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Comparison of Severity of Exposure in ASTM E 119 and ISO 834 Fire Resistance Tests

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RÉSUMÉ

A l'aide d'échantillons semblables à ceux décrits dans le projet de révision d'ASTM E 119, on a réalisé des essais dans des fours servant à contrôler la résistance au feu de planchers et de murs. Ces essais ont été conçus en vue de comparer les conséquences pratiques de l'utilisation des spécifications d'ASTM E 119 et d'ISO 834 concernant la mesure et le contrôle de la température nominale du four. On a constaté que dans les essais de tenue au feu de courte durée, peut-être jusqu'à 1,5 h, l'essai de l'ASTM est légèrement plus sévère que celui de l'ISO. Dans les essais plus longs, la différence est négligeable. Certaines observations concernant la non-uniformité de l'absorption de chaleur par l'échantillon utilisé font ressortir l'importance d'une bonne conception du four si l'on veut que celui-ci ait une performance satisfaisante.

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ABSTRACT: Using specimens similar to those described in the draft revision of ASTM E 119, tests were conducted in floor and wall fire test furnaces. The tests were designed to compare the practical consequences of following the ASTM E 119 and ISO 834 specifications for measuring and controlling the nominal furnace temperature. It has been found that in fire tests of shorter duration, perhaps up to 1.5 h, the ASTM test is slightly more severe than the ISO test. In longer tests the difference in severities is negligible. Some observations concerning the non-uniformity of heat absorption by the test specimen point to the importance of proper furnace design in the satisfactory performance of test furnaces.

KEY WORDS: ASTM E 119, ISO 834, fire exposure, fire severity, fire test furnaces, furnace design

Nomenclature

- a Distance from surface, m
- c Specific heat, J kg^{-1}K^{-1}
- E Total heat absorbed per unit area, J m^{-2}
- H Normalized heat load, s$^{1/2}$K
- ΔH Incremental normalized heat load, s$^{1/2}$K
- k Thermal conductivity, W m^{-1}K^{-1}
- t Time, min
- T Temperature, K or °C
- κ Thermal diffusivity, m^{2}s^{-1}
- ρ Density, kg m^{-3}
- τ Length of fire exposure, s or h
- $\Delta\tau$ Incremental fire endurance, h

Subscript

- m Maximum

Introduction

There has been a movement for some time to bring the ASTM fire test standards closer to the ISO standards. An opportunity to reduce the differences between the ASTM E 119 fire endurance test method and its counterpart, ISO 834, has arisen with the rewriting of E 119. The members of the ASTM Task Group in charge of preparing the rewrite have looked favorably on a shift towards the ISO standard, yet some reservations have been expressed in view of the fact that the effects of adopting some ISO techniques on the result of fire endurance tests are not clearly understood.

At the latest meeting of the Task Group it was agreed that the ISO temperature-time curve for furnace control and the ISO technique of measuring the furnace temperature will be tentatively included in the rewrite, and that quantitative information on the effect of this change will be provided to the members of ASTM Subcommittee E 05.11 on Construction Assemblies when the draft is sent to Subcommittee ballot. The Fire Research Section of the Institute for Research in Construction, National Research Council of Canada (NRCC) conducted the experiments necessary for developing that information.

Experimental Procedure

The floor and wall furnaces of the Fire Research Laboratory of NRCC were used in the experiments. The experimental arrangements are shown in Figs. 1 and 2. The floor furnace was 4570 mm long by 3660 mm wide by 2440 mm deep; the wall furnace was 3610 mm wide by 3050 mm high by 580 mm deep. Both furnaces were lined with 38-mm-thick fibrous ceramic blanket.

The floor test specimen was castable refractory brick, marketed as KS-4, composed of 20 rectangular slabs, 1220 mm long by 788 mm wide by 150 mm thick, suspended on steel beams. The slabs were tightly butted (with ceramic sheets along their perimeters) to form a unit 4880 mm by 3940 mm.

The wall test specimen was made from corrugated sheet steel, with 38 mm fibrous ceramic blanket attached to its surface to be exposed to fire. The overall dimensions of the specimen were 3610 mm wide by 3050 mm high. Five so-called measuring elements, blocks of KS-4 castable refractory brick, 300 mm square by 150 mm thick, were inserted into the simulated wall, one at its center and four at the centers of its quarter sections. The test assembly was built in a concrete frame with inside dimensions equal to those of the furnace opening.

Five 36-gage Chromel-Alumel thermocouples were installed into the specimens. With the floor test specimen, they were placed in five slabs in such a way as to have their junctions positioned approximately at the center and at the centers of the quarter sections of the specimen. With the wall test specimens, the thermocouples were installed into the five measuring elements. In all cases the

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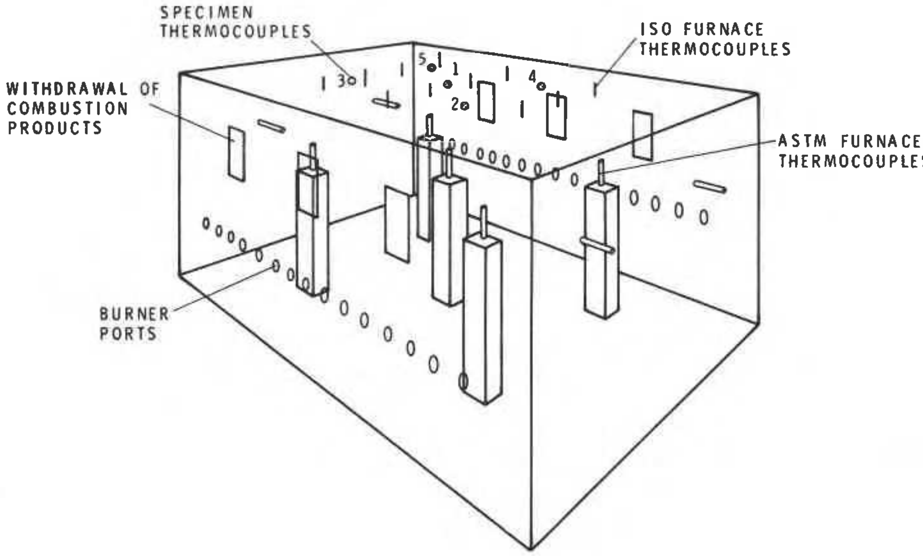

FIG. 1—*Floor furnace experimental setup.*

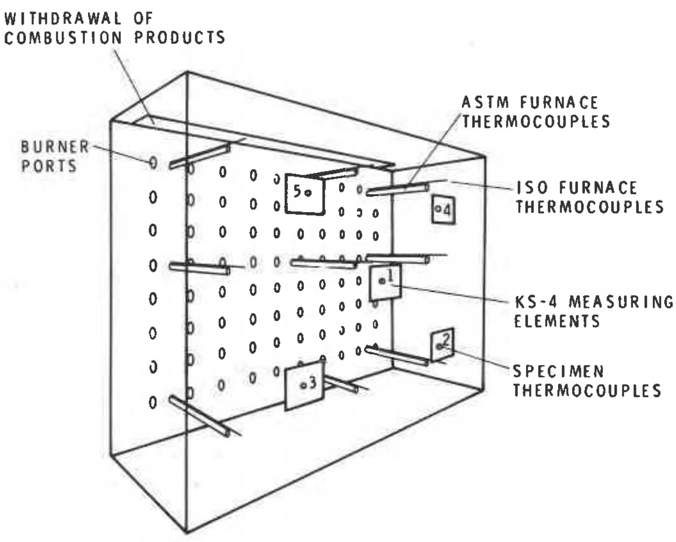

FIG. 2—*Wall furnace experimental setup.*

thermocouple junctions were located 40 mm from the surface to be exposed to fire, and the lead wires were conducted at the same depth to the edges of the slabs or blocks, and then through the test specimen to the recorder.

In the ASTM tests nine furnace thermocouples (Chromel-Alumel) were used, arranged to comply with the E 119 specification. The thermocouples were enclosed in Inconel protection tubes. The time constants were 5 min and 5.9 min for floor furnace and wall furnace thermocouple assemblies, respectively, when measured in accordance with Ref *1*.

Bare 18-gage thermocouples (Chromel-Alumel) were employed in the ISO test, twelve in the floor test runs, and nine in the wall test runs. The thermocouple junctions were set 100 mm from the exposed surface of the test specimens. For further details see Figs. 1 and 2.

Sixteen tests were conducted. The test schedule and the results are summarized in Tables 1 to 3.

Propane gas was used as fuel. Efforts were made to run the furnaces at maximum efficiency with respect to heat transmission, which is usually realized at low excess air for the combustion [*2*]. An attempt was made to run the tests at above-atmospheric pressure near the top of the furnace chamber, as required by ISO 834

TABLE 1*a*—*ASTM experiments on floor furnace (duration of fire exposure: 45 min).*

Location of Specimen Thermocouple[a]	Max. Temperature Rise (°C) in Spec. in Run No. 1	2	3	Avg. Temp. Rise, °C	Normalized Heat Load, $10^4 s^{1/2} K$
1	351	348	345	348	4.42
2	313	310	308	311	3.95
3	318	315	312	315	4.00
4	303	301	298	301	3.82
5	277	276	272	275	3.49

[a]See Fig. 1.

TABLE 1*b*—*ISO experiments on floor furnace (duration of fire exposure: 45 min).*

Location of Specimen Thermocouple[a]	Max. Temperature Rise (°C) in Spec. in Run No. 5	6	7	Avg. Temp. Rise, °C	Normalized Heat Load, $10^4 s^{1/2} K$
1	319	323	320	321	4.08
2	284	288	285	286	3.63
3	287	291	288	289	3.67
4	275	279	276	277	3.52
5	251	254	252	252	3.20

[a]See Fig. 1.

TABLE 2*a*—*ASTM experiments on wall furnace (duration of fire exposure: 45 min).*

Location of Specimen Thermocouple[a]	Max. Temperature Rise (°C) in Spec. in Run No. 9	10	11	Avg. Temp. Rise, °C	Normalized Heat Load, $10^4 s^{1/2} K$
1	358	354	355	356	4.52
2	325	317	322	321	4.08
3	321	318	313	317	4.03
4	352	353	358	354	4.50
5	361	357	360	359	4.56

[a]See Fig. 2.

TABLE 2*b*—*ISO experiments on wall furnace (duration of fire exposure: 45 min).*

Location of Specimen Thermocouple[a]	Max. Temperature Rise (°C) in Spec. in Run No. 12	13	14	Avg. Temp. Rise, °C	Normalized Heat Load, $10^4 s^{1/2} K$
1	340	344	339	341	4.33
2	305	295	292	297	3.77
3	292	280	279	284	3.61
4	342	347	344	346	4.40
5	343	350	346	346	4.40

[a]See Fig. 2.

TABLE 3—*ASTM and ISO experiments on floor and wall furnaces (duration of fire exposure: 90 min).*

Location of Specimen Thermocouple[a]	Max. Temperature Rise (°C) in Specimen in Floor Furnace Test Per ASTM	ISO	Wall Furnace Test Per ASTM	ISO
1	510	513	527	526
2	463	462	485	478
3	466	467	476	470
4	450	451	529	530
5	421	423	533	532

[a]See Figs. 1 and 2.

and the ASTM E 119 rewrite. By substantially narrowing the cross-sectional area of the exhaust duct, a 10 Pa positive pressure could be maintained in the wall furnace at 200 mm below the top of the test specimen. Because of the shortcomings in the construction of the floor furnace (the exhaust ports are too close to the top of the furnace chamber), above-atmospheric pressure could not be realized in that furnace.

The temperature-time curves prescribed by the two standards were usually followed with a ±5°C accuracy. As furnace operators know, controlling the furnace temperature during the first 10 min of the test presents some difficulties. During this initial period, differences between the average "furnace" temperatures and the temperatures prescribed by the standards usually amounted to 10 to 30°C. After this time the agreement was better, and the occasional differences rarely amounted to more than 20°C.

Discussion

The purpose of the experiments was to evaluate the differences in the severities of the ASTM E 119 and ISO 834 tests in terms of normalized heat load [3] and, ultimately, fire endurance.

There are two major differences in conducting fire tests in accordance with ASTM E 119 and ISO 834. One is that in the ASTM tests the furnace thermocouples are enclosed in protection tubes, while in the ISO tests the thermocouples are bare. The other difference is that the temperature-time curves to be imposed on the furnace are somewhat different (Fig. 3). The ISO curve offers the slight advantage of being describable by the formula

$$T_f = T_0 + 345 \log_{10}(1 + 8t) \tag{1}$$

where

T_f = average "furnace" temperature, °C,
T_0 = initial temperature, °C, and
t = time, min.

As will be seen later, the difference in the severities of the two kinds of tests is, in fact, less than one would infer from the inspection of the two curves in Fig. 3.

Owing to radiative heat exchange between the thermocouples and the furnace boundaries (formed by the furnace surfaces and the test specimen), the temperature yielded by bare thermocouples (as in the ISO test) is only a nominal temperature lying somewhere between the temperature of the gases and that of the boundaries [2]. That nominal temperature may come close to the temperature of the fire gases if the thermal absorptivity of the furnace bounda-

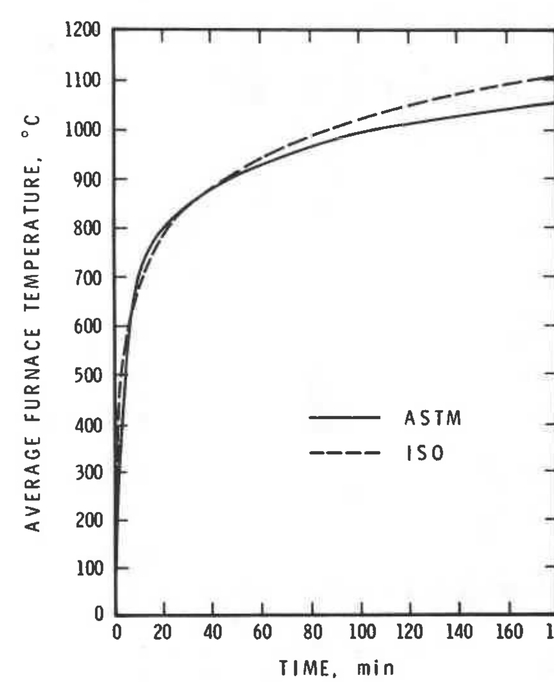

FIG. 3—*Comparison of ASTM E 119 and ISO 834 temperature-time curves.*

ries (i.e., $\sqrt{k\rho c}$, where k (W $m^{-1}K^{-1}$) is thermal conductivity, ρ (kg m^{-3}) is density, and c (J $kg^{-1}K^{-1}$) is specific heat) is very small and at the same time the coefficient of heat transfer (by radiation and convection) between the gases and the furnace boundaries is very high. In ASTM tests the protection tubes delay the response of the furnace thermocouples; therefore the nominal furnace temperature may be substantially higher than either the ASTM or ISO curve in Fig. 3 during the first 15 min of testing, when the rise of temperature is very steep. Later on, the nominal furnace temperature will run less and less above the temperature recorded by the ASTM thermocouples and probably fairly close to the ISO curve.

Based on these considerations, it is expected that in the earlier phases of the fire test the ASTM test will be more severe on the specimen than the ISO test, but the severity of the two tests will become approximately equal after about 1 h into the tests. This expectation is confirmed by the information reported in Tables 1 to 3. To understand the significance of some of the information, a few words have to be said about the normalized heat load.

It has been shown [*3*] that the severity of fires, real-world fires as well as test fires, can be quantified by the normalized heat load, H ($s^{1/2}K$). It is defined as

$$H = E/\sqrt{k\rho c} \tag{2}$$

where E (J m^{-2}) is the heat absorbed by unit area of a boundary of a compartment or a test furnace during the entire fire exposure, and $\sqrt{k\rho c}$ is the thermal absorptivity of that boundary. The normalized heat load can be determined from the maximum temperature rise at a point below the boundary surface [*4*]:

$$H = 2.3\, a\, \kappa^{-1/2}\, (T - T_0)_m \tag{3}$$

where a (m) is the depth of the point below the boundary surface, κ (m^2s^{-1}) is thermal diffusivity of that boundary, and $(T - T_0)_m$ (K or °C) is the maximum temperature rise at that point, which occurs following the fire exposure. The depth of the point, a, should be selected to fulfil the condition

$$0.8 \leq \frac{\kappa\tau}{a^2} \leq 1.2 \tag{4}$$

where τ is the length of fire exposure (s).

With standard fire endurance tests, the normalized heat load is a function of the length of standard fire exposure. From a correlation between H and τ for ASTM E 119 tests, the following equation can be derived [*3*]:

$$\Delta\tau = (0.16 \times 10^{-4} + 0.26 \times 10^{-9} H)\Delta H \tag{5}$$

where $\Delta\tau$ is the incremental fire endurance (h) corresponding to an incremental normalized heat load of ΔH.

The maximum temperature rise reported in Tables 1 to 3 was measured in the specimen in floor furnace tests, and in the measuring elements in the wall furnace tests, all made from castable refractory brick, KS-4. The thermal diffusivity for this material is 0.524×10^{-6} m^2s^{-1}. With a 45-min (2700-s) fire exposure, Eq 4 requires that the temperature rise be measured at a depth somewhere between 34 and 42 mm. As mentioned in the previous section, the specimen thermocouples were installed at a depth of 40 mm.

The maximum temperature rises at that depth and the corresponding normalized heat loads (calculated from Eq 3) are reported in Tables 1 and 2. In 45-min fire tests the ASTM tests are indeed more severe than the ISO test. At the center of the specimen, the (average) difference of normalized heat load in the two kinds of test is $\Delta H = 4.42 \times 10^4 - 4.08 \times 10^4 = 0.34 \times 10^4$ $s^{1/2}K$ for floor furnace tests, and $\Delta H = 4.52 \times 10^4 - 4.33 \times 10^{-4} = 0.19 \times 10^4$ $s^{1/2}K$ for wall furnace tests. Using Eq 5, one will find that a specimen expected to fail at 45 min in an ASTM test would last an additional 3 to 6 min when tested in accordance with the ISO test.

The difference between the ASTM and ISO test results can be expected to diminish in tests conducted longer than 45 min. Table 3 shows that for 90-min tests the maximum temperature rise in the specimen is about the same for the ASTM and ISO tests, indicating equal fire test severities.

Remarks Concerning Furnace Design

It is interesting to note that in floor furnace tests the temperature at the center of the specimen is relatively high in relation to those at the centers of the quarter sections (Table 1). It was thought at first that this finding could be attributed to slight differences either in a, the depth of the thermocouples, or in κ, the thermal diffusivity of the material, at the five locations. Using a heat pulse technique [*5*], it was found, however, that, though a moderate spread in the values of a and κ was obvious, the temperature at the center of the specimen was consistently high, probably owing to the large furnace volume (Fig. 1) and the resulting lower level of turbulence in some peripheral regions of the furnace. The uniformity of the specimen temperature was much better in wall furnace tests (Table 2) in spite of the lower emissivity of the furnace gases on account of the smaller furnace volume. Apparently, the lower level of radiative heat exchange was more than compensated for by the high level and more uniform convective heat transfer owing, to some extent, to the large number of burners per furnace volume.

Another factor that may have played some part in the different performance of the two furnaces was the specimen material. In the floor furnace tests the whole specimen was made from castable refractory brick, while in the wall furnace tests 96% of the specimen was covered with fibrous ceramic blanket, a material of very low thermal diffusivity.

It appears that the furnace construction, in particular the uniformity of turbulence that is achieved in the furnace chamber, is an important aspect in the performance of the furnace.

Conclusion

Tests were conducted to compare fire severities arising in tests conducted in accordance with ASTM E 119 and ISO 834 specifications for measuring and controlling the nominal furnace temperature. It has been found that in fire tests of shorter duration (up to about 1.5 h) the ASTM test is slightly more severe than the ISO test. In longer tests the difference in severities is negligible.

Acknowledgments

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