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Fire-resistance tests — Elements of building construction —

Part 3:
Commentary on test method and test data application

Essais de résistance au feu — Éléments de construction —

Partie 3: Commentaires sur les méthodes d'essais et application des données d'essais

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO members bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented in that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 834-3, which is a Technical Report of type 1, was prepared by Technical Committee ISO/TC 92, *Fire tests on building materials, components and structures,* Subcommittee 2, *Fire resistance.*

ISO 834 consists of the following parts, under the general title *Fire resistance tests — Elements of building construction:*

— *Part 1: General requirements for fire resistance-testing*

— *Part 2: Special requirements for different elements*

— *Part 3: Commentary on test method and test data application*

Annex A of this part of ISO 834 is for information only.

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Fire-resistance tests — Elements of building construction —

Part 3:
Commentary on test method and test data application

1 Scope

The information provided in this part of ISO 834 is advisory in nature and is intended to provide guidance on the use of the fire resistance test method and the application of the data obtained. This part of ISO 834 also identifies a number of areas where future editions may benefit by research: into phenomena associated with the performance of assemblies under test and their relationship with actual building construction; and into technology related to the instrumentation and testing techniques.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 834. At the time of publication, the edition indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 834 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards

ISO 834-1:—[1], *Fire resistance tests — Elements of building construction — Part 1: General requirements for fire resistance testing.*

ISO/TR 3956:1975, *Principles of structural fire-engineering design with special regard to the connection between real fire exposure and the heating conditions of the standard fire-resistance test (ISO 834).*

ISO/TR 10158:1991, *Principles and rationale underlying calculation methods in relation to fire resistance of structural elements.*

3 Standard test procedure

Practical considerations dictate that it is necessary to make a number of simplifications in any standard test procedure in order to provide for its use under controlled conditions in any laboratory with the expectation of achieving reproducible and repeatable results.

Some of the features which lead to a degree of variability are outside of the scope of the test procedure, particularly where material and constructional differences become critical. Other factors which have been identified in this part of ISO 834 are within the capacity of the user to accommodate. If appropriate attention is paid to these factors, the reproducibility and repeatability of the test procedure can be improved to an acceptable level.

3.1 Heating regimes

The standard furnace temperature curve described in ISO 834-1, subclause 5.1.1 is substantially unchanged from the time-temperature curve employed to control the fire test exposure environment for the past seventy or so years. It was apparently related in some respects to temperatures experienced in actual fires in buildings using references such as the observed time of fusion of materials of known melting points.

The essential purpose of the standard temperature curve is to provide a standard test environment which is reasonably representative of a severe fire exposure condition, within which the performance of various representative forms of building construction may be compared. It is, however, important to remember that this standard fire exposure condition does not necessarily represent an actual fire exposure situation nor is it necessarily indicative of the expected behaviour of the structural element under test should it become involved in an actual building fire. The test does, nevertheless, grade the performance of separating and structural elements of building construction on a common basis. It should also be noted that the fire resistance relates to the test duration and not to the duration of a real fire.

The relationship between the heating conditions, in terms of time-temperature prevailing in real fire conditions and those prevailing in the standard fire-resistance test is discussed in ISO/TR 3956. A series of cooling curves is also discussed.

1) To be published.

It should be noted that the standard furnace temperature curve may also be expressed in exponential terms which closely approximate the curve expressed by $T = 345 \log_{10} (480t + 1)$ and which may be considered preferable for calculation purposes. The expression thus becomes

$$T = 1\,325(1 - 0{,}325\ e^{-0{,}2t} - 0{,}204\ e^{-1{,}7t} - 0{,}471\ e^{-19t})$$

where

T is the temperature increase, in degrees Celsius;

t is the time at which temperature increase has occurred, in hours.

The comparison of the areas of the curves represented by the average recorded furnace temperature versus time and the above standard curve, in order to establish the deviation present, d, as specified in ISO 834-1, subclause 5.1.2, may be achieved by using a planimeter over plotted values or by calculation employing either Simpson's rule or the trapezoidal rule.

While the heating regime described in ISO 834-1, subclause 5.1.1, is the fire exposure condition required by this Technical Report, it is recognized that it is not appropriate for the representation of the exposure conditions such as may be experienced from, for example, fires involving hydrocarbon fuels. Such exposure environments will, more appropriately, be provided for in other standards which cover fire resistance tests of other than building constructions. An example of one heating regime which has recently been proposed to represent hydrocarbon fires is as follows:

$$T = 1\,100(1 - 0{,}325\ e^{-0{,}1667t} - 0{,}204\ e^{-1{,}417t} - 0{,}471\ e^{-15{,}833t})$$

where

T is the temperature increase, in degrees Celsius;

t is the time at which temperature increase has occurred, in hours;

or, in practical terms:

$$T = 1\,100(1 - 0{,}33\ e^{-0{,}17t})$$

where t is the time, in hours.

3.2 Furnace

The heating conditions prescribed in ISO 834-1, subclause 5.1.1, are not sufficient by themselves to ensure that test furnaces of different design will each present the same fire exposure conditions to test specimens and hence provide for consistency in the test results obtained among these furnaces.

The thermocouples employed for controlling the furnace temperature are in dynamic thermal equilibrium with an environment which is influenced by the radiative and convective heat transfer conditions existing in the furnace. The convective heat transfer to an exposed body depends upon its size and shape and is generally higher with a small body such as a thermocouple bead than with a large body like a specimen. The convective component will therefore tend to have greater influence upon the thermocouple temperature while the heat transfer to a specimen is mainly affected by radiation from the hot furnace walls and the flames.

Both gas radiation and surface to surface radiation are present in a furnace. The former depends on the temperature and absorption properties of the furnace gas as well as being significantly influenced by the visible component of the burner flame.

The surface to surface radiation depends on the temperature of the walls and their absorption and emission properties as well as the size and configuration of the test furnace. The wall temperature depends, in turn, on its thermal properties.

The convection heat transfer to a body depends on the local difference between the gas and the body surface temperature as well as the gas velocity.

The radiation from the gases corresponds to their temperature, and the radiation received by the specimen is the sum of that from the gases and the furnace walls. The latter is less at the beginning and increases as the walls become hotter. The thermocouples prescribed by this part of ISO 834 are small and will adjust to the gas temperature. The specimen, on the other hand is more sensitive to the irradiance.

From the foregoing discussion, it is apparent that the ultimate solution in the matter of achieving consistency among testing organizations utilizing the requirements of this part of ISO 834 will only be realized if all users of this part of ISO 834 and idealized design of test furnace which is precisely specified as to size, configuration, materials, construction techniques and type of fuel used.

One method of reducing the problems which have been outlined, which can be applied to existing furnaces is to line the furnace walls with materials of low thermal inertia that readily follow the furnace gas temperatures such as those with the characteristics prescribed in ISO 834-1, subclause 4.2. The difference between the gas and wall temperatures will be reduced and an increased amount of heat supplied by the burners will reach the specimen by radiation from the furnace walls and hence there will be an improvement in the commensurability of the results yielded by furnaces of different designs.

Where possible existing furnace designs should also be reviewed to position burners and possibly flues so as to avoid turbulence and associated pressure fluctuations which result in uneven heating over the surface of the test specimen.

While the design of the thermocouple to be employed in measuring and hence controlling the test furnace environment is specified in ISO 834-1, subclause 4.5.1.1, it is also suggested that experimental work be performed on the possible use of thermocouples which are more sensitive to the combined effects of radiation and convection for this purpose as a further measure for reducing the problem of varying heat characteristics of test furnaces (see reference [1]).

Finally, one of the most effective "tools" in the adjustment of existing furnace designs so as to improve consistency concerning them is the use of a calibration routine (see 3.11).

3.3 Conditioning

3.3.1 Correction for non-standard moisture content in concrete materials

At the time of test, ISO 834-1, subclause 6.4, permits the specimen to exhibit a moisture content consistent with that expected in normal service.

Except in buildings that are continuously air-conditioned or are centrally heated, elements of building construction are exposed to atmospheres that, in varying degrees, tend to follow the cycling of temperatures and/or moisture conditions of the free atmosphere. The nature of the materials comprising the element and its dimensions will determine the degree to which the moisture content of an element will fluctuate about a mean condition.

Relating the specimen condition to that obtained in normal service can therefore result in a variation in the moisture content of specimen construction assemblies, particularly those with hygroscopic components having a high capability for moisture absorption such as portland cement, gypsum and wood. However, after conditioning such as prescribed in ISO 834-1, subclause 6.4, from among the common inorganic building materials, only the hydrated portland cement products can hold a sufficient amount of moisture to affect, noticeably, the results of a fire test.

For comparison purposes, it may therefore be desirable to correct for variations in the moisture content of such specimens using, as a standard reference condition, the moisture content that would be established at equilibrium from drying in an ambient atmosphere of 50 % relative humidity at 20 °C.

If the fire resistance with respect to thermal insulation of a specimen is known at one moisture content, then the fire resistance at some other moisture content can be calculated according to the following equation:

$$T_{\mathrm{d}}^2 + T_{\mathrm{d}}(4 + 4b_{\Phi} - T_{\Phi}) - 4T_{\Phi} = 0$$

where

Φ is the volumetric moisture content;

T_{Φ} is the fire resistance at moisture content Φ, in hours;

T_{d} is the fire resistance in the oven-dry condition, in hours;

b is a factor which varies with the permeability.

(For brick, dense concrete and gun-applied concrete, b may be taken as 5,5, for lightweight concrete as 8,0 and for cellular concrete, as 10,0).

Alternatively, it can be calculated by employing the procedures described in references [2] and [3].

If artificial drying techniques are employed to achieve the moisture content appropriate to the standard reference condition, it is the responsibility of the laboratory conducting the test to avoid procedures which will significantly alter the properties of the specimen component materials.

3.3.2 Determination of moisture condition of hardened concrete in terms of relative humidity

A recommended method for determining the relative humidity within a hardened concrete specimen with electric sensing elements is described in Appendix I of reference [4]. A similar procedure with electric sensing elements can be used to determine the relative humidity within the fire test specimens made with other materials.

With wood constructions, the moisture meter based on the electrical resistance method can be used, when appropriate, as an alternative to the relative humidity method to indicate when wood has attained the proper moisture content. Electrical methods are described in references [5] and [6].

3.4 Fuel input and heat contribution

At the present time the measurement of the fuel input is not among the data required during the performance of a fire test although this parameter is often measured by testing laboratories and users of this part of ISO 834 are encouraged to obtain this information, which will be of assistance in its further development.

When recording the fuel input rate to the burners, the following guidance on experimental procedures may be helpful.

Record the integrated (cumulative) flow of fuel to the furnace burners every 10 min (or more frequently if desired). The total fuel supplied during the entire test period is also to be determined. A continuous recording flowmeter has advantages over periodic reading on an instantaneous or totalizing flowmeter. Select a measuring and recording system to provide flowrate readings accurate to within ± 5 %. Report the type of fuel, its higher (gross) heating value and the cumulative fuel flow (corrected to standard conditions of 15 °C and 100 kPa) as a fraction of time.

Where measurements of fuel input have been made, they typically indicate that there is a heat contribution to the test furnace environment during the latter stages of tests of test assemblies incorporation combustible components. This information is not usually taken into account by national codes, which generally regulate the use of combustible construction on the basis of occupancy classification and limitations on the height and area of buildings in which this type of construction is employed.

It should also be noted that fuel input measurements may be considerably different when testing water-cooled steel structures or massive sections by this method.

3.5 Pressure measurement techniques

When installing the tubing used in pressure sensing devices, the sensing tube and the reference tube must always be considered as a pair and their path (together) traced from the level to which the measurement relates, all the way to the measuring instrument. As far as the reference tube is concerned, it may be physically absent, in places, but it must be regarded as implicitly existing (the air in a room between two particular levels, representing the reference tube in this case).

Where the reference and the sensing tubes are at the same level, they may be at different temperatures.

Where the reference and the sensing tubes curve from one level to another, they must, (at every level) be at the same temperature. They may be hot at the top and cool at the bottom but the temperature at each level must be the same (see also reference [7]).

Care should be taken with the positioning of sensing tubes within the furnace so as to avoid them being subjected to dynamic effects due to the velocity and turbulence of furnace gases (see also reference [8]).

3.6 Post heating procedures

ISO 834-1 contains no requirements for, or reference to, post heating procedures. It is, however, the practice in some countries to maintain the test load, or a factored test load, for a period, usually 24 h, subsequent to the fire test. The objective of this procedure has been to obtain general information concerning the residual strength or stiffness of the building construction represented by the test specimen, after a fire. Since this information is difficult to relate to a fire (or post fire) situation, it has been concluded that such requirements are outside the purview of this specification.

Some countries follow the practice of additionally assessing the performance of separating elements by subjecting them to some form of impact test immediately following the fire test. This is intended to simulate the effect of failing debris or of hosestream attacks upon a fire separation, where that separation is required to maintain its effectiveness during or after the attack on the fire. Such impact tests may be applied after the complete fire test duration or after only a portion (e.g. half) of the rating period; and is often considered as a measure of stability apart from any assumptions with respect to simulated attacks with hosestreams by firefighters.

It should be noted that both of the foregoing practices will, in most cases, discourage the possibility of continuing a fire test beyond the required fire endurance period. With the increasing need to provide data for extrapolation and other calculation purposes, testing organizations should be encouraged to continue the fire exposure period for as long as the limiting criteria may be safely exceeded.

3.7 Specimen size

ISO 834-1 has prescribed a general philisophy that fire-resistance tests should be carried out on full-size specimens. It also recognizes that this is not always possible because of the limitations imposed by the size of the equipment available. In those cases where the use of a full-size specimen is not possible, an attempt has been made to accommodate this shortcoming by specifying standardized minimum dimensions for a specimen representative of the size needed for a room of 3 m height and 3 m by 4 m cross-section.

The strong recommendation to use full-size test specimens arises from difficulties in achieving completely representative fire behaviour in model scale of most loadbearing and some separating elements of building construction.

For most non-load-bearing elements a reduction in overall dimensions to a convenient size for test purposes does not pose any serious problems, particularly where the construction is modular.

For loadbearing systems, it is necessary to emphasize the importance of keeping the functional behaviour unchanged when decreasing the dimensions of a fire-resistance test specimen. For example, the ratio between the side lengths should be unchanged when the dimensions of a full-scale floor are reduced. Similarly, the relative proportions of structural members to the elements that they support should be maintained. In other words, it is necessary to maintain a balance between the different types of stresses to which the representative scaled down element is subjected, as well as establish the correct representation of the stresses in the scaled down version of the building construction in question.

3.8 Specimen construction

ISO 834-1 specifies that the materials used in the construction of the test specimen and the method of construction and erection shall be representative of the use of the element in practice.

This means that such features as joints, provision for expansion and special fixing or mounting features should be included, in a representative manner, in the test specimen.

It should be noted that there will be a tendency, unless otherwise specially contrived, to construct test specimens to a higher standard than may be experienced in practice. On the other hand it is also important in the interests of consistency to construct a test specimen which will not be conductive to extraneous results because of flaws in the construction.

An accurate and detailed description of the test specimen and its condition at the time of test is therefore a most necessary adjunct to the test data and where necessary such features should be highlighted to rationalize apparent anomalies in test results.

3.9 Loading

The load applied to a test specimen during a fire test has a significant effect upon its performance as well as being an important consideration in the further application of the test data together with its relationship to data from other and similar tests.

ISO 834-1, subclause 5.4, specifies the different bases on which the load may be selected. The basis which offers the widest application of test data is that which relates the determination of the test load and hence the induced stresses to the measured material properties of the actual structural members employed in the construction of the test specimen while, at the same time, causing material stresses to be developed in the critical areas of these members which are the maximum stresses permitted by the design procedures in nationally recognized structural codes. This provides for the most severe application of the test load as well as providing a realistic basis for the extrapolation of test data and its use in calculation procedures.

The second basis relates the required test load to the characteristic properties of the materials comprising the test specimen. The values may typically be provided by the material producer or may be obtained by reference to literature relating to the standard properties of the materials in question (usually given in a range). In most cases this results in a somewhat conservative value for the test load, since actual values are generally higher than characteristic values and the structural elements are not subjected to the limiting stresses contemplated by the design procedures. On the other hand this practice relates more closely to typical national design procedures and the corresponding practices in regard to the specification of materials employed in building structures. The usefulness of the results obtained from such tests may be enhanced if the actual material properties are, nevertheless, determined and/or the actual stresses in the structural components of the fire test specimens are measured during the fire test.

The third approach differs from the preceding provisions because the resulting load is related to a specific and therefore limited application. The test load is invariably less than that which would normally be applied and, provided the structural members have been selected in consideration of their having to sustain normal design loads as provided by recognized structural codes, there will be a greater margin of safety and improved fire resistance, when compared with the performance of test specimens loaded in consideration of the first and second bases above. Again, the usefulness of the test results may be improved if data can be obtained concerning the actual physical properties of the structural materials in the structural members and the stress levels obtaining in these members when loaded as prescribed.

In addition to the respective bases for developing the load to be applied during a test it should be noted that the nationally recognized structural codes employed in the design of building construction, to which these bases relate, may themselves provide for a number of different design elements which are not always accorded the same consideration in different countries. There is a significant variation in philosophies with regard to the accommodation of such features as wind, snow and earthquake loads.

It is therefore important to note that whatever method has been employed for developing the load during the fire test, it is desirable that it be related to the ultimate load of the test element before heating and it is essential that the basis for its development be clearly given in the report as well as any other pertinent information such as material properties and stress levels which affect the significance and application of the test results.

For the most part, concentrated loading points can provide a close simulation of the stress conditions likely to be experienced with beams and columns. With floors and walls greater care is needed to simulate the effect of uniform loading. The maximum number of loading points should be employed while, at the same time, the loading system should be able to accommodate the full deflection anticipated during a test while maintaining the required load distribution.

3.10 Boundary conditions and restraint

3.10.1 Introduction

ISO 834-1, subclause 5.5, provides some options for the application of restraint, or resistance to thermal expansion or rotation, for various load bearing systems. The clause reflects the inherent philosophy of the test method described by ISO 834-1, that of testing the specimen in a manner which represents as closely as possible the most severe application of its use in practice.

For the purpose of relating the restraint applied to the test specimen to the conditions experienced in actual building construction the following philosophy applies:

Floor and roof assemblies, wall constructions, columns and individual beams in buildings shall be considered to offer resistance to thermal expansion and/or rotation when the surrounding, supporting or supported structure is capable of providing substantial resistance to such forces throughout the range of elevated temperatures represented by the standard time-temperature curve.

While the exercise of engineering judgement is required to determine what is capable of providing "substantial resistance to such forces", it may be noted that the necessary resistance may be provided by such features as the lateral stiffness of supports for floor and roof assemblies and intermediate beams forming part of an assembly, or the weight of supported structure. At the same time connections must be adequate to transfer the forces resulting from thermal expansion and/or rotation to such supports or resisting structures. The rigidity of adjoining panels or structures should also be considered in assessing the capability of a structure to resist thermal expansion. Continuity, such as that occurring in beams acting continuously over more than two supports will also induce the resistance to rotation anticipated by this philosophy.

From test results it is well known that variations of restraint conditions can significantly influence the time fire resistance for a structural element or assembly. In most cases, the application of restraint during a fire test is beneficial to the performance of the specimen. In some cases, however, excessive axial restraint can accelerate an instability failure or give rise to accelerated spalling such as may occur in a concrete structure. In other cases, such as with a statically indeterminate slab of reinforced concrete exposed to fire on one side, a moment restraint can cause serious crack formations in non-reinforced or weakly reinforced regions leading to shear failure of the structure.

As experience with fire testing of restrained structures has been gained it has, however, been possible to anticipate some of the anomalous behaviour referred to above. It has also been possible to relate in a general way the condition of restrained test specimens to that of actual building construction. Nevertheless, much remains to be done and where it is not possible to relate the required boundary conditions of a test specimen to the boundary conditions that structure would experience in actual building construction, it has been the practice to test a specimen in a condition which offers little or no resistance to expansion or rotation.

3.10.2 Flexural members (beams, floors, roofs)

Specimens incorporating flexural members are either subjected to fire exposure while resting on roller supports or are tested within the confines of a restraining frame. In the latter case restraint to thermal expansion, axially, or rotationally, may be applied in a number of ways. In the least sophisticated equipment, the specimen is mounted within a restraining frame of such proportions that it is capable of reacting to the axial thrust of specimen structural members without significant deflection. In some cases this axial thrust has been measured by calibrating the restraining frame. In other cases, a degree of control has been exercised by leaving expansion gaps between the ends of the structural member and the restraining frame. Such arrangements also provide rotational resistance because of the contact and hence quasi fixing of the end of the structural member over its depth and the depth of the restraining frame. In the more sophisticated arrangements restraint and its measurement are provided by the use of hydraulic jacks arranged axially and normal with respect to the structural member(s).

In those cases where restraint to thermal expansion occurs, the heating during a fire resistance test gives rise to an axial, compressive force in the members concerned. In most cases this force occurs at a position in the cross-section of the member such that the corresponding bending moment tends to counteract the bending moment due to the applied load, leading to an increased loadbearing capacity and fire resistance unless the potential for spalling or instability failure outweighs this favourable effect.

In most cases, if a flexural structural member has been tested in an unrestrained condition it is on the safe side to employ representations of that member in a building construction where it would likely be subjected to thermal restraint in the event of fire exposure.

3.10.3 Axial members (columns, load-bearing walls)

Fire tests on columns and loaded walls performed in laboratories show idealization with respect to the stresses which are experienced during an actual fire. For example, it is not yet possible to reproduce, in a test, the changing end moments which would occur under actual fire exposure conditions. The effect of restraint, in practice, depends upon the localized nature of the fire in a fire compartment. In the event that a substantially uniform heating condition were to be experienced in a fire compartment then the significance of the restraint against elongation would likely be much less.

The load-bearing capacity and related test load of columns and load-bearing walls depend to a large extent upon the supporting conditions. In slender members of this kind, which are assumed to be hinged, even small forces arising from friction within the supports may considerably increase the load-carrying capacity. In a fire test an unintentional application of end restraint on the test specimen may considerably increase the load-carrying capacity. It has also been the experience of some laboratories that it is generally quite difficult to provide truly concentric axial reaction (or loading) points for columns, notwithstanding the use of spherical end supports and it is the recommended practice to introduce a small, known degree of eccentricity.

For these reasons it is probably preferable to perform tests on columns or load-bearing walls with either no resistance to expansion (elongation) or with fully restrained ends.

3.10.4 Non-load-bearing walls and partitions

All non-load-bearing walls and partitions are, logically, tested without the application of external loads. However, in practice, these elements will be affected by either the transfer of loads from other building elements or by the reactions to their own expansion under fire exposure. Tests on these elements should therefore be performed in a closed restraining frame of sufficient stiffness to react to the expansion forces generated by the specimen under test with little or no deformation.

3.10.5 Laboratory measurements

In view of the present lack of information concerning the effects of restraint to thermal expansion or rotation, testing laboratories should be encouraged, when testing specimens which are restrained in any manner, to attempt to determine the magnitude and direction of such restraining forces.

3.11 Calibration

Calibration involves a procedure for ensuring that identical specimens tested according to this part of ISO 834, in different furnaces or in the same furnace at different times, will provide comparable results. If this objective is met, the time at which well-defined specimens reach prescribed performance levels associated with load-bearing capacity and insulation will not be appreciably different.

A major feature of all fire-resistance test calibration involves the procedures and instrumentation for controlling and measuring furnace temperatures, pressures and atmospheres. The aim of the calibration test it to establish that heating conditions are uniform over the exposed surface of the test specimen and that the prescribed level of heating exposure is achieved. It is also the purpose of such a test to ensure that a linear static pressure gradient is obtained over the exposed face of vertically oriented test specimens and that a uniform static pressure is obtained over the exposed face of horizontally oriented test specimens.

A calibration procedure addressing the temperature and pressure conditions in the furnace is described in reference [9].

The load-bearing capacity of a test specimen may also be affected by such factors as: specimen support; restraint and boundary conditions; application of the design load; and the temporal measurement of load magnitude, deformation and deflection, with devices which have been compared with referenced standards. No calibration procedure directly assessing these characteristics has been provided and reliance is placed upon consistency in the specifications of these parameters in the test method and achievement of the temperature and pressure conditions using the procedure described in reference [9].

4 Fire-resistance criteria

4.1 Objective

The objective of determining fire resistance, as described in ISO 834-1, is to evaluate the behaviour of an element of building construction when subjected to standard heating and pressure conditions. The test method described in this part of ISO 834 provides a means of quantifying the ability of an element to withstand exposure to high temperatures by establishing performance criteria. These criteria are intended to ensure that under the test conditions a specimen element continues to perform its design function as a load supporting structure or a separating element, or both. The criteria establish loadbearing capability and resistance to fire transmission. A fire can be transmitted from one compartment to another in two ways, either because of loss of integrity or through the excessive transmission of heat which has resulted in higher than acceptable unexposed face temperatures.

The time-temperature curve specified in this part of ISO 834 is representative of only one of many possible fire exposure conditions at the developed fire stage and the method does not quantify the behaviour of an element, for a precise period of time, in a real fire situation (see 3.1).

4.2 Load-bearing capacity

This criterion is intended to determine the ability of a loadbearing element to support its test load during the fire test without collapse. As it is desirable to have a measure of load-bearing capacity without having to continue the test until the element collapses, a limit on rate of deformation and maximum deflection has been included for floors, beams and columns. It has not been possible to include a limit for walls as experience has indicated that deformations recorded just prior to collapse vary in magnitude from one type of wall to another.

4.3 Integrity

This criterion is applicable to separating constructions and provides a measure of the ability of the specimen to restrict the passage of flames and hot gases from its fire exposed side to the unexposed surface in terms of the elapsed time prior to the ignition of a cotton wool pad which is placed over any cracks or openings. The ability of the pad to ignite will depend upon the size of the opening, the pressure inside the furnace at the position of the opening, the temperature, and the oxygen content.

Flaming on the unexposed face of the element can constitute an unacceptable hazard and therefore, where this can lead to ignition of the pad, this also constitutes failure under the integrity criterion.

4.4 Insulation

This criterion is applicable to separating constructions and provides a measure of the ability of the specimen to restrict the temperature rise of the unexposed face to below specified levels.

Where the separating construction being tested is uninsulated or has exceeded the specified temperature limits, the radiation from the unexposed surface may of itself be sufficient to ignite a cotton wool pad.

The specified levels are intended to ensure that any combustible material in contact with the unexposed surface will fail to ignite at temperatures below these levels. The limit for maximum temperature rise is included to indicate any potential areas on the construction that will provide a direct path for heat transmission and create a hot-spot on the unexposed face when the test specimens are instrumented in accordance with ISO 834-1, subclause 4.5.1.2.

Suggestions have been made to the effect that the specified limiting values of temperature rise may be somewhat conservative since they were apparently based upon the premise that the unexposed surface temperature continues to rise after the exposing fire has been removed from the assembly under test. Experiments have been conducted[10] whereby boxes filled with either cotton or wood shavings were placed against the unexposed surfaces of brick walls subjected to fire exposure in accordance with the standard fire test. There was no evidence of ignition of the wood or cotton at temperatures below 204 °C (or 163 °C temperature rise) at durations of fire exposure for 1,5 h to 12 h. Evidence of approaching ignition was observed at temperatures between 204 °C and 232 °C and conclusive evidence of ignition was observed at temperatures between 232 °C and 260 °C.

4.5 Other characteristics

While the materials comprising the test specimens which are subjected to this test method may exhibit other undesirable characteristics during the conduct of the test, such as the development of smoke, such phenomena are not subject to the criteria applicable to this test method and are more appropriately evaluated by test methods designed for the purpose.

5 Classification

Buildings are typically regulated in terms of height, area, occupancy category and spatial separation by requiring their principal separating and supporting elements to exhibit specific minimum periods of fire resistance in terms of the results of the standard fire test applied to sample constructions representative of those building elements.

This part of ISO 834 provides a system for expressing the performance of such constructions which have been subjected to fire test which relates to the characteristics which have been considered when measuring the performance, i.e. structural stability, integrity and insulation. The performance is expressed in units of time pertaining to the period during which acceptance criteria applicable to these characteristics have been accommodated.

In practice the codes and regulations in different countries employ a variety of methods of stating a requirement for fire resistance. In some countries, it is implicit in the requirement that the construction in question has met all of the performance criteria for the period concerned. In some other countries and circumstances it may be necessary for only one or two of the performance characteristics to have been accommodated for all or part of the fire test period. It is therefore desirable, in codes and regulations, to provide appropriate and significant qualifications when such relaxations are permitted.

The fire resistance requirement is typically referred to as a fire-resistance classification or rating. The classification or rating periods are usually designated in half-hourly or hourly intervals ranging from 0,5 h to 6 h. To qualify for such a designation it is necessary that the assembly accommodates the criteria for a period at least equal to the hourly designation. In some countries, letters of the alphabet are used to correspond to specific periods of fire resistance and in other countries, where permitted, a code letter is also employed to indicate which of the criteria has been accommodated.

It should also be noted that some countries make a distinction between the classifications assigned to combustible and non-combustible construction. Finally, it is the practice in some countries to include code letters or other forms of designation in the assigned classification to signify the type of building construction element concerned.

6 Repeatability and reproducibility

While this part of ISO 834 has been revised with the intention of improving repeatability and reproducibility no comprehensive test programme has heretofore been conducted to develop data on which to derive statistical measures of repeatability and reproducibility of the fire tests it describes. Since replicate testing of nominally identical specimens is not required and not customary, statistical data on variability is scarce. Some sources of assembled data do, however, exist[11].

Repeatability and reproducibility are often expressed in terms of a standard deviation or a coefficient of variation (the ratio between standard deviation and overall mean, expressed as a percent); it may also be expressed in terms of a critical difference or a relative precision (the critical difference within which two averages can be expected to lie 95 % of the time).

No good estimate of the coefficient of variation of reproducibility is available at present, but experience indicates that between-laboratory reproducibility may be two or three times the within-laboratory repeatability.

Repeatability and reproducibility may be further improved by consideration of the following:

6.1 Repeatability

Repeatability is a measure of the variability in fire resistance time associated with replicate tests on the same nominal assembly conducted within a single laboratory. Variability in the measured fire resistance time may be due to random or systematic factors, and may be associated with

a) specimen assembly;

b) apparatus (furnace and loading equipment);

c) control equipment;

d) operator (control and observations);

e) environmental effects.

Random factors include material variability and workmanship; load magnitude and application (e.g. degree of restraint, end fixity, load eccentricity); sensor and instrument variability; operator-conditional effects; environmental changes (temperature, humidity, etc.).

Systematic factors include aspects of the factors cited above, e.g. different assembly personnel equipment operators; systematic changes (high or low) in furnace temperature and pressure; shifts in sensor and instrument calibrations.

In some cases, a critical factor may have both random and systematic aspects. For example, the magnitude (and variability) of furnace pressure may initiate premature failure of a suspended ceiling forming part of a floor-ceiling assembly. This may occur randomly at one (controlled) pressure level and systematically at a slightly higher pressure level.

6.2 Reproducibility

Reproducibility is a measure of the variability in fire-resistance time associated with tests on the same nominal assembly conducted in different laboratories. The random and systematic factors stated above also apply to between-laboratory variability. Specific systematic factors likely to increase variability include

— differences between furnaces (e.g. size of specimen; type of fuel; number, type and orientation of burners);

— structural loading (e.g. method of applying load; load distribution; load eccentricity);

— boundary conditions (e.g. restraint; perimeter cooling);

— control and recording instrumentation (e.g. automatic/manual; temperature; pressure);

— interpretation of test conditions and criteria.

7 Interpolation and extrapolation

a) Interpolation

Determination of the effect of variations on an element of construction which has been previously subjected to a series of fire-resistance tests and accorded fire-resistance classifications with the intention of deriving a classification which is within the range established by test. Interpolation requires mathematical or empirical relations being developed on the basis of a minimum of two test results. Factors which can be considered are: dimensional, material, or design variations within the range of variables examined by tests.

b) Extrapolation

Determination of the effect of variations on an element of construction which has been subjected to a fire-resistance test and accorded fire-resistance classification with the intention of deriving a classification which extends beyond the range established by test. Extrapolation requires a fire model being developed on the basis of one or more tests and other pertinent data on fire performance. Factors which can be considered are: dimensional, material, or design variations, usually outside the range of variables examined by tests. The reliability of extrapolation depends upon the exactness of the fire model used and this needs to be specified when the procedure is undertaken.

A number of factors affect the ability to make interpolations and extrapolations. Where it is known before hand that this extension of data will be required, all relevant parameters should be controlled and, if necessary, additional measurements made to facilitate this work. There are three main parameters which need to be considered for this purpose:

a) dimensional variations – length, width, thickness, etc.;

b) material variations – strength, density, insulation, humidity;

c) load or design variations – load, boundary conditions, jointing, fixing methods.

The relevance of these parameters will depend upon the type of specimen and the changes being considered. It is only possible to indicate some of the factors which may be relevant in a few typical cases. For this purpose, the specimens can be divided into loadbearing and separating categories. In the former case, the main interest is to ensure that the variant will be able to successfully support the loads and in the latter case, that it will retain integrity and insulation characteristics. In some cases, both concepts will apply.

The main loadbearing elements for which simple rules are possible are insulated steel systems, concrete constructions, depending upon reinforcement protection, and wood constructions where the rate of charring is a critical factor. In the case of steel elements, the effect of varying the size, the load, and the design concept will result in a new critical goal for the insulating material. For concrete elements, a similar approach is possible for simple systems where either the steel of the concrete has to be prevented from reaching the critical state, or with more complex arrangements, the redistribution of stresses and strains has also to be taken into account. Most timber structures can be analysed on the basis of considering the ultimate strength of the uncharred section. A number of publications provide guidance on some typical constructional systems in these materials.

Interpolation and extrapolation methods can be divided into the following four groups, each with an increasing degree of sophistication. Precise rules and application limits will need to be agreed upon by the national bodies using the procedures:

a) Quantitative design rules based on fire tests and general concepts. Such rules are only useful for experts in the fields;

b) Quantitative design rules (or empirical rules) based on fire tests which attribute a certain value to the fire resistance contribution of materials or products with safeguards against unrealistic results;

c) Regression techniques: Examination of a number of parameters in a systematic series of tests and the determination of a relationship using regression techniques to obtain the best fit;

d) Physical models: Development of a physical model relating fire resistance to material properties either from first principles or by working from the test data. After the model has been validated fire resistance can be determined by input of the appropriate properties.

Caution should be exercised in regard to the use of interpolation or extrapolation techniques for the derivation of fire-resistance classifications in cases where there is insufficient data or where the construction under consideration is significantly unrepresentative of the fire tested construction upon which the interpolation or extrapolation is based.

Reference is also made to ISO/TR 10158.

8 Relationship between fire resistance and building fires

In considering this relationship it is necessary to understand that the determination of fire resistance is by means of a complete test procedure. When making comparisons with building fires, attention is usually focussed on the time-temperature curve and its relation to the temperatures and growth rates achievable in "real" compartment fires under various fire scenarios.

The test is used to qualify building structures so that they provide the requisite level of safety in fire. This is achieved by applying a fire resistance test result through some code or prescriptive document which will determine the performance needed in a given situation. Adequacy of the approach is monitored by practical feedback which generally means avoidance of an unacceptable failure rate.

The result of the test is stated in terms of a fire-resistance classification or rating expressed as a period of time for which certain criteria are satisfied.

This period of time represents a relative ranking of performance and cannot be related directly to a particular building situation. It is important to recognise this transformation from an arbitrary time base to the engineering performance of buildings in fire, made through the building codes.

The actual performance achieved in a fire-resistance test is intimately connected with the test conditions, the extent to which the test models the building, and the criteria applied to determine failure. A small change in conditions for failure, particularly with respect to integrity and thermal insulation, could have a significant effect on the rating obtained.

In particular, the time recorded in the fire-resistance test in respect of these criteria bears no direct relationship to the failure times in real fires. This has been recognised in principle from the inception of the test[12], [13].

The verification of performance by carrying out fire tests can be traced back about 100 years. These early tests used gas, oil and wood for fuel, or even a combination of these. With such a wide variety of test conditions it was difficult to compare and evaluate the findings.

The first moves towards a more uniform approach were in the USA when in 1918 an ASTM Committee introduced a time-temperature relationship close to our current ISO standards[14]. The natural time constants of the original furnaces probably had much to do with the originally established time-temperature curve. It is well established over a variety of furnaces, even in different countries, that a furnace once "on" the standard tends to "run itself", i.e. follow the curve with little operator interference.

A classification system was evolved in which elements lasting for a longer time in the furnace test with respect to chosen criteria were assumed to have the potential for better performance in actual building fires. Ingberg, using an equal area concept, was the first to try and express the standard test in real fire terms, deriving an equivalence relationship between a notional fire loading and the measured fire resistance period[15].

Many later attempts have been, and still are being, made to strengthen the link between the test method and actual building fires[16]. These have been extended to include factors such as ventilation, compartment size, fire loading and the compartment thermal properties. The aim is to be able to quantify the likely fire severity in a building, and hence through empirically derived relationships, to be able to assign a prescribed fire resistance period to be achieved in the test that will provide sufficient safety. Much of this work has been reviewed by Ödeen[14].

The fire test is to be regarded as a way of measuring the comparative response of building elements to fire scenarios which involves an approximation in both the fire and the physical model.

Attempts to make the test "more realistic" should be viewed with caution. Any measure which significantly alters the current rankings of the fire test should be considered in the light of the control which uses the test result and only implemented if the implied changes in level of safety are recognized, needed and accommodated.

Annex A
(informative)

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