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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0903-20-4428	July 27, 1959	6475

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

by

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Sponsored by

Department of the Navy
Bureau of Yards and Docks

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

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NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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1. INTRODUCTION

The purpose of this project is the development of criteria for the fabrication of jet exhaust resistant concretes. Concretes under development are evaluated by exposure to hot gases from a combustion chamber. The combustion chamber delivers these gases at velocities and temperatures approaching field conditions.

2. X-RAY EXAMINATIONS OF NEAT CEMENTS

X-ray patterns have been obtained on four specimens of neat portland cement after the following treatments. Cement was mixed with 27.5% water and placed in the cylinders of bombs*. One sample was taken from a bomb after fog-room curing for 12 days. A second sample was taken from a bomb that had received 12 days fog-room curing and seven days evacuation (constant weight). A third sample was taken from a bomb that had received the fog-room and evacuation treatments followed by heating to 280° C under increasing pressures to 1000 psi. The cement from which the third sample was taken was removed from the bomb and placed in a porcelain crucible and heated at atmospheric pressure to 300° C. The fourth sample was taken from this material.

The patterns have not as yet been interpreted.

* A schematic diagram of the bomb appears in Figure 2, NBS Report 5233.

3. EFFECT OF THE LENGTH OF CURING AND DRYING PERIODS ON THE RESISTANCE OF BLAST FURNACE SLAG CONCRETE TO JET IMPINGEMENT

Panels made with blast furnace slag aggregate, that were cured in the fog-room for 28 days prior to various drying periods, evidenced no visible loss in the jet blast test. The panels, and the test results, were reported in NBS Report 6398; for convenience the test results are also given in Table I of this report. To determine if similar concrete with only 14 days moist curing would also resist spalling, three 18x18x6 in. panels were fabricated. The proportions used were similar to that previously reported. A second shipment of blast furnace slag was required for the work. The grading, bulk specific gravity, and absorption were similar to the slag of the first shipment.

The properties of the fresh concrete were as follows:

Proportion, by weight of cement, to fine, to coarse aggregate	1:1.36:2.04
Cement content, sacks/yd^3	7.73
Vinsol resin, by weight of cement, percent	0.01
Water content, gallons/yd^3	29.40
W/C ratio, by weight	0.41
Air content, gravimetric, percent	3.9
Slump, inches	3.5
Remarks	good workability

Five 6x6x36 in. beams were also cast from this concrete. Tests made on these specimens are described in Section 5.

The fog-room curing period for the panels was reduced from 28 to 14 days and the drying periods of the 3 panels were 7, 14, and 21 days respectively. The panel P-BF-5-1 (Table 1), after 14 days fog-room curing

TABLE 1. Effect of Curing, Drying, and Jet Impingement on Panels Designed with Portland Cement and Blast-Furnace Slag

Identification 1/	Ratio of Ct. to Fine & Coarse Agg.	W/C Ratio	Cement Content	Air Content	Percent water based on wet weight 2/			Jet Impingement Test					Remarks
					Mixing	Out of fog-room	Drying 3/	Duration	Temp. of Pan. at Cen. Surf.	Loss During Test 1 4/	2 4/	3 4/	
			Sacks/yd3	%	%	% 5/ 6/	% 6/	min	°F	%	gms	cc	
P-B-F-1	1:2.04:1.36	0.40	7.35	3.69	11.37	[1] 11.85 (28)	11.37 (21)	10	1305	0.32	No visible loss		
						[2] 11.85 do	11.21 (28)	10	1290	0.16			
						[3] 11.85 do	11.05 (35)	10	1315	+0.32			Subjected to 2" rainfall before Jet impingement.
P-B-F-5	do	0.41	7.73	3.86	11.34	[1] 11.88 (14)	11.25 (7)	10	1255	0.64	204.18	286.87	Water on back of panel: Pink 7/
						[2] 11.82 do	11.19 (14)	10	1135	0.16	No visible loss		No water Pink 7/
						[3] 11.81 do	11.18 (21)	10	1185	0.19			do do Pink to light red during test 7/

1/ The design of the concrete used in fabricating these beams is given in the text; it also appears in N.B.S. Report 6398.

2/ Based on wet weight of batch.

3/ 50% relative humidity and 73°F.

4/ Three methods of calculating loss (1) based on weight of whole panel
(2) " " " of concrete spalled
(3) " " volume of cavity resulting from spalling

5/ The numeral in brackets is number of Panel.

6/ The figure in parenthesis denotes days of fog-room storage or drying.

7/ This phenomena is discussed in text.

and 7 days drying, showed a loss measurable by methods 1, 2, and 3, appearing under column, "Jet Impingement Test". Panels 2 and 3, for which the drying periods were 14 and 21 days respectively, showed no loss. These data indicate that a concrete made with blast furnace slag may be expected to resist the jet blast when fog-room cured for 14 days and dried, at 50% humidity and 73°F, for the same period of time.

The appearance, disappearance, and reappearance in a different location, of pale pink areas, approximately two inches in diameter, noted in the column headed "Remarks", Table I, is a phenomena as yet unexplained. It is noticeable only in concretes that show no visible loss in the jet impingement test and occurs after a duration of about one minute of the test.

Repeated jet impingement tests on successive days on panel P-BF-5-3 affected the temperature gradient in the top 1/4 inch. The curves shown in Figure I give the results of temperature measurements on and within the same panel during three successive jet impingement tests.

The difference between surface temperatures and those one quarter inch below the surface at the end of each time interval was greater during the first test than during subsequent tests. We attribute this to the presence of more moisture in the concrete available for cooling by evaporation during the first test.

The studies that were made of the effect of reducing the angle of impingement of the jet stream from 90 to 15° did not materially alter the temperature pattern. Temperature data at other positions and depths during the three tests gave similar results.

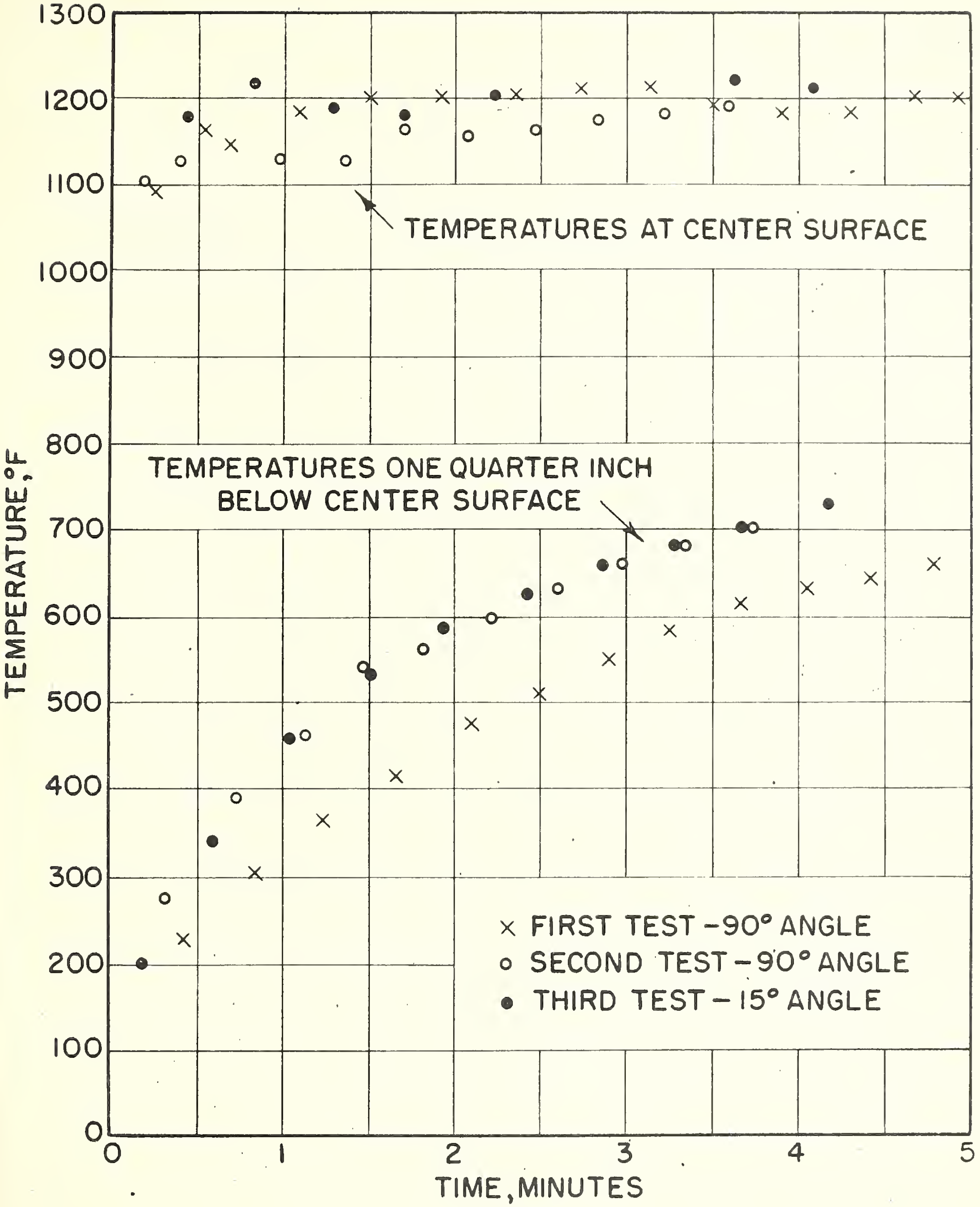

FIG. 1–TIME–TEMPERATURE CURVES AT CENTER SURFACE AND ONE QUARTER INCH BELOW CENTER SURFACE OF TEST PANEL DURING THREE JET IMPINGEMENT TESTS.

4. EVALUATION OF WATER REPELLANTS

To evaluate the merit of surface water-repelling treatments in reducing the water absorption of concrete during exposure to moisture, rainfall or high humidities, and thereby improving the concrete's ability to resist jet impingement, two 18x18x6 in. panels were fabricated using a portland diabase concrete. Five, 36x6x6 in., beams were also fabricated from the same mix. The tests made on these beams will be described later in Section 5 of this report.

The concrete was a seven-sack mix with 65% coarse diabase and 35% fine. The W/C ratio was 0.48 resulting in a slump of 6 in. A more detailed description of this concrete was given in NBS Report 5123. Since it was believed that vacuum-processed concrete has a more open structure than conventionally placed concrete, this method was used in placing the panels. These panels were fog-room cured for 21 days. The drying period prior to the jet blast test was shortened to 14 days with the expectation that an untreated panel would show some spalling. One panel was treated with a silicone water repellant at the end of the drying period and permitted to dry for four hours. Both panels were subjected to the equivalent of a two inch rainfall for 24 hours; and immediately exposed to the jet blast for 10 minutes. The untreated panel gained weight during the rainfall exposure, 0.17%; the treated panel did not, but there was a slight increase in weight from the silicone treatment. During the jet blast test, the treated panel evidenced some spalling, the untreated none. However, after a cooling period of several hours the untreated panel did show some pop-off failure. This latter type of failure is common when refractories are

subjected to a thermal spalling test. As a result of this limited test we have concluded that (1) our effort to choose a control concrete that would show appreciable spalling failed; (2) a longer period of time should elapse between application of the water repellant and rainfall exposure, and (3) the concrete should be alternately wetted and dried through several cycles before exposure to the jet test.

5. ASSESSMENT OF THE EFFECT OF STEAM PRESSURE AND THERMAL PROPERTIES ON THE FLEXURAL STRENGTH AND BEHAVIOR IN THE JET BLAST TEST

The resistance to jet blast of room-dry beams was compared to that of oven-dry beams, with the thought that only thermal stress would be involved in the latter, while thermal and steam pressure stresses would occur in the former. The beams, previously mentioned in this report, sections 3 and 4, were cured in the fog-room, sealed on all but the top surface, as cast, and dried at 50% relative humidity and 73°F. The seal was removed when the beams completed this drying period. Some of the beams were further dried to apparent constant weight at 110°C. The length of the beams, 36 inches, permitted two tests to be made on 18 in. spans with each beam. Five of the ten beams were fabricated using blast furnace slag as the aggregate (see part 3 for batch mix), the other five were fabricated using diabase aggregate (see part 4 for batch).

The curing and drying periods together with the flexural strength and behavior during the jet impingement tests for the five beams fabricated with blast furnace slag are given in Table 2. Although this type of concrete, with a comparatively short period of curing and drying, will withstand exposure to jet blast without spalling, the flexural strength is materially affected. Data, given in Table 2, indicate that slow heating

TABLE 2. Effect of Storage, Drying at 110°C, and Jet Impingement on the Flexural Strength of Concrete Beams Designed with Blast-Furnace Slag and Portland Cement

Identification 1/	Change in Weight During Curing and Drying 2/			Jet Impingement Test 4/		Flexural Strength 6/			Remarks
	Fog-room 14 days	Storage 50% rh 73°F.	Drying 110°C. 3/	Loss 5/	Remarks	Storage 50% rh 73°F.	Drying 110°C.	After Jet Imp. Test	
	%			%		psi	psi	psi	
P-BF-5-1a	+0.23	-0.23 7/ (7)				725			Damp on inside 50% pull-outs 50% aggregate fracture
1b	do	do		-1.02	Cracked at center of exposed surface. Water forced out of crack. Pink glow 9/			380	Damp on inside 75% pull-outs 25% aggregate fracture
do 2a	+0.22	-0.23 7/ (7)	-6.70				745		75% pull-outs 25% aggregate fracture
2b	do	do	do	-0.22	No visible loss			590 [6,735] 8/	75% pull-outs 25% aggregate fracture
do 3a	+0.46	-0.23 7/ (14)				765 [5,280] 8/			50% pull-outs 50% aggregate fracture
3b	do	do		-0.64	Same as 1b			435	50% pull-outs 50% aggregate fracture
do 4a	+0.46	-0.23 7/ (14)	-6.93				715		50% pull-outs 50% aggregate fracture
4b	do	do	do	-0.00	Same as 2b			515 [5,970] 8/	75% pull-outs 25% aggregate fracture
do 5a	+0.23	-0.46 7/ (21)				715 [6,085] 8/			all aggregate fracture
5b	do	do	-6.76				725 [7,220] 8/		50% pull-outs 50% aggregate fracture

1/ The design of the concrete used in fabricating these beams is given in the text; it also appeared in N.B.S. Report 6398. "a" and "b" denote section of same beam.

2/ Based on weight, out of mold, and assumed to be water loss.

3/ Temperature increased at approximately 8°C. per day. Loss in weight, during last 24 hours, less than 0.1%.

4/ The beams were positioned at right angles to jet stream with top surface, as cast, exposed directly to jet blast.

5/ Based on weight of the portion of beam tested before jet impingement.

6/ The load was applied to the top surface of the beams (as cast).

7/ The number in parentheses denotes the time, in days, stored at 50% rh and 73°F.

8/ The values in brackets are compressive strength.

9/ This phenomena is discussed in text.

to 110°C, and apparent constant weight, does not affect flexural strength. Upon jet impingement portions of beams that had been dried at 73°F and 50% relative humidity decreased in flexural strength 45% while those also dried at 110°C decreased in strength but 25%. As shown in Table 2 column "Jet Impingement Test, Loss", drying at 110°C did increase the resistance of this concrete to jet impingement. The specimens with additional drying also showed no evidence of cracking during jet impingement (see Figure 1, NBS Report 6398).

The results of tests on the five beams fabricated using concrete made with diabase aggregate appear in Table 3. The proportions of this concrete were given in part 4 of this report. Drying at 110°C, after 28 days fog-room curing, and storage at 73°F and 50% relative humidity, increased the flexural strength of this type of concrete by 30%; jet impingement decreased the strength of those dried at 50% relative humidity and 73°F by 20%, and of those receiving the additional drying at 110°C by 30%. The beams of this set showed little or no spalling during jet impingement regardless of previous treatments. In those not dried at 110°C there was cracking at the center of the jet impingement area and evidence of water being forced from the cracks during the test.

These tests were suggested when it was found that beams subjected to the jet blast on the top surface, as cast, and those broken in flexure with loading on the side of the beam, showed much greater loss in strength than could be accounted for by the small depth of material undergoing temperature change during the jet blast. The tests are limited in number and are not conclusive. It appears, however, that the flexural strength test is not

TABLE 3. Effect of Storage, Drying at 110°C, and Jet Impingement on the Flexural Strength of Concrete Beams Designed with Diabase Aggregate and Portland Cement

Identification 1/	Change in Weight During Curing and Drying 2/			Jet Impingement Test 4/		Flexural Strength 6/			Remarks
	Fog-room 28-days	Storage 50% rh 73°F	Drying 110°C 3/	Loss 5/	Remarks	Storage 50% rh 73°F	Drying 110°C 3/	After Jet Imp.Test	
	%	%	%	%		psi	psi	psi	
P-Di-4-1a	+0.48	+0.12 (14) 7/				600			Damp inside when broken 85% pull-outs 15% aggregate fracture
1b	do	do		Not determined	Cracked at center of impingement area. Water forced out of crack during jet test.			410	85% pull-outs 15% aggregate fracture
do 2a	+0.20	-0.18 (14)	-5.18				750		90% pull-outs 10% aggregate fracture
2b	do	do		-0.29	No cracking No water visible			455	95% pull-outs 5% aggregate fracture
do 3a	+0.40	-0.20 (28)				495			Damp inside when broken 90% pull-outs 10% aggregate fracture
3b	do	do		-0.81	Same as 1b			400	95% pull-outs 5% aggregate fracture
do 4a	+0.40	-0.13 (28)	-5.08				680 [6,030] 8/		50% pull-outs 50% aggregate fracture
4b	do	do		-0.28	No apparent spalling			540	80% pull-outs 20% aggregate fracture
do 5a	+0.35	-0.36 (42)				790 [5,540] 8/			75% pull-outs 25% aggregate fracture
5b	do	do	-4.85				880 [6,015] 8/		75% pull-outs 25% aggregate fracture

1/ The design of the concrete used in fabricating these beams is given in the text; it also appeared in N.B.S. Report 5123. "a" and "b" denote sections of the same beam.

2/ Based on weight of beam, out of mold, and assumed to be water loss.

3/ Temperature increased at approximately 8°C per day. Loss in weight in last 24 hours was less than 0.1%.

4/ The beams were positioned at right angles to the jet stream with top surface (as cast) exposed directly to jet blast.

5/ Based on weight of the portion of beam tested before jet impingement.

6/ The load was applied to the top surface of the beams (as cast) in all but the two portions a and b of beam 1.

7/ The numbers in parentheses denote the number of days stored at 50% rh and 73°F.

8/ The figure in brackets is the compressive strength.

suitable to assess damage resulting from jet blast. It is presumed that while only a relatively thin layer of concrete undergoes appreciable temperature rise during the jet blast, damage from thermal expansion in the form of small cracks extends to greater depths. Such damage might not result where the jet blast is directed on a large slab, and if it did occur, might not be permanent because of the possibility of autogenous healing.

6. PERMEABILITY

Earlier work on this project has indicated that concretes made with a fine grained trap-rock aggregate show better performance in the jet blast test than concrete with other dense aggregates. Recently it was found that concretes made with blast furnace slag, a relatively porous and light-weight material, also performed well. It is evident, that while specifying a dense, fine grained aggregate may lead to a more satisfactory product, such a requirement is unduly restrictive and other properties of the aggregate, or of the resulting concrete, may be of equal or greater importance. Jet blast tests on evacuated concrete have indicated that permeability to fluid flow is one of these important properties. An apparatus to measure this property is being assembled. This apparatus was used by Mong and Massengale in their work on the air permeability of refractories*. A study of the results in this publication and literature on the permeability of concretes indicated that the air permeability of concrete falls within the range of this apparatus.

* Permeability and Some Other Properties of a Variety of Refractory Materials, 1 and 11, J.A.C.S., Vol. 36, No. 7 & 8, July and August, 1953.

7. MISCELLANEOUS

Differential thermal analysis and thermal gravimetric analyses were made on the three samples of rock submitted by your laboratory at Port Hueneme. All samples exhibited a gradual loss of weight, in addition to the initial loss of free water. The weight losses for Napa Quarry, Napa Basalt, and Juarez Basalt at 500°C were 1.25, 1.5 and 2.8% respectively. All three aggregates show an exothermic reaction at approximately 300° C with some indication that this reaction is accompanied by weight gain.

The thermal conductivity of blast furnace slag concrete was determined by the NBS Heat Transfer Section. At a mean temperature of 118.3°F it was 4.29 Btu-in/hr-ft^2-°F. The density of the specimen tested was 125.2 lbs/ft^3. The value for thermal conductivity falls mid-way between those reported for dense and light-weight aggregate concrete.