Les guides

PASSIVE FIRE PROTECTION SYSTEMS

Justification of performance for road tunnel structures

Updated version of March 2017

Centre d'Études des Tunnels

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DISCLAIMER

This guide is the result of a process of synthesis, methodological assessment, research and feedback, either carried out or commissioned by CETU. It is designed to be used as a reference for the design, construction and operation of underground structures. As the guide takes stock of the state of the art at a particular time, the information it contains may become outdated, either due to developments in technology or regulations, or to developments of more efficient methods.

Passive fire protection systems

Justification of performance for road tunnel structures

Updated version of March 2017

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TABLE OF CONTENTS

APPENDICES

FOREWORD

This document supersedes the guide on “Passive fire protection systems” published in March 2013.

In comparison with the version of 2013, the following significant changes have been made:

- the guide and in particular the appendix A “HCM test method” have been brought into compliance with NF EN 13381-3 published in May 2015;
- the paragraph 3.2 of this document has been brought into compliance with the Construction Products Regulation which entered into force the 1st of July 2013, repealing the Construction Products Directive 89/106/EEC;
- the period of validity of a *“Procès-Verbal”* assessing the performance of a fire passive protection system under HCM is now one year;
- ambient temperature in the furnace is now measured with plate thermocouples only (paragraph A.9 of appendix A);
- the duration of a HCM test has been specified in function of the water content of the fire passive protection product under test (paragraph A.11 of appendix A);
- limits of applicability of the results of the HCM assessment have been defined depending on the strength class of the tested concrete specimen and the characteristic temperature at the exposed surface of the concrete behind the fire protection system during the fire test (paragraph A.14 of appendix A);
- follow-up tests necessary for the annual renewal of a *“Procès-Verbal”* assessing the performance of a fire passive protection system under HCM have been defined (paragraph A.15 of appendix A).

This document is available in French and in English.

DEFINITIONS

Accredited laboratory:
Laboratory with accreditation for the reference NF EN ISO 17025, for fire resistance tests. Accreditation is issued by a European accreditation body such as the Comité français d'accréditation (Cofrac - French accreditation committee). The European cooperation for Accreditation (EA) body includes all European accreditation bodies.

"Avis de chantier":
Approval by a French approved laboratory defining the fire resistance performance of a protection system for a given site. The *"avis de chantier"* is required if the design of the passive fire protection system for the site in question has particularities not covered in the original report. The *"avis de chantier"* is mainly based on an analysis of test results, knowledge acquired during fires, and/or on the use of digital results from simplified or advanced calculations.

Characteristic temperature:
Average of the mean temperature and the maximum individual temperature [(mean+maximum)/2] for each thermocouple group at equivalent location. The characteristic temperature must be used to assess test results.

Classification report:
Report drafted by a laboratory accredited for the test method, on the basis of one or several test reports.

Fire protection material:
Material or combination of materials applied to the surface of a concrete member in order to increase its fire resistance by thermal insulation.

Fire protection system:
Fire protection material together with a prescribed method of attachment to the concrete member.

Follow-up test:
Fire test performed in order to assess the constancy of the heat transfer characteristics of the fire protection system under the HCM fire curve, according to paragraph A.15 if this guide. This test is performed each year as part of the renewal of the *"Procès-Verbal"* of the fire protection system.

French approved laboratory:
Laboratory with an approval issued by the French Ministry of the Interior, according to the amended decree of 5 February 1959 on the approval of laboratories for material fire behaviour.

Performance test:
Fire test performed in order to determine the contribution of a fire protection system to the fire resistance of a concrete structural member, according to Appendix A of this guide under the HCM fire curve and to NF EN 13381-3 under the ISO curve.

"Procès-Verbal":
Laboratory approval drafted by a French approved laboratory on the basis of one or several test reports. The *"Procès-Verbal"* defines the fire resistance performance of a protection system.

Reference test:
First follow-up test performed at the same time as the performance test of the fire protection system.

Test report:
Report drafted by the laboratory accredited for the concerned test method and performing the fire test. The test report specifies construction details, test conditions and results obtained.

1 INTRODUCTION

To comply with the French regulation related to "The safety of road tunnels with a length of more than 300 metres" (called *«Instruction Technique»* in French) [1, 2], implementation of passive fire protection systems is often required to guarantee an adequate level of fire resistance for existing structures. This method of protection can also be used for new structures. However, the *"Instruction Technique"* defines neither the type of product to be used in order to achieve a given performance level, nor the methodology to be applied to specify or quantify the fire protection systems to be used. Some information is provided in the French Government amended decree of 22 March 2004[1] [3]. Indeed, this decree concerning "The fire resistance of products, construction and structural components", defines methods and performance criteria, which refer to French Regulations on fire safety.

Since the publication of the *"Instruction Technique"*, some information concerning fire tests and preparation of technical specifications (CCTP) has been described in other documents. These documents are intended to simplify the application of the *"Instruction Technique"* but do not include a complete summary of the subject. For instance, one could mention the Guide to fire behaviour of road tunnels published by the CETU in 2005, its Addendums in 2011, the guidelines of the Working Group 37 of the AFTES[2] in 2008, and the catalogue of passive protection systems available on the website of the CETU and regularly updated [4, 5, 6, 7].

The experience acquired during the last ten years, the publication of standards on fire tests and information provided by product suppliers, take the lead in meeting a real need of the tunnel industry. Together with the French approved laboratories: CSTB, EFECTIS France and CERIB, CETU has drafted this guide in order to clarify the procedure justifying the performance of passive fire protection systems for concrete road tunnel structures. In particular, this guide specifies a test method for HCM fire exposure. This guide is written in accordance with the amended decree of 22 March 2004 [3].

This guide is intended for companies, fire resistance test laboratories, suppliers and installers of passive fire protection systems, as well as project managers and tunnel owners, in order to provide assistance in justifying and accepting passive fire protection systems for road tunnel structural components.

In addition, appendix A defines a test method for applied protection to concrete members exposed to the HCM curve and is particularly intended for fire resistance test laboratories.

1. The decree of 22 March 2004, after being consolidated on 6 October 2006, was amended by the decree of 14 March 2011.
2. AFTES: French Association for Tunnels and Underground Space (Association Française des Tunnels et de l'Espace Souterrain).

2

GENERAL PRINCIPLES FOR FIRE PROTECTION

The application of a fire protection system on tunnel structural components aims to satisfy the fire resistance ratings required by the French Regulations. It limits damages to structural components to ensure their ability to fulfil their intended function. This damage can be caused by:

- an increase of temperature of materials leading to a downgrading of their mechanical properties,
- thermal deformations inducing stresses,
- material loss due to concrete spalling.

In this guide, the term "spalling" refers to all phenomena (explosive spalling, progressive spalling, falling-off, etc.) with the effect of detaching superficial concrete of structural components exposed to fire. For more details on the definitions of the different phenomena, one can refer, for instance, to the CETU guide on the fire behaviour of road tunnels [4].

The two temperature-time curves used to design the structures of road tunnels are the standard temperature-time curve, called "ISO" and the Modified Hydrocarbon curve called "HCM"[3] (see figure 1). In accordance with the *"Instruction Technique"* [1], the effects of spalling are considered as negligible for ordinary concrete exposed to the ISO curve[4]. Spalling should be explicitly taken into account for all types of concrete exposed to the HCM fire curve and for high-performance concrete exposed to the ISO fire curve. However, no simple rule has as yet been determined in order to estimate the thickness of concrete spalling as a function of time or as a function of temperature whatever the type of concretes is.

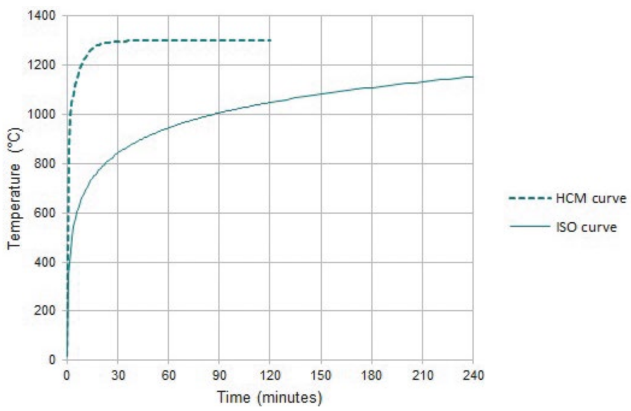

Figure 1: temperature-time curve

The fire behaviour of structures protected by passive fire protection systems is assessed on the basis of thermo-mechanical calculations taking into account the profiles of temperature vs. depth within concrete structural components. For numerical simulation of road tunnel fire behaviour, the CETU guide "Fire behaviour of road tunnels" and its addendums should be used [4, 5].

The fire resistance criterion can be defined as a maximum characteristic temperature on the exposed surface of the concrete in the technical specifications of the project. The technical specifications may also mention a maximum critical temperature of the structural reinforcement. This temperature can be defined with reference to Eurocode 2 part 1.2 (NF EN 1992-1-2).

A thermal insulation criterion may be required on unexposed surfaces in some cases (e.g. inner panel of a shelter or wall of an evacuation route).

In practice, passive fire protection systems are currently used when:

- the required fire resistance is not achieved by the existing structure,
- it is not possible to experimentally assess the risk and quantify the amount of spalling for existing structures,
- spalling assessment results are not compatible with the required fire resistance.

The installation of a passive fire protection system on structure reduces the increase of the concrete temperature. Then, despite HCM fire exposure, the surface temperature of the protected concrete will generally remain far below the ISO fire curve. On this basis, and only in the context of the assessment of thermal transfers, spalling phenomena may be ignored in the presence of passive fire protection materials. In fact, in this case, the materials remain in position and contribute to the thermal insulation of the structure.

Fire resistance tests therefore aim to ensure the integrity of the passive protection system. Furthermore, characterisation can be carried out on the basis of the characteristic temperatures of the exposed surface of the concrete behind the protection.

3. In some publications, the Modified HydroCarbon curve (HCM) is also called the Increased Hydrocarbon curve and is noted HC_{inc}.
4. The *"Instruction Technique"* is based on ENV 1992-1-2, which only considered spalling under the ISO curve for high-performance concretes. Since this date, Eurocode 2 part 1-2 (EN 1992-1-2) including the 3% water content rule (see. article 4.5.1) has taken effect. Therefore, the question of studying the spalling of concrete with a water content of more than 3% under the ISO curve should normally be considered independently to its mechanical strength.

3

PASSIVE FIRE PROTECTION SYSTEMS AND THEIR IMPLEMENTATION ON-SITE

3.1 BOARD TYPE OR SPRAYED TYPE FIRE PROTECTION MATERIALS

Board type fire protection

Sprayed type fire protection

Figure 2: the different types of passive fire protection systems

The different passive fire protection materials currently consist of either boards applied to the hardened concrete surface or placed at the bottom of formwork, or mortar sprayed or cast in place.

Boards are rigid prefabricated materials, usually with hydraulic binders. Their design and manufacture must be suitable for the geometry of the structure and the parts to be protected (coating of the roof or side walls, slabs or cable raceways). Boards are fitted according to a precise layout. They can be fixed either directly on the support to be protected or on steel frames. They should be butted to minimise any joints, which will therefore not need specific treatment.

Depending on the part of the structure to be protected, the mortar can be either sprayed or cast in place. These materials are prepared using conventional or refractory hydraulic binder (calcium aluminate type). The bond of the sprayed mortar on the concrete surface can be guaranteed by preparing the surface and/or installing a steel mesh bolted to the surface.

For both boards and mortars, the thickness must be adapted to each application in order to meet the temperature requirements (maximum characteristic temperature on the surface of the concrete behind the fire protection system or maximum critical temperature on steel rebars).

3.2 CONSTRUCTION PRODUCTS REGULATION AND CE MARKING

The Construction Products Regulation (CPR) is entered into force the 1st of July 2013, repealing the Construction Products Directive 89/106/EEC. It lays down harmonised rules for the marketing of construction products in the EU. It is now mandatory for manufacturers to declare a “performance conformity” and to apply CE marking to any of their products covered by a harmonised European standard or a European Technical Evaluation (ETE).

No ETE covers performances under the HCM thermal exposure.

For road tunnel components for which French regulatory requirements are formulated in terms of fire resistance performance as defined by the standard NF EN 1363-1 (ISO thermal exposure), only products with either a French official assessment (*“Procès-Verbal”*) delivered by a French approved laboratory or CE marking with reference to an ETE[5] and associated classification reports translated in French can be used.

When higher fire resistance levels are required: N1+HCMt[6], N2 or N3, French regulations consider a fire scenario corresponding to a HCM thermal exposure and are therefore outside of the scope of the European Technical Approval Guidelines: ETAG 018. Nevertheless, some approaches described in ETAG 018 can be taken as references for the assessment of the performances of products exposed to HCM thermal exposure, and products exposed to ISO thermal exposure without ETE (see above).

This guide recommends the priority use of fire protection systems having followed the processes defined to ensure the conformity of the product in the context of a conformity certification system i.e.:

- the test laboratory must apply the specific sampling procedure before characterisation tests for fire protection materials. This sampling procedure is intended to assess the material as manufactured continuously, and not to assess a material sample specifically produced for the characterisation test,
- a Factory Production Control (FPC) procedure must be applied. This procedure is intended to check that the materials produced and implemented on the site remain in conformity with the materials used for the test-based assessment. This point limits performance deviation from the initial type test. Furthermore, in the specific case of a material subjected to a limited production run, the FPC type procedure can be carried out via a thermal transfer test on a sample in order to check initial properties. Finally, if the material is a prototype, the formulation characteristics or thermal characteristics can be used as tracers to check the performance of the material during routine production checks.

It is also recommended the priority use of fire protection systems where constant performance levels are guaranteed by at least a qualification for exposure and ageing effects in accordance with ETAG 018.

3.3 CONSIDERATION OF THE ENTIRE FIRE PROTECTION SYSTEM

In addition to the characterisation of the material itself, the entire passive fire protection system must be characterised. Therefore passive fire protection systems must prove their fire resistance under ISO or HCM thermal exposures with reference to a classification report associated with the CE marking including the fire resistance requirement or to a French approval *"Procès-Verbal"*. These documents are drafted on the basis of one or several test reports (see paragraph 4.4 and figure 3 of this guide).

The following points in particular must be taken into account when defining the system:

- the thickness of the protection and multi-layers if applicable,
- type of the concrete members[7],
- the type of attachment and implementation (type of fixation, number and spacing, any joint backing strips, joint cover strips or sliders in case of boards protection material; presence of a steel mesh, attachments, preparation of the concrete surfaces if necessary in the case of sprayed or cast in place protection material).

Board dimensions and loading may also have consequences on the system performance.

Finally, it is necessary to pay attention to the type and representativeness of the materials tested (regular performances and properties, water stabilisation, etc.), and the construction and preparation of the concrete member (concrete strength class and mix design, hygrometric stabilisation, etc.).

5. Without harmonized standards, CE marking on protection products relate to an ETE generally established on the basis of the European Technical Approval Guidelines: ETAG 018.
6. Level N1 (defined by the ISO curve) is sometimes completed by checking the fire resistance of the structure under a fast developing fire (HCM thermal exposure) for a given period t. This requirement is then written "HCMt", with t expressed in minutes.
7. A certain degree of tolerance can be accepted for the concrete member however this support must remain of the same type and have a thickness in accordance with this guide (see paragraphs 4.2 and 4.3).

3.4 ON-SITE APPLICATION

When the performance of the fire protection system has been assessed, it is necessary to check the representativeness of the system tested with respect to actual site conditions (type of concrete member, implementation conditions, etc.).

Article 18 of the amended decree of 22 March 2004 [3] lists the different options to certify the fire resistance performance of a product, a construction or a structural component, in the specific context of its implementation on a given site.

In application of this article for a given structure, it may not be possible to justify the fire resistance performances of the protection system directly on the basis of a classification report or a French approval *"Procès-Verbal"* (due, e.g. to excessive deviation between the type of system tested and that actually implemented, or between test conditions and site conditions). In this case, an approval by a French approved laboratory is requested. This official laboratory approval will then take the form of either an extended application of the classification report, or an extended application of the *"Procès-Verbal"*, or a specific approval called *"Avis de chantier"* valid exclusively for the given tunnel.

Paragraph 4.4 of this guide includes details on the process and documents used to certify the fire resistance performance of a passive protection system on the construction site in accordance with the amended decree of 22 March 2004.

4 ACCEPTANCE CONDITIONS FOR PASSIVE FIRE PROTECTION SYSTEMS ON THE CONSTRUCTION SITE

4.1 "CONVENTIONAL" TESTING ACCORDING TO EUROPEAN STANDARDS

Appendix 1 of the amended decree of 22 March 2004 [3] defines conventional tests according to standardised European methods on one hand, and according to national methods on the other hand (doors, dampers, structural components, controlled mechanical ventilation fans, fire resistant ceilings and fire dampers). Conventional tests must be differentiated based on the type of component.

Various European standards apply to passive fire protection systems (standards in the following series: NF EN 1364, NF EN 1365, NF EN 13381). **For the specific case of passive fire protection systems for concrete structures, the applicable reference is the standard NF EN 13381-3.** For all the other situations (steel structures, vertical membranes, etc.), reference to the appropriate European standards should be made.

4.2 OVERVIEWS AND CURRENT PRACTICES

The acceptance of a passive fire protection system for a given site is the responsibility of the project manager. This will depend on the characterisation of the entire system and its on-site application as specified in paragraphs 3.3 and 3.4.

Generally, the project manager will check the following points:

- the supply of documents certifying the fire resistance performance of the protection system, as defined in article 18 of the amended decree of 22 March 2004 (see paragraph 4.4 and figure 3 of this guide),
- compliance with the criterion defined in the technical specifications when applicable. This criterion may be defined by the surface temperature of the concrete or the allowable temperature of reinforcement (see paragraph 2 of this guide).

The project manager will also check the conformity of the system implemented on the construction site with the tested system. This conformity will relate to the following points:

- the concrete type of the members,
- the thickness of the fire protection material and its main characteristics (dimensions for board protection material, density, water content),
- the implementation procedure (steel mesh, attachments for sprayed protection material or those cast in place; layout diagram, type of fixations, joint backing strips, joint cover strips or sliders in case of board protection materials).

Differences between tests and site conditions can however be accepted. They relate to:

- the concrete type of the member: in the range of temperatures for the exposed surface of the concrete behind the protection (250°C – 400°C), it is assumed that the type of concrete will not affect the behaviour of the protection material,
- the thickness of the concrete member used for tests: this thickness is usually lower than the thickness of the structure. However, in the range of temperatures of the exposed surface of the concrete (behind protection) and considering the mechanical loads, this test configuration would appear unfavourable as the support slab will deform more during the test than in the tunnel,
- the loading of the concrete member: in real circumstances, loading will vary in function of location and time. Loading during the tests, whatever its value, is not therefore generally representative of the structure. The CETU guide [4] therefore recommends the loading defined by standard NF EN 13381-3, which has the advantage of being standardised,
- some characteristics of sprayed protection material: in practice, it is more difficult to check the implementation procedure for this type of protection, particularly for the density, the water content and the thickness applied for each layer.

Some deviation from the test conditions according to standard NF EN 13381-3 have also been accepted in the past based on the delay required to develop experimental resources. Strictly speaking, as standard NF EN 13381-3 only applies to tests under ISO thermal exposure, the deviation from test conditions for this standard when performing HCM tests could have been tolerated. These deviations related to:

- the loading of the support slab: loads other than that defined in the standard NF EN 13381-3 (see absence of loading) could have been applied,
- the dimensions of the concrete member: even if the CETU guide [4] recommends the dimensions of standard NF EN 13381-3, some tests were carried out in order to reproduce a specific structure with dimensions other than those of the standard. It was accepted that the dimensions of the concrete member had little effect on the behaviour of the fire protection system as deformation matters the most.

This guide recommends rejecting deviation from test conditions when assessing the performances of a fire protection system. Concerning HCM tests, paragraph 4.3 and appendix A of this guide now specify the method to perform HCM test. Deviation may however be authorised in some cases, when they are intended to represent real conditions in the context of application to a specific construction site.

4.3 DEVELOPMENTS AND RECOMMENDATIONS IN THE CONTEXT OF HCM TESTS

According to the amended decree of 22 March 2004 [3], the fire resistance performances of a protection system tested under HCM thermal exposure must be defined in the *"Procès-Verbal"* (see article 11 of the decree). In order to establish this *"Procès-Verbal"*, this guide recommends the HCM test method described below.

HCM tests for passive fire protection systems applied to concrete structures are performed in accordance with the general conditions of standard NF EN 1363-1 and the specific conditions of standard NF EN 13381-3, plus or replaced by the complementary provisions indicated in appendix A of this guide. Some of these provisions, such as the HCM thermal program, have been drafted by analogy with the procedure described in standard NF EN 1363-2.

To accept the performance of products assessed with a test under RWS thermal exposure [8] (in the same way as under HCM thermal exposure), this guide recommends that RWS tests be performed in accordance with the HCM test method described above, with the only exception of the thermal programme.

4.4 VALIDITY AND ACCEPTABILITY OF FIRE RESISTANCE TESTS

The validity and acceptability of fire resistance tests justifying the performance of passive protection systems are described below for ISO and HCM tests, in accordance with the amended decree of 22 March 2004 [3].

According to the definitions of the amended decree of 22 March 2004, ISO and HCM tests are considered as conventional fire resistance tests (tests performed with predetermined thermal actions).

ISO and HCM tests must be performed by an accredited laboratory. For ISO tests, the laboratory must be accredited for the test methods defined in the standard NF EN 13381-3. For HCM tests, the laboratory must be accredited for the HCM test method described in this guide (see paragraph 4.3 and appendix A).

The accredited laboratory will draft a test report for each test.

Fire resistance performances will then be defined by:

- a classification report, in French, provided that it is attached to the conformity declaration through CE marking;
- a *"Procès-Verbal"* drafted by a French approved laboratory.

If the system tested is modified, a French approved laboratory must be requested to carry out an approval in view of extending the application of the classification report or the *"Procès-Verbal"*.

If the construction site has particularities not identified in the classification report or the *"Procès-Verbal"*, a French approved laboratory has to establish an *"Avis de chantier"* for the fire protection system. On the contrary to the extension of the application of the classification report or the *"Procès-Verbal"*, the *"Avis de chantier"* is only valid for the considered tunnel.

8. The RWS curve is a regulatory curve used in the Netherlands, which is very similar to the HCM curve (see [9]).

Figure 3 shows the characterisation process for passive fire protection systems and the required documents. The content of these documents is described in appendix B.

In order to establish extensions and *"Avis de chantier"*, French approved laboratories should be able to evaluate the influence of specific parameters as best as possible. Complementary tests listed in appendix C may also be required.

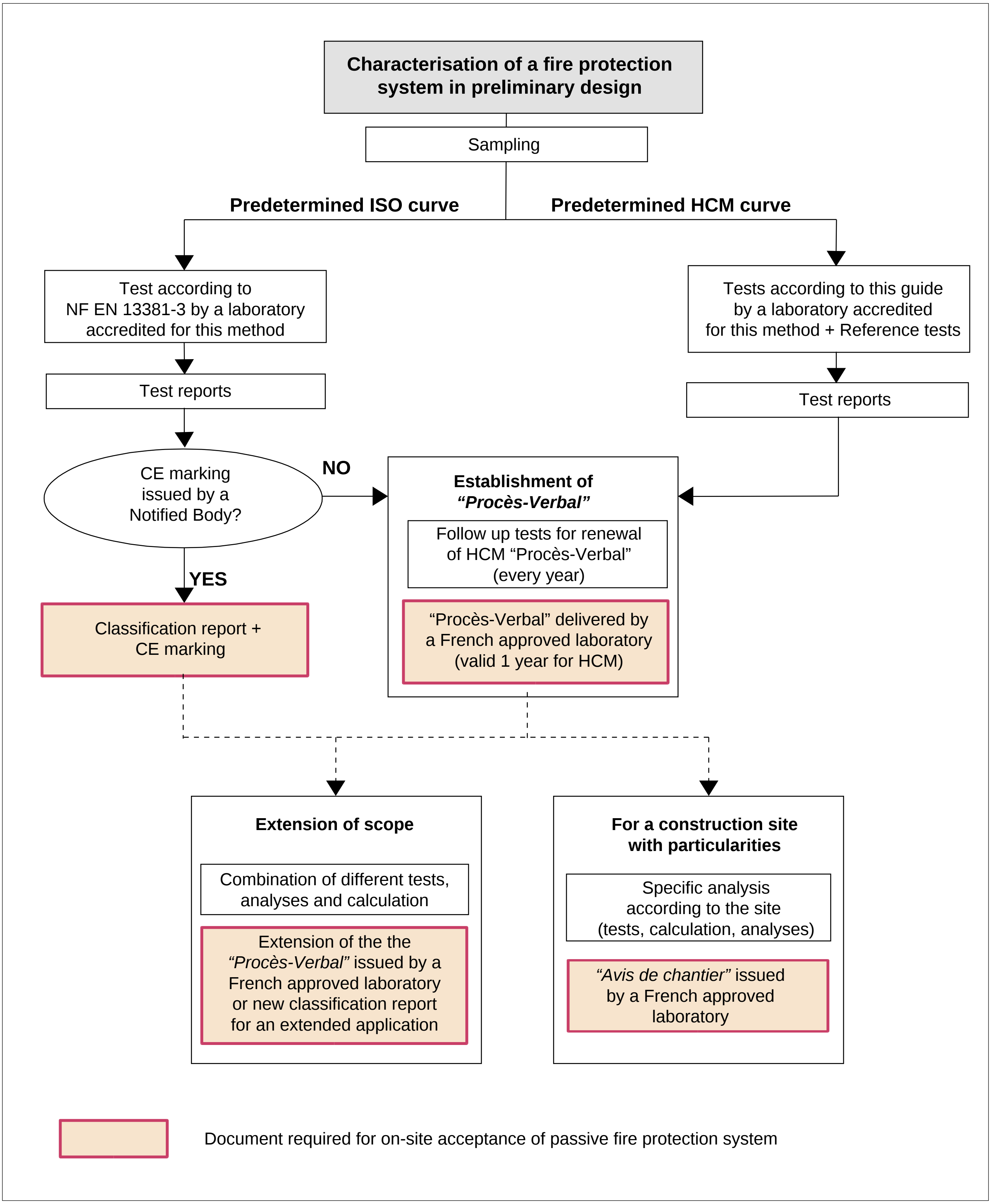

Figure 3: characterisation process for passive fire protection systems

5

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[2] French government circular no. 2006-20 of 29 March 2006 on the safety of road tunnels with a length of more than 300 metres.

[3] French government decree of 22 March 2004 on the fire resistance of products, construction and structural components, amended by the order of 14 March 2011.

[4] Guide du Comportement au feu des tunnels routiers (Guide for the fire behaviour in road tunnels), CETU, March 2005.

[5] Addendum to the Guide for the fire behaviour in road tunnels, CETU, March 2011.

[6] Road tunnels: fire resistance, AFTES GT37 recommendation, Tunnels et ouvrages souterrains (Tunnels and underground structures), no. 205, January/February 2008.

[7] Catalogue of passive protection systems, CETU, December 2005, updated on-line on the CETU website: www.cetu.developpement-durable.gouv.fr.

[8] French government decree of 19 October 2006 applicable to fire protection products and enforcing decree no. 92-647 of 8 July 1992 on the suitability for use of construction products, amended by decrees no. 95-1051 of 20 September 1995 and no. 2003-947 of 3 October 2003.

[9] Fire and smoke control in road tunnels, PIARC, 1999.

[10] NF EN 13381-3, Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members.

APPENDICES

APPENDIX A: HCM TEST METHOD

This appendix describes the complementary provisions to NF EN 13381-3, and therefore represents a test method for determining the contribution of fire protection systems to the fire resistance of structural concrete members exposed to the HCM curve.

A.1 Test representativeness

Fire protection materials to be tested must be sampled by an independent third party from standard industrial stock.

A.2 Dimensions and thicknesses of test specimens

Performance tests for fire protection systems intended for use on slabs or walls/panels must be performed on large flat slabs ("large samples"), as defined in NF EN 13381-3.

A.3 Number of test specimens and thicknesses of fire protection materials

To assess a fire protection system used on site with one single thickness, only one single test shall be performed on a large slab, as defined above and protected with the thickness to be evaluated.

To assess a fire protection system used on site within a range of thicknesses defined by [E_{min}, E_{max}], two large specimens should be tested as defined above and protected with the thicknesses E_{min} and E_{max} respectively.

A.4 Class and characteristics of the concrete

Unless specifically requested otherwise, the compressive strength class of the concrete in the test specimen shall be C25/30 to C30/37. Concrete cylinders shall be systematically produced during the casting of slabs, using the same concrete. These cylinders shall be prepared according to the standard NF EN 206 and shall be used to determine the mechanical characteristics of the concrete:

- 28 days after casting,
- 90 days after casting,
- on the date of the fire test unless it is carried out on the 90th day

These samples shall be stored with the slab test members and in the same ambient conditions.

Three concrete prismatic samples of size (200 ± 5) mm × (200 ± 5) mm × (140 ± 5) mm shall be systematically prepared during the casting of the slabs, using the same concrete. They shall be covered on at least 4 sides to ensure that only the upper and/or lower surfaces exchange with the environment in a representative way compared to the slab test members. They shall be used to estimate the moisture stabilisation of the concrete. They shall be stored together with the slab test members and in the same ambient conditions.

Fire tests shall only be performed after the moisture stabilisation of these concrete samples. On the date of the fire test, they shall be used to determine:

- bulk density (kg/m^3),
- water content, after drying at a temperature of 105°C (% of dry weight).

These characteristics shall be determined in accordance with the procedures specified for this purpose in NF EN 1363-1 and NF EN 13381-3.

A.5 Fire protection material characteristics

The characteristics of fire protection materials (density and water content) shall be determined on the basis of three samples per thickness to be qualified. The minimum dimensions of these samples are 300 mm × 300 mm. These samples will be prepared with, or taken from, the same batches of fire protection materials as those applied on the concrete test slabs. These samples will be stored with the concrete test slabs and in the same ambient conditions.

Fire tests shall only be performed after the moisture stabilisation of the fire protection materials and the concrete samples (see paragraph A.4). On the date of the fire test, the samples will be used to determine:

- bulk density (kg/m^3),
- water content, after drying at a temperature of (105 ± 5)°C, or (50 ± 5)°C for gypsum-based products (% of dry weight). The test duration can depend on this water content (see paragraph A.11).

These characteristics shall be determined in accordance with the procedures specified for this purpose in NF EN 1363-1 and NF EN 13381-3.

A.6 Conditioning of concrete test slabs

The minimum conditioning time of 90 days recommended in NF EN 13381-3 may be reduced to 85 days subject to the moisture stabilisation of all the three concrete samples (200 ± 5) mm × (200 ± 5) mm × (140 ± 5) mm prepared for this purpose with the same concrete as the concrete test slabs.

A.7 Instrumentation of concrete test slabs

The instrumentation of concrete test slabs recommended by NF EN 13381-3 is not sufficient to properly assess the mechanical resistance of the fire protection system under HCM thermal exposure, the temperature upon the exposed surfaces of the concrete beneath the fire protection material, and, if applicable, the temperature upon the exposed surfaces of the concrete beneath the joints of board type fire protection materials. It is therefore necessary to increase the number of measuring sections at the locations described in paragraphs A.7.1 and A.7.2 depending on whether sprayed, cast mortar or board type fire protection materials are used.

The measured temperatures may be used to interpolate results for intermediate fire protection material thicknesses, between the maximum and minimum thicknesses actually tested. This can be done by using thermal transfer simulations.

A.7.1 For sprayed renderings or casted mortars

For sprayed or casted passive type fire protection material, instrumentation for the measurement of the test specimen temperature shall consist of 7 sets of thermocouples located in the central part of the slab (3 sets at mid-width and quarter-width on the smallest median, and 4 sets at the centre of each quarter part of the slab (see figure A.1 - sets S1 to S7)).

Each of the 7 sets of thermocouples shall include 7 measuring points as given below and shown in figure A.2:

- 5 thermocouples in the thickness of the concrete slab as requested in paragraph 9.3.2 – sub-paragraph v of the standard NF EN 13381-3 (see figure A.2 - positions B to F),
- 1 thermocouple on the exposed surface of the concrete beneath the fire protection material (see figure A.2 - position A),
- 1 thermocouple on the unexposed surface of the concrete slab (see figure A.2 - position G).

Thermocouples on the exposed surface of the concrete shall be placed at the bottom of the formwork as requested in NF EN 13381-3. Particular attention shall be paid after removing the formwork concerning traces of concrete laitance on thermocouples. The copper disc shall be cleaned, and if necessary shall be re-fixed to the concrete slab with glue. A photo of each thermocouple before the application of the fire protection system shall be included in the test report.

A.7.2 For Board type fire protection materials

For board type fire protection material, instrumentation for the measurement of the test specimen temperature shall consist of:

- 7 sets of thermocouples located in the exposed surface of the slab (3 sets at mid-width and quarter-width on the smallest median, and 4 sets at the centre of each quarter part of the slab (see figure A.1 - sets S1 to S7)). Each of the 7 sets of thermocouples shall include 7 measuring points (see figure A.2) as given below:
  - 5 thermocouples in the thickness of the concrete slab as specified in paragraph 9.3.2 – sub-paragraph v of the standard NF EN 13381-3 (see figure A.2 - positions B to F),
  - 1 thermocouple on the exposed surface of the concrete beneath the fire protection material (see figure A.2 - position A),
  - 1 thermocouple on the unexposed surface of the concrete slab (see figure A.2 - position G),
- 3 additional sets of thermocouples in the middle of 3 protection boards, not in the immediate proximity of board fixations (minimum spacing of 100 mm) and in a 3,000 mm × 3,000 mm square centred on the slab (see figure A.3 - sets S8 to S10). In these locations, temperatures shall be measured as follow:
  - on the exposed surface of the concrete beneath the fire protection material (see figure A.4 - position A),
  - at 15 mm and 30 mm from the exposed surface of the concrete (see figure A.4 - positions B and C),
  - on the unexposed surface of the concrete slab (see figure A.4 - position G).

  If one of these locations is less than 200 mm from a set of thermocouples as described in the previous point, then this additional set of thermocouples is omitted.

- additional thermocouples on the exposed surface of the concrete slab (beneath the fire protection system) at joints and in a 3 m × 3 m square centred on the slab:
  - at longitudinal joints between 2 boards (see figure A.3 - position X),
  - at transversal joints between 2 boards (see figure A.3 - position Y),
  - at joints between 3 or 4 boards (see figure A.3 - position Z).

Thermocouples located at the exposed surface of the concrete and included in the sets of thermocouples for the first two points (positions A of figures A.2 and A.4 on sets S1 to S10 of figures A.1 and A.3) shall be placed at the bottom of the formwork as required in NF EN 13381-3.

Similarly, thermocouples located on the exposed surface of the concrete beneath the joints of the fire protection material (positions X, Y and Z – figure A.3) shall be either Inconel 1.5 mm diameter thermocouples installed at the bottom of the formwork or on the slab after casting, or thermocouples with copper disc according to NF EN 1363-1 installed at the bottom of the formwork.

Particular attention shall be paid after formwork removal concerning traces of concrete laitance on thermocouples. The copper disc shall be cleaned, and if necessary re-fixed to the concrete slab with glue. A photo of each thermocouple before the application of the fire protection system shall be included in the test report.

The sponsor shall provide the layout plan of board protection materials prior to to the casting of the concrete test slabs to allow the laboratory to place the additional sets of thermocouples in the formwork as specified above.

Figure A.1: positions of the sets of thermocouples in the concrete test slab (plan view)

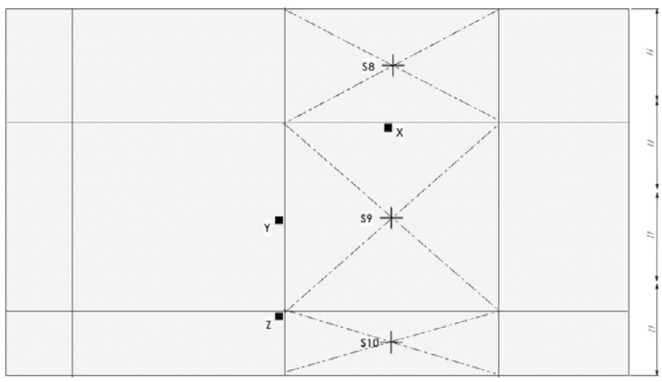


Figure A.3: positions of the additional sets of thermocouples and additional thermocouples in the case of board type fire protection materials (plan view)

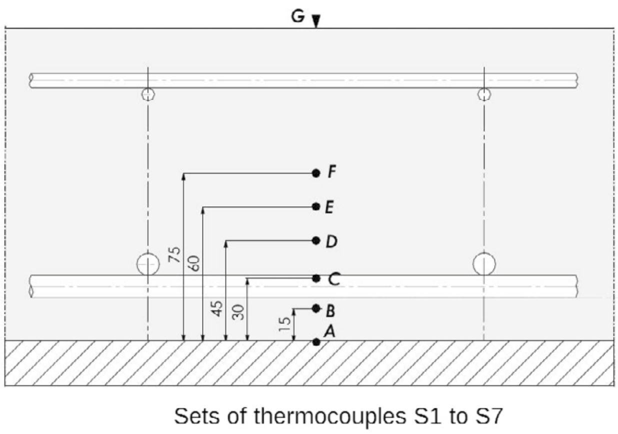


Figure A.2: positions of the thermocouples in the concrete test slab (cross-section)

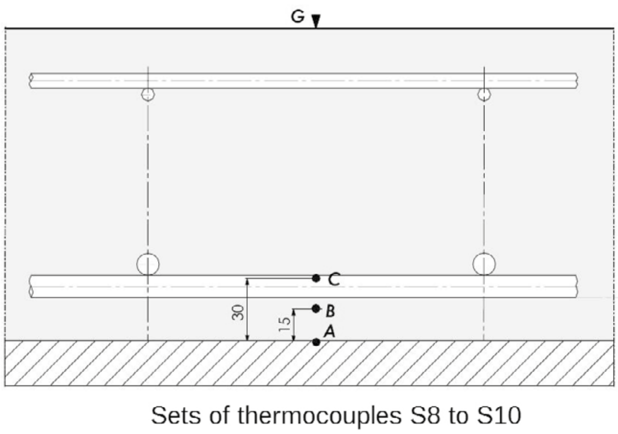


Figure A.4: positions of the additional thermocouples in the concrete test slab in the case of board type fire protection materials (cross-section)

A.8 Loading of test specimen

Unless loading conditions are representative of the structure, they shall comply with the requirements of NF EN 13381-3.

The test load can also be applied using dead weights distributed evenly over the entire surface of the test specimen, which corresponds to the width multiplied by the span of the slab.

The test load shall be calculated in order to produce a bending moment inducing a tensile stress in the lower reinforcement bars of the concrete test slab equal to 300 MPa according to NF EN 13381-3. The dead-weight of the slab and the fire protection system shall be taken into account when calculating the load to be applied.

The load shall be applied until a deformation of $L_{span}/30$ at mid-span of the slab is reached. Once this maximum deformation is reached, the load shall be totally removed; the assessment is completed. The fire test may be continued for informational purposes only.

A.9 HCM thermal programme

The HCM thermal programme or **"Modified HydroCarbon"** programme is defined below.

The ambient temperature of the furnace shall follow the analytical function:

$$\mathbf{T = 1\,280\left(1 - 0.325\,e^{-0.167t} - 0.675\,e^{-2.5t}\right) + 20}$$

where: t = time (min)
T = Average temperature of the furnace at time t (°C)

Ambient temperatures in the furnace shall be measured at (100 ± 50) mm from the exposed surface of the tested fire protection system. The furnace thermocouples shall be plate thermocouples as required by NF EN 1363-1.

Measurements must satisfy the following requirements:

- At any time after the first 10 minutes, the temperature recorded by any thermocouples in the furnace must not differ from the theoretical heating curve by more than 130 °C (see figure A.5).
- The percentage deviation in the area of the curve of the average temperature recorded by the furnace thermocouples from the area of the theoretical heating curve must comply with the following requirements (see figure A.6):
  - 20% from 5 to 10 min. after the start of the test,
  - 15% from 10 to 20 min. after the start of the test,
  - 10% from 20 to 30 min. after the start of the test,
  - 5% from 30 to 60 min. after the start of the test,
  - 2.5% after 60 min. of testing.

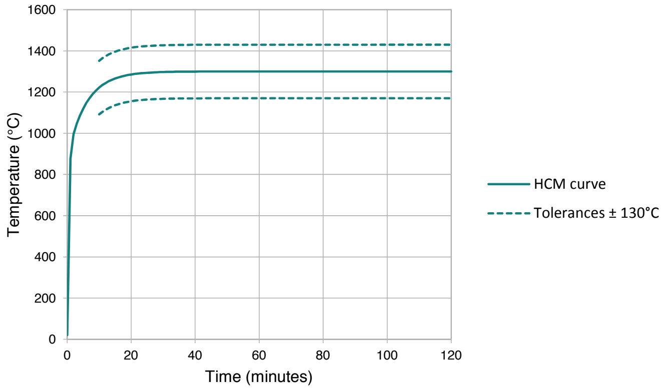


Figure A.5: furnace temperature curve

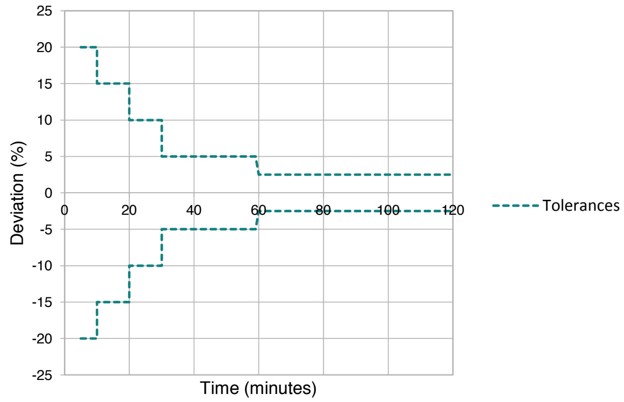


Figure A.6: maximum acceptable percentage deviations in the area of the curve of the average temperature recorded by the furnace thermocouples from the area of the theoretical heating curve

A.10 Pressure

No pressure criterion is recommended.

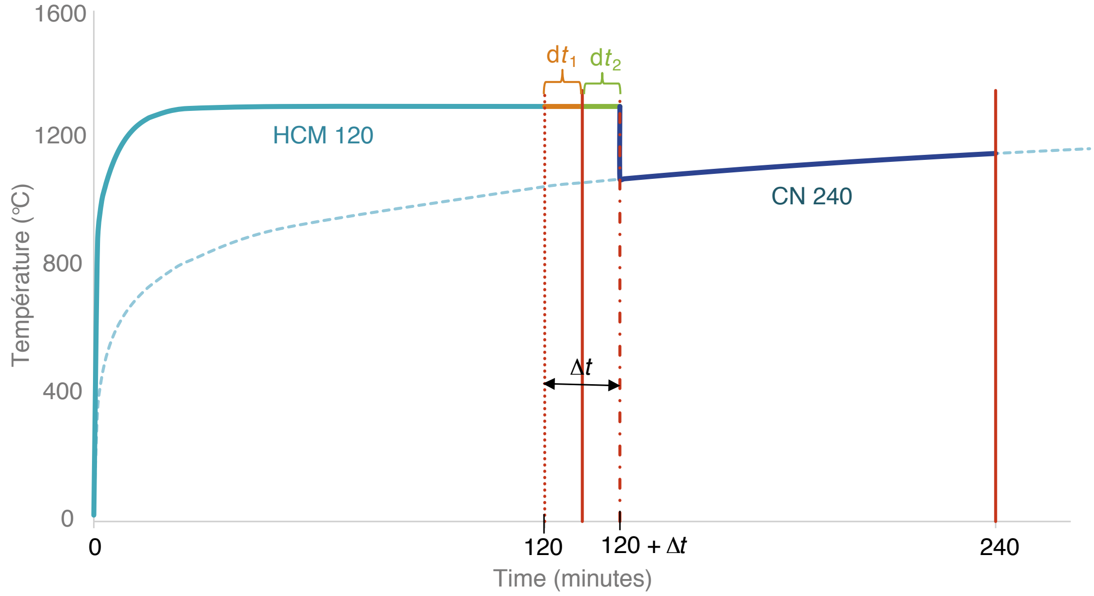
A.11 Termination of test

The duration of the test shall be equal to the time corresponding to the target safety level, incremented by +10% (e.g.: 132 minutes when the fire resistance target is equal to 120 minutes).

If the measured water content of the fire protection material is higher than 3%, the duration of the test shall be extended by the maximal value between the +10% described above and the difference of duration of the initial steady vaporisation phase (temperature between 85°C and 100°C) compared to a product with a water content of 3%.

If two thermal programmes are run successively, i.e. a HCM 120 test continued with an ISO test performed up to 240 minutes, the results obtained after these two periods are acceptable to assess a safety level N3 (HCM 120 and ISO 240).

Example 1: test HCM 120 continued with an ISO test performed up to 240 minutes for the assessment of a safety level N3 (HCM 120 + ISO 240):



With:

- Duration of the HCM test = 120 min + Δt
- $\Delta t = dt_1 + dt_2$ (≥ 12 min*)
- $dt_1 \geq 0$ min : difference of duration of the initial steady vaporisation phase of a product with a water content higher than 3% compared to a product at 3%
- $dt_2 = \begin{cases} 12\text{ min}^* - dt_1 & \text{if } dt_1 < 12\text{ min}^* \\ 0 & \text{if } dt_1 \geq 12\text{ min}^* \end{cases}$
- Duration of the ISO test = 240 min
- Time for calculation of the characteristic temperatures HCM120 = 120 min + dt_1
- Time for calculation of the characteristic temperatures ISO 240 = 240 min

* The 12 min correspond to the 10% of the targeted HCM test duration (here 120 min) and should be calculated for each fire test (e.g. 6 min for HCM 60, 12 min for HCM 120 etc.)

Figure A.7: thermal programme for a HCM 120 + CN 240 test (level N3)

The test is terminated for one or more of the following reasons:

- non-compliance with safety conditions for laboratory personnel and other test participants,
- impending damage to laboratory test equipment,
- elapsed time,
- temperature criterion on the lower reinforcement bars HA10 exceeds 550°C,
- request of sponsor.

A.12 Determination of reference temperatures of the fire protection system

Reference temperatures correspond to the characteristic temperatures as defined in paragraph 13.1 of NF EN 13381-3. These temperatures are measured on the exposed surface of the concrete behind the fire protection system (in the main area of the boards for board-based protection), at 15 mm and 30 mm in the concrete and on the unexposed surface of the test slab.

With board type fire protection materials, the temperatures measured upon the exposed surface of the concrete behind the joints are not taken into consideration in the calculation of the characteristic temperature of the exposed surface of the concrete (behind the fire protection system). Indeed, the concrete temperatures behind the joints can be substantially affected by significant contraction of board near the joints during fire tests. These temperatures shall only be used to highlight any particular points over the joints.

If the measured water content of the fire protection material is higher than 3%, characteristic temperatures at time t have to be determined with the measurements at the time $t + dt_1$ where dt_1 is the difference of duration of the initial steady vaporisation phase compared to a product with a water content of 3% (see. Paragraph A.11).

> *Example 2*
>
> The fire protection material under test has a water content of 5%. The duration of the initial steady vaporisation phase of the material at 5% is 10 min. Then, the characteristic temperature at 60 min should be calculated with the temperatures measured at 64 min (60 min + 10 min x (5 % - 3%) / 5%).

A.13 Test report

The test report shall present the data and results according to paragraph 12 of NF EN 13381-3.

In particular, this report shall include the following data:

- the generic description and accurate detail of the fire protection system,
- the characteristics of the concrete,
- the characteristics of the fire protection material,
- stickability criteria as defined in paragraph 13.5 of NF EN 13381-3,
- a table summarizing the characteristic temperatures at 1 h, 2 h, and if applicable 4 h (see paragraph A.12),
- results of the reference tests (see paragraph A.15),
- all results of the additional testing described in appendix C, if performed,
- photos of the different fitting phases including:
  - the photos of each thermocouples on the exposed surface of the concrete slab during the formwork removal phase,
  - the photos of the exposed surface of the test specimen after testing.

A.14 Limits of applicability of the results of the assessment

The results of the assessment are only applicable to fire protection systems where the fixing and jointing systems are the same as those tested.

The following table indicates the limits of applicability of the results of the assessment. These limits depends on the strength class of the tested concrete specimen and the characteristic temperature at the exposed surface of the concrete behind the fire protection system during the fire test.

Characteristic temperature at the exposed surface of the concrete behind the fire protection system during the fire test	Strength class of the tested concrete specimen defined according to NE EN 206/CN	
	≤ C50/60	> C50/60
≤ 400 °C	The results of the assessment are applicable to concrete members in which the concrete strength class is equal to or lower than C50/60.	The results of the assessment are applicable to concrete members in which the concrete strength is equal to or one strength grade higher than tested.
≥ 400 °C	The results of the assessment are applicable to concrete members in which the concrete strength is equal to or one strength grade higher limited at C50/60, than tested.	The results of the assessment are only applicable to concrete members with the same strength grade as the tested element.

Table 1: limits of applicability of the results of the assessment

A.15 Follow-up tests

Follow-up tests aim to assess the constancy of heat transfer characteristics of the fire protection system under the HCM curve and hence to check any variation due to modifications in the material's production that could affect its fire resistance performance.

A first test of this type called "reference test" shall be performed at the same time as the performance test of the fire protection system, on the same product batch in order to obtain the reference temperatures needed for follow-up tests.

Follow-up tests shall be performed each year to assess the consistent performance of the fire protection system performance as part of the renewal of the *"Procès-Verbal"*.

Inspired by the durability tests of ETAG 018-3, the procedure of follow-up tests shall be as follows:

- the test specimen is composed of a reinforced concrete slab plus the fire protection system under test.
- two concrete slabs shall be tested, respectively protected with the maximum and the minimum thicknesses of the range of the fire protection material under test.
- the type of concrete (strength class and type of aggregates) and the concrete cover of the slab test members shall be the same as those used for the qualification test defined in this annex (see paragraph A.4).
- the test specimens shall be of the sizes required to provide a minimum exposed surface of 400 mm × 300 mm and a nominal thickness of (140 ± 5) mm. Particular attention should be paid by the test laboratory on the thickness of the support frame to maximize the exposed surface.
- the instrumentation for the measurement of test slab temperature shall consist of a minimum of 5 sets of thermocouples located as shown on figure A10 (1 set at the centre of the slab and 4 sets at the quarters of the diagonals). Each of the 5 sets of thermocouples shall include 2 measuring points: 1 thermocouple on the exposed surface of the concrete beneath the fire protection system and 1 thermocouple at 15 mm in the thickness of the concrete slab (see figure A.11). The type and method of fixation of these thermocouples shall comply with the specifications of paragraph A7.
- the thermal exposure shall be the HCM fire curve defined in paragraph A.9 for a minimum duration of 120 min. In the same manner as the performance test (see paragraph A.11), if the measured water content of the fire protection material is higher than 3%, the duration of the test shall be extended by the difference of duration of the initial steady vaporisation phase compared to a product with a water content of 3%.

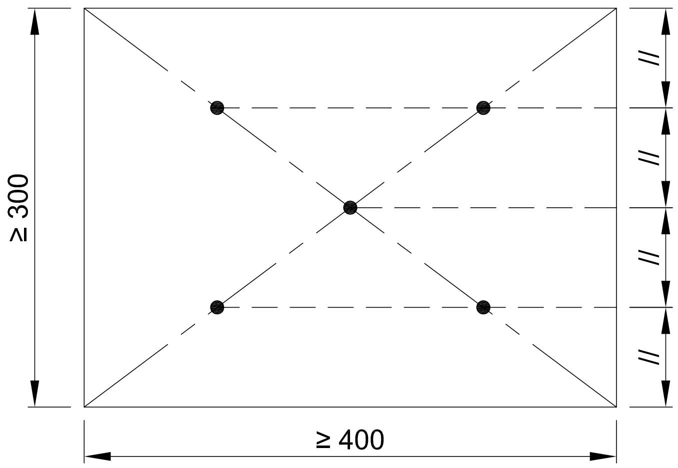


Figure A.8: positions of the sets of thermocouples in the concrete slab for follow-up test (plan view)

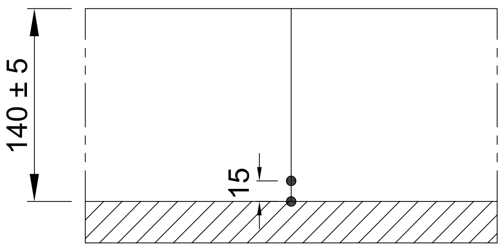


Figure A.9: positions of the thermocouples in the concrete slab for follow-up test (cross-section)

The assessment of the constancy of the heat transfer characteristics of the fire protection system shall be based on the time required to reach the average temperature at 15 mm in the concrete slab determined at 120 min during the reference test. This temperature is called "reference temperature". The time obtained to reach this temperature during the follow-up test shall be longer than 102 min (which represents 85% of 120 min).

If the measured water content value of the fire protection material is more than 3%:

a) when using this material for the reference test, the characteristic temperature at 120 min shall be calculated in accordance with paragraph A.12;

b) when using this material for annual follow-up test, the time when the reference temperature at 15 mm in the concrete slab is reached shall be calculated by taking off from the time obtained during the follow-up test, the difference of duration of the initial steady vaporisation phase compared to a product with a water content of 3%.

Example 3

The fire protection material under test has a water content of 5%. The duration of the initial steady vaporisation phase at 5% is 10 min. Then:

a) if the protection material is used for the reference test: The characteristic temperature at 120 min should be calculated with the temperatures measured at 124 min (120 min + 10 min × (5% – 3%) / 5%);

b) if the protection material is used for the annual follow-up test: During the follow-up test, the reference temperature at 15 mm was reached at 116 min. This time should be corrected as follow: 116 min – (10 min – (5% – 3%) / 5%) = 111 min. In this example, we obtain 111 min which is superior to 102 min. The performance criteria of the follow-up test is therefore satisfied.

APPENDIX B: DOCUMENTS TO PRODUCE / TO REQUEST

The documents to be produced by the French approved laboratory and required by the project manager to justify the performance of the passive fire protection systems are mentioned in paragraph 4.4 of this guide. Their content is described below, with the exception of the classification report, for which it is necessary to refer to the amended decree of 22 March 2004.

B.1 *"Procès-verbal"*

On the basis of the test reports issued by an accredited laboratory, the French approved laboratory will draft a report called *"Procès-Verbal"* describing the following points:

- name of the test laboratory having issued the *"Procès-Verbal"*,
- name and address of the sponsor,
- reference number of the test report(s),
- brief description of the passive fire protection system,
- method of assembly and installation of the passive fire protection system, as required for on-site checks,
- representativeness of the component,
- table of results for characteristic temperatures taking water content into consideration,
- table of maximum temperatures over joints (for board protection material),
- scope of validity,
- expiry date for validity,
- date of issue of the minutes,
- name and signature of the issuer.

For HCM tests, the *"Procès-Verbal"* is valid for 1-year, renewable provided to the justification of the constancy of the heat transfer characteristics (see paragraph A.15 of Appendix A).

B.1 Extended application and *"Avis de chantier"*

Reminder: the *"avis de chantier"* is required if there is slight deviation between the actually implemented design and the test configuration or conditions. These modifications may relate to the following points in particular:

- layout,
- fixation type and density,
- board dimensions,
- board thickness,
- type of concrete support,
- fire resistance criterion.

An *"avis de chantier"* is determined in accordance with the amended decree of 22 March 2004 [3], on the basis of:

- one or several test reports,
- one or several *"Procès-Verbaux"*,
- available experimental data,
- additional numerical assessments.

The laboratory will carry out checks on the basis of knowledge acquired on the date of issue of the *"avis de chantier"*. This knowledge can be the result of a combination between existing tests or tests to be performed and calculations or expertise.

As defined in the amended decree of 22 March 2004, an *"avis de chantier"* is valid exclusively for the site indicated.

If the request is generic and likely to affect several sites, a laboratory approval can be drafted in order to extend the field of application of the results (see paragraph 4.4 of this guide). Extensions in relation to the above reasons must be justified. The combination with tests on small test specimens may be taken into consideration.

A significant difference can be highlighted between the test configuration and the behaviour of the concrete within the structure (type, mechanical characteristics, loading, etc.). Should any doubt arise on the transposition of fire resistance performance of the tested protection system to the structure in question, additional testing may be required.

APPENDIX C: OPTIONAL ADDITIONAL TESTING

Reminder: on the date of the test, the bulk density (kg/m^3) and water content of fire protection material, after drying at 105°C (% of dry weight), or even 50°C for gypsum-based products, (see paragraphs A.4 and A.5 of appendix A) must be systematically measured.

In order to establish extensions and *"avis de chantier"* (see paragraph 4.4 of this guide), the French approved laboratory may require to perform the following additional testing to characterise other thermal and physical properties of the fire protection material such as:

- thermal conductivity (W/m·°C) over 10 temperature points between 20 and 1,250°C,
- specific heat (J/kg·°C) over the temperature ranging between 20 and 1,250°C,
- heat diffusion,
- the contraction/expansion coefficient over the temperature ranging between 20 and 1,250°C.

The temperature points for thermal conductivity determination will cover the interval between 20 and 1,250°C. A DTA/TGA (Differential Thermal Analysis / Thermo-Gravimetric Analysis) will be carried out beforehand to determine which temperatures indicate a change in the fire protection material. The samples used for these tests will be taken from the same batches of fire protection materials as those implemented on the fire resistance tests performed in accordance with the standard NF EN 13381-3. The characterisation tests will be performed for each fire protection material thickness required for extensions and *"avis de chantier"*.

The thermal conductivity and specific heat will be used for thermal transfer simulations based on a finite element modal to determine the thermal insulation performance of an intermediate thickness for the fire protection material, including between the minimum and maximum thicknesses actually tested.

The thermal expansion/contraction coefficient curve may be used to correlate with the hot mechanical behaviour of the fire protection material, as recorded during tests, as well as any contraction along joints between boards if applicable.

For the concrete, the density and water content taken into account in calculations will correspond to those determined based on (200 ± 5) mm × (200 ± 5) mm × (140 ± 5) mm reference samples prepared for this purpose when casting the concrete slabs. The thermal conductivity and specific heat will correspond to those indicated in the standard EN 1992- 1-2 Eurocode 2: "Design of concrete structures – Part 1-2: General rules – Structural fire design": December 2004.

Contributors

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