

Technical performance and principles of system design

Fire performance

Principles of fire performance

Fire growth

The choice of materials for internal and external walls and ceilings can significantly affect the spread of fire and its rate of growth, even though they are not likely to be the materials first ignited. The specification of linings is particularly important in circulation spaces where surfaces may offer the main means by which fire spreads, and where rapid spread is most likely to prevent occupants from escaping.

Two properties of lining materials that influence fire spread are the rate of flame spread over the surface when it is subject to intense radiant heating, and the rate at which the lining material gives off heat when burning.

Compartmentation

The spread of fire within a building can be restricted by sub-dividing it into compartments separated from one another by walls and / or floors of fire resisting construction. Two key objectives are:

- To prevent rapid fire spread, which could trap occupants in the building.
- To reduce the chance of fires becoming large, which are more dangerous - not only to occupants and fire service personnel, but also to people in the vicinity of the building.

The appropriate degree of sub-division depends on:

- The use and fire loading of the building, which affects the potential for fires and their severity, as well as the ease of evacuation.
- The height to the floor of the top storey in the building, which is an indication of the ease of evacuation and the ability of the fire service to intervene effectively.
- The Authority Having Jurisdiction (AHJ), commonly Civil Defence.

Structural fire precautions

Premature failure of the structure can be prevented by the provision for loadbearing elements to have a minimum period of fire resistance to failure of loadbearing capacity. The purpose in providing the structure with fire resistance is:

- To minimise the risk to the occupants, some of whom may have to remain in the building for some time (particularly if the building is a large one), while evacuation proceeds.
- To reduce the risk to fire fighters engaged in search and rescue operations.
- To reduce the danger to people in the vicinity of the building who may be hurt by falling debris, or because of the impact of the collapsing structure on other buildings.

Structural behaviour of steel in fire

Steel generally begins to lose strength at temperatures above 300°C and eventually melts at about 1500°C. Importantly for design, the greatest rate of strength loss is in the range of 400°C to 600°C.

Using international fire design codes, the load on the structure at the time of the fire can be calculated by treating it as an accidental limit state. If used, this will allow designers to specify to the fire protection contractor a limiting or failure temperature for a given structural section. The fire protection contractor will then be able to use the required thickness of material to ensure that the steel section does not exceed this temperature within the fire resistance period. This process could be simplified by the designer specifying a maximum steel temperature, based on the worst case, for all beams or columns on one floor level.

Buildings that are not primarily used for storage, e.g. offices, residential units, schools and hospitals, have a high percentage of non-permanent loads. For this type of building, some structural codes assume that a proportion of the design load will not be present at the time of the fire. Other types of buildings, such as warehouses and libraries, are primarily used for storage, so a high percentage of the load is permanent, and the codes allow for no reduction in design load for the fire condition. Please refer to the Fire and Life Safety (FLS) strategy for the exact project requirements.

The fire testing standards effectively base the failure criteria for loadbearing elements on strength. However, beams are often designed for deflection requirements, which mean that their strength is not fully utilised in the cold state and they would therefore have an additional reserve of strength at the fire limit state.

Columns are frequently designed so that a single length will be two or three storeys high. The lowest storey will be loaded the highest and the upper storey will be lightly loaded.

In buildings with a degree of non-permanent load (in terms of duration and magnitude), the load ratio of the structural members is unlikely to be greater than 0.6. In storage buildings, where the majority of load is permanent, the load ratio would normally be higher, but is unlikely to be greater than 0.65.

The thicknesses of protection required are specified for design temperatures of 550°C, unless otherwise stated. It is the responsibility of the design engineer, to specify the appropriate limiting steel temperatures.

The loss of strength of cold-formed steel at elevated temperatures exceeds that of hot-rolled steel by between 10% and 20%. Expert advice should be sought in determining the strength reduction factor at the limiting temperature.

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Why gypsum is so effective in fire



Glass fibres within the core of a Glasroc specialist board



Failure of fire rated partition

Fire resistance

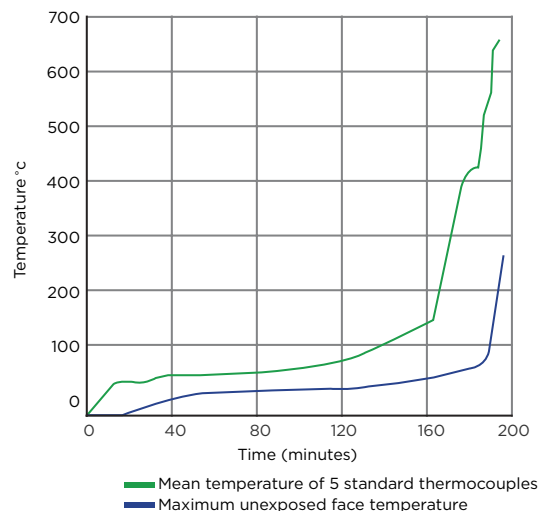
Gyproc Plasterboards and Glasroc specialist boards provide good fire protection due to the unique behaviour of gypsum in fire. When gypsum-protected building elements are exposed to fire, dehydration by heat (calcination) occurs at the exposed surface and proceeds gradually through the gypsum layer. Calcined gypsum on the exposed faces adheres tenaciously to uncalcined material, retarding further calcination which slows as the thickness of calcined material increases. While this continues, materials adjacent to the unexposed side will not exceed 100°C, below the temperature at which most materials will ignite, and far below the critical temperatures for structural components. Once the gypsum layer is fully calcined, the residue acts as an insulating layer while it remains intact.

Figure 1 - Temperature profile on the unexposed face of a partition system, shows a typical unexposed temperature profile for a plasterboard lined partition. The graph shows that there is a significant plateau in the temperature rise, while the plasterboard is undergoing calcination. After this period the temperature gradually rises until the boards lose their integrity and fall away.

The inclusion of glass fibres and shrinkage inhibitors within the gypsum core of certain plasterboards improves the cohesive properties and fire integrity performance. This enables a much higher fire protection performance to be achieved compared to Gyproc Regular board.

In terms of reaction to fire, gypsum products are excellent performers as the endothermic hydration reaction requires energy to be taken from the fire, so gypsum is a negative calorific contributor.

1 Temperature profile on the unexposed face of a partition system



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British test standards



Fire resistance test – integrity testing on 3m high partition

Fire resistance test standards

Building Regulations and supporting documentation require elements of structure and other building elements to provide minimum periods of fire resistance, expressed in minutes, which are generally based on the occupancy and size of the building.

Fire resistance is defined in BS 476: Part 20: 1987 as ‘the ability of an element of building construction to withstand exposure to a standard time / temperature and pressure regime without loss of its fire separating function or loadbearing function or both for a given time.

BS 476: Part 20: 1987

Describes the general procedures and equipment required to determine the fire resistance of elements of construction.

BS 476: Part 21: 1987

Describes the specific equipment and procedures for determining the fire resistance of loadbearing elements.

BS 476: Part 22: 1987

Describes the procedures for determining the fire resistance of non-loadbearing elements.

BS 476: Part 23: 1987

Describes the specific equipment and procedures for determining the contribution made by components to the fire resistance of structures.

Loadbearing capacity

A loadbearing element must support its test load. For floors, flat roofs and beams, allowable vertical deflection is limited to $\frac{1}{20}$ of the clear span.

Integrity

A separating element must resist collapse, the occurrence of holes, gaps or fissures through which flames and hot gases could pass, and sustained flaming on the unexposed face.

Insulation

A separating element must restrict the temperature rise of the unexposed face to below specified levels.

Reaction to fire test standards

Non-combustibility



Non-combustibility testing

To help provide maximum fire safety in buildings, certain building elements need to be constructed of non-combustible materials. A building material is designated as non-combustible if it satisfies performance criteria when tested in accordance with:

BS 476: Part 4: 1970 (1984) Non-combustibility test for materials.

BS 476: Part 11: 1982 (1988) Method for assessing the heat emission from building materials.

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Materials of limited combustibility

- (a) Any non-combustible material.
- (b) Any material of density 300 kg/m^3 or more, which does not flame or cause a 20°C temperature rise when tested to BS 476: Part 11.
- (c) Any material with a non-combustible core at least 8mm thick having combustible facings (on one or both sides) not more than 0.5mm thick. Where a flame spread rating is specified, these materials must also meet the appropriate test requirements.

Gyproc plasterboards are all designated as materials of limited combustibility.

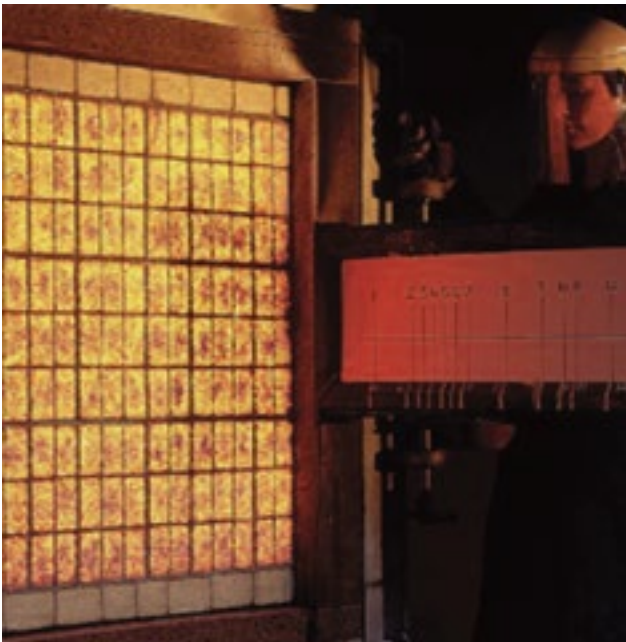
Glasroc X is designated as a non-combustible material.

Surface spread of flame

Flame spread over wall and ceiling surfaces is controlled by providing materials that are either non-combustible or materials of limited combustibility. Combustible materials (or certain materials of limited combustibility that are composite products) when tested to the standards below, are classified Class 1, 2, 3 or 4. Class 1 provides the greatest resistance to surface spread of flame.

BS 476: Part 7: 1997 Method of test to determine the classification of the surface spread of flame of products.

The exposed plasterboard surfaces of Gyproc plasterboards and Glasroc specialist boards are all designated as Class 1.



Surface spread of flame test

Fire propagation

Investigations concerned with the growth of fires in buildings show that the surface spread of flame test does not measure all the properties that are relevant for placing combustible materials in the proper order of hazard. Such considerations led to the test which is described in BS 476: Part 6: 1989 Method of test for fire propagation for products. This test takes into account the amount and rate of heat evolved by a specimen whilst subjected to a specified heating regime in a small furnace. The standard describes the method of calculating the results to obtain indices of performance, which help to determine the suitability of combustible wall and ceiling lining materials when used in areas requiring maximum safety.

Class 0

In addition to the degree to which combustible materials used as wall and ceiling linings can contribute to the spread of flame over their surfaces, consideration must also be given to the amount and rate of heat evolved by these materials when used in areas requiring maximum safety. Designers may choose to make provisions that wall and ceiling surfaces must be Class 0 in circulation spaces (which are often escape routes) and in other specific situations. In UK Building Regulations, Approved Document B (AD B), a Class 0 material is defined as either:

- (a) composed throughout of materials of limited combustibility (this term includes non-combustible materials)

or

- (b) a Class 1 material that has a fire propagation index (I) of not more than 12 and a sub-index (i1) of not more than 6.

The exposed surfaces of Gyproc plasterboards and Glasroc specialist boards are designated Class 0 in accordance with Approved Document B (AD B).

Although Class 0 is the highest performance classification for lining materials, it is not a classification identified in any British Standard.

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American test standards

Fire codes

Fire codes are intended to establish minimum requirements that provide a reasonable degree of safety from fire in buildings and structures. These requirements vary depending on the use, occupancy, and construction details of the specific building. From the standpoint of building materials the codes are generally concerned with flammability ratings of interior finish materials, combustibility of the construction and its components, and the ability of a construction to resist exposure to fire.

Interior finish

Wall and ceiling surfaces are rated by their *flame spread index (FSI)* and *smoke developed index (SDI)*. These ratings are determined in accordance with ASTM E84, Standard Method for Test of Surface Burning Characteristics of Building Materials. This test method determines the relative performance value of the material being tested as compared to inorganic reinforced cement board (FSI = 0) and red oak (FSI = 100). Test methods designated UL 723 and UBC Standard 8-1 are recognised as being equivalent to ASTM E84.

International Building Code (IBC) have established three classes of performance, based upon flame spread and smoke developed indexes, which are used to specify requirements within the code:

CLASS DESIGNATION	FLAME SPREAD INDEX	SMOKE DEVELOPED INDEX
A	0-25	0-450
B	26-75	0-450
C	76-200	0-450

Materials classified as non-combustible

Materials that meet the criteria of ASTM E136, Standard Test Method for Assessing Combustibility of Materials Using a Vertical Tube Furnace at 750°C, are classified as being non-combustible. In this test, a material sample is placed in the test furnace and its flaming time and the furnace temperature are measured. This test method is for the base material only and does not cover any surface coverings or coatings.

For materials that have a surface covering, the model building codes further define a non-combustible material as having a base material that meets the requirements of ASTM E136 and a surface covering less than 1/8" (3mm) in thickness whose flame spread index is not greater than 50.

Fire resistance

The ability of a structure to remain in place and prevent the spread of flames and heat when exposed to fire conditions is termed its fire resistance or time fire rating and is determined in accordance with ASTM E119, Standard Test Method for Fire Tests of Building Construction and Materials. In this test, a large scale construction sample is exposed to a standardised fire condition and performance is measured against test criteria which include temperature rise, ignition of cotton on the unexposed side of the sample, the ability of the sample to remain in place during the test period, and its ability to withstand a hose stream test after the fire test is completed.

The fire resistance rating is stated in periods of time such as 2 hour, 1 hour, 45 minutes and 30 minutes. The test allows the construction to be further classified as load bearing or non-load bearing walls. Test methods recognised UL 263 and UBC Standard 7-1 are recognized as being equivalent to ASTM E119.

Building codes regulate the type and location of materials used in building construction to provide for structural stability as well as for an acceptable degree of occupant safety when the building may be exposed to fire. Local code requirements must be consulted in order to determine specific compliance requirements.

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Useful reference documents covering international legislation and guidance

Fire safety - building regulations

UK Building Regulations Approved Document B (AD B) is one of a series of documents approved by the Secretary of State as practical guidance on meeting the requirements of Schedule 1 and Regulation 7 of Building Regulations 2000 (England and Wales). AD B Volume 1 covers dwelling houses and AD B Volume 2 covers buildings other than dwelling houses.

The documents classify the use of a building into purpose groups and specify minimum periods of fire resistance to be achieved by the building elements. The periods of fire resistance vary according to the use and the size of building. The greater the fire hazard a building presents then the greater the period of fire resistance required to protect the elements within the building. The materials used to form the internal surfaces of the building are also controlled to reduce the risk of fire growth and internal fire spread.

Healthcare buildings - HTM 05 Firecode

Hospitals and healthcare environments, by their very nature, contain people who are at risk from fire. The recommendations given in the suite of HTM (Health Technical Memorandum) 05 Firecode (UK) includes internal fire spread, elements of structure, compartmentation, fire hazard areas, hospital streets, penetrations, protected shafts, ceiling membranes, cavity barriers and fire-stopping.

Educational buildings - Building Bulletin 100 (BB100)

In the UK the design of fire safety in schools is covered by BB100.

Fire protection for structural steel in buildings, ASFP Yellow Book

A UK publication prepared by the members of the Association for Specialist Fire Protection (ASFP). Presents the theory behind, and methods for, fire protection of structural steelwork. It provides a comprehensive guide to proprietary materials and systems.