Fire testing procedures in the United States and Europe are examined and compared. Notes that although the standards of different countries are similar in general considerations, differences exist in the details of application. Specimen restraint is discussed.

Fire Endurance TESTING PROCEDURES

By C. C. Carlson

STANDARD FIRE TESTS FOR ACCEPTance purposes, and often for research investigations, are conducted in the United States and Canada in accordance with methods and criteria in "Standard Methods of Fire Tests of Building Construction and Materials" (ASTM E 119). This same standard is also found under other designations such as Underwriters' Laboratories (UL) No. 263, National Fire Protection Association (NFPA) No. 251, and American Standards Association (ASA) No. A2-1.

ASTM E 119 is the product of effort and experience applied through the years (conceived in 1906 and published as a tentative standard in 1917) by many technically trained people who comprise a group which is now known as ASTM Committee E 5, Fire Tests of Materials and Construction. Currently, the membership of ASTM Committee E 5 is drawn from a number of areas of interest in the fire safety of building construction: the building materials manufacturing industry, testing laboratories, insurance organizations, and governmental agencies.

ASTM E 119 describes and defines the fire testing procedures which are to be applied in the evaluation of the fire endurance of walls, columns, beams, and floor and roof assemblies. Certain criteria are also given for gaging and interpreting fire test results. Thus by close adherence to the procedures and performance criteria, fire test results may be appraised and compared from a common base.

Overseas countries also have their standards for fire tests, for example, British Standard 476, Dutch Standard NEN 1076, and West German Standard DIN 4102.

The standards of the different countries which engage in fire testing of building materials and structures are strikingly similar with respect to general considerations such as rate of heating the test furnace, application of load, hose stream test, and determination of the end point in fire tests. This similarity had its beginning in certain agreements reached at the International Fire Prevention Congress held in London in 1903. However, differences will be found in some of the details for the conduct of standard fire tests. Some of these differences can lead to differences in results. Hence, one should be cognizant of the factors which may affect the comparison of American fire test data with data from other countries.

The purpose of this paper is to examine some of the procedures for conducting standard fire tests in various countries and to point to some of the significant differences in the detailed application of the procedures.

TIME-TEMPERATURE CURVE

The furnaces which are used for standard fire tests of the different parts of buildings, that is, floors, walls, columns, beams, etc., assume a variety of shapes according to the needs of the tests and according to the ideas of the furnace designers. Furnace design has not been standardized. One element which is common to all testing furnaces, however, is the rate in which heat is applied. All are heated in accordance with a time-temperature relationship which is accepted and required under the standard of the particular country in question. A further requirement of all testing furnaces is that they be fired in a manner that insures uniform heating of all exposed surfaces of the specimen.

The time-temperature regime which is followed by all testing laboratories in the United States and Canada is shown graphically in Fig. 1. It will be noted from the graph that the furnace temperature must be raised very rapidly during the first 30 min: to 1000 F in 5 min, to 1300 F in 10 min, and to 1550 F in 30 min. A slower rate is used for the balance of the exposure to 2300 F. Fire tests are seldom continued in America for periods beyond 8 hr. But when they are, the furnace temperature is maintained at a constant level of 2300 F.

European laboratories engaged in fire testing employ approximately the same time-temperature relationship as United States and Canadian laboratories. American and European time-temperature curves are compared in the composite plot shown in Fig. 2. The curves of countries not represented in Fig. 2 assume similar shapes.

With the possible exception of the German and Swedish standards, the variations of the standard time-temperature curves of other countries from the American standard curve are not in excess of allowable deviations from the standard of actually recorded furnace temperatures in American fire tests. ASTM E 119 stipulates, under Section 3(c), that in the conduct of standard fire tests "The accuracy of the furnace control shall be such that the area under the time-temperature curve, obtained by averaging the results from the pyrometer readings, is within 10 per-

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cent of the corresponding area under the standard time-temperature curve shown in Fig. 1† for fire tests of 1 hr or less duration, within 7.5 percent for those over 1 hr and not more than 2 hr, and within 5 percent for tests exceeding 2 hr in duration."

When deviations occur, a correction of the indicated fire endurance time is required. Section 5(c), ASTM E 119, states the correction procedure as follows:

> "When the indicated resistance period is ½ hr or over, determined by the average or maximum temperature rise on the unexposed surface or within the test sample, or by failure under load, a correction shall be applied for variation of the furnace exposure from the prescribed, where it will affect the classification, by multiplying the indicated period by two thirds of the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period and dividing the product by the area between the standard curve and a base line of 68 F (20 C) for the same part of the indicated period, the latter area increased by 54 Fahr-hr or 30 Cent-hr (3240 Fahr-min or 1800 Cent-min), to compensate for the thermal lag of the furnace thermocouples during the first part of the test. For fire exposure in the test higher than standard, the indicated resistance period shall be increased by the amount of the correction and be similarly decreased for fire exposure below standard.

†Fig. 1 in ASTM E 119 is essentially the same as Fig. 1 in this paper—Editor.

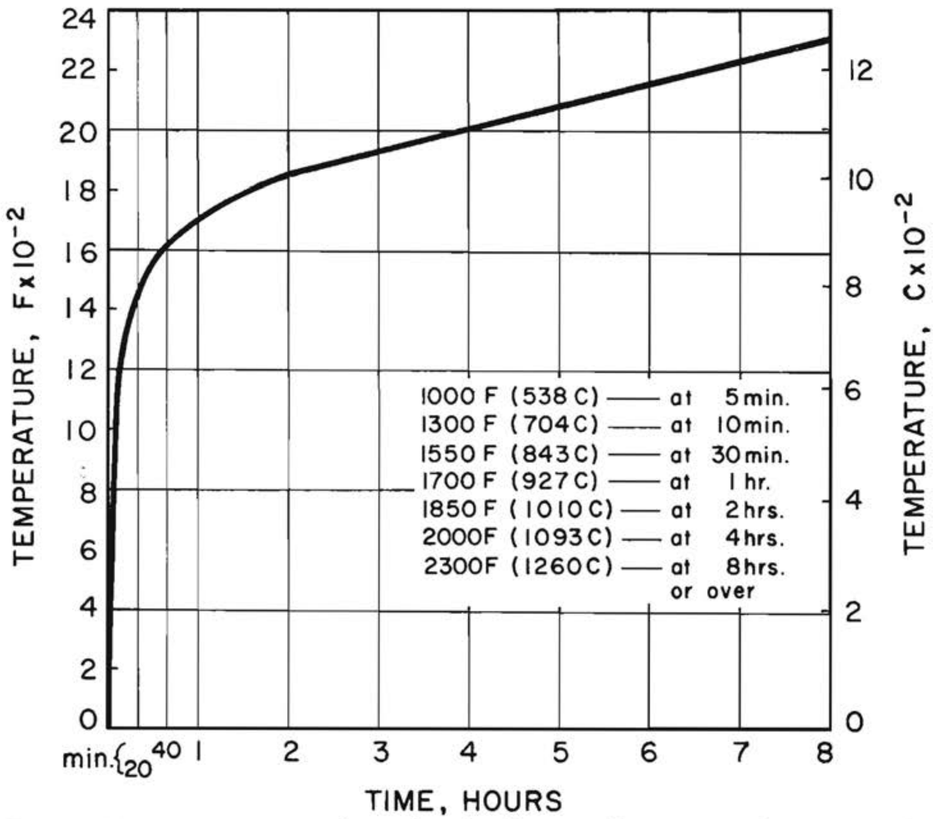

Fig. 1—Time-temperature relationship for heating fire testing furnaces in the United States and Canada (from ASTM E 119)

"The correction can be expressed by the following formula:

$$C = \frac{2I(A - A_s)}{3(A_s + L)}$$

where:

C = correction in the same units as I

I = indicated fire-resistance period

A = area under the curve of indicated average furnace temperature for the first three fourths of the indicated period

A_s = area under the standard furnace curve for the same part of the indicated period

L = lag correction in the same units as A and A_s [54 Fahr-hr or 30 Cent-hr (3240 Fahr-min or 1800 Cent-min)]"

TEMPERATURE MEASUREMENT

Viewing the similarity of standard time-temperature curves shown in Fig. 2, it might be concluded that American and European fire tests may be directly compared or corrections applied in the manner described above. However, furnace temperatures relative to the specimen are measured in American fire tests in a manner which differs in detail from the procedure employed in fire tests in other countries. In fire tests which are conducted according to ASTM E 119, the furnace thermocouples are encased in ½-in standard-weight wrought iron pipe tubes, sealed at the ends. As a permissible alternate, they may be encased in sealed ceramic tubes of comparable diameter and wall thickness. One purported reason for the use of thermocouple shields is to avoid the more rapid deterioration of chromel-alumel thermocouples which seems to occur in a reducing furnace atmosphere. Another reason is to avoid the rapid oscillations in recorded furnace temperature which are exhibited with bare thermocouples when flame may intermittently impinge upon the hot junctions.

Practices vary in Europe with regard to the protection of furnace thermocouples. The standard of Great Britain[1] stipulates the use of bare furnace thermocouples—the thermocouple assembly is sheathed in a porcelain tube except for the tip or hot junction which is bare. The standard of Holland[2] is not clear on this issue but from the observations of visitors at the Holland laboratory it seems that bare furnace thermocouples are employed here too. From reports of visitors to the laboratories of West Germany, France, and Italy, shielded furnace thermocouples are used but it is not known whether the shielding is similar to that specified in ASTM E 119.

Thermocouple clearance

It was found that there are differences in American and European practices in the clearance between furnace thermocouples and the test specimen. For American fire tests of beams, columns, or floor and roof assemblies, the furnace thermocouples are placed 12 in. away at the beginning of a test. As the specimen deflects this clearance changes, since the thermocouples are fixed, but at no time are they to touch the specimen. For fire tests of walls and partitions, the clearance at the beginning of a test is 6 in. In Great Britain and Holland, the clearance between bare thermocouples and the specimen generally is 3 in.; maintained throughout the test by the furnace operator. In a published report of column tests performed in West Germany,[3] it was noted that a clearance of 4 in. between furnace thermocouple hot junctions and the specimen was employed.

Bare thermocouples will, of course, respond more quickly to temperature changes than will thermocouples which are encased in protective tubes. The correction formula of ASTM

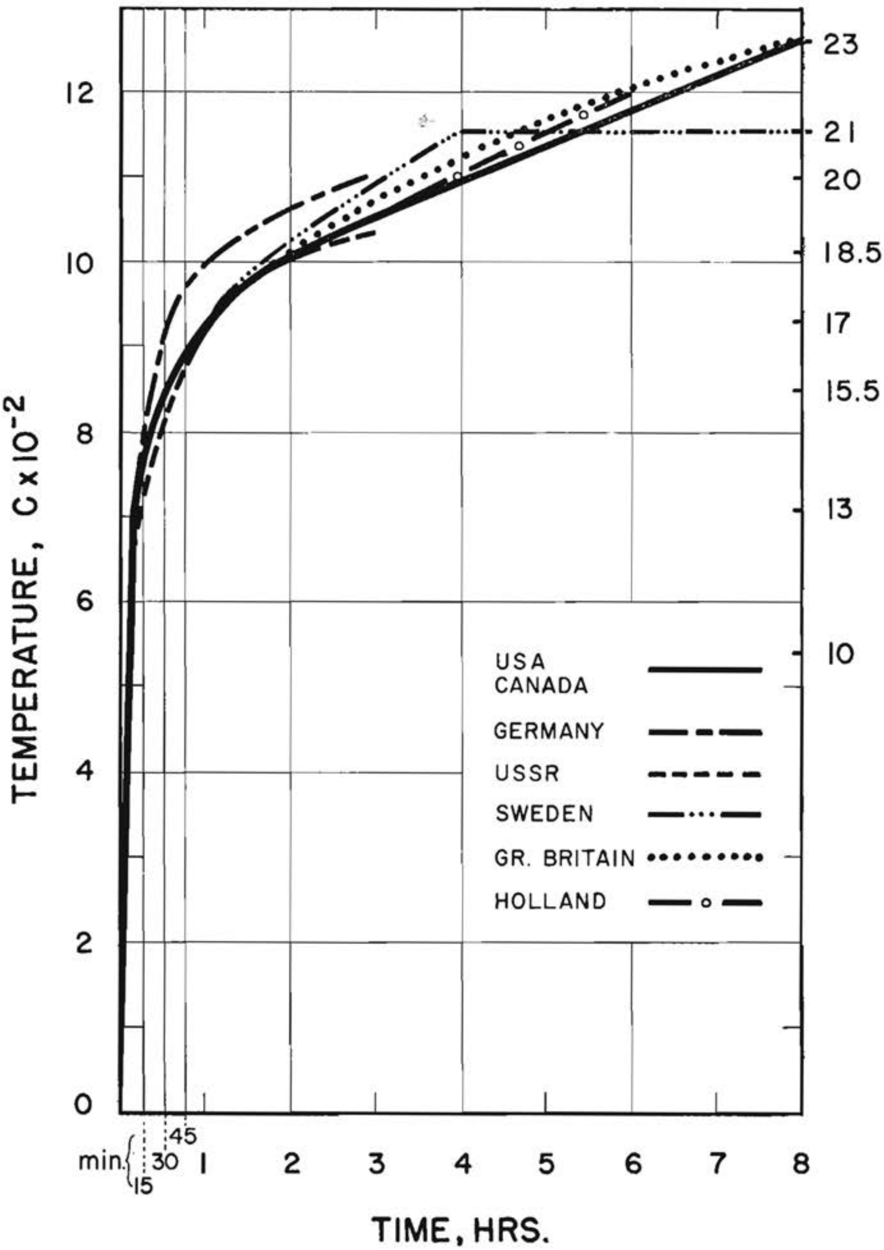

Fig. 2—Comparison of time-temperature curves of various countries

E 119, given on p. 4, recognizes the effect of shielding by the use of the thermal lag factor *L*. The temperature indicated by shielded thermocouples will lag that indicated by bare thermocouples to the greatest extent during the early portion of the fire test when the furnace temperature must be raised rapidly. As the test progresses, the temperature lag becomes less due to the slower rate of furnace temperature change.

From an unpublished study by the National Bureau of Standards in which the temperatures from shielded thermocouples were compared to temperatures from bare thermocouples, it was found that the shielded thermocouple temperatures lagged the temperatures registered by the bare thermocouples by 154 C at 5 min, 46 C at 1 hr, 34 C at 2 hr, and 26 C at 4 hr. These results were obtained in one test, of a series of fire tests of concrete beams, in which the furnace temperature was controlled by bare thermocouples positioned in the furnace, relative to the specimen, in accordance with the requirements of the British Standard.

Had the furnace been heated in the same manner as above but controlled by shielded thermocouples as required by ASTM, it would seem that the recorded time-temperature curve would have been located somewhat above the American time-temperature curve. In other words, the actual furnace temperature produced by the ASTM procedure at a given time will be somewhat higher than the temperature which may be registered by shielded thermocouples, assuming that the real furnace temperature is that measured by bare thermocouples.

TABLE 1 — COMPARISON OF ACCUMULATIVE EXPOSURE

Test time, hr	Area under standard time-temperature curve, percent: Bare thermocouple	Area under standard time-temperature curve, percent: Protected thermocouple	Difference, percent
½	100.8	92.0	8.8
1	100.3	94.2	6.1
2	100.5	95.4	5.1
3	100.3	95.8	4.5
4	99.9	96.1	3.8
4½	99.7	96.3	3.4

Relative exposure severity

The relative severity of fire exposures may be more accurately determined by comparing the area under the resulting time-temperature curves of the tests. This comparison is made in Table 1 indicating that the American test is perhaps more severe than the British test.

It should be pointed out that these differences are within the limits of variation from the standard curve allowed by both British Standard 476 and ASTM E 119. The American standard requires that the recorded exposure be corrected to the standard exposure where the variation may effect the classification. The British standard does not require a correction so long as the recorded time-temperature curve is within the prescribed limits listed in BS 476 (Table 2).

As previously explained, the clearances between specimen and furnace control thermocouples vary under the American standard but are about the same for all specimen types tested under the standards of foreign countries. Just what effect the variation in clearance in American tests has on exposure severity is not known, but it is believed that the effect is small where the method of firing the testing furnace provides for good mixing and turbulence of furnace gases.

The differences shown in Table 1 were obtained from furnace thermocouples placed at 3 in. (British) and 12 in. (American) away from the specimen. The furnace in which the tests were conducted was fired by gas burners which produced a brisk flame and considerable turbulence. Therefore, these indicated exposure differences stemmed largely from the effects of thermocouple shielding. Data from tests performed in Great Britain on a wall specimen indicate that for clearances of 6 in. and 3 in. between the specimen surface and furnace thermocouples there was practically no difference in the temperature readings. But when the furnace thermocouples were placed on the fire exposed surface of the specimen, the resulting temperature readings were considerably lower.

METHODS OF HEATING TEST FURNACES

Another detail of standard fire testing procedure which has not been standardized is the mode for heating the test furnaces. ASTM E 119 does not specify the fuel nor the manner of burning the fuel. Neither do the standards of other countries. Evidently the only requirement with respect to firing a test furnace is that the resulting heating follow the standard time-temperature curve and that the heating of the specimen, in turn, be uniform on all exposed surfaces. The fuel commonly used for firing test furnaces in America is gas and currently, with one or two exceptions, natural gas because of its wide availability and comparatively low cost. In Europe, manufactured gas, propane, gasoline, and fuel oil are among the fuels employed for testing furnaces.

One prominent laboratory in the United States fires its test furnaces with natural gas flames which are luminous and have been variously described as rolling, lazy, and somewhat smoky. The gas is burned in a manner that simulates the air-starved combustion which has been observed in actual building fires. Another American laboratory employs gas burners for its furnaces which produce active, short, and almost colorless flames while yet another fires its furnaces with flames that are about a median between these extremes.

A furnace in Holland which is used for tests of long beams is fired by propane gas. The burners of this unit are directed downward upon a bed of crushed refractory material. The specimen is heated by a combination of radiation emitted by the glowing bed of refractory and the movement of hot products of combustion which are taken out of the furnace through ports near the top of the beam specimen. The furnaces employed at the Herts fire research station in England make use of multiple gas burners which produce short, bluish flames.

Apparently, in furnaces where the burner flame is short or where the burners are oriented in a manner

TABLE 2 — MAXIMUM TOLERANCE FOR AREA UNDER TIME-TEMPERATURE CURVE (BS476)

Duration of test, hr	Elements subject to requirements of clause 11 a, b, c,† percent	Elements subject to requirements of clause 11 a, b, only,† percent
½	15	15
½-1	10	15
1-2	10	15
more than 2	5	—

†Refers to mode of failure: a = failure by collapse, b = failure by passage of flame, and c = failure by heat transmission.

which avoids flame impingement, bare thermocouples can be successfully used. The bare furnace thermocouple is favored in Great Britain because of its more rapid response compared to shielded thermocouples. Nevertheless, shielded furnace thermocouples have been used in American fire tests for many years.

Influence of flame color

The question has been posed by persons engaged in fire research as to the influence of flame color on the heating of test specimens. Heat reaches a test specimen principally by radiation and by convection of furnace gases. Observations made in column tests at the Herts fire research laboratory showed that temperatures measured by thermocouples were, on the average, 150 C higher than temperatures measured by radiometers. It was therefore suggested[4] that the main quantity of heat absorbed by the specimen was delivered by moving furnace gases.

Thermocouples do not readily register radiant heat effects unless mounted on the surface of the body receiving radiation. In instances where furnaces are fired by burners producing highly luminous flame or where radiant heat is purposely created as in the beam furnace in Holland, it is possible that the greater portion of heat absorbed by a specimen may come from radiation which would not be precisely detected by thermocouples located some distance away from the exposed surface. A person involved in the design of a test furnace might wonder about this detail and the differences in laboratory practices concerning it. It appears that these differences are not of important consequence 40 to 60 min after the start of a fire test since after this interval the refractory and other furnace parts become sufficiently heated as to serve in themselves as heat radiating bodies no matter what the fuel or how it is burned.

SIZE OF SPECIMENS FOR STANDARD FIRE TESTS

Minimum dimensions for fire test specimens are specified in the standards of a number of countries in which acceptance fire tests are carried on. Some advisory statements were encountered in the literature to the effect that test specimens ought to be full size whenever possible and shall truly represent the design, materials and workmanship for which classification is desired. When constructions exceed in size the practicable limits of furnace equipment, the testing agency is advised to employ a representative portion of the construction whose dimensions are to be no less than the specified minimum dimensions. Only when the actual construction is smaller may the dimensions of the specimen be less than the given minimums. Table 3 gives the minimum dimensions or areas of specimens which are employed by several countries for fire tests of building components.

The dimensions given in Table 3 for countries other than Great Britain, Canada, and the United States are for furnace openings and were originally expressed in metric units. Only for British and American procedures was specific mention made of minimum areas or dimensions to be exposed to fire. It may be that all dimensions given in Table 3 for other countries refer to that proportion of the specimen which is to be exposed to fire, but this is not a cer-