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Fire Tests of Gunite Slabs and Partitions

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report 131

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Fire Tests of Gunite Slabs and Partitions

Nolan D. Mitchell

Building Materials and Structures Report 131

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Foreword

The use of noncombustible constructions for restricting the spread of fire makes necessary a knowledge of the fire-resistive properties of the materials used in them.

This paper gives the results of fire tests on gunite concrete in the form of slabs and partitions. In addition to reporting the fire-endurance limits of gunite of conventional cement and sand mix, a means of improving the fire resistance of this type of concrete by modifying the aggregate is presented. Such modification would probably be effective in other types of concrete as well.

A. V. Astin, *Acting Director.*

CONTENTS

Fire Tests of Gunite Slabs and Partitions

Nolan D. Mitchell

Eight slabs and four partitions made with gunite concrete on wire-fabric reinforcement were subjected to fire-endurance tests at the National Bureau of Standards. The slabs were made with aggregates composed of sand and wood sawdust, the sawdust ranging from 0 to 50 percent by volume of the aggregate. The aggregate for two partitions was sand, a third had a minor amount of asbestos added, and that of the fourth consisted of equal volumes of sand and sawdust. Fire-endurance limits for the slabs increased almost linearly with increased percentages of sawdust incorporated into the mix. Partitions made with sand aggregate only in the concrete or with the addition of a small amount of asbestos fiber to the concrete showed early failure by spalling and holing through. The explosive violence of the disruptions suggested the presence of entrapped water in the dense concrete. A partition made with a concrete having equal volumes of sawdust and sand as aggregates did not spall and failed by a limiting 325 deg F rise of temperature at a single point on the unexposed side after 70 min of fire exposure, whereas the partitions having asbestos and sand or sand only as the aggregate reached fire-endurance limits through explosive spalling in 16 to 26 min. Subsequent to the fire-endurance test, the partition with sawdust successfully withstood the application of the hose-stream test. The effect of the sawdust is to lower the thermal conductivity of the concrete and increase its porosity, thus making easier the escape of moisture in the form of vapor.

1. Introduction and Scope

Fire-endurance tests were conducted at the National Bureau of Standards on eight slabs and four partitions made of gunite concrete with welded-wire fabric reinforcement. In addition to its extensive use as linings for flumes, conduits, sewers, and reservoirs, gunite has been used as fire-protective coverings on structural members and as readily applied coatings, such as stucco on buildings. This type of concrete has also been suggested as suitable for the construction of fire-resistant curtain walls to prevent or reduce the spread of fire among flammable materials. The tests described in this report were made to investigate the properties of gunite in slabs and partitions when subjected to standard fire exposures.

Tests on steel columns with gypsum fire-protective coverings had shown that a gypsum concrete having wood chips as the aggregate was superior in fire protection to other types of gypsum encasement tested.[1] For this reason, sawdust was suggested as a substitute for part of the sand aggregate in six of the eight gunite slabs and in one of the partitions. The mix for another partition was altered by the addition of fibered asbestos.

2. Materials

Two slabs were made from each of four mixes. The aggregate for one pair of slabs was composed of siliceous concrete sand. For the other three pairs, sawdust was mixed with the sand in the amounts of 30, 40, and 50 percent of the volume of the aggregate. The ratio of cement to aggregate was 1:4 by volume.

Potomac River sand was used in the construction of the partitions. The aggregate for two partitions consisted of 3 parts of building or mortar sand and one part concrete sand by volume. The other two partitions had building and concrete sands in equal quantities in the aggregate. The mix for one partition (125) was modified by the addition of 6 lb of asbestos fiber to each bag of cement.[2] Another partition (139) was made with aggregate consisting of equal volumes of sand and sawdust.

The sawdust for partition 139 consisted principally of white pine and maple, mostly fine, but with some planer shavings of size to pass a No. 2½ screen, and weighed about 10½ lb/ft^3.

The welded-wire fabric used for reinforcing in both the slabs and partitions was of 4- by 4-in. mesh made with No. 6 galvanized wire.

Oiled plywood sheets were used to support the wire fabric and served as backing panels against which to project the gunite during the construction of the slabs and partitions. The frames for the gunite slabs as well as the supporting members of the plywood backing-up forms, were of ordinary lumber.

3. Construction of Slabs and Partitions

The slabs and partitions were constructed by blowing the gunite mix against plywood held as a

[1] Nolan D. Mitchell, fire tests of columns protected with gypsum, BS J Research 10, 737 (1933) RP563.

[2] S. H. Ingberg and N. D. Mitchell: results of these tests were summarized in NBS Report BMS71, fire tests of wood- and metal-framed partitions (1941).

backing within the construction or fire-test frames. The water was added as the mixture left the nozzle. Wire fabric was placed in these frames so as to be in the midplane of a slab or partition. The slabs, made in the shops of the Cement Gun Company of Allentown, Pa., were shipped by truck to the National Bureau of Standards with the wood frames still attached. These frames were removed after delivery. The partitions were made at the National Bureau of Standards in the movable steel test frames of the furnace in which they were to be tested.

The concrete was placed with a cement gun having a 3-bag batch capacity. One bag of cement (94 lb) was considered as one cubic foot. The weight of one cubic foot of sand varied with the moisture content, ranging from 73 to 100 lb/ft ^{3}. Six of the slabs and one partition, 139, had sawdust mixed with the sand aggregate. The ratio of cement to aggregate was 1:4 by volume, but varied considerably in proportion by weight because of differences in the moisture content of the sand and the low density and varied amounts of sawdust. When the gunite had been deposited to the required thickness, its surface was leveled and finished with a float.

Two groups of slabs made up of one from each mix were placed for drying, the one consisting of odd-numbered slabs before the fan outlet of a high-pressure-steam unit heater, the other on the floor of the laboratory building. To determine the condition of dryness, the slabs were weighed periodically. The first fire-endurance test was made after the slabs had aged for a period exceeding 4 months.

Inasmuch as dryness also affects their fire resistance, the seasoning time of the partitions was prolonged to assure normal dryness. Partitions 124 and 125 were kept moist for 4 days, after which they were dried 8 weeks in a heated laboratory. Partitions 138 and 139 were left in their frames and dampened for 7 and 10 days, respectively, and were subsequently aged 4 months in the heated laboratory before testing.

The slabs were 30 in. square and nominally 2.75 in. thick. The partitions were nominally 2.5 in. thick, 16 ft long, and 10 ft high, filling the opening of the test frames for the wall-testing furnace.

Other characteristics of the slabs and partitions are given in section 5.

4. Equipment and Method of Testing

The equipment for constructing the partitions was supplied by the manufacturer of the cement gun.

The slabs and partitions were placed to form one wall of the combustion chamber of each of two gas-fired furnaces. Details of the furnace used for testing the partitions are shown in figure 1. Temperatures in the combustion chamber of this furnace were measured with nine thermocouples. A smaller furnace used in the slab tests had four thermocouples for the same purpose.

In order to control the fire exposure in conformity with the standard reference curve, furnace temperatures were determined at 5-min intervals during the first hour of a test and at 10-min intervals thereafter, if the test continued. This standard requires furnace temperatures of 1,000° F at 5 min, 1,300° F at 10 min, 1,550° F at 30 min, 1,700° F at 1 hr, and 1,850° F at 2 hr, etc.[3]

Temperatures on the unexposed surfaces of the slabs were measured at three locations, and on the partitions at nine locations. The surface thermocouples were covered with 6- by 6- by 0.4-in. asbestos felt pads secured to the surface. The disposition of the thermocouples on the unexposed face of a partition can be seen in figure 2.

The fire exposures were continued beyond the time when the first criterion of failure in the test had been observed to determine the effects of additional exposure. Failure occurred when one of the following conditions limiting fire resistance was attained: (a) Fire damage sufficient to allow the passage of flame or gas hot enough to ignite cotton waste on the unexposed surface, or (b) the transmission of heat through the partition to raise the average temperature 250 deg F (139 deg C) on the unexposed surface or 325 deg F (181 deg C) at one point on the unexposed surface. The tests of the partitions were conducted in accordance with the Standard specification for fire tests of building construction and materials, ASA No. A2–1934. The tests of the slabs, except for size, followed the same general procedure.

All but slab 2 were set within a strong structural frame to give restraint against expansion in the plane of the slabs. The partitions were similarly restrained. No load was applied to either the slabs or partitions during the test.

5. Results of Tests

5.1. Slabs

Before proceeding to give the results of the tests, it may be well to call attention to the lack of uniformity in the thicknesses of the slabs. At the locations where the thermocouples were placed, the thicknesses, which were intended to be 2.75 in., ranged from 2.56 to 3.06 in. The density of these slabs ranged from 134 lb/ft ^{3} for slabs with sand aggregate to 92 lb/ft ^{3} for those having equal volumes of sand and sawdust for the aggregate. These data on thickness as well as the average

[3] See Appendix A of BMS71.

of the thicknesses and the principal results of the tests are given in table 1.

The relations of composition and thickness to time to failure for the eight tests of slabs are shown in figure 3. It should be observed that the time to failure for slabs varied with the composition and the average thicknesses at the points where the surface temperatures were measured. The time to reach limiting surface temperatures in previously reported fire tests of solid partitions of both neat and sanded plasters varied, for a given composition, approximately as the 5/3 power of the thickness. Assuming that the same relation applies for gunite specimens, curves

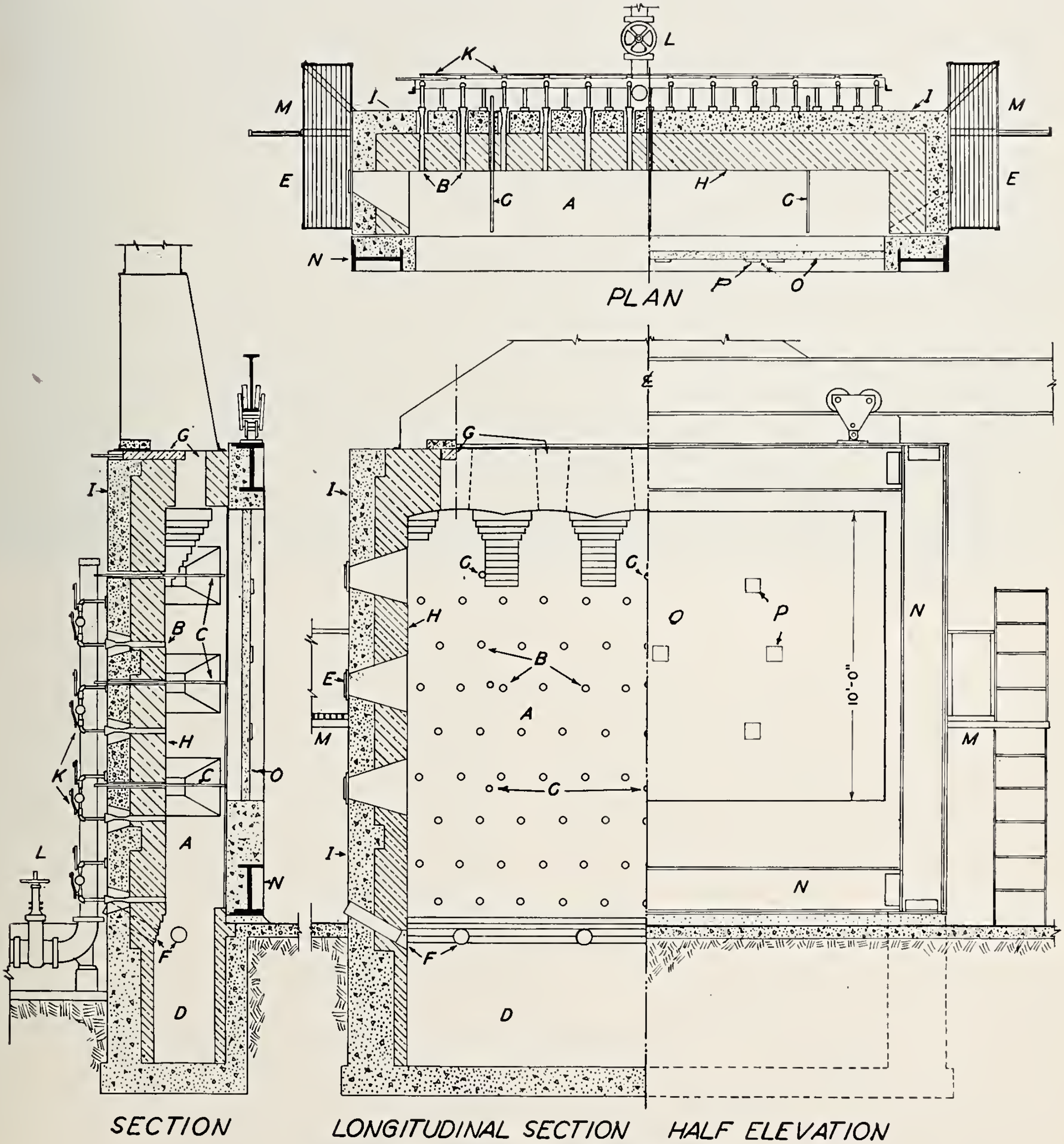

FIGURE 1. *Details of wall-testing furnace.*

A, Furnace chamber; B, burners; C, thermocouple protection tubes; D, pit for debris; E, observation windows; F, air inlets; G, flue outlets and dampers; H, firebrick furnace lining; I, reinforced-concrete furnace shell; K, gas cocks; L, control valve; M, ladders and platforms to observation windows; N, movable test frame; O, test wall; P, felted asbestos pads covering thermocouples.

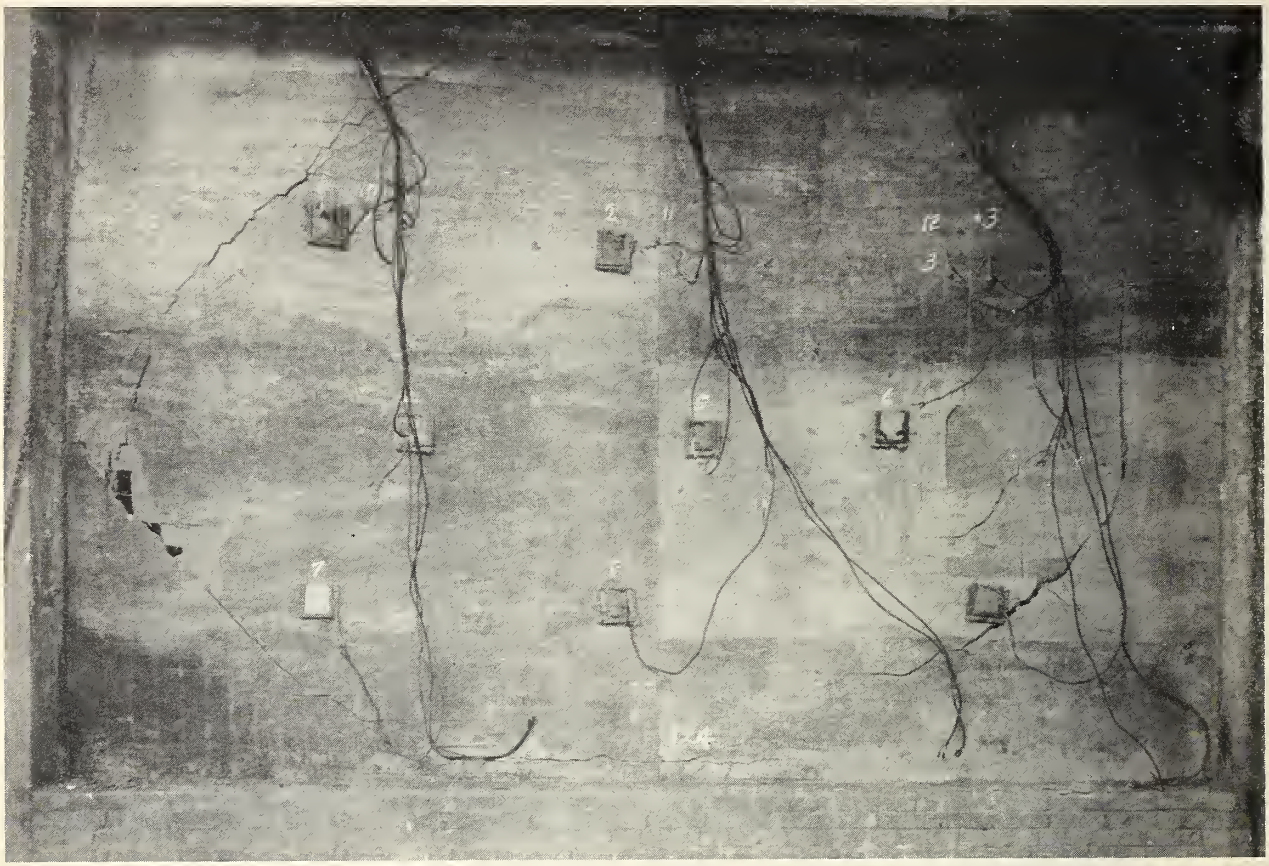

FIGURE 2. *Partition 124 after 1-hr exposure of the opposite face to the fire.*

showing the relation between thickness and time to failure have been drawn for each aggregate composition. These given a fair approximation of the performance to be expected from fire tests of slabs of similar compositions and of thicknesses in the range 2 to 3 in. By interpolation, dashed lines have been inserted to indicate the results to be anticipated from fire tests of slabs having, respectively, 10 and 20 percent of sawdust in the aggregates. Some of the data from the tests of partitions have also been plotted to show the relation of the results of these tests to those derived from the tests of the slabs.

Early in tests of slabs 1 and 2—the slabs with sand aggregate—steam condensed on the unexposed faces. Slab 1 showed minor cracking during the test, together with spalling of a small section at one corner, due to expansion of the slab in its frame. However, slab 2 did not crack on either face until cooling occurred, at which time

TABLE 1. *Slabs made of gunite concrete*

Slab	Composition, by volume			Average thickness at edges	Thickness of slabs at thermocouple locations				Weight of slabs		Exposure	Time for limiting temperature rise [a]	
	Cement	Sawdust	Sand		Upper north quarter	Upper south quarter	Center	Average	As received	After drying		Average	Maximum
				in.	*in.*	*in.*	*in.*	*in.*	*lb*	*lb*	*Percent*	*min*	*min*
1	1	0	4	2.62	2.69	2.69	2.88	2.75	203	193	96	38	53
2	1	0	4	2.56	2.62	2.75	2.69	2.69	197	189	102	39	51
3	1	1.2	2.8	2.5	2.62	2.75	2.88	2.75	170	155	101	71	77
4	1	1.2	2.8	2.56	2.88	2.56	2.88	2.77	169	156	108	66	75
5	1	1.6	2.4	2.69	2.88	3.06	3.0	2.98	168	149	101	88	97
6	1	1.6	2.4	2.5	2.62	2.62	2.69	2.64	168	142	99	70	76
7	1	2	2	2.56	2.75	2.75	2.75	2.75	152	134	101	85	94
8	1	2	2	2.5	2.88	2.88	3.06	2.94	158	142	101	103	107

[a] Limiting rise of temperature under asbestos pads on surface; average 250 deg F (139 deg C), maximum 325 deg F (181 deg C).

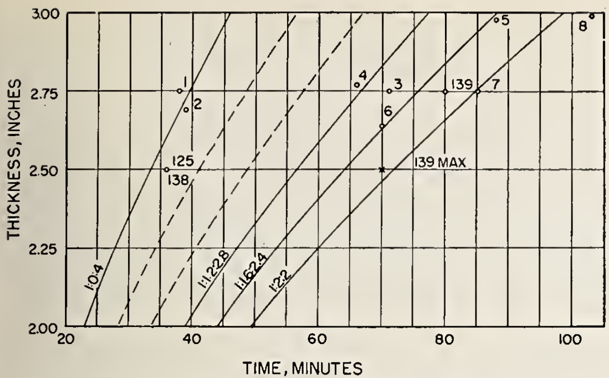

FIGURE 3. *Effects of composition and thickness of gunite on time for limiting temperature rise.*

The first number in the proportions shown indicates portland cement, the second sawdust, and the last sand, that is, 1 : 1.2 : 2.8 equals 1 part of portland cement, 1.2 parts of sawdust, and 2.8 parts of sand, by volume.

fine edge cracks developed. Bowing of either slab amounted to less than ¼ in. The limiting average temperature rise of 250 deg F was reached on slab 1 at 38 min, and on slab 2 at 39 min. The maximum one-point rise of 325 deg F occurred at 53 and 51 min on slabs 1 and 2, respectively. The thicknesses of the slabs at the points of maximum rise were 2.88 in. on slab 1 and 2.69 in. on slab 2.

Although steam issued from each of the six slabs made with sawdust in the aggregate, in no case was condensation observed on the surface. Upon cooling, each slab developed a few cracks.

Slabs 3 and 4, with 30 percent of sawdust in the aggregate, showed a little steam and a small quantity of smoke, more or less acrid, at the surface of the panels. Fire-endurance limits for slab thicknesses of 2.75 and 2.77 in., by average 250 deg F rise of temperature, occurred at 71 and 66 min and by maximum one-point rise of 325 deg F at 77 and 75 min for slabs 3 and 4, respectively. No spalling was apparent on either slab.

In substituting 40 percent of sawdust for an equal volume of sand, slabs 5 and 6 gave results similar to those obtained with aggregate containing 30 percent of sawdust. A small quantity of steam and smoke was generated but there were no cracks. The time to the fire-endurance limits by temperature rise on the unexposed surface showed a further increase, particularly in slab 5. The limiting average temperature rise on slab 5 occurred at 88 min and on slab 6 at 70 min. The respective limiting one-point temperature rises were reached at 97 min and 76 min, with the respective thicknesses measured at 2.88 and 2.62 in.

Slabs 7 and 8, having aggregate composed of equal volumes of sand and sawdust, showed greater fire resistance than that of the other slabs. Only negligible quantities of steam and smoke appeared. The limiting average temperature rises were reached at 85 and 103 min, and the limiting maximum temperature rises at one point were observed at 94 and 107 min. The average thicknesses at thermocouple locations were 2.75 and 2.94 in. for the respective slabs and where maximum surface temperatures were observed the thicknesses were 2.75 and 2.88 in.

Time-temperature curves for slabs 2, 3, and 7 are shown in figure 4, which gives the curves of average temperatures and the one-point maximum temperature on the unexposed surfaces. The three slabs were of nearly the same average thickness. Also shown is the standard furnace curve and the curve (F) of the average furnace temperatures for each test. The fire exposures for these three slabs were approximately 100 percent of the standard. The fire exposure is measured by the ratio of the area under the curve of furnace temperature to that under the standard reference curve and both above the base temperature of 68° F (20° C) expressed as percent.

5.2. Partitions

The partition tests were performed in two groups. The first group included partitions 124 and 125, the second, made several months later after the tests of the slabs had indicated the effectiveness of the sawdust admixture in the aggregate, included 138 having only sand as the aggregate and 139 in which the aggregate was a mixture of sand and sawdust.

The principal characteristics of the partitions of both groups and a summary of the results of the tests are given in table 2.

TABLE 2. *Partitions made with gunite concrete*

Partition	Composition, parts by volume			Average thickness	Test data			
							Failure	
	Cement	Sawdust	Sand		Kind of test	Exposure	Time	Kind
				in.		*Percent*	*min*	
124	1	0	[a] 4	2.5	Fire endurance.	97	26	Hole through.
							36	Temp avg.
125	1	[b] 0	4	2.5	do	96	16	Hole through.
138	1	0	4	2.5	do	86	26	Do.
							26	Glow in cotton waste.
139	1	[c] 2	2	2.75	do	100	70	Temp max.[d]
							80	Temp avg.
					Fire and hose stream.	----	----	No failure in hose stream test.[e]

[a] Because of different degrees of dampness of sand used in the gunite mixes, the proportions of cement to sand by weight were, respectively, 1:4.25; 1:3.4; 1:3.1; and 1:1.53.
[b] Six pounds of asbestos fiber per bag of cement was added to mix.
[c] The 2 volumes of sawdust weighed 22 percent of the weight of 1 volume of cement.
[d] The thickness of the partition where the maximum rise of surface temperature was observed was 2.5 in.
[e] The hose stream was applied to the heated surface at the end of 82 min of fire exposure.

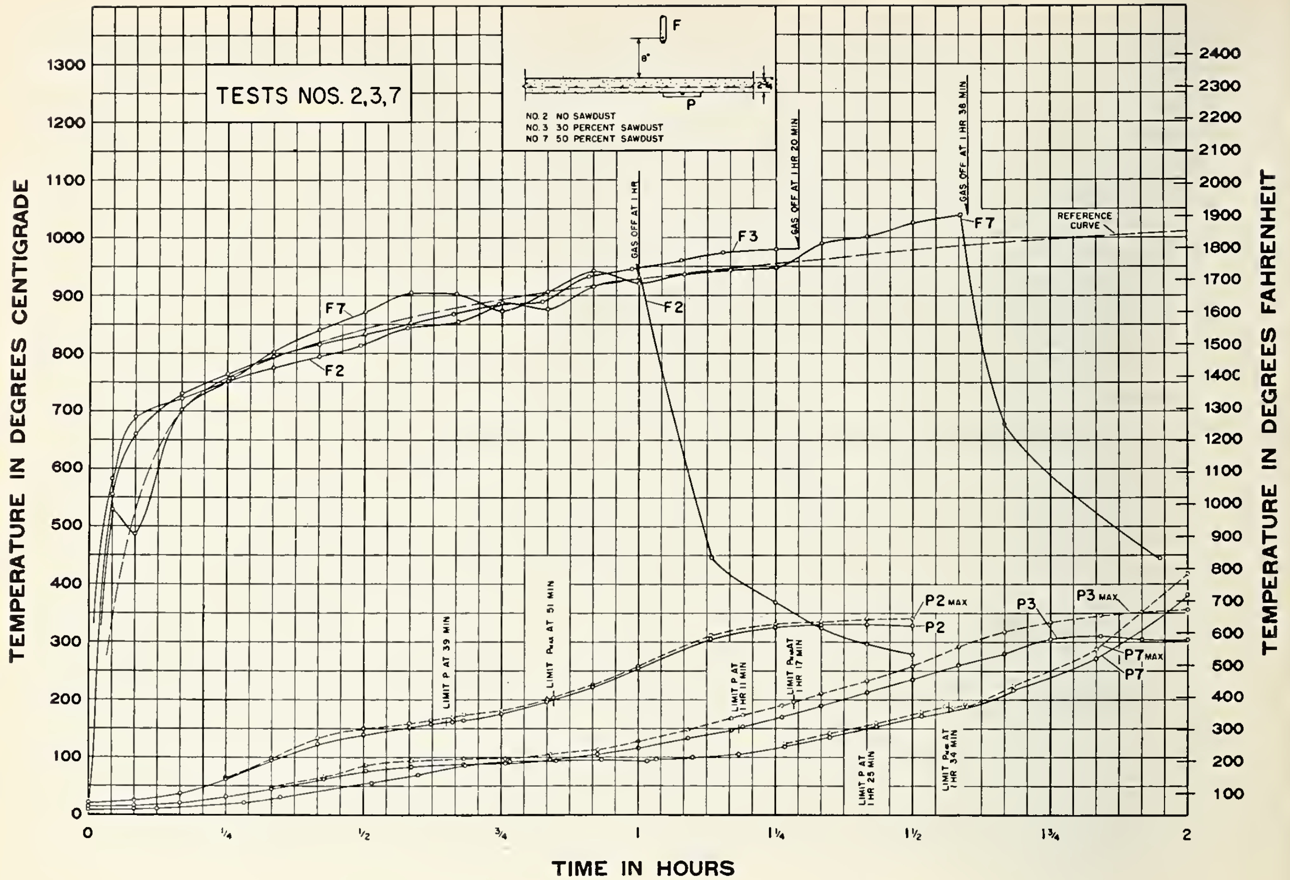

FIGURE 4. *Time-temperature curves for slabs 2, 3, and 7.*

Partition 124 was made with a mix consisting of 1 part of portland cement to 4.25 parts of dry sand by weight, or 1 : 4 by volume.

Spalling of the fire-exposed surface accompanied by explosive reports began within 6 min after the start of the test and continued at frequent intervals to the end. By 11 min, about half of the fire-exposed area had spalled, some places reaching depths of 1 in. The panel failed by the explosive formation of a hole blowing through at 26 min. The limiting average rise of temperature on the unspalled remaining portions of the partition did not occur until 36 min. At this time the partition had a very large center deflection. The fire was continued to 1 hr. Practically all of the fire-exposed surface had spalled off during the test. Steam began issuing from cracks at 15 min after the start of the test and continued throughout the test. At the conclusion, much of the reinforcing fabric in the lower third of the partition was exposed. Figure 2 shows the condition of the partition after 1-hr fire exposure of the opposite side.

Partition 125 had 1 part of portland cement to 4 parts of damp sand by volume or to 3.4 parts of dry sand by weight. Six pounds of asbestos fiber for each bag of cement was added to the mix.

Prior to starting the test, shrinkage of the gunite had opened a $\frac{1}{32}$-in. space between the partition and test frame at the ends and top. However, there were no visible cracks in the fire-exposed face until explosive spalling commenced at about 10 min after the start of the test. At 16 min, an explosion tore a hole about 4 ft^2 in area through the partition. This constituted failure. The fire was continued, however, for 20 min after start of the test. A considerable volume of steam issued from numerous cracks formed in the partition in the latter part of the test. The condition of the badly spalled fire-exposed side of this partition can be seen in figure 5.

Time-temperature curves for partitions 124 and 125 are shown in figure 6. In addition to the temperatures on the unexposed surface, curves 1 and 1 max show those for thermocouples at the reinforcing wire in the midplane of a partition. The temperature rise at this location is given as information but is not to be interpreted as affecting the criterion of failure.

FIGURE 5. *Fire-exposed side after 20-min fire test of partition 125.*

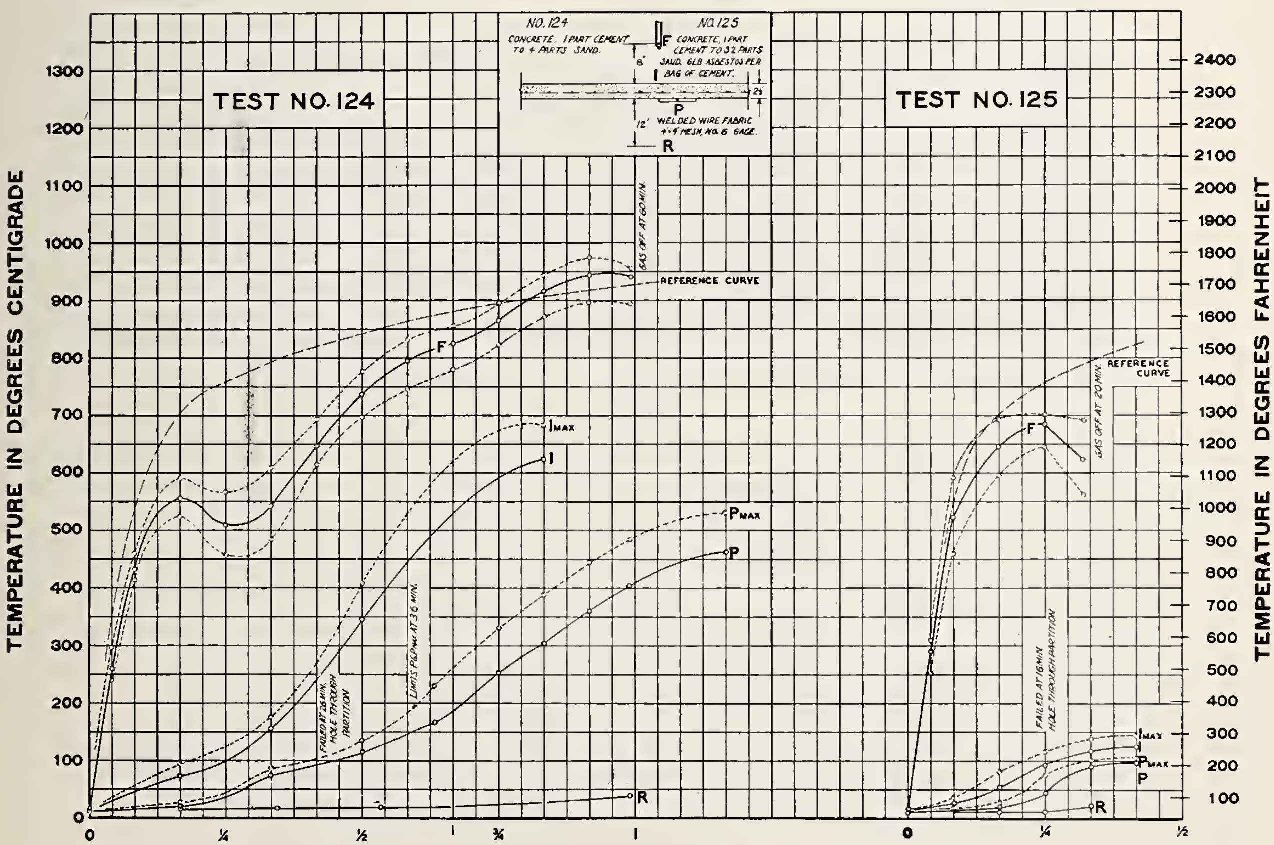

FIGURE 6. *Time-temperature curves for partitions 124 and 125.*

Partition 138 consisted of 1 part of portland cement to 4 parts by volume of wet sand or 3.1 parts of dry sand by weight. This partition differed from 124 in its richer mix and longer drying time. At 6 min, steam issued from several cracks. A minute later explosive popping began, and after 18 min considerable areas of the fire-exposed surface had spalled. The panel failed at 26 min by the transmission of sufficient heat to cause glow in waste on the unexposed surface. Also, at this time, a hole 1/4 by 2 1/2 in. was opened at the edge of a previously spalled area. The limiting maximum temperature rise at one point occurred at 28 min, the limiting average rise in 36 min. The test fire was continued to 40 min. Large cracks developed, but there was little additional steaming. The deflection of the partition away from the fire amounted to 6 1/2 in. at the time of failure and to almost 8 in. at the conclusion of the fire exposure. The condition of the fire-exposed side of this partition after the test is shown in figure 7.

FIGURE 7. *Exposed side of partition 138 after 40-min fire test.*

The mix for partition 139 was also 1:4 by volume of cement to aggregate or 4.5 parts of cement, one part of sawdust, and 6.9 parts of sand by weight of dry materials. The aggregate consisted of equal volumes of sand and sawdust.

Before the test, it was noticed that there were several sag cracks up to 1/8 in. wide in the exposed face of the partition. A number of fine cracks followed the horizontal and vertical reinforcing wires. Three minutes after the start of the test, fine cracks began to form in the unexposed surface. At 9 min, water droplets formed as condensate from steam issuing from cracks. This continued until the test had progressed for almost 1 hr, when the wet spots disappeared and the steam was succeeded by small quantities of smoke. At 1 hr 12 min, there were no surface cracks over 1/16 in. wide. Three minutes later, the first mild-to-moderate popping sounds occurred. These were not of sufficient intensity to suggest explosive disruption of the partition. The fire exposure was continued to 1 hr 22 min, although the end point of fire endurance had occurred at 70 min, when the limiting rise of temperature at one point on the unexposed side was attained. The limiting average rise occurred at 80 min.

At the conclusion of the fire-endurance test, the panel successfully withstood the application of a 1 1/8-in.-diameter hose stream at 30-lb/in.^{2} pressure. The water was applied for 2 min 24 sec to the side that had been exposed to the fire. There was no passage of water through the gunite concrete, the unexposed face remaining dry. This partition met the requirements for a 1-hr fire-resistance rating.

The condition of the exposed side of the partition immediately after the fire-endurance test can be seen in figure 8. Figure 9 shows the same surface of the partition after the application of the hose stream. The impact of the cold water had little erosive effect.

FIGURE 8. *Exposed side of partition 139 after 1-hr 22-min fire test.*

FIGURE 9. *Partition 139 after 2-min 24-sec application of hose stream.*

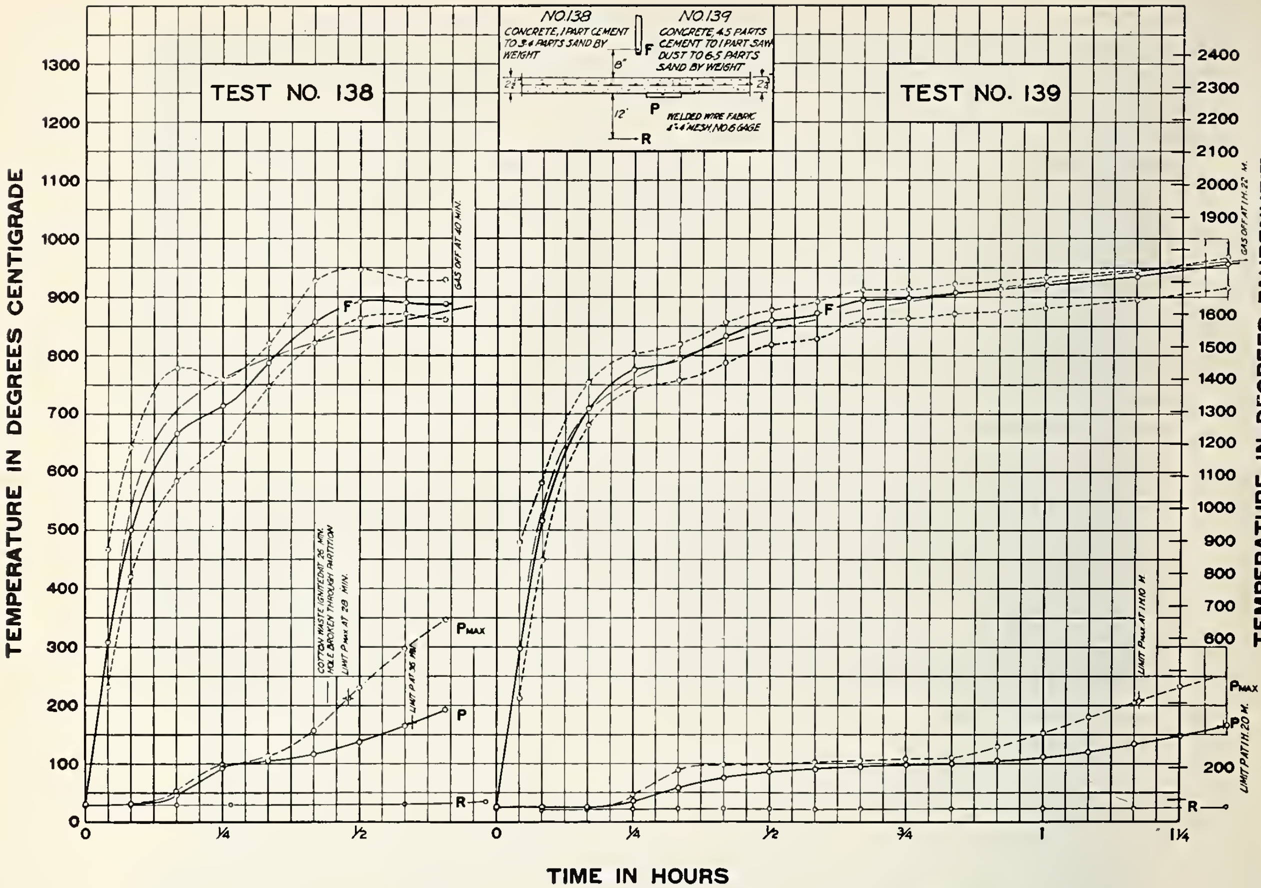

Figure 10. *Time-temperature curves for partitions 138 and 139.*

Time-temperature curves, including those for the furnace and the unexposed surfaces of partitions 138 and 139, are shown in figure 10.

6. Summary and Discussion

In each of the tests of slabs, failure occurred through average rise of temperature on the unexposed surface before the limiting rise of temperature at one point was reached. The slabs with no sawdust failed by 250 deg F rise in 38 and 39 min. The substitution of an equal volume of sawdust for 30 percent of the sand increased the fire-endurance limits to 66 and 71 min. By substituting sawdust for 40 percent of the sand, limits of 70 and 88 min were attained. With the largest quantity of sawdust used in the tests of slabs (50 percent by volume of the aggregate) limiting average temperature rises were reached at 85 and 103 min. The time required to reach the limiting maximum temperature rise at one point ranged from 51 min for a slab with no sawdust to 107 min for a slab having 50 percent of the sand replaced by sawdust. The increase of fire resistance of 2.75-in.-thick

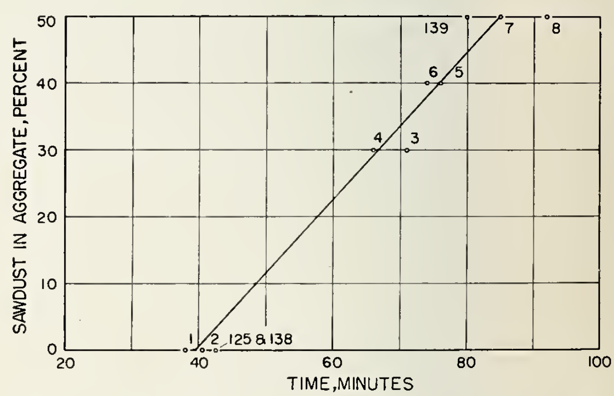

Figure 11. *Effect of composition of aggregates on the fire resistance of 2.75-in.-thick gunite slabs and partitions.*

gunite slabs resulting from increasing percentages of sawdust in the aggregate is shown in figure 11. The values for tests of partitions 125 and 138 are those from the rise of surface temperatures in areas where previous spalling of the fire-exposed surface had not occurred. The values derived

Errata Sheet

Building Materials and Structures Report 131
Fire Tests of Gunite Slabs and Partitions

The Formula on page 11 should read:

$$T = 7.3\ (1 + 2.3p)\ t^{\frac{5}{3}}$$

from tests have been projected to the 2.75-in. thickness on the basis of the fire resistance, varying as the 5/3 power of the thickness of the slab.

The partitions without sawdust failed early in the fire tests by the formation of holes through them. This occurred in 26, 16, and 26 min for partitions 124, 125, and 138, respectively. In addition, partition 138 failed by transmission of heat sufficient to cause glow in waste on the unexposed side at the same time that a hole was formed elsewhere on the partition. Addition of asbestos fiber to the mix, as for partition 125, did not enhance the fire resistance; rather, this partition failed in less time than did any of the others. However, when the aggregate consisted of half sand and half sawdust, as in partition 139, a fire-endurance limit of 70 min, determined by the rise of maximum temperature at one point, was achieved. The limiting average rise of temperature was reached at 80 min. Not only were the fire-endurance limits greater for this partition, but there were none of the disruptive explosive effects which characterized the tests of the other three partitions.

An empirical formula suitable for estimating the time required to raise the surface temperature of gunite slabs or partitions 250 deg F, provided that spalling is avoided, has been developed from the derived data and from data obtained in previous tests with partitions of other aggregates having a greater range of thickness.[4] This formula is applicable to gunite composed of 1 part of portland cement to 4 parts of aggregate composed of silica sand and sawdust. The amount of sawdust is limited to not more than one-half of the total of aggregate. The formula is

$$T=7.3(1+2.3p)t_{\frac{5}{3}}(1+2.3p)t_{\frac{5}{3}},$$

where

T=the time in minutes to reach the average rise of 250 deg F under asbestos pads on the unexposed surface.

t=the thickness in inches of the wall or slab in the range 2 to 3 in.

p=the proportion of sawdust by volume in the aggregate in the range 0 to 0.5.

Gunite, as usually made with concrete sand aggregate, was found to be generally unsatisfactory for fire-resistive constructions. The spalling that caused the early failure in the partitions was accompanied by explosive violence endangering those in the nearby area. Failure of the gunite by spalling was attributed to expansion stresses and the water retained in the dense material. Unable to escape and with little space for expansion, the water became heated during the fire test and increased in pressure until it attained a force sufficient to disrupt the thermally strained concrete. Absence of violent spalling in the two slabs made without sawdust was considered to be the result of a somewhat lower density concrete (134 lb/ft^3) and a more thorough drying than had been accorded the partitions. To eliminate the possible presence of excessive free water, the drying time of one partition having only sand aggregate was greatly increased over those previously tested, however, little diminution of spalling was apparent in the fire test. Perhaps the dense structure of gunite concrete prevented the escape of water within a reasonable drying period.

The use of wood sawdust as part of the aggregate of the gunite increased the time to failure by temperature rise on the unexposed side and obviated explosive effects. The sawdust, by increasing the porosity of the concrete, allowed the occluded water, together with the distillation products of the wood, to escape as vapor. As the greater temperature rise occurred on the fire-exposed side of the test structure, the vapors tended to issue first on that side. Thus the sawdust serves to provide channels for the escape of the water retained in the concrete and prevent spalling. It also slows the rise of temperature on the unexposed side by the early transfer of heat-absorbing vapor to the fire side of the test structure.

As is true for other lightweight aggregates, the use of sawdust reduces the strength of the concrete. However, the current and proposed uses of gunite as a fire-protective covering or in curtain-wall constructions are such that great strength is often of minor importance. Chemically treated or inert sawdust should have little deleterious effect on the portland cement of the mix.

The improvements achieved by increased proportions of sawdust to sand in the concrete mixes described in this report suggests that the optimum proportions for fire protection had not been reached.

WASHINGTON, September 13, 1951.

[4] See BMS71, p. 32, Tests Nos. X 1 and X 2.

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BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page II]

[List continued on cover page IV]

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page III]