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Fire resistance tests — Elements of building construction —

Part 11: Specific requirements for the assessment of fire protection to structural steel elements

Essais de résistance au feu — Éléments de construction —

Partie 11: Exigences spécifiques d'évaluation de la protection au feu appliquées aux éléments des structures en acier

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

ISO 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* [Technical Report]
- *Part 3: Commentary on test method and guide to the application of the outputs from the fire-resistance test* [Technical Report]
- *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*
- *Part 10: Specific requirements to determine the contribution of applied fire protection materials to structural steel 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

Technological advances in the fire protection of structural steelwork have resulted in a range of materials being developed that are now in widespread use throughout the building construction industry. These are broadly categorized as intumescent coatings, sprays, renders, and boards and are often referred to as lightweight systems in comparison to the some of the more traditional materials such as brick, block, and concrete.

Fire protection materials reduce the rate of temperature rise of steel members when exposed to fire by a variety of methods. Apart from influencing heat transfer mechanism, such as conduction, convection, and radiation, they often involve thermo-physical transformations, exothermic chemical reactions, as well as shape changes that increase the thickness of the material and delay the rate at which the underlying steel substrate heats up. Relatively simple changes such as the release of free moisture at around 100 °C, or water of crystallization and sublimation, which all occur within specific temperature ranges, often result in a plateau of rising temperature versus time of varying magnitude depending upon the type of material and even the way in which it is applied to the steel substrate.

Understanding the behaviour of fire protection materials is complicated, not least when the physical/chemical reactions and changes in thermal properties occur at different temperatures and at different rates, depending on their chemical constitution and reaction temperature. This makes the development of suitable standards for testing and quantifying their behaviour as insulation materials difficult.

In addition, with recent advances in structural fire engineering in which steel members are no longer considered to fail at a unique temperature, information on fire protection thicknesses is a requirement that can be specified over a range of limiting temperatures depending upon the type of loading system (bending, shear, tension, and compression), the magnitude of the applied loads, and the degree of exposure of the surface with respect to the fire/furnace.

Therefore, to rationalize the behaviour of fire protection products for protecting structural steelwork into simple design tables that manufacturers can use to specify their products involves the permutation of a large number of parameters.

In Europe, the development of testing and assessment protocols for fire protecting structural steel commenced during the 1990s under a European mandate within CEN TC127 (Fire resistance tests) and was the beginning of drafting European standards such as DD ENV YYY5. Since then, fire protection manufacturers in collaboration with the test laboratories throughout Europe have developed a series of test packages and assessment methods over the past 15 years which have been through a rigorous appraisal process by the fire protection industry. This work has culminated in the drafting of EN 13381 Parts 4 and 8 which broadly cover passive and reactive products.

Some of the key issues in developing these standards have been identifying the number of specimens required in a test package to characterize the performance of a fire protection product over the range of fire resistance times, applicable section factors, type of structural element, and design temperature. In addition, because of the vagaries in fire resistance testing, it has been necessary to establish a rationale for applying correction factors to the test results for use in the assessment process partly to maximize the validity of the data and keep the costs of testing to a minimum.

In Europe, four assessment methods have been developed, referred to as Graphical method, Differential equation analysis (variable l), Differential equation analysis (constant l), and Numerical regression analysis. Each method has been through a process of validation and are now included in the standards EN 13381 Parts 4 and 8.

In this part of ISO 834, the four methods have been directly incorporated into the standard and technically are identical to the European counterparts. However, it is recognized that other assessment methods may be suitable and therefore this part of ISO 834 provides a set of criteria for their acceptability. One such method which has undergone an evaluation process and meets the criteria for acceptability is the 3D method developed in the UK and currently used for reactive materials.

The 3D assessment was formerly presented as a published research paper at the SC2/WG2 meeting in Kyoto, Japan in November 2006 (N414). Since 2006, it has been published and presented in various forms in the technical journals and seminars and is now included in the Dutch Standard NEN 7878 (2011) and the Dutch Fire Safety Handbook (2011).

This part of ISO 834 recognizes that some assessment method/s are more suited to particular types of fire protection materials, and for this reason, they are presented as Informative Annexes, which enables freedom of choice in their application. However, only a single method can be used for the assessment process for a particular data set and cannot be mixed.

This part of ISO 834 specifies methods for assessing fire protection systems applied to structural steel members, employed in buildings as beams, columns, or tension members. This part of ISO 834 is intended for use in conjunction with the testing described in ISO 834-10.

Fire resistance tests — Elements of building construction —

Part 11:
Specific requirements for the assessment of fire protection to structural steel elements

1 Scope

The assessment detailed in this part of ISO 834 is designed to cover a range of thicknesses of the fire protection material, a range of steel sections characterized by their section factors, a range of design temperatures, and a range of valid fire resistance classification periods.

This part of ISO 834 covers fire protection systems that include both passive (boards, mats, slabs, and spray materials) and reactive materials as defined in this document.

The assessment procedure is used to establish

a) on the basis of the temperature data derived from testing loaded and unloaded specimens, a correction factor and practical constraints on the use of the fire protection system (the physical performance) and

b) on the basis of the temperature data derived from testing unloaded short steel specimens, the thermal properties of the fire protection material (the thermal performance).

The limits of applicability of the results of the assessment are defined together with permitted direct application of the results to different steel section sizes and strength grades (but not stainless steels) and to the fire protection system tested. The results of the tests obtained according to ISO 834-10 and the assessment in this part of ISO 834 are directly applicable to steel sections of “I” and “H” cross-sectional shape and hollow sections. Results from analysis of I or H sections are directly applicable to angles, channels, and T-sections for the same section factor, whether used as individual elements or as part of a fabricated steel truss.

The results of the assessment are applicable to fabricated sections.

This part of ISO 834 does not apply to concrete-filled hollow sections, beams, or columns containing holes or openings of any type or solid bar.

Any assessment method is acceptable provided it meets the acceptability criteria given in 5.5. Examples of assessment methods in common use are given in Annexes C to G.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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, *Fire-resistance tests — Elements of building construction — Part 1: General requirements*

ISO 834-10, *Fire resistance tests — Elements of building construction — Part 10: Specific requirements to determine the contribution of applied fire protection materials to structural elements*

ISO 8421-2, *Fire protection — Vocabulary — Part 2: Structural fire protection*

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 834-1, ISO 13943, ISO 8421-2, and the following apply.

3.1
characteristic steel temperature
temperature of the structural steel member which is used for the determination of the correction factor for stickability which is calculated according to 5.2.2

3.2
design temperature
temperature of the steel member for structural design purposes

3.3
fire protection
protection afforded to the steel member by the fire protection system such that the temperature of the steel member is limited throughout the period of fire exposure

3.4
fire protection system
fire protection material together with any supporting system including mesh reinforcement as tested

Note 1 to entry: The reactive fire protection materials system includes the primer and top coat if applicable.

3.5
fire protection thickness
dry thickness of a single-layer fire protection system or the combined thickness of all layers of a fire protection system

Note 1 to entry: The thickness of elements of the supporting system or joint cover strips is not included in the fire protection thickness.

Note 2 to entry: For reactive fire protection systems, the thickness is the mean dry film thickness of the coating excluding primer and top coat if applicable.

3.6
H section
steel member with wide flanges compared with the section depth whose main function is to carry axial loads parallel to its longitudinal axis which can be combined with bending and shear

3.7
I section
steel joist or girder with short flanges shaped like a letter "I" whose main function is to carry loads transverse to its longitudinal axis

Note 1 to entry: These loads usually cause bending of the beam member. The flanges may be parallel or tapered.

3.8
passive fire protection material
material, which do not change their physical form on heating, providing protection by virtue of their physical or thermal properties

Note 1 to entry: Passive fire protection materials may include materials containing water or undergo endothermic reactions which, on heating produce cooling effects. These may take the form of sprayed coatings, renderings, mat products, boards, or slabs.

3.9
reactive fire protection material
material which are specifically formulated to provide a chemical reaction upon heating such that their physical form changes and in so doing provide fire protection by thermal insulative and cooling effects

3.10
reference section
steel section which is taken from the same length of steel as its equivalent loaded section

3.11
section factor (unprotected steel)
ratio of the fire exposed perimeter area of the structural steel member, per unit length, A_m to its cross-sectional volume per unit length, V

3.12
section factor (profiled fire protection system):
ratio of the fire exposed outer perimeter area of the steel structural member excluding the protection material, per unit length, A_m to its cross sectional volume per unit length, V

3.13
section factor (boxed fire protection system)
ratio of the internal surface area of the smallest possible rectangle or square box encasement which can be measured around the steel structural member, A_m, to its volume per unit length, V

3.14
steel member
element of building construction, which is load bearing and fabricated from steel

Note 1 to entry: For the purpose of this part of ISO 834, the steel used in the testing must be of the same grade.

3.15
steel temperature
overall mean temperature to be used as input data for the analysis is calculated according to 5.2.1

3.16
stickability
ability of a fire protection system to remain sufficiently coherent and in position for a well-defined range of deformations, furnace, and steel temperatures, such that the efficacy of the fire protection is not significantly impaired

3.17
test package
set of steel sections which may include short or long specimens that is tested to evaluate the stickability of the fire protection system and to provide thermal data over a range of protection thickness, steel section factor, and steel temperatures

3.18
test specimen
steel section plus the fire protection system under test

Note 1 to entry: The steel test section, representative of a steel member for the purposes of this test, comprises long and short steel columns or beams.

4 Symbols and abbreviated terms

Symbol	Unit	Description
A	m^2	area
A_m	m^2	exposed perimeter area of the structural steel member, per unit length

Symbol	Unit	Description
A_p	m^2	for profile protection: exposed outer perimeter area of the structural steel member excluding the protection material, per unit length for encased protection: the internal surface area of the smallest possible rectangle or square box encasement which can be measured around the structural steel member
c_a	J/(kgK)	temperature-dependent specific heat capacity
c_p	J/(kgK)	temperature-independent specific heat capacity of the fire protection material
$c_{n,n+1...}$	-	regression constants in constant λ method of assessment
d	mm	thickness
d_i	mm	protection thickness of the short section
$d_{n,n+1...}$	-	regression coefficients
d_{max}	mm	maximum protection thickness of the loaded section
d_{min}	mm	minimum protection thickness of the loaded section
d_p	mm	thickness of fire protection material
$d_{p(max)}$	mm	maximum thickness of fire protection material
$d_{p(min)}$	mm	minimum thickness of fire protection material
d_{SC}	mm	thickness of fire protection material on an unloaded short column section
d_{UB}	mm	thickness of fire protection material of an unloaded beam section
D	mm	protection thickness for the loaded section or tall section
D_1	mm	protection thickness for the reference section
D_p	min	length of the moisture plateau
k	-	correction factor
k_i	-	stickability correction factor for the short section at thickness d_i
k_{imax}	-	stickability correction factor at maximum protection thickness
k_{imin}	-	stickability correction factor at minimum protection thickness
K	-	constant applied to $\lambda_{\delta\ (p)}$
K_d	-	range factor for thickness
K_s	-	range factor for section factor
n	-	number of specimens
P	m	perimeter of the steel section exposed to fire
S	m^{-1}	section factor of the loaded or tall section
S_1	m^{-1}	section factor of the reference section
s_p	m^{-1}	section factor at factor K_s
s_{max}	m^{-1}	maximum section factor at K_s factor of 1
s_{min}	m^{-1}	minimum section factor at K_s factor of 0
t_w	mm	thickness of the wall of the hollow steel section
t	min	time from the commencement of the test
t_1	min	time for the reference section to reach the design temperature
t_c	min	corrected time for thickness and section factor

Symbol	Unit	Description
t_d	min	time required for a short section to reach the design temperature
t_e	min	time for an unloaded section to reach an equivalent temperature to the loaded beam at time t
t_i	min	time for the loaded section to reach the design temperature
t_{recal}	min	time at recalculated steel temperature
V	m^3/m	volume of the steel section per unit length
Δt	min	time interval
$\Delta\theta_{at}$	°C	increase in steel temperature during the time interval Δt
θ	°C	design temperature
θ_{at}	°C	average steel temperature at time t
$\theta_{c(SC)}$	°C	corrected mean temperature of an unloaded column section
$\theta_{c(uC)}$	°C	corrected mean temperature of an unloaded beam section
θ_{LB}	°C	characteristic steel temperature of a loaded beam
θ_{LC}	°C	characteristic steel temperature of a loaded column
$\theta_{m(SC)}$	°C	modified steel temperature of an unloaded section
θ_t	°C	average temperature of the furnace at time t
θ_p	°C	protective material temperature at time t
θ_{LC}	°C	characteristic steel temperature of a loaded column
θ_{UB}	°C	characteristic temperature of a short unloaded reference beam
$\lambda_{ave(p)}$	W/(mK)	mean value of λ_p calculated from all the short sections at a temperature θ
$\lambda_{char(p)}$	W/(mK)	characteristic value of the thermal conductivity of the fire protection material
λ_p	W/(mK)	effective thermal conductivity of the fire protection material
$\lambda_{p,t}$	W/(mK)	thermal conductivity of the fire protection material at time t and for a thickness d_p of protection material
$\lambda_{\delta(p)}$	W/(mK)	standard deviation of λ_p calculated from all the short sections at a temperature θ
ρ	Kg/m^3	density
ρ_a	Kg/m^3	density of steel (normally 7 850 kg/m^3)
ρ_{LB}	Kg/m^3	density of the fire protection on a loaded beam
$\rho_{protection}$	Kg/m^3	density of the fire protection material
ρ_{UB}	Kg/m^3	density of the fire protection material on the unloaded beam
ρ_{UC}	Kg/m^3	density of the fire protection material on the unloaded column section
LB	-	loaded beam
LC	-	loaded column
TC	-	tall column
LHB	-	loaded hollow beam
LHC	-	loaded hollow column
SIB	-	short I-section beam
SIC	-	short I-section column

Symbol	Unit	Description
TCHS	-	tall circular hollow beam
TRHS	-	tall rectangular hollow beam
SHB	-	short hollow beam
SHC	-	short hollow column
RB	-	reference beam

5 Assessment

5.1 General

The assessment shall begin with the collection of the data from the fire testing obtained according to ISO 834-10.

The temperature data obtained from the loaded and unloaded steel sections are used as a basis for relating the time to reach a specified steel temperature, the thickness of fire protection material, and section factor. Where the performance at minimum and maximum protection thickness of the loaded section or tall column is less than that of the equivalent short reference section, the time to reach the design temperature shall be corrected in accordance with Annex A.

The section factor and applied material thickness of the reference sections shall be within ±10 % of their equivalent loaded or tall sections. The analysis of the data shall be made on the basis of an assessment of the test data where the predicted performance satisfies the acceptance criteria given in 5.5 and is fully described in the assessment report.

The results of the assessment may not be used to extrapolate fire protection thicknesses beyond the maximum thicknesses evaluated.

Examples of the methods of analysis are given in Annexes C to G. It is incumbent upon the test laboratory or other approved organization/company, in consultation with the manufacturer, to utilize the most appropriate method to provide the best fit of the test data.

Only one method shall be utilized to provide the full scope of the assessment of the data from the testing of the product, i.e. different methods cannot be used to evaliate different portions of the test data.

This part of ISO 834 defines test packages to suit the scope of the assessment for the methodologies described in this International Standard determined in accordance with the principles given in ISO 834-10.

I or H sections and hollow sections are treated separately for the purposes of the assessment.

5.2 Temperature data

5.2.1 Steel temperature for calculations

The steel temperature for calculation purposes shall be the overall mean temperature of each section calculated as follows:

— For I and H section beams, this refers to the mean temperature of the upper flange plus the mean temperature of the web plus the mean temperature of the lower flange, divided by three.

— For I, H, and hollow section columns, this refers to the sum of the mean temperature of each measuring station divided by the number of measuring stations.

— For hollow section beams, this refers to the mean temperature of the sides of the section plus the mean temperature of the bottom face, divided by two.

5.2.2 Characteristic steel temperature

The characteristic temperature is calculated as (mean temperature + maximum temperature)/2.

5.3 Correction for discrepancy in stickability and insulation performance over the thickness range tested

Correction factors shall be determined for the thickness range tested in accordance with Annex B. Linear interpolation shall be applied to correct the time to reach the design temperature for the short sections.

The characteristic steel temperature derived in accordance with 5.2.2 will be used to determine the correction factor assessment procedures for thermal performance

5.4 Assessment procedures for thermal performance

Assessment of thermal performance shall be carried out on the basis of the corrected times to reach the design temperatures of each short section and they must satisfy the criteria for acceptability and limitations given in 5.5 and Clause 7 respectively.

A minimum number of short steel sections shall be tested according to ISO 834-10. If further data points are required, additional specimens shall be tested.

5.5 Criteria for acceptability of the assessment method used and the resulting analysis

The acceptability of the analysis within the range of steel section temperatures (as defined by ISO 834-10 or the sponsor) and duration of the test shall be judged up to the maximum temperature tested on the following basis:

a) For each short section, the predicted time to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15 %.

b) The mean value of all percentage differences as calculated in a) shall be less than zero.

c) A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be more than zero.

d) The results of the analysis which satisfy a) to c) above must comply with the following rules provided all other parameters remain constant:

   1) The thickness of fire protection material increases with fire resistance time.

   2) As the section factor increases, the fire resistance time decreases.

   3) As the fire resistance time increases, the temperature increases.

   4) As the thickness increases, the temperature decreases.

   5) As the section factor increases, the temperature increases.

   6) As the section factor increases, the thickness increases.

The criteria for acceptability shall be individually applied to all design temperatures included in the scope of the assessment. This should be carried out in 50 °C steps, starting at 50 °C below the minimum temperature within the scope or 350 °C, whichever is the higher, up to the maximum temperature within the scope. There must be at least three temperature steps of 50 °C within the scope of the assessment.

Modification of the analysis should be made until the criteria of acceptability are met.

6 Report of the assessment

The report of the assessment shall include the following:

a) The name/address of the body providing the assessment and the date it was carried out. Reference to the name/address of the test laboratory, the unique test reference number, and report number(s).

b) The name(s) and address(es) of the sponsor(s). The name of the manufacturer of the product or products and the manufacturer or manufacturers of the construction.

c) Generic description of the product or products, particularly the fire protection system and any component parts (where known). If unknown, this shall be stated.

d) General description of the test specimens forming the basis of the assessment including the measured dimensions of the test specimens.

e) The reason for the omission of any test data.

f) The assessment method used.

g) The mean steel temperatures used in the analysis in accordance with 5.2.1.

h) The corrected times used in the analysis determined as described in Annex A.

i) The values of all thermal data required to be calculated by the chosen assessment method.

j) For all methods of analysis the ability of the method to satisfy the criteria for acceptability as specified in 5.5.

k) The thermal analysis shall produce a series of tables and graphical presentations relating to fire resistance classification periods appropriate to the performance of the protection material. Each table or graphical presentation shall show the minimum thicknesses of fire protection material required to maintain the design temperature. (An example of the presentation of such tabulated information is given in Table 1). Any alternative presentation of the data specified by the sponsor appropriate to local/National needs and different design temperature limits and intervals of section factor may be used. Whatever the presentation of the data are adopted, interpolation is only allowed over a maximum range of 50 °C and 10 m^{-1}.

l) The report shall also include a statement regarding the limits of direct application of the assessment procedure, especially with regard to the range of section factors, design temperatures, material thicknesses, fire resistance periods, three- or four-sided protection, etc.

m) The report will include tables of actual and predicted times.

Table 1 — Example of tabulated data

Fire resistance period – 30 minutes								
Design temperature °C	350	400	450	500	550	600	650	700
Section factor m^{-1}	Thickness of fire protection material to maintain steel temperature below design temperature							
40								
50								
60								
70								
80								
90								
100								
110								
120								
130								
140								
150								
160								
170								
180								
190								
200								
210								
220								
230								
240								
250								
260								
270								
280								
290								
300								

Temperature range for illustration only. Actual range to be determined by the scope of the assessment.

7 Limits of the applicability of the results of the assessment

7.1 General

The results from the assessment procedure are applicable to the fire protection system over the range of fire protection material thicknesses tested, the values of section factor A_m/V tested, and the maximum temperatures established during the test.