NATIONAL BUREAU OF STANDARDS REPORT

4767

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

by
W. L. Pendergast, E. C. Tuma, L. E. Mong
and R. A. Clevenger

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U. S. DEPARTMENT OF COMMERCE
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Refractories Section
Mineral Products Division

Sponsored by
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Approved:

Dr. Samuel Zerfoss
Chief, Refractories Section

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1. INTRODUCTION

This phase of the project includes the determination of the cause or causes of failure that occur in concrete aprons and runways exposed to jet exhaust gases. A combustion chamber that delivers hot gases at velocities and temperatures approximating those of field conditions is being used. The approach includes instrumentation of the concrete test panels to determine the heat gradients and stresses set up during flame impingement at several locations on the test area and at varying depths below the surface.

2. PREPARATION AND TESTING

A study of the rate and the amount of water that is absorbed by concrete during curing and evaporated during drying is being continued. As mentioned in the last quarterly report three-inch square tile of various thicknesses were used. The weight change of the tile during the test was assumed to indicate the movement of water. The two sets of tile used in this work were fabricated using concretes designed with portland cement and either White Marsh or crushed building brick as the aggregate.

The specimens were weighed at seven day intervals during curing. After the 28-day fog-room curing, they were water sealed on all but one three by three-inch face and dried at 73°F at a constant humidity of 50 percent. The water lost during the drying period was determined at seven-day intervals also.

Five concrete panels, together with other test specimens, have been fabricated and are being cured in the fog-room. These specimens were fabricated with concrete, designed with crushed olivine and portland cement, and the properties of the fresh concrete were in agreement with those appearing in NBS Report 3201, March 31, 1954, Table 1. Thermocouples were positioned on the surface of the panels, within the test area, and imbedded at one quarter and one-half inch depths below the surface. These panels, after fog-room curing for 28 days, will be dried, at 73°F and 50 percent relative humidity, for increasing time intervals and subjected to the jet exhaust. Sets of prisms (3 x 4 x 16 inches) fabricated from the same concrete batch will be cured and dried with each test panel. These prisms will be used to determine such properties as shrinkage, Young's modulus of elasticity and flexural strength. Tile, of the same concrete, three inches square with increasing thicknesses from one-half to six inches will be used to determine the movement of water in the concrete during curing and drying.

Ten concrete panels (18 x 18 x 6 inches) were subjected to the jet blast. All ten were designed using portland cement. Five contained White Marsh aggregate and five crushed building brick. All panels were cured for 28 days in the fog-room but the drying period varied at seven, or multiples of seven, day intervals. Each panel was placed in position perpendicular to the jet stream and subjected to a five minute exposure. The temperature, in the combustion chamber, of the hot gases was kept constant at 1400°F which resulted in temperature of approximately 1200°F on surface of panel. The velocities were constant at 1200 feet per second.

An examination of the panels after exposure to the jet blast has shown that when failure occurred the aggregate fractured parallel to the exposed surface. This type of failure suggested that it might be due to water absorbed by the aggregate and expanded to steam during exposure to jet blast. To determine the liability of the aggregates alone to this mode of fracture pieces of three aggregates, White Marsh gravel, crushed building brick, and crushed olivine, were selected according to size (-1 1/2 + 1 inch) and shape. Surface texture and coloration were added factors in selecting the White Marsh and olivine aggregate. One set of specimens of each aggregate was dried at 110°C to constant weight. A second set was saturated. All

specimens were placed in a wire mesh container and positioned in the jet stream at 1200°F and velocities of 1200 feet per second for a two-minute interval.

3. RESULTS AND DISCUSSION

The curves given in Figure 1 indicated that there was a variation of water with time and the thickness of the specimen which had a single exposed face.

Considering the gain in moisture during the 28-day fog-room curing, the relation:

$$a_c W_c^3 = T \text{ or } W_c = \sqrt[3]{\frac{T_c}{a_c}} \qquad (1)$$

where, W_c = increase in water in percent of the weight of the (one day old) concrete when placed.

T_c = Time, in days, after placing

a_c = constant for a given specimen of a given concrete during curing.

This relation fits the data quite well within the curing period of 28 days but obviously would not fit for longer periods of time because water addition to the concrete would eventually stop.

The data for the drying process follows the relation:

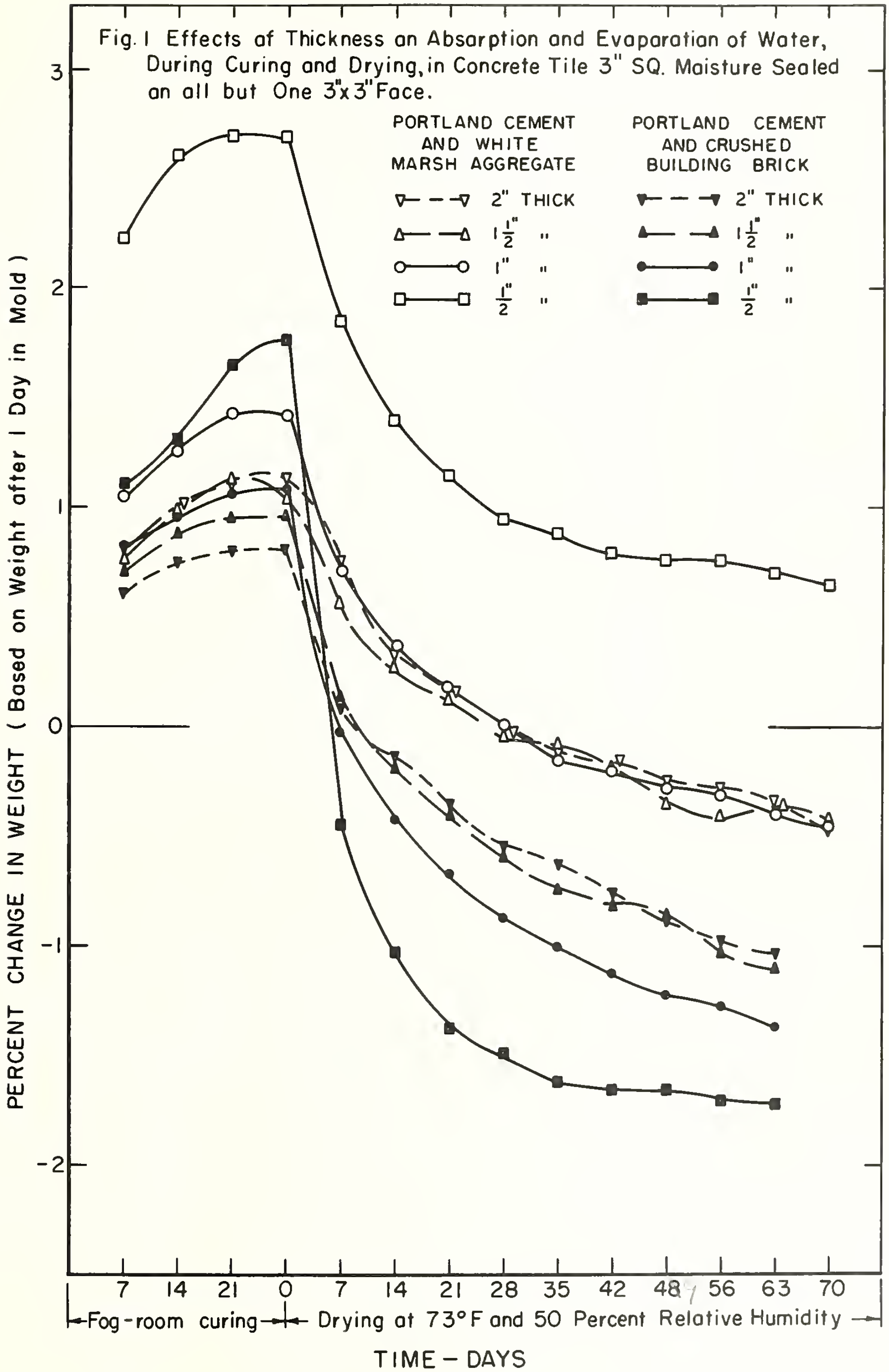

Fig. 1 Effects of Thickness on Absorption and Evaporation of Water, During Curing and Drying, in Concrete Tile 3" SQ. Moisture Sealed on all but One 3"x3" Face.

$$-a_d W_d^2 = T_d \text{ or } W_d = -\sqrt[2]{\frac{T_d}{a_d}} \qquad (2)$$

where, W_d = water in percent lost from beginning of drying process to time T_d.

T_d = Time, in days, from beginning of of drying process.

a_d = constant for a given specimen of a given concrete during drying exposed to 50 percent relative humidity and 73°F temperature.

This relation fits the data quite well to approximately 56 days, but cannot fit for longer periods when water equilibrium is approached.

While a_c and a_d are constant for a given specimen, they vary linearally with the depth of the specimen; i.e. the dimension of the specimen at right angles to the exposed surface, and have different values for different concretes. During curing, for the portland-crushed building brick concrete:

$$a_c = 19.5d - 4 \qquad (3)$$

and for portland White Marsh concrete

$$a_c = 13.4d - 6.5 \qquad (4)$$

During drying, for the portland-crushed building brick concrete:

$$a_d = 8.5d - 1 \qquad (5)$$

and for portland-White Marsh concrete

$$a_d = 14.3d + 1 \qquad (6)$$

where, d = thickness in inches at right angle to the exposed face.

If the values of a are substituted in formulas (1) and (2) then for curing:

for portland-crushed building brick concrete

$$W_c = \sqrt[3]{\frac{T_c}{19.5d - 4}} \qquad (7)$$

for portland-White Marsh concrete

$$W_c = \sqrt[3]{\frac{T_c}{13.4d - 6.5}} \qquad (8)$$

and for drying:

for portland-crushed building brick concrete

$$W_d = \sqrt[2]{\frac{T_d}{8.5d - 1}} \qquad (9)$$

for portland-White Marsh concrete

$$W_d = \sqrt[2]{\frac{T_d}{14.3d + 1}} \qquad (10)$$

From equations (7) through (9) it is apparent that the portland-White Marsh concrete, having the lower cement concentration, gains more water during curing and loses less water during drying than the portland-crushed building brick concrete. This performance is contrary to the expected,

for the water, added during mixing, available for hydration is slightly greater in the portland-White Marsh batch. Also, since the water exchanged depends on the thickness of the specimen, it appears that volume changes of the concretes, dependent on the cement, the aggregate, and specimen dimensions, may affect the pore structure and the value of the constant a. Apparently, the factor a is dependent on a number of variables that happen to be constant for a given specimen.

These equations are useful in calculating the amount of water present in concrete at any given time provided an accurate value of a is obtained from a pair of observations. Fortunately, a is quite large for thick masses of concrete and the resulting change in water is small during curing and drying. The results for the small laboratory specimens reported in Figure 1 are interesting in explaining the changes in water, but have limited application for large masses of concrete.

The total quantity of water present in a concrete specimen at a given time, desirable for correlation with losses resulting from the jet impingement test, can be expressed by the following equation:

$$W = W_m + \sqrt[3]{\frac{T_c}{a_c}} - \sqrt[2]{\frac{T_d}{a_d}} \qquad (11)$$

where, W_m = total water present in batch at the time of placing.

Since W_m falls in the range from 6.5 to 8.5 percent of the batch, the amount of water exchanged during curing and drying may be insignificant since it ranges from about 0 to 3 percent. The determination of water actually present by taking the sum of these three quantities is not desirable due to possible accumulated errors.

Direct measurements on cores from the concrete would be desirable to obtain the total water and its distribution as pore water and hydration water. Hydration water is subject to definition but can be differentiated from that held by other mechanisms. The distribution of water within the concrete mass would be obtained from cored samples or by embedded humidity indicators, of the Dunmore type, rather than from specimens of different thickness which are subject to variables due to the mass of the specimen.

The temperature as indicated by thermocouples placed at various positions on the test area and at different depths below the surface of the tested panels fall in the bands shown in Figures 2 and 3. The width of the bands show the variation in temperature that occurred during a five-minute exposure of two sets of five panels each. The width of the bands is a measure of the accuracy of the

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1/ "Studies of the Physical Properties of Hardened Portland Cement Paste" by T. C. Powers and L. T. Brownyard, Bull. 22, J. Amer. Concrete Institute.

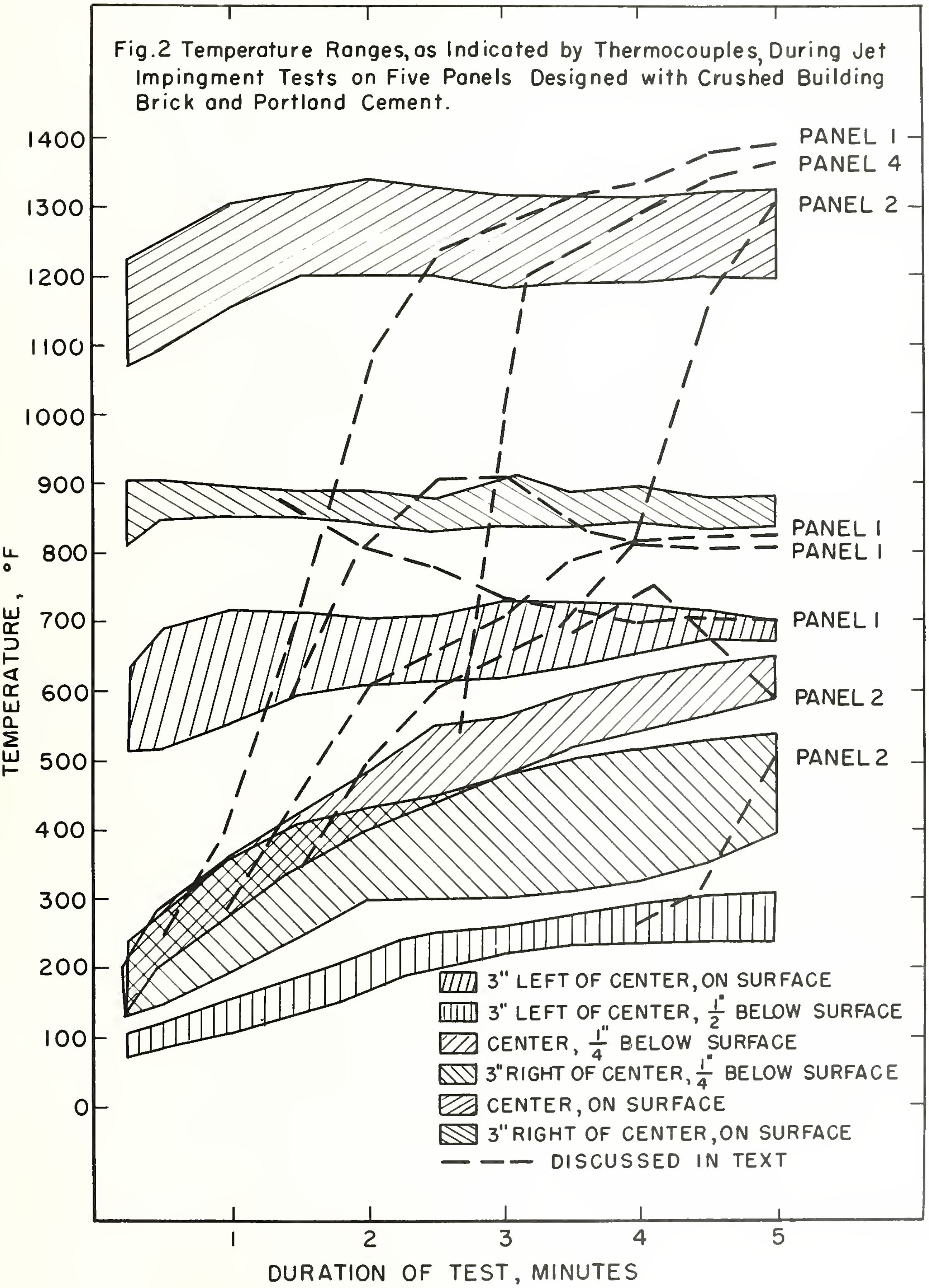

Fig. 2 Temperature Ranges, as Indicated by Thermocouples, During Jet Impingment Tests on Five Panels Designed with Crushed Building Brick and Portland Cement.

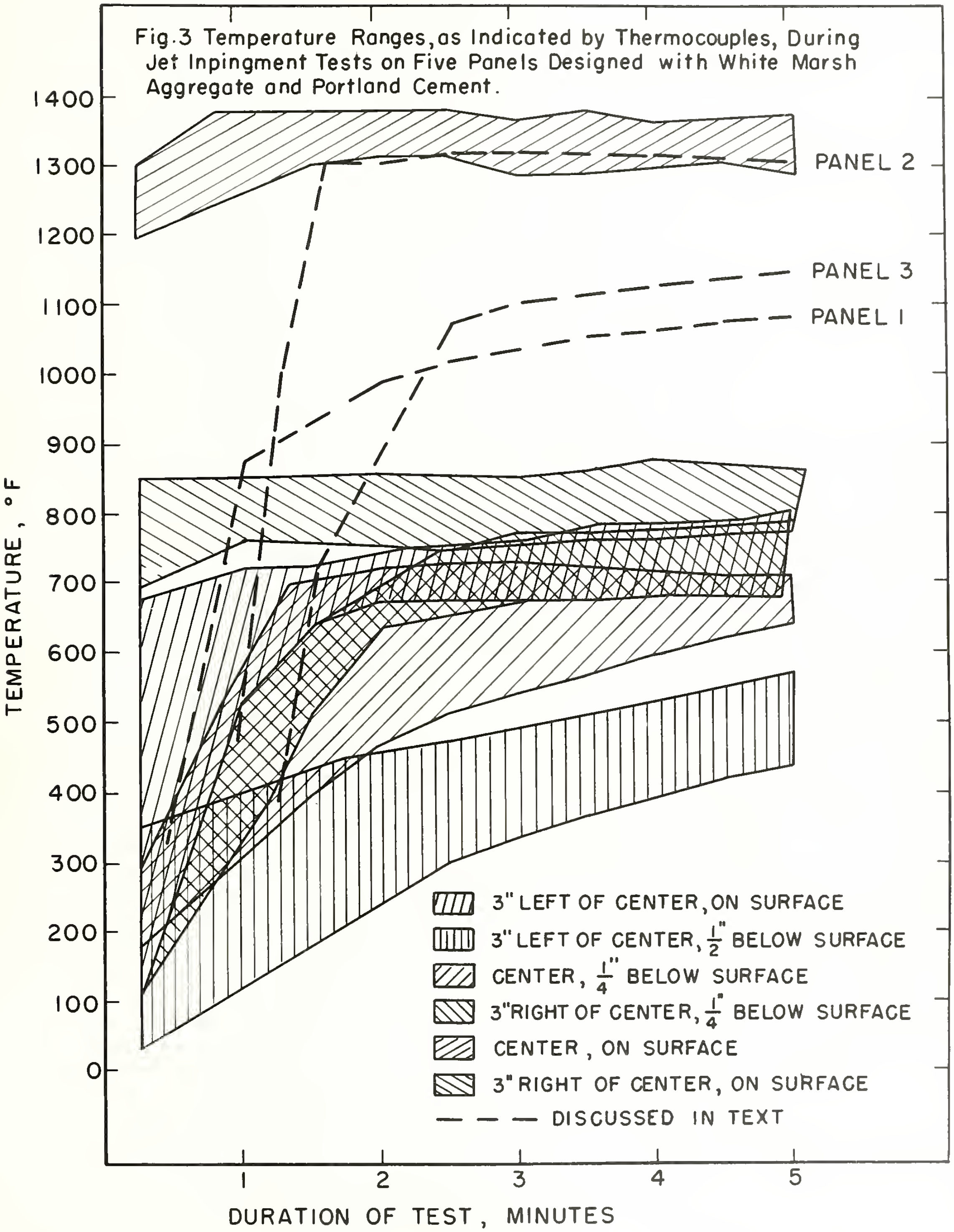

Fig. 3 Temperature Ranges, as Indicated by Thermocouples, During Jet Inpingment Tests on Five Panels Designed with White Marsh Aggregate and Portland Cement.

placement of the thermocouples and the positioning of the test panel in reference to distance and angle to jet stream. The dash lines, with origin in some band but deviating from it, indicate the abrupt change in temperature associated with fracture.

The temperature of the buried thermocouples, when exposed by spalling of the surface, rapidly approached the surface temperature. This evidence of fracture occurred in most instances during the first one and one-half minutes of the test.

When the temperature, as indicated by the surface couples, left the band, this deviation was probably caused by a change in direction of the impinging gases caused by a change in contour of the exposed area.

Table 1 gives the modulus of elasticity (dynamic method) and flexural strength of (3 x 4 x 16 inch) prisms cured and dried in the same manner and for the same time interval as the respective test panel. Increasing the drying period did not materially effect these properties. Drying at a controlled temperature of 73°F and 50 percent humidity resulted in negligible losses of water during the drying time in contrast to larger and variable losses previously reported for panels exposed to variable atmospheric conditions. This in turn would favor the hydration process for the controlled atmosphere.

Table 1. Some Properties of the Concretes and Spalling Loss of Panels During Jet Impingement.

Concrete Design	Panel	Drying Time in Days	Total Water at Time of Test	Flexural Strength	Young's Modulus of Elasticity Dynamic:Longitudinal	Spalling Loss from Weight[a]	Spalling Loss from Volume[b]
			percent	psi	$lbs/inch^2 \times 10^6$	cc	cc
Portland cement and White Marsh sand and gravel	1	14	6.74	650	5.601	152.90	93.7
	2	21	6.86	575	5.667	114.67	134.0
	3	35	6.80	675	5.089	111.48	85.4
	4	42	6.85	700	5.440	76.40	47.1
	5[c]	7	6.68	- [d]	- [d]	38.23	67.7
Portland cement and crushed building brick aggregate	1	7	8.56	665	5.200	299.45	260.7
	2	14	8.63	730	5.198	378.86	363.0
	3	28	8.56	690	5.172	38.23	- [e]
	4	35	8.62	685	5.203	219.78	100.7
	5	42	8.46	640	4.920	- [e]	- [e]

a/ Calculated from weight loss.

b/ Determined by the sand volume method.

c/ This panel was tested after 21 days fog-room curing and seven days drying at 73°F and 50 percent relative humidity. The duration of test was two minutes.

d/ Not determined.

e/ Spalling loss visible but not measurable by methods used.

The total water content at time of test was the sum of the water added while mixing plus that absorbed during curing minus that evaporated during drying and was determined on the (18 x 18 x 6 inch) panels. This water content does not necessarily represent the amount of water present in that portion of the panel subsequently fractured in the jet impingement test. The spalling loss of the tested panels was determined by two methods. The first method, from weight, was calculated as cubic centimeters of volume which was equivalent to the difference in weight, obtained from the weights of the panel before and after testing, divided by the calculated density. The second method, from volume, was the volume of sand required to fill the cavity remaining after impingement test. The first method probably included the water avaporated from the concrete adjacent to the cavity. This probably accounts for the high value when determined by the first method.

Figure 4 shows the shape of the concrete fragments removed by fracture. The size of the particles, however, increases with time of test and depth of failure. An examination of the flake like fragment indicates no bond failure.

The results of the exposure of aggregates of White Marsh and crushed building brick to the jet stream for two minutes are shown in Figure 5. The two dark specimens are

Figure 4. Fragments that popped from panel during jet impingement test. Left an edge view, right a surface parallel to face of panel.

Figure 5. Dark specimens are brick aggregate, light specimens are White Marsh gravel; left specimens previously soaked, right specimens dried to constant weight.

the crushed building brick and the two light are the White Marsh gravel. The two specimens on the right, one light and one dark, were dried to constant weight before exposure. The two on the left were saturated. Both saturated specimens were shattered by exposure. The White Marsh fracture followed no definite pattern. The building brick failure shows the usual fracture that occurs in dense ceramic materials. The specimens of olivine included in this study whether completely dry or saturated did not fracture. The results of this improvised test would indicate that the presence of water in the aggregate of concrete is a factor in its destruction when heated rapidly.

A conference was held at this Bureau, June 14. The names of those attending follow:

F. Knoop P. P. Brown	Bureau of Yards and Docks
John Bishop	N A V C E R E L A B
S. Zerfoss W. L. Pendergast	National Bureau of Standards

The purpose of the conference was to formulate a program to be undertaken by NAVCERELAB that would augment the presently planned investigation at the National Bureau of Standards.

A review of the work completed at this laboratory indicated that a further study of the following phases would offer material assistance toward the accomplishment of the basic objective of the project.

(1) Moisture content determined by capacitance measurements.

(2) Effects of aggregate size.

(3) Effect of rate of heating on neat cement.

All present concurred in the desirability of continuing these studies at NAVCERELAB.

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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