NATIONAL BUREAU OF STANDARDS REPORT

3201

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

by

W. L. Pendergast, R. A. Clevenger, Edward C. Tuma

NBS

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
0903-21-4428

March 31, 1954

NBS REPORT
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by

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Sponsored by
Department of the Navy
Bureau of Yards and Docks
Washington, D. C.

Reference: NT4-59/NY 420 008-1
NBS File No. 9.3/1134-C

Approved:

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TECHNICAL REQUIREMENTS

The technical requirements are the same as those given in the NBS Report 3012.

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 physical and chemical tests of the cements used in the preparation of concretes during this quarter have been previously reported.

2.2 Aggregates

One thousand pounds of calcined Kentucky flint clay have been crushed. Sufficient amounts have been screened through the eleven required screens to enable the determination of the loss in the Los Angeles abrasion test; bulk specific gravity; the percent absorption; the unit weight in pounds per cubic foot; the correction factor for use with the air meter; and to design several trial batches of concrete.

2.3 Concretes

Five concretes were designed, mixed, and complete sets of test specimens fabricated. Three of the five concretes were designed with crushed building brick as the aggregate and either portland, portland pozzolan, or high-alumina hydraulic cement. The other two were designed with olivine as the aggregate and either portland or portland pozzolan cement. The mixer of five-cubic foot capacity, necessitated preparing three charges of each concrete to yield the 15 cubic-feet used in fabricating complete sets of test specimens.

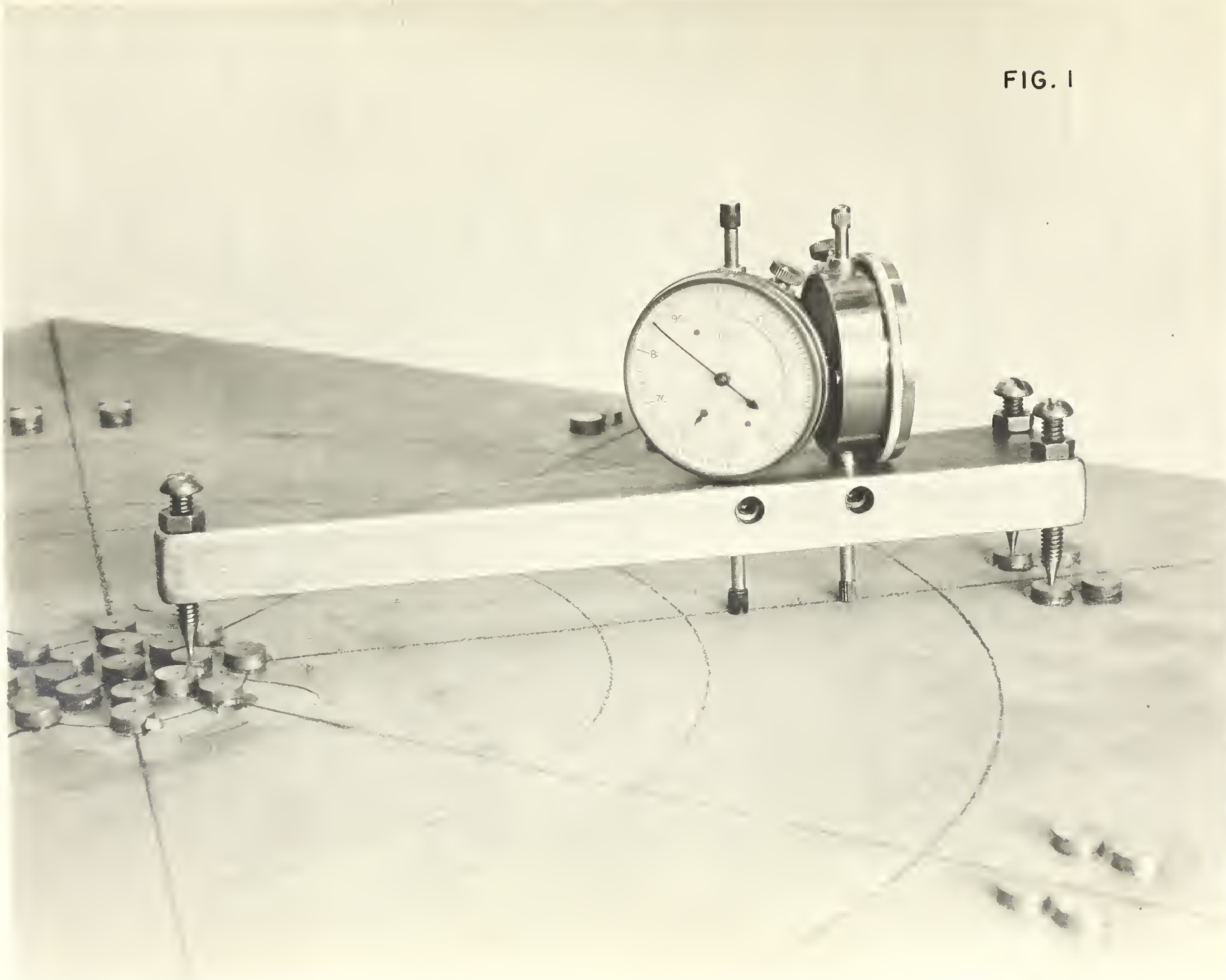
The results obtained on one-cubic foot trial batches of these concretes, reported previously in N.B.S. Report 3012, were used as a basis for designing the final batches.

2.3.a A Laboratory Method of Measuring the Depth of Wear of an Abraded Refractory Concrete Slab.

A series of systematic measurements were made for the purpose of determining the average depth of the abraded area of concrete slabs. The test slabs were 24 x 24 x 2 1/2 inches and were abraded using the apparatus for determining relative wear resistance designed by Schuman and Tucker.[1/]

The apparatus for making the depth measurements consisted essentially of a triangular steel plate with three legs, which supported two dial indicators graduated in 0.001 inch, as shown in Figure 1.

FIG. 1



The triangular table upon which the dial indicators were mounted was constructed of 3/4-inch steel plate with equal sides of ten inches and a base of 1 3/4 inches. The legs were set screws made from 1/4-inch drill-rod with the point lathe ground to a 45° angle and polished. The gauge shafts pass through the table are 1.2 inches apart and are held in position by Allen set screws. The entire assembly weighs slightly over three pounds. It is of sufficient weight to firmly seat the legs and the plungers (rounded).

In order to systematize the pattern for the depth readings certain geometric patterns were established on the slab as indicated in Figure 2. This was done so that readings would be taken at 45° intervals around the abraded track and four readings would be taken across the width of the track at the same intervals.

The reference marks were cylindrical gauge disks with 0.0465 inch holes drilled (No. 56 Twist drill) sufficiently deep to clear the ends of the points on the legs of the dial indicator table. These centrally located holes were reamed with a 60° reamer to remove any burrs. The points on the table legs have an angle of 45° (see Figure 1), and will seat where the reamer meets the holes. Forty-eight of these reference markers were cemented to the test slab. The surface was first roughened, brushed clean, and Duco cement applied in the desired area. For purposes of

FIG. 2

explaining the procedure involved in making depth measurements of an abraded area five circles are shown in Figure 2. Starting with the two inner circles, one set each of eight reference markers are placed on the perimeter of each circle. The centers of these concentric circles with radii 0.7 and 1.3 inches respectively is the center also of the test slab. The reference points are placed on the perimeter of these innermost circles at the intersection of the radii at 45° intervals. The third concentric circle having a radius of five inches places the abrasion apparatus preparatory to a test, in the proper position with reference to test slab. The only purpose of the fourth and fifth circles, with radii of six and nine inches, is merely to show the boundary of the area to be abraded. The other 32 reference markers in sets of two to take care of the two legs at this end of the table are located outside the abraded area as is shown in Figure 2. Sixteen of these markers are related to the smallest circle and are spotted by placing the leg, which is at the apex of the triangular shaped table, in the reference marker on the inside circle and revolving the table till the plunger of the two dial indicators fall on the correct radius. The outside set of 16 markers is located by a similar operation but with the one table leg in the marker on second smallest circle.

The difference between the average of 32 dial readings before abrasion and the average of 32 dial readings after abrasion was considered the depth of wear.

3. RESULTS AND DISCUSSION

3.1 Concretes

Table I gives the properties of the fresh concretes that were designed and mixed during this quarter.

The cement content, as calculated, was slightly above the maximum permissible 7 1/2-sack mix in the concrete designed with the olivine aggregate and the pozzolan cement. This also held true for the concrete designed with crushed building brick aggregate and high-alumina hydraulic cement.

The air contents, as determined by the pressure method (air meter) were maintained within the three to six percent range required, except in the concrete designed with olivine aggregate and pozzolan cement. The results of tests on trial batches of this concrete indicated that a concrete using this type aggregate would not develop the required flexural strength of 650 psi if the air content was above three percent.

The results of the slump tests were within the normally reproducible limits for two-inch slump concrete. There is no specified requirement, in this project, for slump of concretes designed with high-alumina hydraulic cement.

All the concretes designed with olivine aggregate were of a more plastic type than normally used in paving due to the high cement content necessary to develop the required strength.

TABLE I - PROPERTIES OF FRESH CONCRETES

Identification[a]	Proportions by Weight; 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
					Gravimetric Method	Air Meter Method				
		Sacks/yd^3 of Concrete	%	Gals/yd^3 of Concrete	%	%	inchee	lbs/ft^3		
P-O-1	1 : 3.50 : 1.50	7.26	.030	34.3	1.02	2.72	1.75	172.23	.39	plastic; fatty
P-O-2	do	7.20	do	33.9	1.75	2.87	2.00	171.00	.39	do
P-O-3	do	7.17	do	33.8	2.25	3.27	2.00	170.00	.39	do
Z-O-1	1 : 3.45 : 1.54	7.80	.025	34.0	0.40	1.51	1.50	174.01	.39	plastic; sticky
Z-O-2	do	7.62	do	36.0	1.05	1.98	1.75	171.00	.42	do
Z-O-3	do	7.58	do	38.3	0.51	2.01	2.00	170.87	.44	do
L-O-1[b]	1 : 3.16 : 2.11	7.09	.035	38.5	2.98	2.92	2.25	166.66	.45	placed well bleeding
L-O-2[b]	do	7.09	do	38.5	2.98	3.17	2.00	166.66	.45	do
L-O-3[b]	do	7.16	do	36.8	2.98	3.02	1.90	168.40	.45	do
P-B-1	1 : 3.12 : 1.47	6.02	.010	33.3	5.38	6.04	2.75	136.46	.46	harsh but placeable
P-B-2	do	6.15	do	33.6	3.74	4.64	1.75	139.08	.46	do
P-B-3	do	6.04	do	34.1	4.72	5.72	2.50	137.34	.47	do
Z-B-1	1 : 2.97 : 1.27	6.90	none	37.3	1.09	2.90	1.75	142.23	.45	harsh but easily placed
Z-B-2	do	6.80	do	38.2	1.65	3.25	2.25	141.13	.46	do
Z-B-3	do	6.78	do	38.0	2.06	3.45	2.50	140.35	.46	do
L-B-1	1 : 2.11 : 1.53	7.61	.010	40.0	4.12	3.52	4.50	136.68	.47	easily placed too wet
L-B-2	do	7.63	do	40.9	3.60	3.72	4.50	137.12	.47	do
L-B-3	do	7.62	do	40.8	3.60	3.24	3.50	137.12	.47	do

a/ The first letters: P = Portland Cement; Z = Portland Pozzolan Cement; L = Lumnite, a high-alumina hydraulic cement.
The second letters: O = Olivine; B = Crushed Building Brock.
The numerals 1, 2, and 3 indicate the number of batches, same design but different charges.

b/ This data appeared in NBS Report 3012 and is repeated here for comparitive purposes.

The workability of the concretes designed with crushed brick aggregate, in contrast to those designed with the olivine, was of the normal harshness of paving concretes containing a crushed aggregate.

From the properties listed in Table I of the three separate charges for each concrete of the same design an indication of the limits of reproducibility may be obtained.

Table II gives the properties of the cured and heat-treated concretes.

The concrete designed with olivine aggregate and high-alumina hydraulic cement did not quite develop the required flexural strength of 650 psi after a 28-day fog-room curing. The trial batch from which this final mix was designed developed a flexural strength of 720 psi with only slightly less water. The W/C ratio for trial batch was 0.44 and for final batch was 0.45. Data collected on trial batches of this type concrete indicated that an increase to a 7-1/2 sack mix would result in a flexural strength, after the 28-day fog-room curing, equal to the required 650 psi.

The two other concretes designed with portland cement, the one containing olivine as the aggregate and the other crushed building brick met the flexural strength requirements after the 28-day fog-room curing. Both increased in strength after the 250°C heat exposure but showed a slight loss in strength after the 500°C heat exposure.

TABLE II - PROPERTIES OF CURED AND HEAT-TREATED CONCRETES

Identification a/	Proportions by Weight of Cement to Coarse and to Fine Aggregate	Treatments Preceding Test b/	Compressive Strength	Flexural Strength	Abrasion: Weight of Dust	Abrasion: 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 - O	1 : 3.16 : 2.11	1					5.894		
		2					6.408	no change	+0.27
		3		490	73.25	0.0142	6.750	-0.02	-0.43
		4	4300	620	28.65	.0056	6.822	no change	+0.55
		5					4.397	-0.03	-3.16
		6		370	226.25 f/	.0372	3.955	-0.03	-3.46
		7		175	200.20 f/	.0383	1.560	-0.08	-5.49
		8		110	432.00 f/	.0756	883	+0.04	-6.98
P - O	1 : 3.50 : 1.50	1					3.803		
		2					6.142	+0.01	+0.41
		3		530	19.75	.0045	6.545	-0.01	-0.99
		4	4740	665	18.15	.0051	7.195	+0.02	+0.61
		5					5.363	-0.03	-3.84
		6		675	66.50 f/	.0155	4.873	-0.06	-4.25
		7		500	96.80 f/	.0219	3.686	-0.13	-4.69
		8		70	616.00 f/	.1138	1.063	-0.13	-6.90
P - B	1 : 3.12 : 1.47	1					3.218		
		2					4.750	+0.01	+0.42
		3		435	21.05	.0075	4.619	-0.01	-2.13
		4	4430	685	16.60	.0047	5.280	+0.02	+0.51
		5					3.788	-0.02	-5.49
		6		580	65.15 f/	.0186	3.305	-0.03	-5.76
		7		395	93.70 f/	.0233	3.867	-0.08	-6.54
		8		125	501.00 f/	.1159	1.610	-0.08	-7.73

a/ The first letters: L = high-alumina hydraulic cement; P = portland cement.
The second letters: O = olivine aggregate; B = crushed building brick aggregate.

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 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.

c/ A description of the apparatus and method used in determining depth of wear is given in this report.

d/ Based on length after 24 hours in mold.

e/ Based on weight after 24 hours in mold.

f/ Aggregate exposed.

The volume change, as indicated by linear measurements, and the weight loss throughout the different exposures are of a much lower magnitude in the concretes with olivine or crushed building brick aggregates than were concretes containing White Marsh or Bluestone previously reported.

The scheduled program included the determination of the compressive strength of cylinders of each concrete after a 28-day fog-room curing. In addition to the compressive strength of cylinders for the first time, the compressive strength of portions of beams broken in flexure, also was determined. The "Strength Correction Factor", given in A.S.T.M. Designation: C42-49[2/] was used in calculating the compressive strength of the beam ends. Figure 3 shows the ratio of compressive strength of the beams to flexural strength to be approximately 7 to 1. This ratio remains fairly constant for the three concretes irrespective of the curing periods or heat exposures. The compressive strengths of cylinders fabricated from the three concretes and cured for 28 days in the fog-room are also shown in Figure 3 for comparative purposes.

Table III gives the results of the abrasion tests. The amount of wear of the slabs was measured by two methods, namely (1) the depth of abrasion and, (2) the weight of dust removed. Fifteen slabs of three concretes were tested after each of two curing periods and after each of three heat exposures.

[illegible]

[illegible]

[illegible]

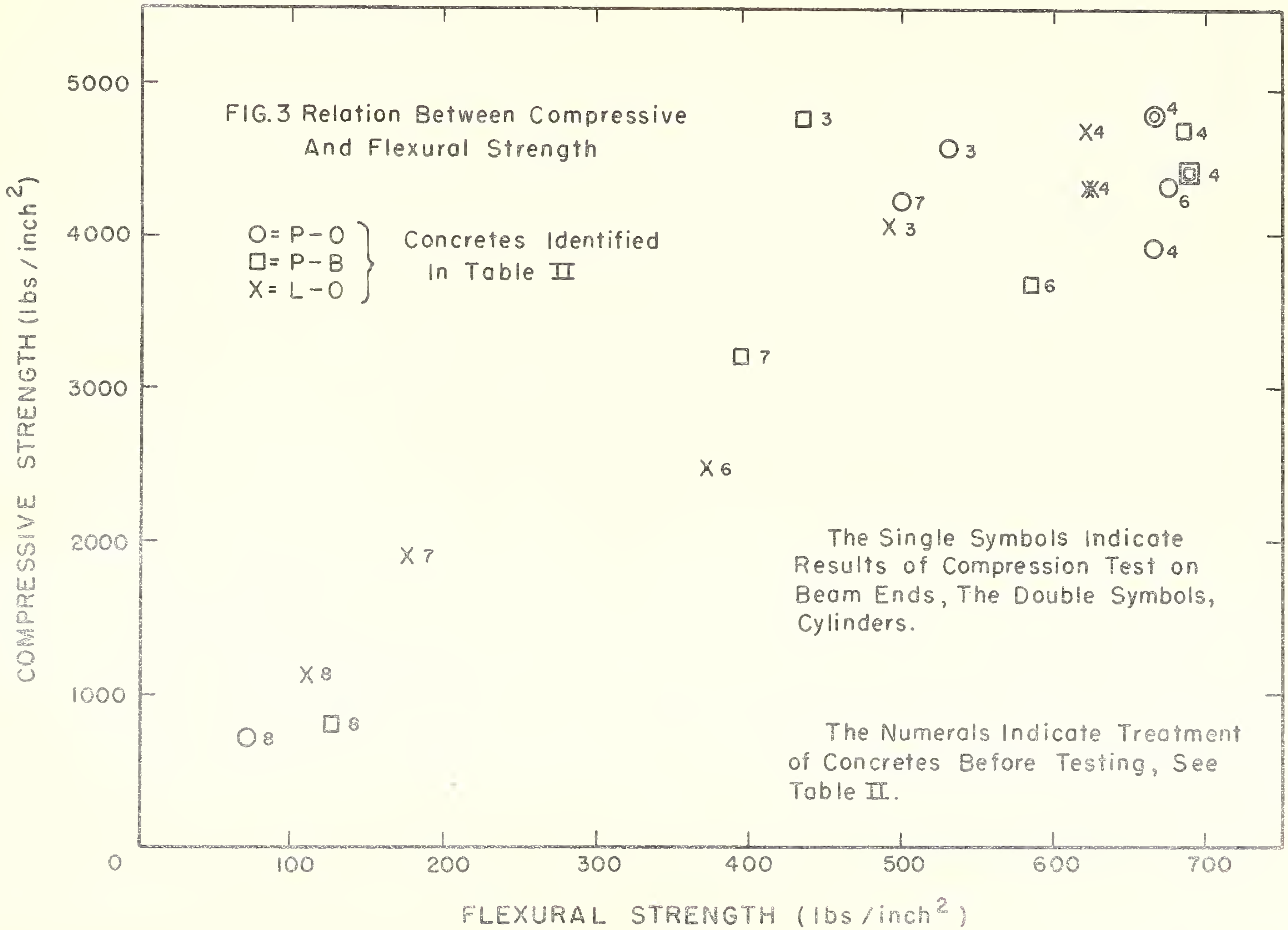


FIG. 3 Relation Between Compressive And Flexural Strength

Identification[b]	Weight of Concrete[c]	Test[d]	Depth of Wear[e]	Weight of Dust		Identi
				Calculated	Obtained	
	grams/inch^3		inches	grams	grams	
L-0-1	44.70	1	0.1416	89.49	73.25	P
		2	.0064	40.57	30.00	
		3[f]	.0076	48.15	37.30	
		4	.0087	55.42	46.40	
L-0-2	44.91	1	.0102	64.59	53.85	P
		2[f]	.0056	35.55	28.65	
L-0-3	43.54	1[f]	.0375	231.06	226.25	P
L-0-4	42.50	1[f]	.0383	229.81	200.20	P
L-0-5	42.11	1[g]	.0756	450.29	432.00	P

a/ See "A Portable Apparatus for Determining the Relative Wear Resistance of C

b/ First letters: L = high-alumina hydraulic cement; P = Portland cement.
Second letters: 0 = olivine aggregate; B = crushed building brick aggregat
The numerals indicate the curing periods and heat exposures:
1 = seven days storage in fog-room plus 21 days at laboratory temperatur
2 = twenty-eight days storage in fog-room.
3 = No. 1 plus heat exposure of 250°C for five hours.
4 = No. 1 plus heat exposure of 500°C for five hours.
5 = No. 1 plus heat exposure of 1000°C for five hours.

c/ This value was calculated from volume and weight determinations on specimen

d/ Tests 2, 3 or 4 made successively on the same specimens and in same abrade

e/ A description of the apparatus and method for determining depth of wear is

f/ Large aggregate exposed.

g/ At this depth the cement bond or matrix appears to wear well below aggregat

TABLE III - ABRASION TEST RESULTS[a]

cation[b]	Weight of Concrete[c]	Test[d]	Depth of Wear[e]	Weight of Dust		Identification
				Calculated	Obtained	
	grams/inch³		inches	grams	grams	
-1	44.89	1 2 3[f] 4	0.0045 .0061 .0044 .0037	28.55 38.71 27.61 23.48	19.75 26.55 22.60 18.60	P-B-1
-2	45.35	1	.0051	32.69	18.15	P-B-2
-3	42.88	1[f] 2 3	.0155 .0108 .0072	93.95 65.48 43.65	66.50 52.50 40.91	P-B-3
-4	43.80	1[f]	.0219	135.60	96.80	P-B-4
-5	42.55	1[g]	.1138	684.54	616.01	P-B-5

crete Floors", N.B.S. R.P. 1252, 549.

and humidity.

of concrete fabricated from the same mix and receiving the same treatments.
area.
yen in this report.

level.

TABLE III - ABRASION TEST RESULTS[a/]

Identification[b/]	Weight of Concrete[c/]	Test[d/]	Depth of Wear[e/]	Weight of Dust	
				Calculated	Obtained
	grams/inch^3		inches	grams	grams
L-O-1	44.70	1	0.1416	89.49	73.25
		2	.0064	40.57	30.00
		3[f/]	.0076	48.15	37.30
		4	.0087	55.42	46.40
L-O-2	44.91	1	.0102	64.59	53.85
		2[f/]	.0056	35.55	28.65
L-O-3	43.54	1[f/]	.0375	231.06	226.25
L-O-4	42.50	1[f/]	.0383	229.81	200.20
L-O-5	42.11	1[g/]	.0756	450.29	432.00

Identification[b/]	Weight of Concrete[c/]	Test[d/]	Depth of Wear[e/]	Weight of Dust	
				Calculated	Obtained
	grams/inch^3		inches	grams	grams
P-O-1	44.89	1	0.0045	28.55	19.75
		2	.0061	38.71	26.55
		3[f/]	.0044	27.61	22.60
		4	.0037	23.48	18.60
P-O-2	45.35	1	.0051	32.69	18.15
P-O-3	42.88	1[f/]	.0155	93.95	66.50
		2	.0108	65.48	52.50
		3	.0072	43.65	40.91
P-O-4	43.80	1[f/]	.0219	135.60	96.80
P-O-5	42.55	1[g/]	.1138	684.54	616.01

Identification[b/]	Weight of Concrete[c/]	Test[d/]	Depth of Wear[e/]	Weight of Dust	
				Calculated	Obtained
	grams/inch^3		inches	grams	grams
P-B-1	35.32	1	0.0075	37.44	21.05
		2	.0047	23.46	16.60
		3[f/]	.0034	16.97	13.35
		4	.0054	26.96	22.25
P-B-2	36.53	1	.0056	28.92	16.05
P-B-3	34.02	1[f/]	.0186	89.45	65.15
		2	.0078	37.51	34.86
		3	.0062	29.82	22.00
P-B-4	33.62	1[f/]	.0233	110.74	93.70
P-B-5	33.59	1[g/]	.1159	550.36	501.00

a/ See "A Portable Apparatus for Determining the Relative Wear Resistance of Concrete Floors", N.B.S. R.P. 1252, 549.

b/ First letters: L = high-alumina hydraulic cement; P = Portland cement.
Second letters: O = olivine aggregate; B = crushed building brick aggregate.
The numerals indicate the curing periods and heat exposures:
1 = seven days storage in fog-room plus 21 days at laboratory temperatures and humidity.
2 = twenty-eight days storage in fog-room.
3 = No. 1 plus heat exposure of 250°C for five hours.
4 = No. 1 plus heat exposure of 500°C for five hours.
5 = No. 1 plus heat exposure of 1000°C for five hours.

c/ This value was calculated from volume and weight determinations on specimens of concrete fabricated from the same mix and receiving the same treatments.

d/ Tests 2, 3 or 4 made successively on the same specimens and in same abraded area.

e/ A description of the apparatus and method for determining depth of wear is given in this report.

f/ Large aggregate exposed.

g/ At this depth the cement bond or matrix appears to wear well below aggregate level.

Concretes when cured for 28 days in the fog-room developed the most resistance to wear. Those cured for seven days in fog-room and stored for 21 days at laboratory temperature and humidity were slightly less resistent. Heat exposures of 250, 500, and 1000°C for five hours decreased successively the resistance to wear. Six of the slabs were subjected to the abrasion test from two to four times. There seems to be no relation between the results of the first, second, third, and forth test on the same specimens of concrete when abraded at increasing depths. An examination of the specimens that had been heated show no indication of the aggregate having been pulled out. The bond or matrix, however, appears to be removed from the abraded area to a level somewhat below that of the exposed aggregate. This condition was not so pronounced in the concrete designed with the high-alumina hydraulic cement and heated to 1000°C.

Figure 4 shows the linear relation between the two methods of measuring the wear or abrasion resistance of concretes. The slope of the line indicates that the difference obtained by the two methods increases with the amount of wear. This increasing difference in results (as obtained) may be explained partially by the decrease in unit weight of the material, Table III, if the same percent of abraded material is lost (disseminated) in the surrounding air.

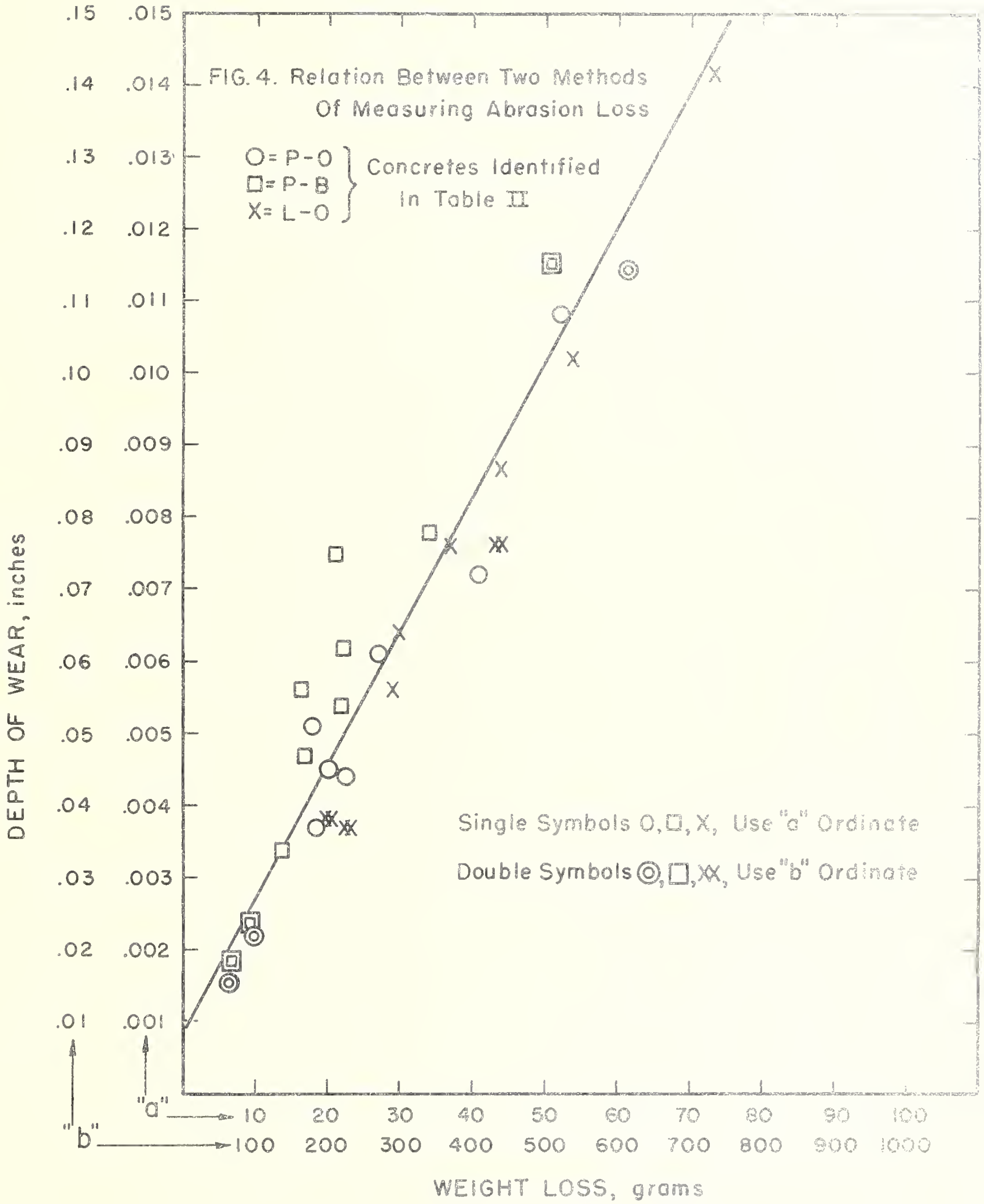


FIG. 4. Relation Between Two Methods Of Measuring Abrasion Loss
O = P-O
□ = P-B
X = L-O
Concretes Identified in Table II
Single Symbols O, □, X, Use "a" Ordinate
Double Symbols ◎, ⧈, XX, Use "b" Ordinate
DEPTH OF WEAR, inches
WEIGHT LOSS, grams
"a"
"b"
.15 .015
.14 .014
.13 .013
.12 .012
.11 .011
.10 .010
.09 .009
.08 .008
.07 .007
.06 .006
.05 .005
.04 .004
.03 .003
.02 .002
.01 .001
10 20 30 40 50 60 70 80 90 100
100 200 300 400 500 600 700 800 900 1000

N O T E S

1/ "Journal of Research of the National Bureau of Standards", Vol. 23, No. 5, pages 549-570.

2/ "A.S.T.M. Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials," October 1952, Securing, Preparing and Testing Specimens from Hardened Concretes for Compressive and Flexural Strength, page 179, paragraph (f).

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

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