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BSI Standards Publication

Fire tests for building elements and components — Fire testing of service installations

Part 3: Single component penetration seals — Guidance on the construction and use of test configurations and simulated services to characterise sealing materials

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National foreword

This Published Document is the UK implementation of ISO/TR 10295-3:2012.

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TECHNICAL REPORT

ISO/TR 10295-3

First edition
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Fire tests for building elements and components — Fire testing of service installations —

Part 3: Single component penetration seals — Guidance on the construction and use of test configurations and simulated services to characterise sealing materials

Essais au feu pour les éléments et composants de bâtiment — Essai au feu des installations de service —

Partie 3: Joints de pénétration à composant unique — Lignes directrices sur la construction et l'utilisation des configurations d'essai et des processus de simulation permettant de caractériser les matériaux d'étanchéité

Reference number
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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.

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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 10295-3 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

ISO/TR 10295 consists of the following parts, under the general title *Fire tests for building elements and components — Fire testing of service installations*:

— *Part 1: Penetration seals*

— *Part 2: Linear joint (gap) seals*

— *Part 3: Single component penetration seals — Guidance on the construction and use of test configurations and simulated services to characterize sealing materials*

Introduction

This Technical Report describes a range of standard test configurations and associated testing procedures designed to determine the relevant characteristics of a penetration seal composed of one material when subjected to the standard fire exposure conditions outlined in ISO 834-1. It is used in conjunction with ISO 10295-1 in order to establish relationships between the parameters that influence the performance of the seal in use. The test data generated by this procedure are intended to assist in the classification of penetration seals based on their intended use and fire resistance under the specified acceptance criteria of this part of ISO 10295, i.e. their field of extended application by use of the methodology given in ISO/TR 12470.

In addition, the methodology is recommended to manufacturers for use when developing new sealing products, as it provides a way of establishing the limiting characteristics of the sealing system in a quantifiable manner. This report describes a procedure intended to be followed utilizing a well selected series of test configurations, which can be used to generate a data set to characterize the fire sealing capabilities of a single component penetration seal material. The data set is intended to contain enough information to provide users with engineering data to determine the suitability of the material in applications other than that in which the material was originally tested.

A wide variety of product types is used to reinstate the integrity of a fire-separating element when penetrated by a service or group of services. These product types include, for example

a) soft fillers (sealants or ‘mastics’);

b) semi-rigid intumescent strip materials on their own or in combination with elastomeric foam materials;

c) rigid fibrous batts;

d) rigid board systems;

e) rigid fillers (epoxies or cementicous);

f) cementicous plasters/clay/vermiculite systems.

A wide variety of materials is used to “firestop” penetrations through which building services pass. These materials all fail at some time during a fire, but the nature of the method of failure; melting, slumping, charring through etc., needs to be fully understood if a field of application is to be determined with any confidence. Standard configurations and their associated test procedures need, in due course, to be derived to replicate the appropriate failure modes and also to increase the range of simulated services so the range of tests and configurations described in this part of ISO 10295 are not exhaustive.

Fire tests for building elements and components — Fire testing of service installations —

Part 3:
Single component penetration seals — Guidance on the construction and use of test configurations and simulated services to characterize sealing materials

1 Scope

This part of ISO 10295 provides guidance in respect of a structured method of characterizing the penetrating seal under test utilizing a series of defined parameters, each one being determined by the use of a selected series of test configurations in conjunction with simulated services. The level of characterization being sought is dependent upon the classification requirement of the system, which in turn determines the complexity of the test program. It is also intended the test method addresses the influence the supporting construction has on the performance of the seal system.

The methods described apply to the determination of data relating to single component penetration seals where the penetration service does not melt out within the appropriate period of exposure to a fully developed fire.

The selection of the appropriate system depends upon many factors. Of particular importance is the size of the penetration, since penetration seal systems are frequently penetration size (or size range) specific.

This is a guidance document, its purpose being to determine the critical parameters relating to the performance of the seal being evaluated. Such parameters can then be used as a basis for interpolation and/or extrapolation of the seal's performance. The procedures used have been developed utilizing small square penetrations, single component penetration seals, and cylindrical conductors; however it is possible to generate a similar series of tests using rectangular cross-section conductors if this is more appropriate to end use.

This part of ISO 10295 provides a structured approach designed to establish

— the mode of failure;

— the parameters critical to the performance of the penetration seal under test.

The mode of failure and critical parameters are ascertained using test configurations appropriate to the potential performance of the product, in conjunction with clearly defined standard penetrations.

The results gained from the application of this technical report are designed to assist a suitably qualified person to develop a direct and extended field of application for the penetration seal under test using in particular, the principles and methodology given in ISO/TR 12470. Using the field(s) of application so generated, it should be possible to classify the penetration seal, thus facilitating its incorporation into specifications.

The test configurations recommended in this part of ISO 10295 are not appropriate for evaluating multi-component penetration seals.

This part of ISO 10295 is not appropriate for characterizing all types of penetration seals, e.g. pipe closers/collars and some gland systems, for which evaluation using ISO 10295-1 is more appropriate.

This part of ISO 10295 does not address the distance required between services that can generate their own heat. When a live service is being evaluated, it is necessary to give consideration to the distance required between penetrations.

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, *Fire-resistance test — Elements of building construction — Part 1: General requirements*

ISO 13943, *Fire safety — Vocabulary*

ISO 10295-1, *Fire tests for building elements and components — Fire testing of service installations — Part 1: Penetration seals*

ISO 10295-2, *Fire tests for building elements and components — Fire testing of service installations — Part 2: Linear joint (gap) seals*

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

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10295-1, ISO 10295-2, ISO 13943 and the following apply.

3.1
single component penetration seal
penetration seal with either a single simulated service, i.e. a cable or pipe, or multiple simulated services passing through it, where the free space between the simulated service(s) and the supporting construction are filled by a single material

3.2
multi-component penetration seal
penetration seal with either a single simulated service, i.e. a cable or pipe, or multiple simulated services passing through it, where the free space between the simulated service(s) and the supporting construction are filled by more than one material

3.3
pipe closer device/collar
pre-fabricated heat activated device which under fire exposure acts to crush plastic pipes or ducts which pass through vertical or horizontal separating elements

NOTE The device normally consists of a metal canister containing pressure producing intumescent material.

3.4
associated supporting construction
supporting construction which is specially designed to replace the element to be sealed in practice and which, when tested in conjunction with the seal, forms the direct field of application

3.5
fire barrier bulkhead
product normally rigid in form, which fills the bulk of the penetration when the simulated services fill a relatively small area of the hole in the separating element

3.6
intumescent
phenomenon of expansion considerably in excess of normal thermal expansion under the action of heat, normally generated by fire

3.7
intumescent seal
sealant that remains flexible after curing and which contains materials that expand on heating to maintain the seal under the action of fire

3.8
fire seal
seal designed to prevent the passage of fire, smoke or hot gases

3.9
free space
void or volume between a single, or group, of simulated service(s) and the supporting construction occupied by the penetration seal

3.10
service (in practice)
building service, typically a metal pipe or a metal cored cable, for the purpose of conveying liquids or gases or for transmitting power which can have a relationship derived with one of the simulated services in terms of its similarity with heat flow, conductivity, etc.

NOTE Services exclude thin steel sheet items such as trunking.

3.11
simulated service
conductor in rod form (usually steel) which penetrates the seal system under test, in a manner similar to a pipe or cable, which is capable of stressing the seal in a defined reproducible manner

3.12
multiple simulated services
several simulated services of the same type

4 Test equipment

Equipment employed in the conduct of this test consists of a furnace, support frames and instrumentation as specified in ISO 834-1 and in this part of ISO 10295.

The internal dimensions of the furnace shall be a minimum of 1 m by 1 m by 1 m. The furnace shall be such that a distance of at least 200 mm exists between any point of the periphery of any penetration seal and the wall of the furnace.

A method shall be provided on the unexposed face for rigidly supporting the simulated service at a distance of between 400 mm – 450 mm from the unexposed face of the penetration seal except where the penetration seal is being evaluated for loading or movement. Refer to Figure 1.

The guide does not replicate the associated supporting construction used in practice.

5 General performance criteria

The simulated service and the single component penetration seal shall be evaluated in accordance with the method described in ISO 10295-1.

The purpose of a penetration seal is to reinstate the fire resistance of the element being penetrated. The recommended test configurations are designed initially to establish the fire resistance of the penetration seal. The use of the cotton pad test shall be discontinued when the temperature of the simulated service reaches 300 °C.

A thermocouple shall be fixed to the simulated service at a distance of 50 mm from the unexposed face of the penetration seal. The purpose of this thermocouple is to determine when it is inappropriate to use the cotton pad test. This test method is not designed to predict the temperature rise on the simulated service, unless the material coincides with that used in practice.

The temperature rise of a simulated service with different thermal characteristics to that tested may be predicted based upon the temperature measured by the thermocouple on the simulated service using the methodology recommended in ISO/TR 12470, but this can require evidence generated by other tests.

6 Guidance on test configurations and procedures

If it is the intention to evaluate the ability of a single component penetration seal to seal a defined penetration and to reinstate the integrity of the fire separating element, then the test should be set up and conducted according to ISO 10295-1. The direct field of application is according to ISO 10295-1.

7 Test procedures

These test procedures are proposed to characterize the capability of the seal to withstand conditions that can be experienced by the seal in square penetrations. If the penetration has another geometry, e.g. circular, it can be necessary to confirm L_c for these penetrations by repeating the configuration A.

No attempt has been made to define in absolute terms the degree of movement (see 7.6), nor the magnitude of any loads (see 7.7) as these need to be representative of the intended market. In the case of movement (section 7.6), an outline of a procedure has been suggested, but other magnitudes of movement may be equally justifiable.

If it is the intention to derive an extended field of application for the single component penetration seal, then further characterization is required. This is achieved by testing the single component penetration seal using a series of test configurations; each one designed to provide information relating to a particular parameter (P). The flow chart shown in Figure 1 can be used to assist in the construction of an appropriate test programme.

The test configurations A, B and C utilize single simulated services which form part of the mandatory entry point of the characterization programme. The test configurations provide the basic information to enable a suitably qualified person to develop a field of application for the single component penetration seal under test. If the product is to be used for multiple simulated then an additional test, test configuration D is mandated to establish the influence of the size of the gap between the penetrations has upon the penetration seal. When the multiple simulated services are of a mixed type then the data generated by the test described in test configuration D is not directly applicable.

The standard simulated service shall be solid mild steel.

Supporting construction shall be according to ISO 10295-1, e.g. blockwork 650 ± 200 kg/m3. The appropriate thickness of the supporting construction shall be based upon the duration of the initial testing, except where the test arrangement is designed to evaluate the influence of supporting construction on the fire resistance of the seal. Alternative supporting constructions may be selected in order to extend the field of application of the penetration seal.

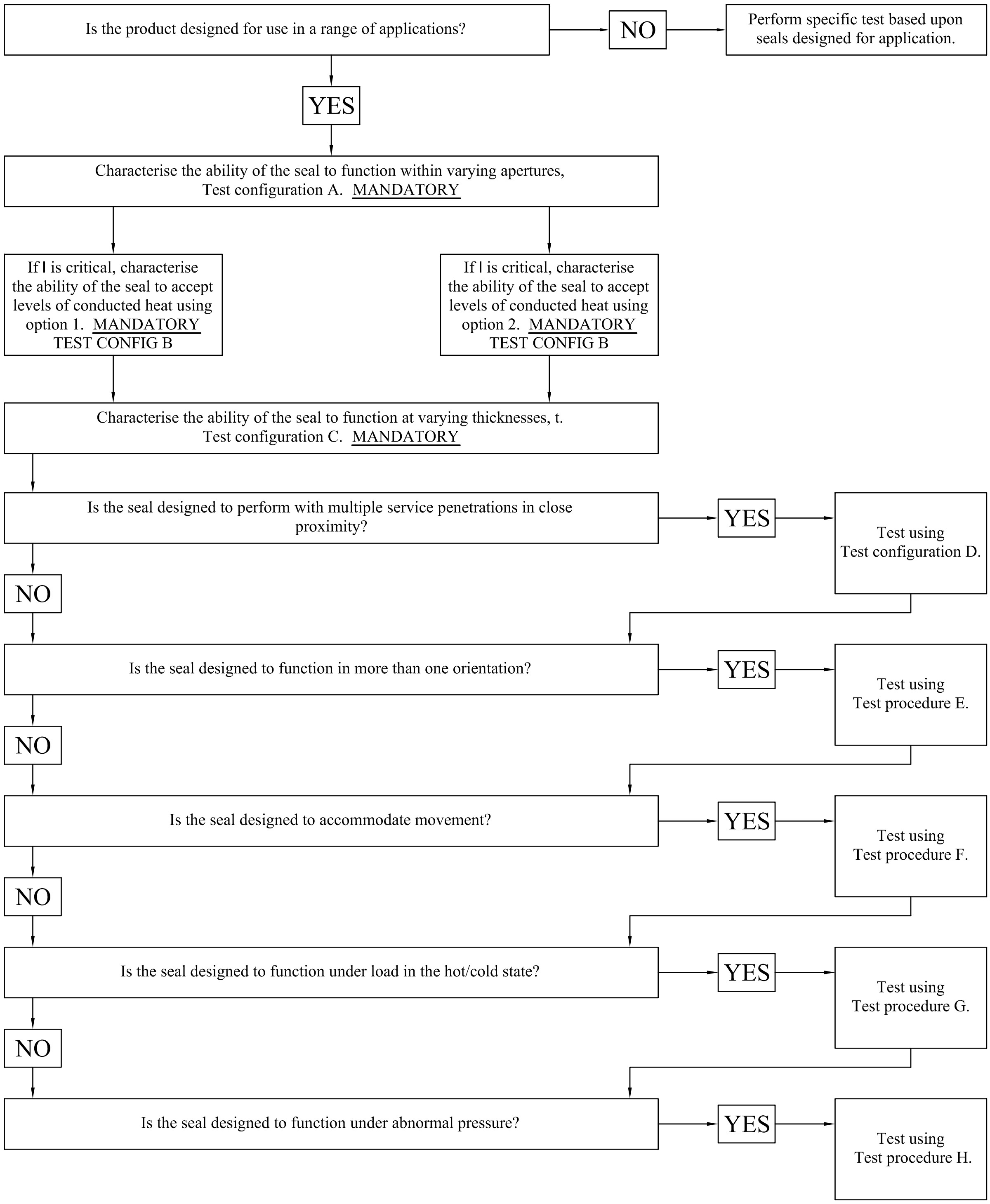


Figure 1 — Flow diagram

7.1 Test configuration A — Size of unsupported free area of penetration seal

This configuration is designed to evaluate the effect of a variation in the free area between the simulated services(s) and the supporting construction on the ability of a single component penetration seal to maintain the integrity of the element being penetrated.

Integrity failure probably occurs via one of two mechanisms.

7.1.1 Distance L is critical when the mechanical/structural failure of the single component penetration seal is due to slumping and/or shrinkage.

7.1.2 Conductivity of the simulated service is critical when the exhaustion of the single component penetration seal is due to erosion or over activation as a result of conductivity (L or M is too small).

NOTE The procedure adopted in test configuration B (7.2) is dependent upon which of the above mechanisms is relevant.

7.1.3 The depth of the single component penetration seal used in test configuration A shall be specified by the sponsor and be related to the fire resistance rating for which the maximum free space is to be established. When the single component penetration seal is used for various fire resistance ratings, then it is likely that the single component penetration seal will be applied at different thicknesses. Similar tests can be needed for all fire resistance ratings unless the evaluation does not demonstrate a mode of failure related to area.

7.1.4 Figure 2 illustrates 1S, 1,33S, 1,67S and 2S, but other increments may be used if required.

7.1.4.1 Refer to Figure 2 as an example of a constant stylised service (e.g. 50 mm diameter) with a variable penetration (height and width varying by fixed increments) and a constant thickness of single component penetration seal (e.g. 50 mm).

7.1.4.2 Other dimensions may be applicable for other applications.

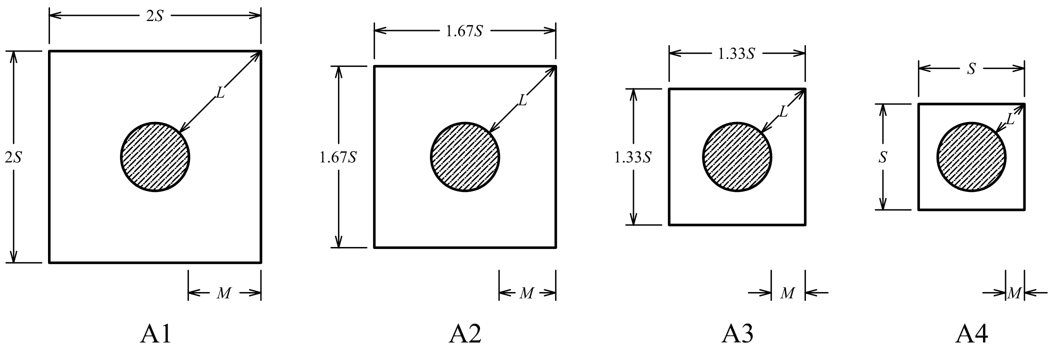


Figure 2 — Test configuration A — Standard (Fixed) simulated service diameter

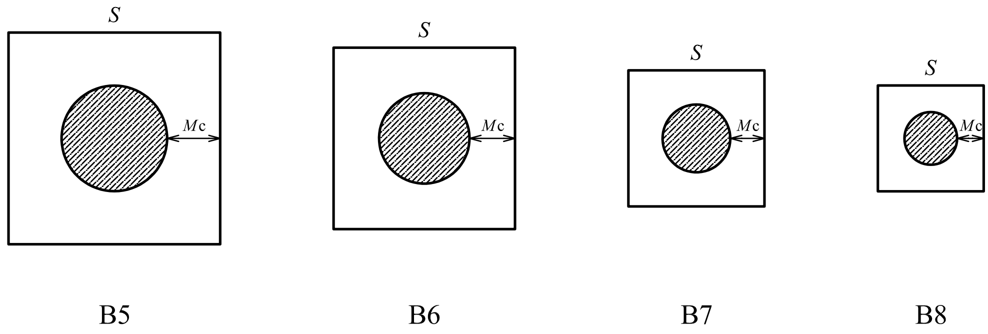
7.2 Test configuration B — Thermal diffusity of the conductor / penetration

This configuration is designed to evaluate the effect of a variation in the heat conducted by a simulated service on the ability of a single component penetration seal to maintain the integrity of the element being penetrated. This is achieved by the incorporation of a series of simulated services of varying diameter, but with constant material in the configuration

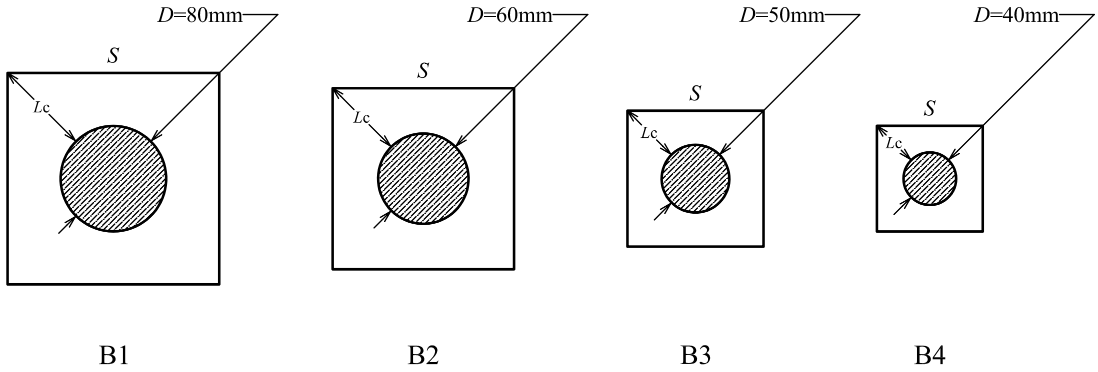
Based upon the information generated by test configuration A, the dimensions S of the penetrations for B1, B2, B3 and B4 are derived from the relationship between the diameter of the simulated service d and L_c using the equation $1{,}4\left(\frac{D}{2}+L_c\right)=S$, for each penetration in turn, if failure mode was as described in 7.1.1 due to slumping or shrinkage or $D + 2M_c$ for B5, B6, B7 and B8, where D = diameter of the simulated service and failure mode was exhaustion as described in 7.1.2.

7.2.1 Figure 3 illustrates an example of constant critical area of seal based upon either L_c or M_c with a conductor, which changes in diameter by fixed increments (e.g. Twenty mm increments) and with a constant thickness of seal (e.g. 50 mm), related to required duration.

7.2.2 In order to reduce the thermal delay of the large diameter conductors it can be necessary to reduce their mass by the use of hollow sections.



Option 1 – Minimum unsupported dimension of sealant, M_c



Option 2 – Maximum unsupported dimension of sealant, L_c

Key

L_c maximum unsupported dimension of the sealant

M_c minimum unsupported dimension of the sealant

Figure 3 — Test configuration B

7.3 Test configuration C

Variation in the thickness, d, of the seal has a considerable effect on the duration for which the seal is able to maintain the integrity/insulation of the penetrated element.

This configuration is designed to evaluate the influence that such a variation in the depth of the single component penetration seal has when installed within the opening relative to one of the faces of the element being penetrated.

The size of the penetration used in this test configuration may be derived from test configuration A, for the fire resistance rating being investigated.

7.3.1 Figure 4 illustrates 1d, 1,33d, 1,67d and 2d, but other increments may be used if it is required to identify the relationship.

7.3.2 Figure 4 is an example of a constant penetration size, constant simulated service (e.g. 50 mm diameter) with a variable thickness of seal, d, which changes by fixed increments.

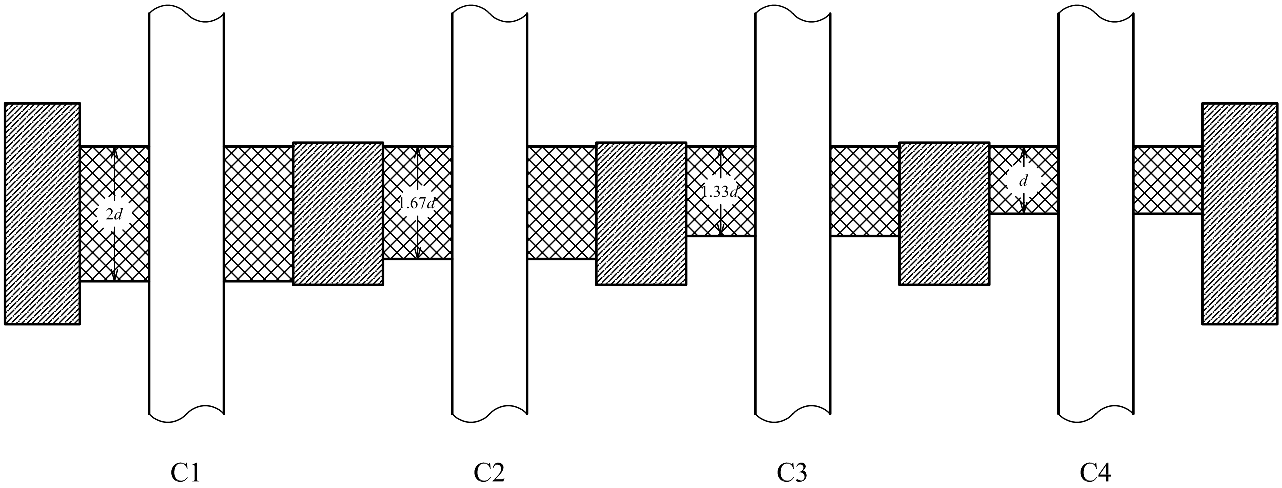


Figure 4 — Test configuration C

7.4 Test configuration D — When multiple simulated services are being tested

This configuration is designed to determine the effect of any interaction between two (or more) simulated services on the single component penetration seal.

Figure 5 is an example of constant simulated services (50 mm), constant sealant depth with gaps between simulated services that vary by fixed increments.

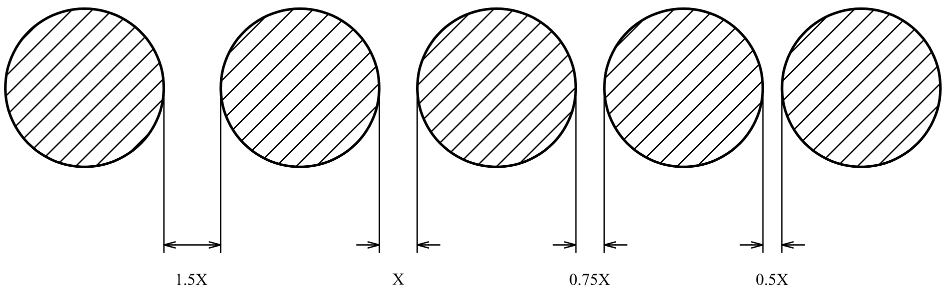


Figure 5 — Test configuration D

7.5 Test procedure E

This test procedure is designed to characterize the ability of the single component penetration seal to be effective in more than one orientation.

Repeat configuration A in alternative orientation.

7.6 Test procedure F

This test procedure is designed to characterize the ability of the seal to accept movement of the simulated service during the fire.

This should be restricted to axial movement only. Configuration A3 is to be displaced axially from the single component penetration seal in 25 mm increments at agreed times during the test, say (a) the fire resistance rating (when known) minus 15 min, (b) the fire resistance rating, and (c) the fire resistance rating plus 15 min.

7.7 Test procedure G

This test procedure is designed to characterize the ability of the single component penetration seal to function while experiencing loads during fire exposure. This can also be used to characterize the ability of the single component penetration seal to withstand a load in the ambient state as a pre-conditioning test.

A configuration, say A3, is to be pivoted on the unexposed face to allow movement in the vertical plane, rather than being rigidly fixed. This is to enable it to exert a load on the single component penetration seal during the test. A number of such simulated services may be tested simultaneously with a load applied to each, which varies in fixed increments.

7.8 Test procedure H

This test procedure is designed to characterize the residual strength of the single component penetration seal, not the simulated service, when the application requires strength after the period of classification has been satisfied in respect of integrity and, if appropriate, fire resistance.

A jet of compressed air at a pressure of 300 Pa is to be applied evenly via a 5 mm diameter orifice at a distance of 300 mm to the surface of the single component penetration seal for a period of say 2 min and increased by fixed (100 Pa) pressure increments at 5 min intervals until failure occurs. The failure pressure is recorded for use by the approval authority.

Test procedure H is not required by any European legislation but being conscious of the need for residual strength evaluation in the USA, normally evaluated by means of the hose stream, this procedure has been included to obtain a basic evaluation of the ability of the seal to demonstrate some strength. The existing hose stream test in the USA has not been called up because of the disproportionate impact force that it would apply. Any other body that requires a residual strength can use this principle, but may, if necessary, use the alternative pressures as appropriate to the application, albeit the report shall give some justification for the pressure used.

8 Deriving the field of application by judgemental analysis

8.1 Analysis using test configuration A

When using the test configuration A (see 7.1) to decide the field of application in respect of maximum free area, characterized by the critical major axis L_C, it is anticipated that during the heating period an integrity failure will occur in one of the penetrations. This identifies the critical free area dimension that can be sealed up to that duration. If the penetration size has been well chosen, it should be possible to seal that penetration further and continue the test to establish the maximum free area at other durations. The maximum free area is not necessarily the maximum penetration, but is the maximum area of seal in a penetration that can be unsupported, either by the simulated services themselves or by a form of framing that may reduce the area. If the critical free area can be established for more than one duration, then these may be presented graphically on a graph of L_C vs. duration (min). More than one series of tests can be needed to achieve this.

When analysing the results, should the integrity failure be seen to occur at the outer perimeter of the seal, then an investigation should be carried out into the influence of the supporting construction as this can well affect the rating that can be claimed. When the integrity failure occurs adjacent to the simulated service, then this can indicate a relationship between the thermal conductivity and thermal inertia of the conductor and the field of application should be established in conjunction with the methodology given in 7.2, option 2.

8.2 Analysis using test configuration B

When evaluating the results of tests using either of the test configurations shown in B (see 7.2), it is anticipated that the integrity will vary in a manner related to the flow of heat along the conductor. Heat flowing from the conductor into the sealant leads to a deterioration of the sealant, which is more rapid when the conductors are closer together. This test should clarify the susceptibility of the sealant to this mode of failure. The conductors should be selected for the application as follows:

— Steel for pipe applications;

— Brass (80/20) for cable conductor applications;

— Glass for fibre optic data cables applications.

As in 8.1, the objective of the test is to establish the critical thermal diffusivity of the simulated service conductor for a range of durations. This can require more than one series of tests to be carried out. If the critical thermal diffusivity can be established over a range of durations at the critical free area, then these may be presented graphically using a graph plotting thermal diffusivity against duration.

8.3 Analysis using test configuration C

The objective of test configuration C is to establish the relationship between seal depth and the duration for which integrity (and insulation if a criteria of the application) can be satisfied using both a critical free area and a conductor with a critical thermal diffusivity for the intended application. It would, hopefully, be possible to re-seal each penetration upon failure in order to continue the test to establish a relationship between seal depth and duration. As previously, a number of test series may need to be run with varying critical free areas and conductors. It would be intended that a graph could be produced giving the relationship between seal depth and duration.

8.4 Analysis using test configuration D

Unlike the previous configurations, it is not intended to establish a relationship between the distance between conductors and the duration for which integrity (and insulation if a criteria of the application) is maintained. The objective of test configuration D is to establish the minimum gap at which the integrity is not compromised as a result of inhibiting the material from sealing when two conductors with critical thermal diffusivity (relative to the rating) are placed in close proximity to each other. This value shall be clearly reported and used as an overriding restriction against all performance claims in the field of direct application.

9 Deriving the field of application by mathematical analysis

In order to determine the fire resistance of a penetration sealing system as a function of the parameters that influence the performance of the sealing system, it is necessary to fire-test many test specimens. For metal pipes, for example, the test specimens may vary with respect to pipe diameter, thickness of the supporting construction, distance from the outer pipe wall to the supporting construction, pipe wall thickness and also with respect to the depth of the seal and the length of any protection material on the pipe.

When fire tested in their protected state, these pipe penetration test specimens provide a wide range of temperatures as measured on the unexposed part of the penetration sealing system and the pipe. The temperatures may vary from 20 °C up to 1 000 °C, all normally with different temperature/time relationships.

Furthermore, the performance of the pipe penetration sealing systems with respect to the integrity criterion can also show a wide range of results if all parameters are varied.

Because there are so many variables it is difficult to find the relationship between them in order to successfully determine the performance of the pipe penetration sealing system with respect to its seal thickness, the pipe diameter, the distance from the outer pipe wall to the supporting construction and the time to reach the maximum allowed temperature rise of 180 °C, i.e. the fire resistance time provided that the thermal insulation performance is the most critical indication of failure.

9.1 Use of the 3-D interpolation method to predict the extended field of application

The typical data set which forms the output of tests performed in accordance with this part of ISO 10295 has four (4) variables; seal thickness d, distance S, diameter D and performance time. A non-subjective way of analysing these data are by means of the 3-D interpolation method developed for the purpose of predicting the dry film thickness of the intumescent coatings based upon a range of tests using steel specimens with various section factors coated with intumescent paint at different thickness. The technique is proposed for inclusion in ISO 834-11 which as of the publication date of this part of ISO 10295 is undergoing Committee Ballot.

This technique is also applicable to the evaluation of penetration sealing systems where the variables have been chosen in a logical way to characterize the material. An example of how the method can be used to generate an accurate prediction of the integrity performance of metal conductors passing through a seal system is given in Annex B.

Annex A
(informative)

Determining the extended field of application

The penetration seal is designed to reinstate the integrity of the penetrated element via a variety of mechanisms. These mechanisms are usually defined as ablative, intumescent, insulative and/or endothermic. Ablative materials maintain the integrity of the penetrated element through a self-sacrificing process of erosion. Intumescent materials maintain the integrity of the penetrated element by expanding to form a fire resistant char. Insulative materials maintain the integrity of the penetrated element by having a very low thermal transmission rate. Endothermic materials maintain the integrity of the penetrated element by absorbing energy. A combination of these mechanisms is also possible.

Unfortunately, all of the materials in the above list fail by different mechanisms making it difficult to derive a field of application for a specimen containing different materials, or combinations of materials.

This part of ISO 10295 is one of the parts of the ISO 10295 fire resistance test procedures. It is designed to characterize the behaviour of penetration seals where a single material is used to seal the penetration between the simulated service(s) and the supporting construction (single component penetration seals).

It defines of a series of test procedures which are designed to generate information additional to that obtained via ISO 10295-1. By so doing it enables a qualified person, i.e. a fire engineer to construct a technical profile of a product designed to function as a single component penetration seal. Using the information generated in such a manner a fire engineer is able to make a qualified judgement as to the suitability of the material in an environment other than that in which its fire resistance was originally evaluated

In practice, services vary tremendously in terms of material, sizes, cross-sectional area and geometry all of which makes the comparison of sealing capabilities difficult. This test procedure recommends the use of simulated services, representative of large conductor cables, or bundles of small conductor cables, (minus their sheathes), metal pipes or metal cable/pipe supports. Such a procedure will reduce the lack of repeatability and reproducibility associated with actual area and thermal inertia.

This relationship might, or might not be one to one, but should be sufficiently quantifiable to enable the influence to be given a value.

Using these simulated services, with their improved repeatability, it is possible to set up a series of tests with controlled specimens where the critical parameter being investigated is varied to establish the relationship between the capabilities of the sealing system and the characteristics of the simulated service/supporting constructions. Such a relationship may utilize appropriate linear regression analysis or other appropriate mathematical techniques to predict the performance when a service penetrates an penetration of different dimensions.

This part of ISO 10295 does not directly address the likelihood of ignition of any insulation applied to cables or for the ability of any coating system to provide insulation to services, although a temperature profile on the unexposed face of the simulated service will assist in making predictions of these aspects. Similarly, the influence of the insulation melting out and affecting the seal is not covered by these tests. The influence of any insulation on the capability of the seal to maintain the period of fire resistance, or otherwise, may be quantified by a small additional programme to evaluate the characteristics of the insulation.

The varying nature of the penetration seal and its mode of operation necessitate a test method capable of generating information sufficient to demonstrate a field of application in excess of that generated by the single test method.

Recommended standard configurations for characterizing the critical parameters of penetration seals where the bulk of the penetration is sealed by a board or a batt are not considered here.

Annex B
(informative)

Example of the application of the principles of 3-D interpolation to the establishment of the extended application of penetrating sealing system

In order to illustrate the use of this mathematical model two product types have been selected. The first is cementicous based (material C) which incorporates some reinforcing fibre. The other is a typical intumescent based product (material I).

For both materials a set of square penetrations are selected which range between 60 and 190 mm in width and height (S) for product C and also between 60 and 190 mm for Product I. The steel conductors used vary between 20 and 85 mm in diameters (D) for Product ‘C’ and also between 20 and 85 mm for Product ‘I’.

For each material three tests are performed. In tests 1 and 2, the distance (M) was varied while the conductor diameter stayed constant, but the conductor diameter (D) was different between the two tests. In test 3 the distance (S) was fixed and the conductor diameter (D) varied for each penetration in the test assembly.

To aid comparison the seal thickness is controlled to 40 mm for all tests.

A series of values typical of, but not identical to results from existing proprietary products have been selected, to demonstrate how the methodology of generating an extended application is achieved in practice.

Table B.1 — Typical test results — Cementicous incorporating reinforcing fibre

Test C1			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
1a	60	20	70
2a	90	20	89
3a	120	20	102
4a	150	20	131
Test C2			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
5a	90	75	55
6a	120	75	77
7a	150	75	96
8a	190	75	140
Test C3			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
9a	125	30	98
10a	125	50	90
11a	125	70	82
12a	125	85	60

Table B.2 — Typical test results — Intumescent containing compound

Test I1			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
1a	60	20	121
2a	90	20	143
3a	120	20	98
4a	150	20	80
Test I2			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
5a	90	75	140
6a	120	75	158
7a	150	75	108
8a	190	75	91
Test I3			
Penetration No.	**Penetration size** mm	**Conductor diameter** mm	**Integrity** min
9a	125	30	98
10a	125	50	125
11a	125	70	130
12a	125	85	101

Both of the above test programmes have been analysed using the 3-D interpolation method to establish the characteristics of the material.

Using the 3-D Interpolation method, it is possible to generate the relationship between the diameter of the conductor (related to the conductivity of the conductor) and the size of the penetration through which the conductor is passing. The relationship is shown for the cementicious material C in Figure B.1, and for the intumescent containing material I in Figure B.2.

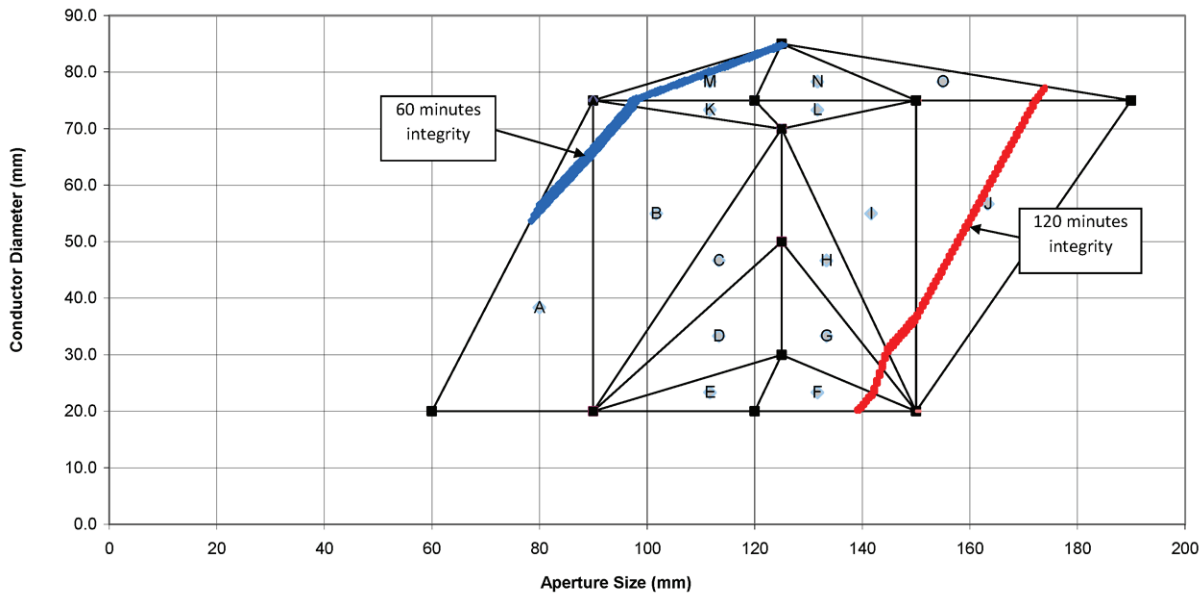


Figure B.1 — Conductor diameter against aperture size for material C

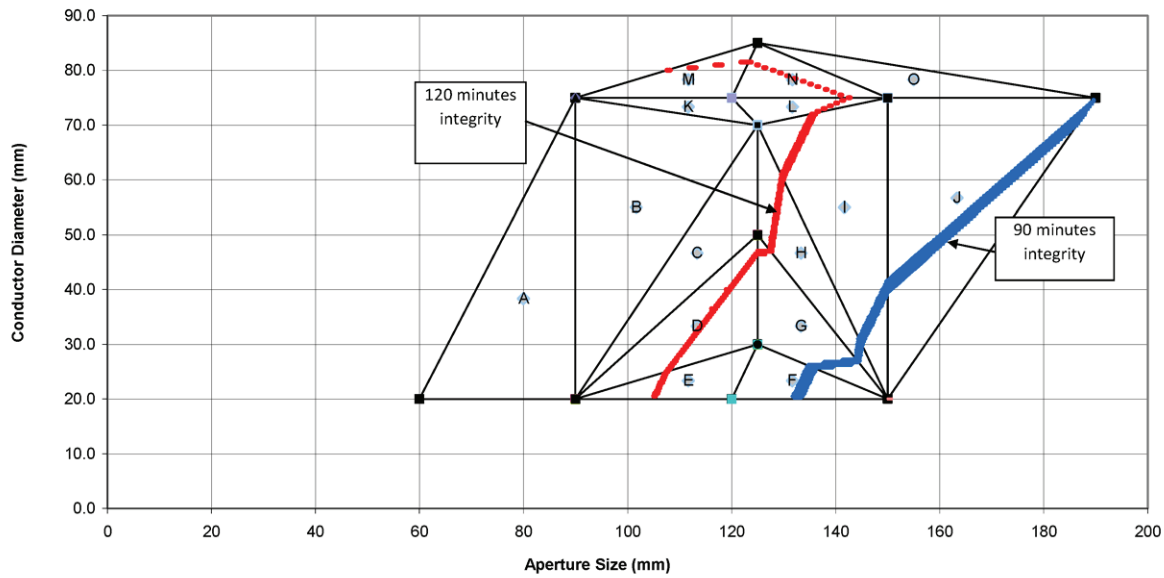


Figure B.2 — Conductor diameter against aperture size for material I

Annex C
(informative)

3-D interpolation method of analysis

C.1 Input data

The data are plotted without adjustment.

C.2 Basic equations

The basic equations are the line equation, given as Equation (C.1) and the plane equation given as Formula (C.2):

$$y = ax + b \quad \text{(C.1)}$$

$$ax + by + cz + D = 0 \quad \text{(C.2)}$$

C.3 Methodology

The following is the stepwise methodology.

— Determination of triangles (domains) (steps 1 to 4).

— Determination of line equations and plane equations (steps 5 to 7).

— Calculate performance time (integrity) as a function of penetration dimension (S) for various conductor sizes (D) (step 8).

— Calculate performance time as a function of conductor diameter (D) for various penetration sizes (S) (step 9).

— Calculate the penetration size, conductor size, seal thickness and integrity time as required (step 10).

C.3.1 Steps 1 to 4: Determination of triangles (domains)

C.3.1.1 Step 1

Prepare an orthogonal xy-axis system, where x represents the penetration size (S) and y represents the conductor diameter (D).

C.3.1.2 Step 2

Determine and plot the coordinates (x_i, y_i) for each test specimen, where x_1 is the penetration size (S) and y_1 is the conductor diameter (D).for test specimen 1, etc.

C.3.1.3 Step 3

Identify and create triangular domains in the xy-plane using the points (x_1, y_1) (x_2, y_2),(x_3, y_3) as the corner points, in accordance with the following algorithm.

— Draw the perimeter of the data set (circumference of all points in the xy-plane).

— Start drawing triangles which share one edge with the perimeter.

— Divide a trapezium shape (formed by 4 points at the corners) into two triangles in such a way that the division line is the shortest possible.

— Work from low penetration size (S) to high penetration size and work from low (D) to high (D).

C.3.1.4 Step 4

Identify every triangle with a reference.

C.4 Steps 5 to 7: Determination of line equations and plane equations

C.4.1 Step 5

Determine the equations for the lines which form the triangles.

The equation for the line through the points has a general form of Formula (C.1).

C.4.2 Step 6

Add a z-axis to the orthogonal xy-axis system, where z represents performance time.

Determine and plot the coordinates (x_i, y_i, z_i) for each test specimen

where

x_i is the penetration size (S) for test i;

y_i is the conductor diameter (D) for test i;

z_i is the integrity failure for test i.

C.4.3 Step 7

For each triangle, determine the equation of the plane that contains the corner points.

The corner points are (x_i, y_i, z_i), where $i = 1, 2, 3$. The equation of the planes has a general form of Formula (C.2).

Each triangular domain has its own unique plane equation.

C.4.4 Step 8: Calculate performance time as a function of the conductor diameter (D)

Calculate the integrity time (t) [for a particular thickness of seal (d)] as a function of conductor diameter (D). This is established by considering a vertical cross-section through the collection of planes for a chosen penetration dimension (S).

Do this for all penetration sizes (S) of interest.

Determine the integrity time (t) for constant penetration dimension (S) by inputting a range of conductor diameters in the plane equation, i.e. calculate the z-value for a range of y-values with constant x. Use the applicable plane equation within the domain of each plane.

C.4.5 Step 9 Calculate performance time as a function of penetration size (S)

Calculate the integrity time (t) as a function of penetration size (S). This is established by considering a vertical cross section through the collection of planes for a chosen conductor size

Do this for all conductor diameter (D) values of interest.

Determine the integrity time (t) for constant conductor diameter (D) inputting a range of penetration dimensions (S) in the plane equation, i.e. calculate the z-value for a range of x-values with constant y. Use the applicable plane equation within the domain of each plane.

C.4.6 Step 10

Once the data have been generated as given in C.3.1 to C.4.5, it is possible to calculate the maximum penetration size (S) for a conductor diameter (D) for an integrity rating t (i.e. 30, 60, 120 min) with a seal thickness d (mm).

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