from these batches were cured and tested, if the curing period was complete.

Six of the trial mixes were designed with the lightweight aggregate, "Rocklite". Four of the six contained portland cement, one portland pozzolan, and one the high-alumina hydraulic cement, "Lumnite".

One trial mix was designed using portland cement, crushed building brick, and white marsh sand. The sand, -30 to -100 mesh, was substituted for the usual crushed brick fines of corresponding sizes. The results from this one trial batch, together with those for certain trial batches reported in NBS Report 3012, December 1953, were used as the basis for designing a 15-cubic foot final batch of concrete containing portland cement, coarse sizes of crushed building brick, and fine sizes of white marsh sand.

One 15-cubic foot final batch of concrete was designed containing portland cement and coarse sizes only of calcined Kentucky flint clay together with fine sizes -30 to -100 of white marsh sand. The results obtained on the trial batches of this concrete, appearing in NBS Report 3399, June 1954, were used as a guide in designing this mix.

The information obtained on two trial batches of sintered slag concrete made this quarter, as well as that on nine trial batches given in NBS Report 3855, December 1954, was used in designing three final batches of concretes of 15-cubic feet each. Five sets of specimens were made of the three concretes containing the sintered slag and either portland, portland pozzolan, or high-alumina hydraulic cement. One set of these specimens was cured in the fog-room for 28 days and tested. Four sets of each concrete were cured for seven days in the fog-room and stored for

21 days under ordinary laboratory conditions. One of these four sets was tested after this curing treatment and another set after having been heated at 250°C; the third set has been heated at 500°C, and the fourth at 1000°C. The specimens exposed to the latter two heat treatments have not as yet been tested.

The thermal length changes from room temperature to approximately 1100°C were observed on specimens of the three concretes containing sintered slag.

3. RESULTS AND DISCUSSION

3.1 Cements

The results of the acceptance tests, of the portland cement received this quarter compared with those made on earlier shipments, indicate that the uniformity between shipments to be very good.

The thermal length changes of the three neat cements, from room temperature to 1180°C are shown graphically in Figure 1. One set of curves shows the length changes of specimens of the three cements after curing for 28 days in the fog-room and drying for 18 hours at 105°C. The second set of curves shows the length changes up to 1180°C of the same specimens after preheating twice to approximately 1180°C.

The curves showing the length changes observed on the three cements that were cured and dried at 105°C indicate that a slight expansion occurred from room temperature to 100°C with no appreciable length change between 100°C and 200°C.

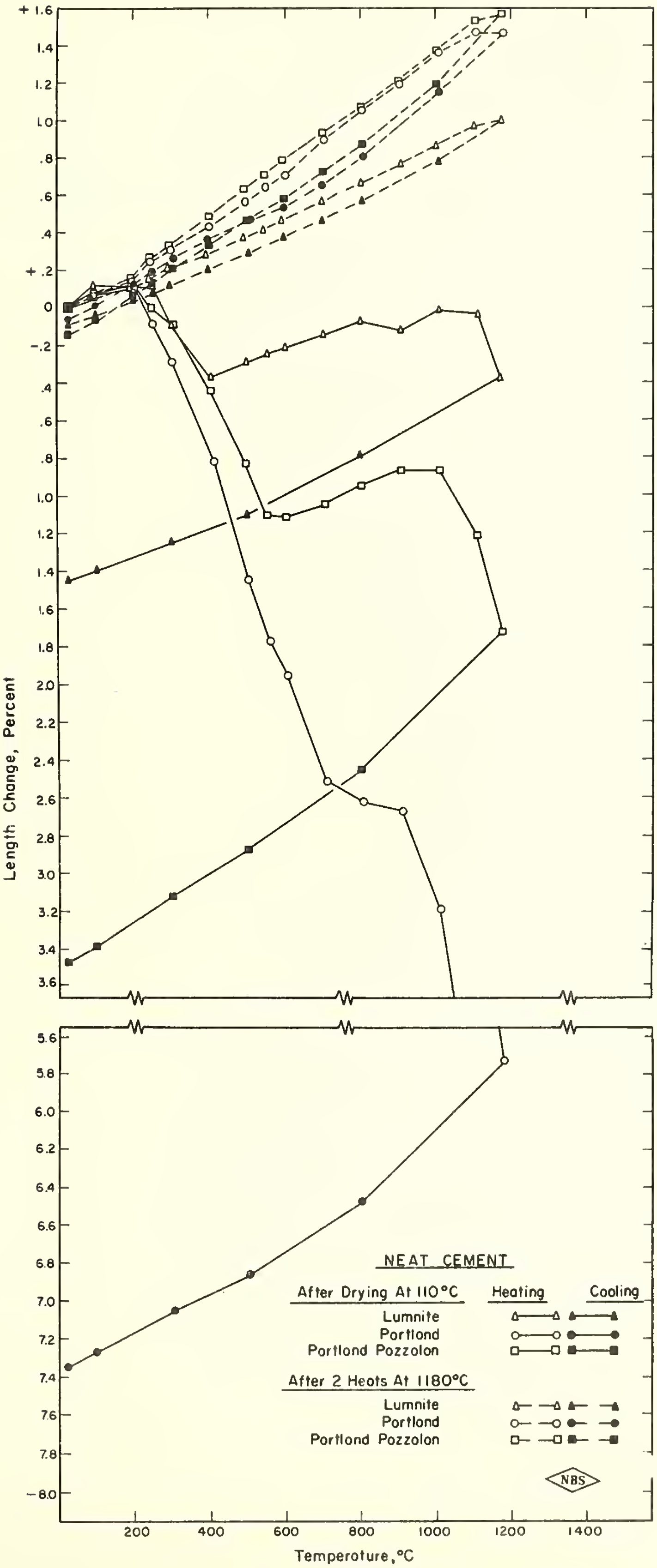

+1.6
1.4
1.2
1.0
.8
.6
.4
+.2
0
-.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
7.2
7.4
7.6
7.8
-8.0
Length Change, Percent
200
400
600
800
1000
1200
1400
Temperature, °C
NEAT CEMENT
After Drying At 110°C
Heating
Cooling
Lumnite
Portland
Portland Pozzolan
After 2 Heats At 1180°C
Lumnite
Portland
Portland Pozzolan
NBS

Figure 1

The portland cement contracted rapidly between 200°C and 700°C (2.7 percent). This length change probably resulted from the loss of water which was indicated by previously reported differential thermal analysis [1]. A decided decrease in rate of contraction occurred between 700°C and 900°C. This is about the temperature range in which the decomposition of calcium carbonate occurs. A rapid shrinkage occurred again between 900°C and 1180°C (2.9 percent) that was due probably to sintering.

The portland pozzolan cement had a rapid shrinkage from 200°C to 600°C associated with water loss [1]. Expansion occurred between 600°C and 1000°C, indicating the resultant linear change of the inert material (pozzolanic) and the contraction of the cement. Shrinkage occurred again between 1000°C and 1180°C which may be attributed to sintering.

The thermal length changes of the high-alumina cement were suggestive of the work reported by R. A. Heindl and Z. A. Post [2]. A rapid rate of shrinkage occurred between 200°C and 400°C, an expansion between 400°C and 800°C, a slight shrinkage between 800°C and 900°C, and a rapid shrinkage, attributed to sintering, occurred again between 1100°C and 1180°C.

All three cements contracted on cooling, the rate being comparatively uniform and the magnitude of the same order as the shrinkage during heating.

The curves, showing the length changes of the same three specimens of cements during the third heating to 1180°C indicate that after such heat exposure all three cements have a low and uniform rate of expansion (see figure 1). The heat treatments at 1180°C apparently reconverted the cements to a sintered material containing glass and bearing little resemblance to the original cement. The thermal expansion of the product resulting from heating the high-alumina hydraulic cement was somewhat lower than that resulting from the heating of the portland or portland pozzolan cement.

The weight losses and the linear shrinkages of the three neat cements after heating are given in Table 1. A high percentage of the weight loss occurred during drying at 110°C. All but a very small percent occurred during the first heating to 1180°C. A very small percentage of the total shrinkage occurred during drying at 110°C. Most of the remaining total shrinkage occurred during the first heating to 1180°C. The over-all shrinkage measurements made by the extensometer method compare favorably with those determined in the thermal expansion apparatus.

3.2 Aggregates

The results of preliminary screen analyses of the second shipment of Rocklite indicated that there is a considerable variation from the first shipment in the

Table 1. Weight Loss and Linear Shrinkage of Neat Cements after Heat Exposures.

Heat Exposures	LUMNITE		PORTLAND		PORTLAND POZZOLAN	
	Weight Loss 1/	Shrinkage 2/	Weight Loss 1/	Shrinkage 2/	Weight Loss 1/	Shrinkage 2/
	percent	percent	percent	percent	percent	percent
110°C for 18 hours	9.51	0.108	10.43	0.284	8.46	0.190
One heating at 1180°C 3/	22.78	1.543	23.44	7.204	20.90	3.570
Three heatings at 1180°C 3/	22.85	1.908	23.71	7.557	21.44	3.851

1/ Based on the weight after 28-day fog-room curing.

2/ Based on the length after 28-day fog-room curing.

3/ Specimens were heated at 100°C per hour and held for 15 minutes at hourly intervals. The specimens cooled with the furnace to room temperature.

gradation of the three lots, namely coarse, medium, and fine sizes in which this material is marketed. This variation in sizes between the two shipments will necessitate screening and recombining the entire 2500 pounds in order to obtain the desired grading.

The small shipment of coarse Kenlite aggregate furnished as +3/4 contained only 50 percent of this size. The producer of this material informed us that his production methods are geared to produce below -3/4 inch and suggested that there might be some difficulty in procuring such a coarse aggregate in many sections of the country.

The thermal length changes, of the building brick aggregate, are shown graphically in Figure 2 and for convenience are repeated in Figures 3 and 4. The curve showing the length changes from room temperature to 1000°C is smooth except for a slightly increased rate in the temperature range of 550°C to 600°C which indicates the presence of small amounts of free quartz. Although the brick has a softening point of approximately 1300°C it started bloating before 1100°C and continued to do so to the top test temperature. The cooling curve shows a low and uniform rate of shrinkage. A permanent expansion of 3.8 percent was indicated because of the bloating of the material.

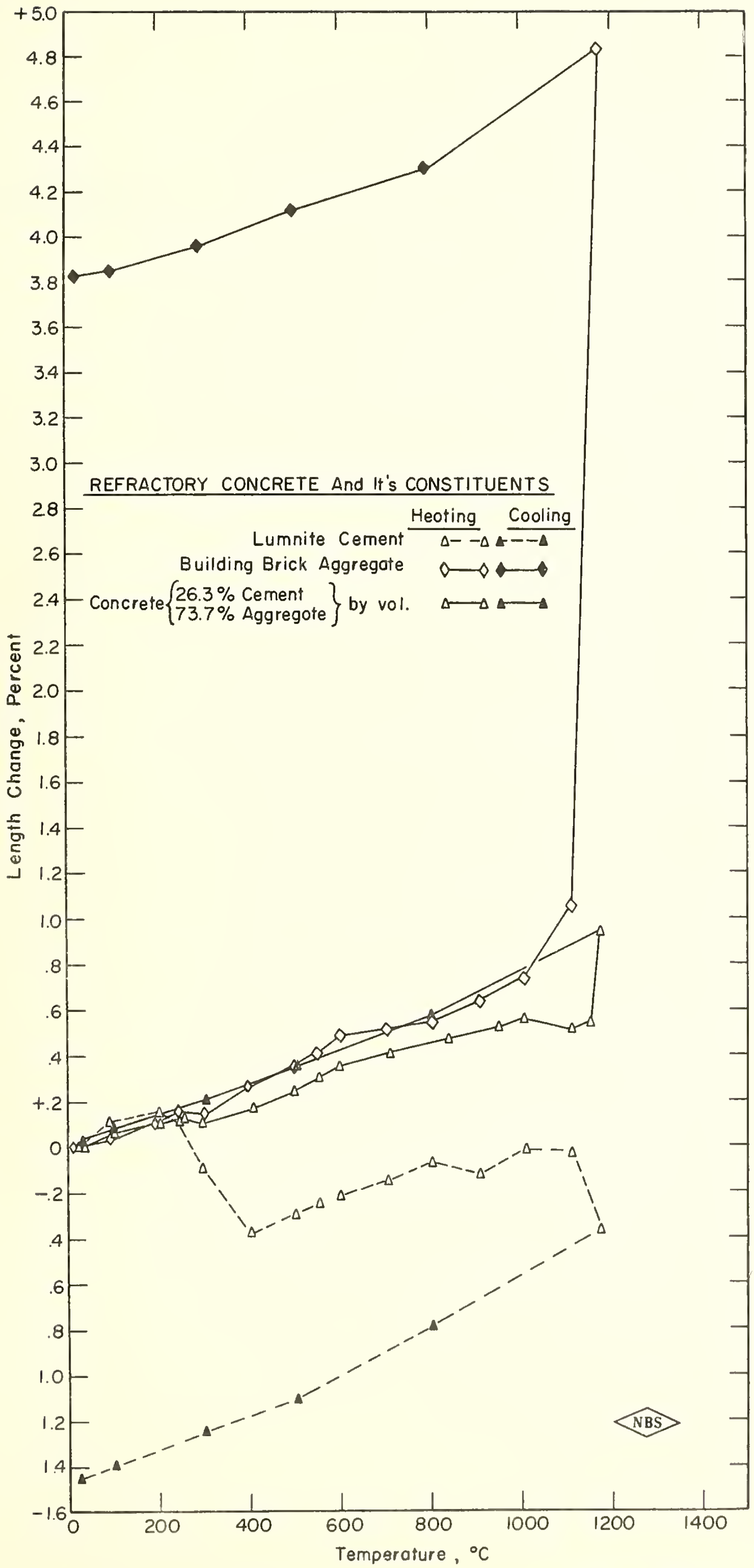

REFRACTORY CONCRETE And It's CONSTITUENTS
Heoting
Cooling
Lumnite Cement
Building Brick Aggregote
Concrete {26.3 % Cement 73.7 % Aggregote} by vol.
Length Change, Percent
Temperoture, °C
NBS

Figure 2

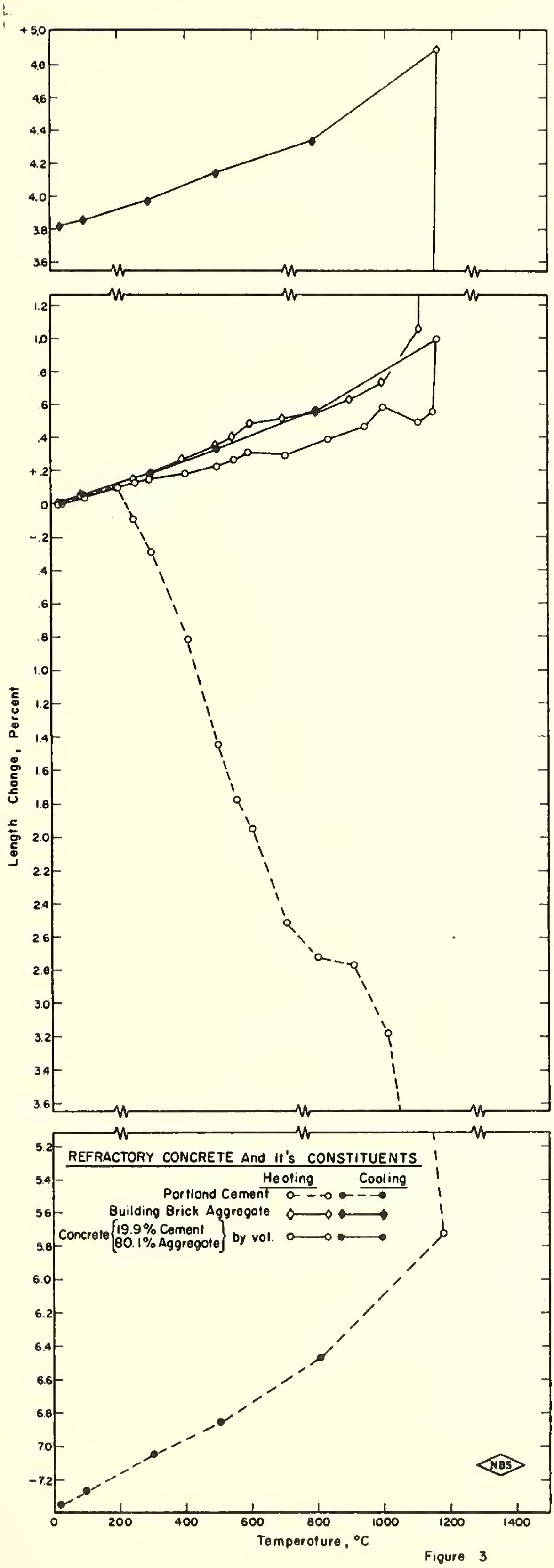
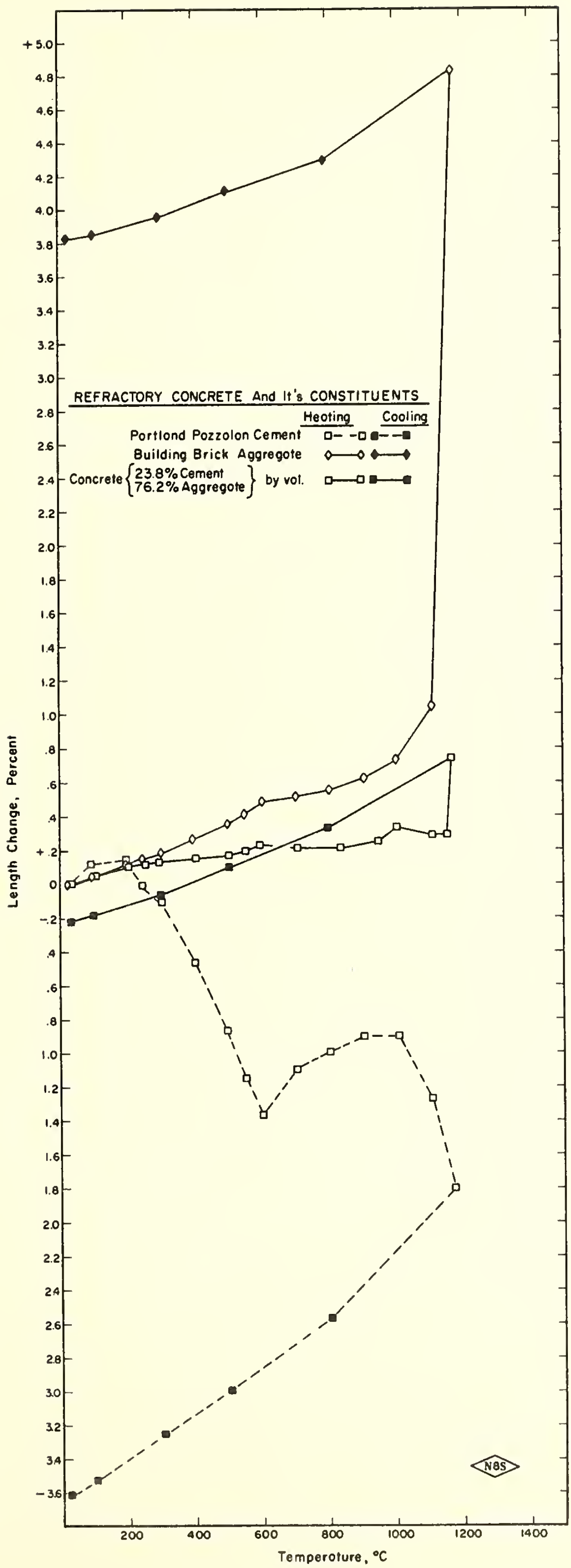

REFRACTORY CONCRETE And It's CONSTITUENTS
Heating
Cooling
Portland Cement
Building Brick Aggregate
Concrete {19.9% Cement 80.1% Aggregate} by vol.
Length Change, Percent
Temperature, °C
NBS

Figure 3



REFRACTORY CONCRETE And It's CONSTITUENTS
Heating
Cooling
Portland Pozzolan Cement
Building Brick Aggregate
Concrete {23.8% Cement, 76.2% Aggregate} by vol.
Length Change, Percent
Temperature, °C
NBS

Figure 4

3.3 Concretes

Table 2 gives the composition, some properties of the fresh concretes, together with the flexural strengths of specimens of trial batches designed with the lightweight aggregate, "Rocklite", sintered slag or building brick.

For the concrete containing the Rocklite only two of the twelve trial batches, six of which were included in NBS Report 3855, December 1954, developed a flexural strength of 600 psi. In designing these twelve trial mixes the ratio of coarse to fine aggregate was increased from 55/45 to 65/35. The percentage of the top sizes of the coarse aggregate was increased until the concrete became too harsh to place well. Reductions in the water-cement ratio and air-entraining agent were made. However, an examination of the beams after breaking show aggregate fracture to be nearly 100 percent.

In the design of the trial batch P-B-WM-A, the substitution of the white marsh sand for the fines of the building brick aggregate permitted a reduction in the water-cement ratio which in turn resulted in diminishing the air content. The sonic modulus of elasticity after 21 days fog-room curing of the beams fabricated with this concrete indicated that the required flexural strength will develop during a 28-day curing period.

Table 2. Properties of Fresh Concretee,[a] Trial Mixes

Identification[b]	Proportion by Weight Cement to Coarse and to Fine Aggregate	Cement Content	Vinsol Resin by Weight of Cement	Water Content	Air Content Gravimetric Method	Slump	Weight of Fresh Concrete	Water Cement Ratio	Remarks Fresh Concrete	Flexural Strength 28-day Fog-room Curing	Remarks Cured Concretee
		sacks/yd^3 of concrete	%	gals/yd^3 of concrete		inches	lbs/ft^3			psi	
P-R-D^3	1 : 0.90 : 0.74	8.64	0.005	35.8	8.37	6.00	95.00	0.37	excese of water bleeding	600	mostly aggregate fracture, few air-voide
Z-R-D^3	1 : 1.07 : 0.71	8.49	none	38.2	2.76	2.00	98.40	0.40	good workability	470	mostly fractured aggregate; few air-voids
L-R-D^3	1 : 1.05 : 0.70	8.61	0.005	28.4	7.42	2.00	95.60	0.29	harsh but placeable	525	few pull-outs, mostly aggregate fracture; some air-voids
P-R-E^3	1 : 0.92 : 0.76	8.93	0.005	38.7	3.04	6.00	100.00	0.38	good placeability	- [d]	- [d]
P-R-F^3	1 : 1.01 : 0.67	8.98	0.005	35.7	2.95	2.50	99.40	0.35	good placeability	- [d]	- [d]
P-R-C^3	1 : 1.09 : 0.59	8.65	0.005	34.1	5.49	2.50	95.60	0.35	slightly harsh but placeable	- [d]	- [d]
P-SS-I	1 : 1.38 : 1.56	7.82	0.005	45.0	1.33	3.00	131.90	0.48	very good	725	50% pull-outs 50% fractured aggregate
Z-SS-I	1 : 1.55 : 1.55	7.90	none	45.8	1.82	2.50	130.30	0.51	very good	640	do
P-B-WM-A[c]	1 : 2.72 : 1.28	7.50	0.005	33.3	2.23	1.00	142.50	0.39	harsh; fair placeability	- [d]	- [d]

[a] For convenience the flexural strength of specimens, fabricated from trial batches 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 letters: R = Rocklite, a lightweight expanded shale, coated; SS = sintered slag; B = crushed building brick; WM = white marsh sand.
The third letters; = batch identification, the superscript 3 indicating that the aggregate was used in the same proportions ae received but with increases in the +3/4 to +3/8 inch sizes.
If no superscript appears with the batch identification letter the Bureau of Yards and Docks' gradation was used.

[c] White marsh sand was substituted for the parent aggregate from +50 to -100 eizes.

[d] Dash indicates tests have not been completed.

Table 3 gives the properties of the final batches of fresh concrete designed with sintered slag, crushed building brick, or calcined Kentucky flint clay.

In the concretes using either crushed building brick or calcined flint clay, white marsh sand was used for the -30 to -100 mesh fines as in the trial batches. The results given in Table 3 for the several properties of the three individual mixes of five cubic feet each for the same concretes indicate the variation that may be expected with laboratory controlled mixing.

The results of the completed tests on concretes designed with sintered slag and either portland, portland pozzolan, or high-alumina hydraulic cement, are given in Table 4. All three concretes developed the required flexural strength after a 28-day fog-room curing.

Figures 2, 3 and 4 show the length changes during heating, from room temperature to approximately 1200°C, for concretes designed with crushed building brick and either high-alumina cement, "Lumnite," portland cement, or portland pozzolan cement, respectively. Although the curves describing the length changes of these three concretes were shown in Figure 6, NBS Report 3705, September 1954, they are shown again for comparison with the length changes of the cement and the aggregate.

Table 3. Properties of Fresh Concretes,[a] Final Mixes

Identification[b]	Proportion by Weight Cement to Coarse and to Fine Aggregate	Cement Content	Vinsol Resin by Weight of Cement	Water Content	Air Content, Method: Gravimetric	Air Content, Method: Pressure[d]	Slump	Weight of Fresh Concrete	Water Cement Ratio	Remarks Fresh Concrete	Flexural Strength 28-day Fog-room Curing	Remarks Cured Concrete
		sacks/yd³ of concrete	%	gals/yd³ of concrete			inches	lbs/ft³			psi	
L-SS-1[c]	1 : 1.31 : 1.31	9.30	0.005	41.0	1.88		1.50	133.10	0.39	slightly harsh but placeable		
L-SS-2[c]	do	9.35	0.005	41.0	1.36		5.50	133.80	0.39	very good	670[e]	mostly pull-outs
L-SS-3[c]	do	9.17	0.005	40.0	3.20		2.25	131.30	0.39	slightly harsh but placeable		
P-SS-1	1 : 1.38 : 1.57	8.48	0.005	43.0	1.24		2.50	133.30	0.44	very good		
P-SS-2	do	8.52	0.005	41.3	1.79		3.00	133.00	0.43	do	795[e]	50% pull-outs 50% fractured aggregate
P-SS-3	do	8.51	0.005	42.0	1.58		3.50	133.00	0.44	do		
Z-SS-1	1 : 1.58 : 1.52	8.34	none	36.0	2.44		2.50	133.52	0.39	slightly harsh but good placeability		
Z-SS-2	do	8.37	none	35.1	2.85		2.00	133.52	0.37	do	725[e]	50% pull-outs 50% fractured aggregate
Z-SS-3	do	8.39	none	35.0	2.50		2.00	133.89	0.37	do		
P-B-WM-1	1 : 2.72 : 1.28	7.21	0.005	37.4	3.43	3.62	2.00	138.55	0.46	harsh but placeable; slight bleeding		
P-B-WM-2	do	7.28	0.005	36.3	3.22	4.00	1.75	139.39	0.44	do		
P-B-WM-3	do	7.30	0.005	36.7	2.84	3.57	2.00	139.82	0.45	do		
P-C-WM-1	1 : 2.84 : 1.33	7.68	0.015	35.3	4.45	3.72	1.00	150.22	0.41	harsh but placeable		
P-C-WM-2	do	7.38	0.015	36.1	5.78	3.25	2.25	144.98	0.43	placed well slightly harsh		
P-C-WM-3	do	7.52	0.015	33.8	2.97	4.73	1.00	146.72	0.40	harsh but placeable		

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

b/ The first letters: L = Lumnite, a high-alumina hydraulic cement; P = portland cement; Z = portland pozzolan cement.
The second letters: SS = sintered slag, second shipment; B-WM = crushed building brick aggregate with White Marsh sand +50 to -100 substituted for parent aggregate.
C-WM = crushed calcined Kentucky flint clay aggregate with White Marsh sand +50 to -100 substituted for parent aggregate.
The numerals 1, 2 and 3 indicate the number of the batch, all of the same design but different charges.

c/ This data, except for the flexural strength results, appeared in the last report N.B.S. 3855 and is repeated here for comparative purposes.

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

e/ The value for flexural strength is an average value for specimens fabricated from mix 1, 2 and 3.

Table 4. Properties of Cured and Heat-Treated Concretes

Identification[a]	Proportion by Weight of Cement to Coarse and to Fine Aggregate	Treatment Preceeding Test[b]	Compressive Strength	Flexural Strength	Abrasion Loss: Weight of Dust	Abrasion Loss: Depth of Wear[c]	Young's Modulus of Elasticity Dynamic; Longitudinal	Total[d] Linear Change	Total[e] Weight Change
			psi	psi	grams	inches	$lbs/inch^2 \times 10^6$	%	%
L-SS	1 : 1.31 : 1.31	1					4.207		
		2					4.596	-0.00	+0.51
		3		505	40.50	0.0114	4.259	-0.02	-1.63
		4	7220	670	58.85	0.0171	4.750	+0.02	+1.63
		5					2.706	-0.03	-6.83
		6		-[f]	-	-	-	-	-
		7		-	-	-	-	-	-
		8		-	-	-	-	-	-
P-SS	1 : 1.38 : 1.57	1					2.756		
		2					4.428	+0.025	+0.363
		3		485	44.75	0.01484	4.260	no change	-2.337
		4	5595	795	-	-	4.697	+0.051	+0.530
		5					3.373	-0.043	-7.624
		6		-	-	-	-	-	-
		7		-	-	-	-	-	-
		8		-	-	-	-	-	-
Z-SS	1 : 1.58 : 1.52	1					1.465		
		2					3.829	+0.022	+0.426
		3		470	26.20	0.00895	3.971	-0.025	-3.027
		4	6445	725	-	-	4.536	+0.187	+0.354
		5					2.895	-0.022	-8.886
		6		-	-	-	-	-	-
		7		-	-	-	-	-	-
		8		-	-	-	-	-	-

a/ 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.

b/ 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.

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

d/ Based on length after 24 hours in mold.

e/ Based on weight after 24 hours in mold.

f/ Dash indicates tests have not been completed.

The curves showing the linear changes that were observed in the concretes designed with sintered slag as the aggregate and either portland, portland pozzolan, or the high-alumina hydraulic cement are shown in Figure 5. The shape of the curves indicating the length changes and the total expansion from room temperature to 800°C is quite similar to the curves describing the length changes observed in the concretes designed with crushed building brick. However, from 800°C to the top temperature, namely 1070°C, rapid expansion occurred in all three concretes. This concrete is the only one of those tested having permanent expansion after cooling.

In order to learn whether the thermal length changes up to 1000°C of a concrete could be predicted when the thermal length changes of its ingredients are known, calculations were made based on data for building brick aggregate and the hydraulic cements. The results indicate that in the concrete containing the portland cement no reliance whatsoever can be placed in the computed values. The observed value at 1000°C was 0.4 percent expansion, the value obtained by computation indicated a shrinkage of 0.4 percent. The corresponding values for the concretes containing Lumnite and portland pozzolan cements were 0.55 versus 0.45 percent, and 0.35 and 0.325, expansion, respectively. Though the values for the last two concretes at 1000°C are in reasonably good agreement, the plotted curves of the calculated values are quite erratic when compared with those developed from observed values.

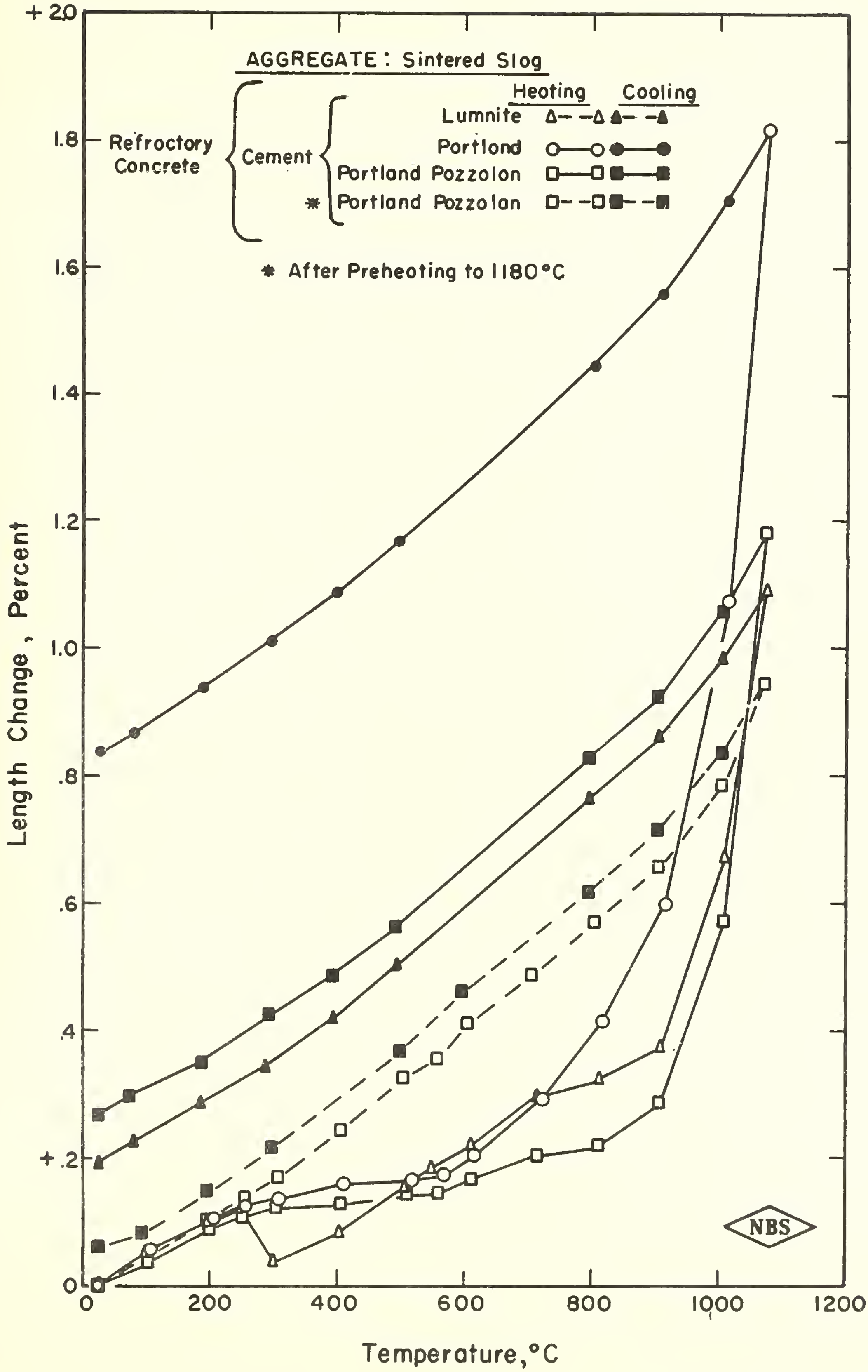

AGGREGATE : Sintered Slag
Heating
Cooling
Refractory Concrete
Cement
Lumnite
Portland
Portland Pozzolan
* Portland Pozzolan
* After Preheating to 1180°C
Length Change , Percent
Temperature, °C
+2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
+.2
0
0
200
400
600
800
1000
1200
NBS

Figure 5

REFERENCES

[1] N.B.S. Report 1817, Figure 4.

[2] Refractory Castables: II, Some Properties, and Effects of Heat-Treatment, Journal American Ceramic Society, Vol. 37, No. 5, May 1954, Figure 2.

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