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REPORT

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Fire-resistance tests — Elements of building construction —

Part 3:
Commentary on test method and guide to the application of the outputs from the fire-resistance test

Essais de résistance au feu — Éléments de construction —

Partie 3: Commentaires sur les méthodes d'essais et guides pour l'application des résultats des essais de résistance au feu

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member 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 on 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, 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), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 834-3 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

This second edition cancels and replaces the first edition (ISO/TR 834-3:1994), which has been technically revised.

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

- Part 1: *General requirements*
- Part 2: *Guidance on measuring uniformity of furnace exposure on test samples*
- Part 3: *Commentary on test method and guide to the application of the outputs from the fire-resistance test*
- Part 4: *Specific requirements for loadbearing vertical separating elements*
- Part 5: *Specific requirements for loadbearing horizontal separating elements*
- Part 6: *Specific requirements for beams*
- Part 7: *Specific requirements for columns*
- Part 8: *Specific requirements for non-loadbearing vertical separating elements*
- Part 9: *Specific requirements for non-loadbearing ceiling elements*

The following parts are under preparation:

- Part 10: *Specific requirements to determine the contribution of applied fire protection materials to structural elements*
- Part 11: *Specific requirements for the assessment of fire protection to structural steel elements*
- Part 12: *Specific requirements for separating elements evaluated on less than full scale furnaces*

Introduction

Fire resistance is a property of a construction and not of a material and the result achieved is to a large extent related to the design of the specimen and the quality of the construction. It is not an “absolute” property of the construction and variations in both the materials and methods of construction will produce differences in the measured performance and changes in the exposure conditions are likely to have an even greater impact on the level of fire resistance the element can provide.

This part of ISO/TR 834 provides guidance to those contemplating testing, the laboratory staff performing the test, the designers of buildings, the specifiers and the authorities responsible for implementing fire safety legislation, to enable them to have a greater understanding of the role of the fire resistance test and the correct application of its outputs.

Fire-resistance tests — Elements of building construction —

Part 3:
Commentary on test method and guide to the application of the outputs from the fire-resistance test

1 Scope

This part of ISO/TR 834 provides background and guidance on the use and limitations of the fire resistance test method and the application of the data obtained. It is designed to be of assistance to code officials, fire safety engineers, designers of buildings and other persons responsible for the safety of persons in and around buildings.

This part of ISO/TR 834 identifies where the procedure can be improved by reference to ISO/TR 22898.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 834-1:1999, *Fire-resistance tests — Elements of building construction — Part 1: General requirements*

ISO/TR 834-2, *Fire-resistance tests — Elements of building construction — Part 2: Guide on measuring uniformity of furnace exposure on test samples*

ISO 3009, *Fire-resistance tests — Elements of building construction — Glazed elements*

ISO/TR 12470, *Fire-resistance tests — Guidance on the application and extension of results*

ISO/TR 22898, *Review of outputs for fire containment tests for buildings in the context of fire safety engineering*

3 Standard test procedure

The primary purpose of a fire resistance test, e.g. ISO 834-1, is to characterize the thermal response of elements of construction when exposed to a fully developed fire within enclosures formed by, or within buildings. The output of the test permits the construction tested by this method to be given a classification of performance within a time based classification system (see Clause 5). The test provides data that may be of use to a fire safety engineer, albeit the test only reproduces one, of many, potential fire scenarios.

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

The fire resistance test is designed to apply to a particular fire scenario within the built environment, but with an understanding of its limitations and objectives it may be applied to other constructions.

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, possibly to an acceptable level.

3.1 Heating regimes

The standard furnace temperature curve described in ISO 834-1:1999, 6.1.1 is substantially unchanged from the time-temperature curve that has been employed to control the fire test exposure environment for the past 80 or so years. It was apparently related in some respects to temperatures experienced in some actual fires in buildings using referenced events, 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 representative of one possible fully developed fire exposure condition, within which the performance of various representative forms of building construction may be compared. It is, however, important to recognize that this standard fire exposure condition does not necessarily represent an actual fire exposure situation. 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 rating accorded to a construction only 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 Clause 8. A series of cooling curves is also discussed. Proposals have been made to simplify the equations to improve their ability to be computer processed.

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, $d_{\mathbf{e}}$, as specified in ISO 834-1:1999, 6.1.2, 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 834-1:1999, 6.1.1, is the fire exposure condition which is the subject of this part of ISO/TR 834, 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.

While the temperature conditions given in ISO 834-1:1999, 6.1.1 are seen to be the same as those used in previous editions of this standard, the method of measuring, and hence controlling the temperature within the furnace has changed significantly in the latest version of the standard.

This change in the measuring instrument has come about as a result of a harmonising process between the European and International test procedures, as a result of implementing the Vienna Agreement. As part of the pan-European harmonisation process, the traditional use of bare wire thermocouples (or sheathed thermocouples with a similar time constant) for measuring the gas temperature within the furnace, has been abandoned in favour of the adoption of a "plate thermometer". The theory behind the plate thermometer is that it receives the same thermal dose as the specimen, unaffected by the geometry of the furnace, the number and position of the burners and the nature of the fuel; all factors having been previously identified as causes of reproducibility and repeatability problems. This method of measuring temperature has been adopted in the latest version of ISO 834-1, and all of its parts.

This device has a greater time constant than the "bare wire" thermocouple described in the 1975 version of ISO 834, and as a consequence the gas temperature at any moment of time is likely to be higher than it was previously, particularly during the first 40 minutes. Therefore, while the latest version of ISO 834 follows nominally the same temperature/time relationship the thermal dose will be measurably greater, particularly over the first 20 to 30 minutes, than when the previous 'bare wire' thermocouples were used. Care should be taken when comparing the results of tests carried out in accordance with the earlier versions of ISO 834 and the present one ISO 834-1:1999, especially for constructions that are temperature sensitive.

Thermocouples do "age" and the current that they generate as a result of the "couple" created between wires of dissimilar resistance at any temperature will differ with time. All temperature measuring devices, but in particular the plate thermometer, should be calibrated on a regular basis or discarded after a short time in use.

3.2 Furnace and equipment design

3.2.1 Factors affecting the thermal dose

The heating conditions prescribed in ISO 834-1:1999, 6.1.1, 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 than with a large body like a specimen. The convective component will therefore tend to have greater influence upon a bead thermocouple temperature while the heat transfer to a specimen is mainly affected by radiation from the hot furnace walls and the flames. For this reason the “plate” thermometer has replaced the bead thermocouple in ISO 834-1:1999, 5.5.1.1. The plate thermometer is more influenced by the total heat flux received by the specimen than the bead thermocouple.

There is currently no method of calibrating plate thermocouples and so a rigid regime of replacement should be implemented. While the “plate thermometer” is the specified device in ISO 834, the introduction of a “directional flame thermometer” measuring device is being considered, which may be introduced into subsequent editions of ISO 834.

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 furnace 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.

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

One method of reducing the problems that have been outlined, which can sometimes 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 834-1:1999, 5.2. 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 in the form of radiation from the furnace walls. While this may improve the reproducibility of results the resulting exposure conditions may represent a more severe condition.

The measurement and control of the thermal dose received by a specimen is complex and further information can be obtained from Reference [4].

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.

Further consideration could be given in the design, or in particular in the refurbishment of furnaces, to the use of a “radiation” screen as proposed for use in ISO/TR 22898, as a way of making the thermal dose more even.

3.2.2 Furnace size

Generally the furnace size should accommodate the full sized element, or in some cases a full sized component which is to be installed within, or onto a proven construction. Often the size of an element in use is greater than the furnace and for these situations it is important that there is a recognized method for extrapolating the result achieved on the tested specimen size to that used in practice (see 3.7). There are, however, many components that are able to be tested at full size in furnaces much smaller than 3m x 3m or 3m x 4m, e.g. building hardware for use on fire doors, penetration sealing systems, electrical components, glazed openings, hatches, single leaf personnel doors, all of which can be tested for their contribution to fire resistance in smaller furnaces. The thermal dose must, however, be delivered in a comparable manner to that which it would receive in the larger furnace.

While the design of the thermometer to be employed in measuring and hence controlling the test furnace environment is specified in ISO 834-1:1999, 5.5.1.1, it is also suggested that experimental work be performed on improved instrumentation for use in measuring the thermal dose received by the specimen.

Finally, one of the most effective “tools” for improving the repeatability of the outputs of fire resistance tests is the use of a calibration routine (see 3.12).

3.3 Conditioning of the specimen

3.3.1 Correction for non-standard moisture content in concrete materials

At the time of test, ISO 834-1:1999, 7.4 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 834-1:1999, 7.4, 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.

Alternatively, the fire resistance at some other moisture content can be calculated by employing the procedures described in References [5] and [6].

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 hygroscopic materials in terms of relative humidity

A recommended method for determining the relative humidity within a hardened concrete specimen using electric sensing elements is described in Reference [7]. 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 [8] and [9].

3.3.3 Curing of non-hygroscopic constructions

Increasingly fire resistance tests are being carried out on materials that rely on a chemical process to be completed before the material reaches its optimum material properties. This period is know as the ‘curing’ period. Before testing such materials it is important that they have achieved this optimum condition, and so there should be adequate “curing” time, which in the case of new materials may need regular monitoring of “parallel” products and associated mechanical tests.

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 performed on test assemblies incorporating combustible components. This information is not usually taken into account by national codes, which sometimes regulate the use of combustible materials based upon the occupancy classification and on the height and volume 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 [10]).

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 [11]).

3.6 Post heating procedures

ISO 834-1 contains no requirements for, or reference to, post heating procedures. In Europe there is an impact test designed for a specific class of fire wall, but it is not meant to be a universally applied post-heating procedure. Similarly, it has been 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 a general assurance concerning the residual strength of the building construction represented by the test specimen, after a fire.

As this information is difficult to relate to a fire (or post fire) situation, it has been concluded that such requirements are outside the scope of the ISO 834-1.

While maintaining a load, or a factored load, for some period after the end of the test will give some general assurance as to the residual strength of the construction, during and after cooling, it does not quantify the strength in measurable terms. The method of loading specimens, especially horizontal ones, e.g. floors, is often not sophisticated enough to carry out load/deflection tests over a limited range of load applications in an easy and repeatable manner. However, if such information was able to be generated at the end of the heating period, and again at various times during the cooling period, all the way down to ambient temperature, this would provide meaningful information to the structural and fire engineering community. Assuming that all other data had been adequately obtained the load deflection test at ambient temperature, after cooling, could be taken to collapse.

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 hose stream 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 hose streams by fire-fighters.

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 design

ISO 834-1 has prescribed a general philosophy that fire resistance tests should be carried out on full-size specimens. It recognizes that for most elements of construction this is not possible because of the limitations imposed by the size of the equipment available (see 3.2.2). 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 in area.

Because this specimen size is invariably smaller than the in-use size it is recommended in ISO 834 that for those elements which are to be used at widths greater than that which can be accommodated by the furnace, they should be tested with a free edge or edges, so that the specimen does not derive artificially high level of support, especially against distortion, that do not exist in reality. Such artificial levels could reduce the stress on boards and board fixings (see 3.11 which deals with the influences of restraint on loadbearing capacity). In the case of walls and partitions that are to be used at widths greater than 3.0 m for the element to be tested with one edge free, even though this has not been normal in the equivalent National fire resistance test standard, gasket of material that has a good resistance to high temperatures may be considered suitable to form a seal between the element and the testing surround on the “free edge”. Resilient materials are often used for this purpose because they provide an enhanced seal when under compression. Materials used as gaskets have included high density mineral rock fibre (MRF) semi-rigid boards and, where permitted by national regulation, ceramic fibre.

However, both the use of a free edge, and the choice of materials used for sealing the free edge, must be subject to a detailed analysis before incorporating in a test construction. Many constructions that may appear to be used in long runs, i.e. office partitions, are frequently supported on one side by cross-partitions forming modular offices, even though the other side forms a long corridor lining. It may be inappropriate to test such systems with a completely unrestrained edge.

Metal faced sandwich panel constructions generally rely on interlocking joints for their stability. A free edge, especially one with a thick compressible gasket may allow the facings to expand freely and cause the panel joints to disengage. As a consequence the use of a free edge which permits expansion when testing metal faced sandwich panels should only be adopted after it has been shown that it will not result in a premature and unrealistic mode of failure. In practice, unlimited lateral expansion will normally be prevented by the structural frame of the building.

Therefore while a specimen with one edge fixed and one edge free is the method recommended in the standard for vertical separating elements, as it is thought to represent a generally demanding situation, other edge conditions may be used in the test as long as the selection is justified in the report of the test, as part of the specimen design. The field of application derived from the test result will need to reflect the restraint conditions used in the test.

It should be noted that the consideration of the use of a “free edge” does not feature in many national standards, but does in ISO 834-1:1999.

It is also important that supporting constructions, as may be used in the testing of fire door assemblies, windows, penetration seals etc, do not incorporate a free edge as this could introduce an element of un repeatability.

In the context of this standard the use of the term full size relates mainly to the components forming the construction and arises from difficulties in achieving completely representative fire behaviour in model scale of most loadbearing and many non-loadbearing separating elements of building construction.

It is now generally appreciated that one should not take a construction that was tested at a 3m x 3m, or 3m x 4m size and use it in a building at a different size without considering the consequences of doing so. Some size variations may be recognized as being either beneficial, i.e. being thicker or shorter than that tested, or of an enhanced size which is not sufficient to produce a reduction in the performance, or which is compensated for by an overrun in the fire resistance achieved. The “rules” that cover these variations in the construction size are known as the direct application and are sometimes given within an Annex to the standard.

With structural elements, however, there is a much greater chance that the element shall be used at sizes in excess of the tested size. For loadbearing structures there will generally be design guides that provide rules for extending the application of the results, but for non-loadbearing elements no such codes exist. It is still necessary though, for the ability of the construction to perform its required task to be confirmed (or otherwise) before it is used in the built environment. This process is generally known as establishing the Extended Field of Application.

Some national classification systems may have rules for “extended application”, but these will generally be simplistic and will rarely cover the size at which the element is proposed for use. When this occurs the building design team will need to carry out a project specific extended application. This will often require the application of engineering judgement which will be achieved by identifying the parameters in the construction of the element that cause it to satisfy the test criteria and analysing the factors that may cause it to perform differently in order to predict the performance at the new size. Where the analysis shows a risk of under performance then compensatory measures may need to be applied to the construction. In some cases the construction may need to be retested in order to establish the contribution that these measures make, but invariably the revised performance may be assessed using quantifiable or judgemental methods.

Further guidance on the application of fire resistance test results is given in Clause 7.

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.

Frequently, especially where the element is part of a system, e.g. a method of sealing penetrations, a dry-wall form of construction, a range of fire doors, it will be impossible to characterize all variations in a single test. In such cases a well planned series of tests should be undertaken. The results of such a test programme would normally best be expressed by a Field of Application Report, or statement, rather than by individual test reports. Some certification bodies may use a “listing” system for expressing the variations, but this may require the specifier to carry out some interpolation to cover unusual combinations.

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 conducive 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. This description permits the construction to be adequately audited on site. Good product description will help to rationalize apparent anomalies in test results.

3.9 Specimen orientation

Despite the changing shape of buildings standard fire resistance testing furnaces designed to perform ISO 834 tests are only generally able to test specimens in the conventional vertical or horizontal applications. For solid homogeneous materials such as concrete or steel the testing of elements vertically or horizontally when, in practice, they may be orientated differently, is not likely to result in significantly different results. Most material design codes will permit the loadbearing capacity of elements in different orientations to be calculated at ambient conditions.

Some protection systems utilized to improve the fire resistance of structural elements may be influenced by the orientation and one such material could be intumescent paint and it should not be assumed that the orientation can be changed.

The main forms of construction that may be adversely affected by a sloping orientation are those elements that are of a composite nature, especially where linings of “fire resisting” materials are attached either side of a framed-out construction. In such a construction the change in orientation could result in a different fire performance as the linings may be adversely influenced by gravity. One material that is particularly sensitive is monolithic glass, because even in its cold state it is not a solid, it is an extremely viscous liquid, and as it gets hotter its viscosity increases and it will demonstrate a tendency to flow. The test procedure for glazing, ISO 3009 has, as a consequence, introduced a method of testing sloping glazing by extending the furnace sides with an appropriate form of furnace closure. This is not ideal because it will be difficult to maintain the temperature/time conditions evenly throughout the extended furnace, or to maintain the specified pressure differential, but it will permit the influence of orientation to at least be compared.

While this particular test procedure has been designed specifically for glass and glazed elements, other non-loadbearing non-vertical elements may be tested to this method by analogy. ISO 3009 has included a field of direct application which permits other orientations to be approved, but if non-glazed materials are incorporated this direct application may not be valid.

Orientation is not just a factor to be considered in evaluating sheet materials. Intumescent coatings and sealants are also prone to the influence of orientation and sloped elements and may need to be evaluated with this influence in mind.

3.10 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 834-1:1999, 5.3, specifies the different basis 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 methods for selecting 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 methods 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 walls, especially if the number of load points can be increased by means pivoted beams that turn each load point into two application points. These are known as spreader beams. With floors greater care is needed to simulate 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. If spreader beams are used to increase the area/length over which the load is applied, care must be exercised to show that bridging will not occur which could result in fewer loading points and higher load concentrations. Beams used to simulate uniform loading of floors invariably need double articulation which the load is applied then care must be exercised to show that bridging will not occur which could result in fewer loading points and higher load concentrations.

3.11 Boundary conditions and restraint and their influence on loadbearing capacity

3.11.1 Introduction

ISO 834-1:1999, 6.4, 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 fire resistance duration 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.

3.11.2 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.

3.11.3 Axial members (columns, loadbearing 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 loadbearing capacity and related test load of columns and loadbearing 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 loadbearing walls with either no resistance to expansion (elongation) or with fully restrained ends.

3.11.4 Gratuitous restraint on non-loadbearing walls and partitions

All non-loadbearing walls and partitions are, logically, tested without the application of external loads. However, in practice, these elements may be affected by either the imposition of load as a result of distortion/deflection in adjacent elements, particularly floors and beams above that are experiencing the same fire exposure conditions or in the case of some metal and/or glazed units, by the reactions to their own expansion under fire exposure. Tests on these elements that are known to expand when heated 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.

Some non-loadbearing partitioning systems or dry wall constructions may incorporate deflection heads, primarily to absorb the post-occupation application of live and dead loads, but which may also be designed to accept some of the expansion that may be generated when heated. When such deflection heads are fitted the decision to test them in the fully compressed, fully relaxed or in a mid-point condition will need to consider the potential mode of failure, i.e. a direct loss of integrity through the deflection head or due to an indirect integrity loss, as a result of buckling or bowing due to thermal restraint. The Field of Extended Application will need to reflect the way the specimen construction was tested.

3.11.5 Laboratory measurements

In view of the present lack of information concerning the effects of restraint to thermal expansion or rotation, testing laboratories are encouraged, when testing specimens which are restrained in any manner, to attempt to determine the magnitude and direction of such restraining forces, normally by means of load cells incorporated in any loading or restraint frame.

3.12 Performance verification

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

Repeatability and reproducibility are maximised by ensuring that instrumentation is calibrated regularly and the procedures and non-calibrated equipment are confirmed by product verification procedures. The instrumentation that requires regular calibration is that used for temperature, pressure, furnaces atmosphere and loading.

It is one of the purposes of a verification 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. In addition to static pressure it is known that turbulence can have a major impact on the results of the fire resistance test, particularly for less robust materials. Again a verification procedure should help to control this.

A calibration procedure addressing the temperature distribution and to some extent pressure conditions in vertical furnace for testing separating elements is described in Reference [12]. The aim of this calibration test was to establish that the heating conditions are uniform over the exposed surface of the test specimen and that the prescribed level of heating exposure is achieved.

This calibration specimen did not address turbulence, and does not therefore, ensure repeatability for elements sensitive to air movement.

The test has been withdrawn in CEN.

The loadbearing 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 [12]. A possible way of harmonising turbulence is proposed in ISO/TR 22898.

A performance verification test requires a standard specimen which should always give the same result regardless of when, or where the specimen is tested. Because the test is destructive it would be necessary to have a construction specification, hopefully one where any differences in the quality of the construction does not override the findings achieved when using the specified form of construction. At this time no such specified constructions exist. Because various building materials are sensitive to different aspects of the exposure conditions then, ideally there should be a range of constructions, e.g. high thermal inertia, low thermal inertia, combustible, non-combustible.

ISO/TR 834-2 provides a method to measure the exposure conditions imposed by furnaces upon a standard test specimen. The standard specimen includes two layers of fire resistive gypsum board attached to non-load bearing steel studs. These materials and test specimen were selected because of their global availability, low cost, ease of construction and consistent moisture content. The test method is applicable to horizontal and vertical furnaces. Measurements taken include temperature, pressure, oxygen content and air velocity across the face of the specimen. Tolerances for these furnace performance parameters, based upon data, are expected as use of ISO/TR 834-2 continues with the resulting improvement in repeatability and reproducibility.

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 the ratings that can be claimed in respect of 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 temperature, or emitted heat fluxes.

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 and Clause 8).

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 loadbearing 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. The limiting deflection and/a rate of deflection have no relationship with a particular life safety risk. 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 failure by one of the identified methods. The primary method of defining the criteria of integrity is by the time interval between the commencement of heating and the ignition of a cotton fibre 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.

Where the ignition of the cotton fibre pad can be influenced by the presence of hot surfaces as may be present on non-insulated specimens (or parts of specimens) such that non-piloted, spontaneous ignition of the pad could occur, then the standard prescribes the use of gap gauges as a way of quantifying the critical dimensions of any gap. Acceptable integrity performance requires that the gap gauge does not penetrate the specimen such that the end of the gap gauge is within the heated furnace chamber.

The gap gauge does not measure the same degree of hazard as the cotton pad and in life safety terms it generally gives a more optimistic result.

Flaming on the unexposed face of the element generally constitutes an unacceptable hazard and therefore, where this can lead to ignition of the pad, this also indicates 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 (see 4.3).

The specified levels are intended to ensure that any combustible material in contact with the unexposed surface will fail to ignite at within the timescale of a fire event. 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 834-1:1999, 5.5.1.2.

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 [13] 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.

Ignition duration of over 4 hours rarely relate to a life safety risk.

4.5 Radiation

Some national, or regional building codes require constructions to be classified for their radiation performance (w). The critical level of radiation is expressed in terms of kW/m^2 at a fixed distance away from the unexposed face of the construction (normally 1 m). Such codes set a maximum level of heat flux for various life safety scenarios. The critical condition that needs to be resolved in life safety terms is the cumulative thermal dose which is the product of the intensity of the received heat flux and the duration of exposure to it.

In respect of the instrumentation there is a difference in the measuring instruments between those where the sensor is protected by a transparent window which measures pure radiation and those meters without a “window” that are influenced by convective air movement and record the “heat flux”.

4.6 Other characteristics

One characteristic of protection systems can be established by the ISO 834 procedure is the “stickability” of the protection material. When gathering data for a thermal analysis of the fire protection properties of a protection system it is often a necessity to establish how tolerant the material is to load/temperature induced distortion. This is known as “stickability” and is established on a full size beam, or column as designated by the calculation procedure. The exact test construction is not well documented and the deflection (rate of, and magnitude) are gratuitous, making it difficult to ensure repeatability.

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 prescriptively 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.

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, see Reference [14] and [15]. Reference [15] includes data from 10 furnaces representing six organizations. The test specimens consisted of a non-load bearing steel stud wall with a single layer of gypsum board on each face. The gypsum board was obtained from a single source manufactured during a special run to ensure tight quality control.

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).

While it is difficult to assign reproducibility or repeatability coefficients to fire resistance testing, a study was undertaken within the European community during the drafting of common European test procedures of the uncertainty of measurement, but this was not published. A paper on the subject was used in the drafting of ISO/TR 22898. This paper is included in Annex A of this part of ISO/TR 834 and it highlights the difficulty of achieving good reproducibility and repeatability.

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.

In the context of a classification system in support of fairly coarse prescriptively derived requirements, the lack of reproducibility and repeatability is unlikely to have a serious direct influence on life safety. Modern fire engineering techniques based upon the functional approach are looking for more reliable data, as both cost, and time pressures invariably cause designers of buildings to remove any obvious overprovision of the fire safety requirements. Reduction of fire resistance durations of 25 %, 33 % are not uncommon, but if the repeatability deviations were to be of similar optimistic magnitude the ultimate performance of the building in fire may be seriously compromised.

Persons using the data from fire tests as part of a functional (fire safety engineered) approach must be aware of the currently inherent weaknesses in the results of such tests and those responsible for the tests and the testing standards must strive to improve this aspect of their outputs.

Repeatability and reproducibility may be improved by consideration and if possible implementation of measures that provide consistent interpretation and methods that address the factors identified in 6.1 and 6.2.

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/construction;

b) specimen handling;

c) apparatus (furnace, loading and restraint equipment);

d) control equipment;

e) operator (control, measurements and observations);

f) 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.

Accredited laboratories operating under a quality control system that identifies and controls the critical aspect of repeatability, may be expected to provide improved comparability of results would be expected to achieve a greater degree of repeatability than those that do not operate such a system. It is stressed, however, that the quality system must target the cause of measures that create the lack of repeatability.

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; shape and depth of furnace chamber, 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 Establishing the field of application of test results

7.1 General

There is now a greater awareness of the need to establish the influence on the fire resistance of an element of construction resulting from variations in the critical parameters e.g. size, orientation, design, component materials and construction methods.

It is often impossible to test every possible variation in an element and so the field of application of a tested construction is generally derived as a result of an expert analysis in order to establish the range of variations to which the result/classification can be applied.

The impact of furnace/specimen sizes on the field of application in respect of the size of the element has been discussed in 3.2.2 and 3.7, but there are many other factors that need to be considered in the determination of the field of application. Guidance on the subject is given in ISO/TR 12470 and it may also be found in certain national standards, such as BS: PD7974-3 [16].

There are considered to be two sub-categories of field of application, **Direct** and **Extended** field of application. The term **Direct Application** is normally applied to all of those variations where the change in the element is obviously beneficial, e.g. the stress in an identical element is lower or the cross-section size of the tested member/section is greater. **Extended Application** covers the situation where the change in the tested element is detrimental to the performance, but where there is, or could be compensatory features.

This is a complex issue and the field of extended application of an element may only be determined accurately if it is performed by persons having the requisite knowledge of the high temperature behaviour of materials and elements.

When carrying out an extended application analysis it is necessary to identify all of the parameters that may change, or in the case of a project specific extension the actual parameters that have changes, and identify the factors that will change for each parameter in turn. It is then necessary to consider the influence of that factor on each of the relevant criteria in turn. In some cases the influence on the criteria may be quantified using appropriate mathematic techniques, such as those considered below, but in many cases the influence may be resolved solely by expert judgement.

In quantifying the degree to which the result can be extended to apply to non-tested assemblies/products there are two basic quantifiable techniques that are used; interpolation and extrapolation.

Interpolation and extrapolation is much easier to apply to load bearing elements for the purpose of predicting load bearing capacity, rather than for the prediction of integrity and insulation (for composite elements) which are much more complex and will need to utilize the methods described in a Technical Report under preparation, *Guide to the Methodology for Establishing the Extended Application of Fire Resistance Test Results*.

7.2 Interpolation

This procedure allows the effect of variations in a component/construction to be established by testing at the extreme ranges of the parameter under investigation and determining the trend between them. This established pattern enables the performance of a component/construction with critical parameters between the two extremes to be assigned a “likely” performance. The trend should not be assumed to be linear because the relationship between the changes in the parameter could be quite complex and the evidence needs to be thoroughly examined. Graphical techniques based upon single curve fitting procedures can be misleading, especially with the lack of repeatability and reproducibility that is inherent in fire resistance testing (see 6.1 and 6.2). Because the limits of the critical parameter have been tested, interpolation is more appropriate for direct field of application.

A method of interpolation has recently been introduced into ISO 834-1 for the interpolation of results in the determination of the dry film thickness of intumescent paint for the protection of steel members in fire. This method is known as the 3D Interpolation Method which can be used for the interpolation of any set of data from fire resistance tests where the result may be dependent upon a series of identifiable variables.

7.3 Extrapolation

This procedure allows the effect of variations in a component/construction to be established where the change in the parameter extends beyond the range established by previous testing.

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.

For any extrapolation to be valid it is important that the likely mode of failure is known and is able to be predicted.

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.

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 focused 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 informal, casual feedback which should ensure 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 the identified relevant criteria are satisfied.

This period of time represents a relative ranking of performance and cannot be related directly to a particular building and/or fire scenario. It is important to recognize 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 solely related to the test conditions. The validity of the result to real buildings depends upon the degree to which the test specimen models the actual construction and the relevance of the failure criteria, 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 recognized in principle from the inception of the test [17], [18].

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 [19]. 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 t/T curve 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 [20].

Many later attempts have been, and still are being, made to strengthen the link between the test method and actual building fires [21]. 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 [19].

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.

The growth in the application of fire safety engineering in the design and construction of buildings means there needs to be clarity between the application of the results of a fire resistance test within a prescriptive legislative framework and the use of the results for providing calculated periods of fire resistance based upon parametric curves.

Materials that are temperature sensitive rather than time sensitive may be graded very optimistically by the standard temperature/time conditions described in ISO 834-1. Therefore while introducing modifications to the test procedure in order to make it more realistic must be viewed with caution in the context of prescriptive legislation it may be sensible to improve the test, or a separate version of the standard, to make it more realistic to obtain a true comparison of materials in the context of real-fire performance.

See ISO/TR 22898 for information as to what changes should be considered in the future. Further information on the relationships between ‘real fire’ and the standard test can be found in the Reference [22].

Annex A
(informative)

Uncertainty of measurement in fire resistance testing

A.1 Background and use

The guidance given in this document has been derived from an informal paper submitted to CEN/TC127 on behalf of EGOLF (the European Group of “Official” Laboratories for Fire).

The objective of Annex A is to assist in establishing whether any unexpected failure or unexplained success or trend in a data set is genuinely related to the tested construction or whether it could be influenced by external factors due to variations in the test which are not product related.

When performing an analysis of test evidence in order to generate an extended application report it is necessary to understand that Fire Resistance is not an absolute measurement. A number of factors can, and do, have an influence on the result.

Listed below are the factors which could have been identified as having an influence on the result of a fire resistance test performed upon an insulated specimen. The factors have been sorted into those which are thought to be significant and those which are thought to be relatively insignificant. In addition, those which are thought to be “unquantifiable”, i.e. those which are probably impossible to measure, quantify or regulate and which are not reported on, but which contribute to the total uncertainty of measurement, have also been identified. A section on the application of these factors to a test specimen represented by a timber doorset is also included.

A.2 Significant factors

A.2.1 Exposure conditions

A.2.1.1 Temperature control

- Non calibration of the controlling plate thermocouple - UNQUANTIFIABLE
- Acceptable limits on the mean furnace temperature (see standard) and the actual level of mean temperature in the furnace during the test, (i.e. running at, or close to the top or bottom of the temperature/time curve)
- Heat flux variations over the face of the specimen due to variations in gas temperature and radiation levels (possibly due to flue openings and view ports in the furnace wall)
- Oxygen level and distribution in the furnace during the test
- Gas velocities and turbulence within the furnace and their variation with respect to time - UNQUANTIFIABLE

A.2.1.2 Pressure differential control

- Magnitude and gradient of pressure differential in the furnace even within the permitted tolerances
- Fluctuation in the pressure differential within the furnace

A.2.2 Measurements performed on the specimen to establish compliance with criteria

A.2.2.1 Insulation - Mean temperature rise measurements

A.2.2.1.1 Specified fixed thermocouples

The mean temperature rise is established by five fixed copper disc thermocouples fixed to the surface of the element and covered by an insulating pad.

- Exact position of disc relative to localized constructional variations in the construction - UNQUANTIFIABLE
- Surface texture of unexposed face of specimen - UNQUANTIFIABLE
- Quality of contact between disc and surface - UNQUANTIFIABLE
- Condition of the surface of the disc (if not new) - UNQUANTIFIABLE
- Flatness of surface of the disc - UNQUANTIFIABLE
- Potential for “couple” to be created remote from disc - UNQUANTIFIABLE

A.2.2.2 Insulation – Maximum temperature rise measurements

A.2.2.2.1 Additional fixed thermocouples

Selection of location of thermocouples at positions likely to exhibit higher temperature rises than the standard five affixed for mean temperature rise, in order to establish maximum temperature rise. This is a completely discretionary at the moment. - UNQUANTIFIABLE

A.2.2.2.2 Use of the roving thermocouple

- Use of cover pad over disc (not clearly specified) - UNQUANTIFIABLE
- Condition of pad over disc (if used) - UNQUANTIFIABLE
- Willingness or judgement of the need for the operator to use it at all - UNQUANTIFIABLE
- Duration of application - UNQUANTIFIABLE
- Pressure of application - UNQUANTIFIABLE
- Quality of surface contact (flatness of disc and surface) - UNQUANTIFIABLE
- Amount of movement around hot spot (heats it up quicker) - UNQUANTIFIABLE

A.2.2.3 Integrity

Integrity as established by the cotton pad, continuous flaming and gap gauges are considered here.

A.2.2.3.1 Cotton pad criteria

- Composition, of the pad, size/shape/distribution of fibres (compressed or fluffed up) - UNQUANTIFIABLE
- Moisture content (variation during period following removing from desiccator, e.g. in a damp, steamy laboratory or a hot dry environment) - UNQUANTIFIABLE
- Position of application - UNQUANTIFIABLE
- Degree of glowing

- Oxygen content of gases being egressing through gap which may be related to the oxygen content of furnace, pressure conditions and specimen consuming oxygen - UNQUANTIFIABLE
- Heat emitted from adjacent specimen - UNQUANTIFIABLE

A.2.2.3.2 Continuous flaming criteria

The visibility of flames by the test operatives depends upon:

- Ambient lighting in laboratory
- Luminosity of flame - UNQUANTIFIABLE
- Oxygen content of gases emerging from specimen - UNQUANTIFIABLE

A.2.2.3.3 Gap gauges

- Capability or readiness to use gauges on uninsulated specimens (dangerous/uncomfortable) - UNQUANTIFIABLE
- Diligence of the engineer/observer to observe gap - UNQUANTIFIABLE
- Judgements/ability to confirm level of penetration - UNQUANTIFIABLE
- Accuracy of measurement to establish length of gap

A.3 Relatively insignificant factors

A.3.1 Exposure conditions

A.3.1.1 Temperature control

- Variations associated with differences in furnace heat flux that are unmeasureable by standard instrumentation at present (balance between convection and radiation)
- Changes to the “plate” thermocouple, surface characteristics during test - UNQUANTIFIABLE
- Variations in heat flux associated with furnace geometry, including view ports, flues, burners
- Distance of furnace control thermocouples from specimen surface - UNQUANTIFIABLE
- Accuracy of temperature measurement data transmitted from thermocouple back to data logger/chart recorder

A.3.1.2 Pressure control

- Accuracy of pressure measurement data transmitted from thermocouple back to data logger
- Response time of damper operation
- Air movement influence on flue/chimney - UNQUANTIFIABLE

A.3.2 Measurements performed on the specimen

A.3.2.1 Insulation

- Accuracy/skill of fixing thermocouples on the surface of the specimen - UNQUANTIFIABLE
- Accuracy of temperature measurement from thermocouples back to logger (This encompasses everything from thickness of copper disc, quality of hot junction, thickness, thermal insulation value and moisture content of insulating pad, type of wire used, calibration of data logger, cold junction compensation etc.)

- Roving thermocouple - accuracy as above - UNQUANTIFIABLE
- Air movement and ambient conditions in the testing laboratory (these will affect temperature measured on unexposed surface as heat flow through specimen will be affected - UNQUANTIFIABLE

A.3.2.2 Integrity

A.3.2.2.1 Cotton pad application

- Compliance of holder with the standard
- Fit of pad in the holder
- Velocity and handling of pad between application and analysis of “glowing”

A.3.2.2.2 Gap gauge application

Level of force, however small, used in application of the gauge - UNQUANTIFIABLE

A.4 Specimen

The potential specimen variations are many and various. Given below, using timber doorsets as an example, are the factors that may produce a variability in the fire resistance. Many of these are quantifiable if characterization and reporting is carried out according to the standard. Similar variations will be identified for other forms of construction.

A.4.1 Variability in the materials used to manufacture the doorset test specimen

A.4.1.1 Variations in all, or any of the following parameters will influence the fire resistance

- Composition of infills or facings
- Density of all components
- Thickness of all components and total product
- Homogeneity of manufactured components
- Species and grade of any timber
- Moisture content of all organic components
- Slope of grain of any timber member/log sawing pattern
- Fixings - distribution and type

When the above materials/components are available for characterization and the characterization of the test specimen is adequate it may be possible to quantify the influence, but if they are not adequately characterized the influence will be UNQUANTIFIABLE

A.4.2 Variability in the manufacturing process used to make the doorsets constructional process will influence the fire resistance

A.4.2.1 Variations in any of the following test specimens

- Voids
- Squareness of construction or components
- Application of fixings

- Evenness in the application of adhesives
- Number and distribution of core joints (if applicable)

Unless the specimen characterization is adequate the influence of the above factors will generally be UNQUANTIFIABLE.

A.4.3 Variability in the installation of the doorset into the supporting construction and the installation of the supporting construction into the test frame (if used)

- Squareness of leaf in its frame and of frame in supporting construction
- Verticality of specimen in supporting construction
- Sealing of any gaps between frames and supporting construction
- Gaps between leaf and frame, if not pre-set

The first three factors above are rarely quantified as part of the test specimen, but it may be possible to QUANTIFY the influence of gaps.

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