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SECURING BUILDINGS AGAINST FIRE: STRUCTURAL DESIGN AND MATERIALS SELECTION

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ABSTRACT

Regarding advancement of sciences and technical knowledge of human, especially in recent years, extensive activities about efficient use of energy resources such as oil, gas and etc have been done and as a result of this technology, constructing buildings according to thementioned fields is in the design priority. Also the growing population and lack of building space, particularly in large and populated cities led to high buildings. Engineers should consider the ability of the structures, during its lifetime, to resist against accidental and abnormal phenomena such as earthquakes, floods, storms or fires to avoid major losses in life and property as far as possible. In this paper, the main goals and safety methods of buildings against fire have been proposed. Fire tests have been explained in two groups: reaction to fire and resistance to fire. Also, classification of materials and structural components regarding the risk of fire spread, and the requirements of finishing material selection in public buildings and hospitals regarding the behavior against fire have been provided.

Keywords: Safety, retrofitting, fire, materials

INTRODUCTION

Fire safety is one of the most important requirements in the design of buildings. The level of fire safety depends mainly upon the building occupancy type and its political, economic and social importance. Fire safety includes life and property safety, while life safety is provided by protecting people from smoke, property safety is satisfied by controlling the heat. However, designers can use these5mainmethods for fire safety [1]:

- Prevention
- Fire alarm systems

- Proper design of exit routes
- Suitable space classification of the building and prevention of the fire spread
- Placing appropriate manual and automatic equipment for fire subsidence

There is always a classification of occupancy type in fire safety regulations of buildings and the requirement level of each group depends on its importance. The designer should identify the expectation level of fire safety for the building and then use suitable fire-resistant materials. Thus, it is essential for designers and engineers to provide the classification (or classifications) of the behavior and characteristics of materials against fire.

In this paper, the test and classification tactics of building materials and elements are presented and then the methods of making fire safe buildings are explained.

Fire Spreading in a Building

In order to understand the relationship between fire tests and actual fire phenomenon, it is needed to know the fire behavior in a closed space and the way it spreads in building. After the fire starts in a closed space, as long as the flammable materials and oxygen are enough, the following steps are passed:

- **The growth stage:** At first a material is catches fire and small flames are produced. The flames gradually grow and the reflected heat will burn more inflammable materials. The larger flames and the increased heat will cause other near flammable materials burn. In addition, the flames can be spread on finishes and so the fire will be bigger. At this stage, flammable gases largely occupy the space inside the room.
- **Steady state fire:** When the flames reach the ceiling, they spread in a mushroom like form there. At this time, the heat reflects to all closed space and causes higher temperature. Subsequently, the flammable gases reach the ignition temperature and all closed space will burn in a very short time. This critical moment is called the hot flushing point. After a while, the fire will be relatively stable depending on factors such as the size and geometry of the room, access to flammable materials, and air-conditioning. This is called the steady state burning or ignition stage.
- **Subsiding**: As the flammable materials burn, their amount reduces so, the fire becomes smaller and eventually will subside. However, it is expected that firefighters extinguish the fire before this stage. In figure1 the steps have been shown. It is called fire growth curve.

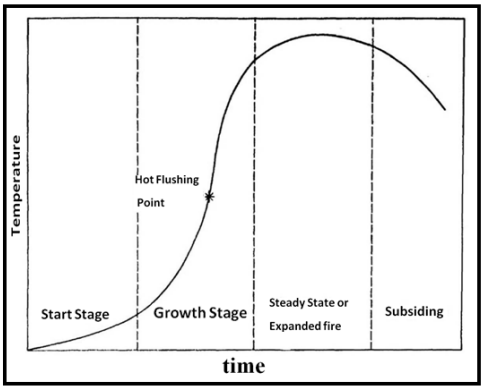

Figure 1: Standard fire growth curve

Fire Tests

Fire tests are used to assess the behavior and specifications of building materials and elements against fire. In the building regulations and other approved documents, classifying, restricting the use or evaluating the building materials and products performance is done by referring to the standard fire tests. . Most countries have their own standards in this field. However, the approach of most of them is to adopt European standards (EN) or international standards (ISO) and the development of national standards in accordance with them. Evaluate the performance of building products to fire is done in two main fields:

Reaction-to-Fire of Materials

The participation rate of a product in fire spreading is assessed by using these tests. The ignition capability, the burning capability, flame propagation on products (finishing), the amount and intensity of heat release and the amount of smoke and toxic gases are some important tests of reaction to fire. Test methods are seen in in various references. Figure 2, the relationship between the tests and fire phenomenon is generally presented.

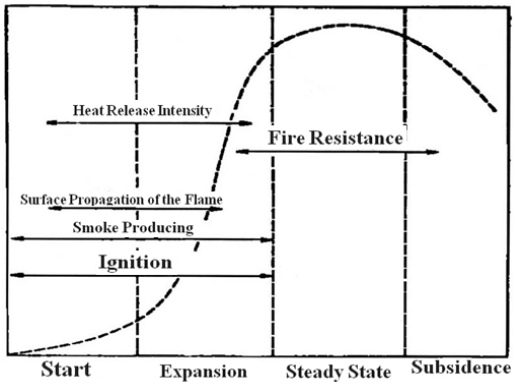

Figure 2: The relationship between the standard fire tests and fire phenomenon

Depending on national or regional standards used in each country materials are classified (Low-risk or high-risk) according to the results of reaction-to-fire tests. This classification is used in building regulations and the allowable use limit of each material group is determined. They may classified based on the way fire spreads in a building or to other buildings, or on different specifications such as ignition. In classifications offered by the Europe Commission [7] building products have been divided into seven groups according to their effects (Table1). The England and Germany classifications provided in this table are their national classifications before the European method [7] and in the near future the will be completely discarded.

Fire Resistance

Fire resistance tests are done to evaluate the ability of a building product or element to continue its performance, and prevent the fire spread to other spaces. Therefore, the fire resistance test is related to expanded fire stage. The fire resistance term is not directly related to flammability of materials, for example, facing a fire, a wood structure may be stronger than a steel structure. Three different furnaces are used for fire resistance tests.

- The horizontal furnace, the approximate dimensions of the opening: (3m × 4m),for the horizontal elements (floors, ceilings, beams, etc.),
- The vertical furnace, the approximate dimensions of the opening: (3m*3m), for the vertical elements (walls, partitions, doors, etc.),
- The column furnace, the approximate height: 3m, for columns.

Smaller furnaces are used for some of other systems such as valves and dampers. In fire resistance studies the target element should be tested in a suitable furnace using a standard time-temperature regimen.

As the furnace becomes hotter, three specifications are tested:

- **Stability:** Facing increasing temperature, the target element should maintain stable, with no failure and collapse.
- **Integration:** To prevent heat and smoke transfer to other spaces the target element must retain its integrity, with no cracks and crevices.
- **Non-conductor:** To prevent rapid heat transfer to other spaces the target element should be insulated as much as possible.

Fire Resistance of building elements (such as roofs, floors, ceilings, beams, columns, external wall, etc.), is classified for different

structures and accordingly the maximum height and area under the occupation of the building is determined. It also depends on the occupation type of the building. For instance, different building structures and their fire resistance rates have been presented in the building protecting code [8] as shown in Tables 2 and 3.

Retro fitting against Fire

1- Materials selection

The main tests required for material classification are:

- The inflammable
- The refractory
- Single Burning Item (SBI)
- Bomb calorimetry

SBI is the most important test for this classification (especially for the middle levels) (Fig. 3). It is done according to European standard EN 13823.

Bakhtiari et al. provided a new classification method by reforming the one presented by Richardson [9, 10].

It makes it possible to classify fire resistant materials using and cone calorimeter test capability allows the classification of fire-safe materials using refractory and cone calorimeter tests and small scale methods.

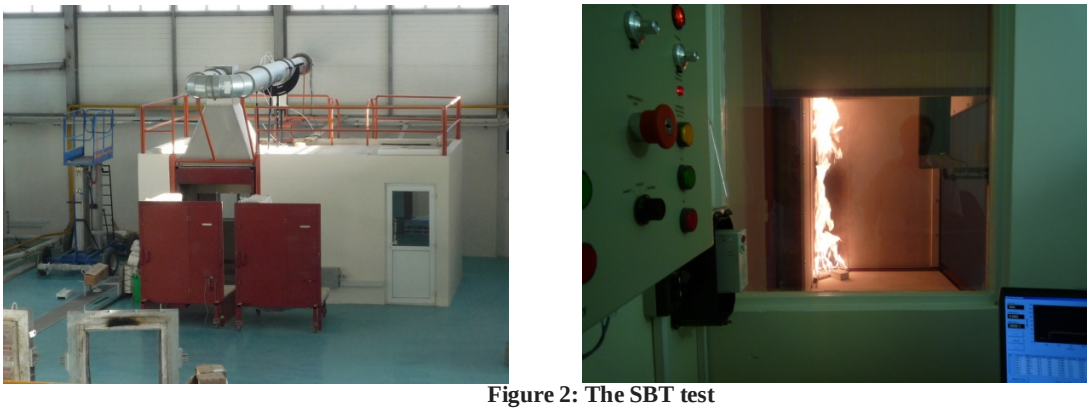

Figure 2: The SBT test

2- Reaction-to-fire Requirements for Finishing Materials in Healthcare Buildings

It is so important for fire safe buildings to have good finishes materials. Finishes materials with high surface propagation of flame can lead to fire spread to adjacent spaces. It not only makes it difficult to control the fire, but also causes further fire spread. Reaction-to-fire requirements for finishing materials in different places are presented in Table4.

The national system of Great Britain recommends high level of fire safety for finishes and emphasizes that these requirements must be respected not only for healthcare buildings, but also for all the space in hospitals.

Building regulations of America presented more strict requirements for finishes materials in hospitals and clinics than that in residential and official buildings (with American standard Test Method). See table 5.

Table 1: Material classifications based on fire hazard in different countries

Country or Area	Classification	
Germany	Non-flammable	Groups A_1&A_2
	Flammable	Group B_1: Difficult ignition
		Group B_2: average ignition
		Group B_3: Easy ignition
America	Group A	Flame Propagation: 0-25
	Group B	Flame Propagation:25-75
	Group C	Flame Propagation: 75-200
Europe Union	Groups A_1&A_2	Ineffective on fire
	Group B	Very limited effect on fire
	Group C	Limited effect on fire
	Group D	Acceptable effect on fire
	Group E	Acceptable reaction to fire
	Group F	not acceptable
England	Non-flammable	Group 0 (Based on building regulations)
	Flammable	Groups 1-4 (Based on BS standard)

Table 2: The requirements for the fire resistance of building elements(hour) in different structures

Building Element	Type I		Type II		Type III		Type IV	Type V	
	A	B	A	B	A	B	Lumber	A	B
Structural frame including columns, main beams and trusses	3	2	1	0	1	0	Lumber	1	0
Exterior load-bearing walls	3	2	1	0	2	2	2	1	0
Interior load-bearing walls	3	2	1	0	1	0	1	1	0
Go to table 3.									
Interior non-bearing walls and partitions	0	0	0	0	0	0	1	0	0
floor structure including supporting beams and joists	2	2	1	0	1	0	Lumber	1	0
Roof structure including supporting beams and joists	1.5	1	1	0	1	0	Lumber	1	0

Table 3: Requirements for the fire resistance of external walls based on fire separating space

fire separating space (m)	Structure type	Group (i)	Groups (p. 1), (k) and (n-1)	Groups (d), (e), (f), (S-2), (d), (m), (n-2) or (F)
$x < 1.5$	all	3	2	1
$x \geq 1.5$ and $x < 3$	IA others	3 2	2 1	1 1
$x \geq 3$ and $x < 9$	IA&IB IIB &VB others	2 1 1	1 0 1	1 0 1
$x \geq 9$	all	0	0	0

Table 4: Acceptable reaction-to-fire class for finishing materials of wall and ceiling in different spaces

The place of finishing	Acceptable reaction-to-fire class(×)
Small rooms with the maximum area of: 4 m^2 for residential spaces 3 m^2 for non-residential spaces	D
Other rooms	C
Building communication spaces and common elements in apartments	B

Table 5: Recommendation of Great Britain national remedial system to limit reaction-to-fire specifications for wall and ceiling finishing materials in hospitals

The place of finishing	Acceptable reaction-to-fire class(×)	
	walls	ceilings
Small rooms with the maximum area of 4 m^2	C	C
Other rooms	B	C
communication spaces (corridors, stairs,..)	B	B

×Better classes are also acceptable. For example, if acceptable class D is noted, classes A to C will also be accepted.

3-Fire-proof Coatings for Steel Structure

To supply sufficient resistance against fire in buildings, the following points should be considered in design and construction of a building. First, proper finishing materials with low or acceptable risk in regard to spreading fire should be used. This issue depends on height of building, its application and types of spaces. For instance, the finishing materials for exits and stairs should be of safe type while requirements on finishing materials of rooms are less strict. Dangerous materials (e.g. plastic foams) should never be used without protective coating. Second, the resistance of structural components and separators against fire should be as defined in regulations and consistent with height and application of the building (and spaces). Usually, about 1 or 2 hours resistance against fire by structural components of the building is needed; however, this could be less or more depending on the case. For instance, between walls of apartments or bedrooms of hotels, there should be at least 1 hour of resistance against fire.

The structural elements cannot often offer essential resistance against fire. In this regard, one could point to steel structures which are resistant against fire for 20-30 minutes. Therefore, for protection of it against fire and retrofitting the building, it is essential to use fire-proof coatings. To do this, wrapping steel by heavy materials such as brick and concrete were used years but in recent decades lightweight coating materials with proper resistance against fire got common. The application of lightweight coatings could contribute to lighter structures, increased rate of construction and reduced costs of construction. In this regard, one should pay attention to the following items.

- Retention of adhesion of coating to its underlying surface as temperature increases
- Offering essential coating thickness to prevent the temperature of structure from attaining critical temperature in which failure occurs.
- Lack of application of details that weaken protective coating against fire such as most of protective coatings that cannot mechanically tolerate heavy facades. For installation of façades over them, one should use proper construction details. As an instance, construction of façade on fireproof paints in a direct manner makes them practically ineffective.

There are different types of fireproof coatings (Bakhtiari, Jafarpur and Morshedian, 2002). The thickness of protective coatings depend on different factors such as essential level of resistance against fire and underlying materials. In general, thin coatings called "retardants" are applied on flammable materials such as wood for reducing flammability or surface flame propagation. These coatings could be used as paint in a thin layer with few microns thickness. The thicker coatings are mostly used as protection of steel components and other structures. This is commonly realized for thickness level ranging from 10 to 50 mm.

The protection of steel structure components by coatings could be done through two contact-based and membranous methods. In contact method, the fireproof coating is directly sprayed on the intended surface. For instance, for a steel column the fireproof material is directly applied on the steel column and as a result the material follows the shape of profile (attention to effective adhesion is essential). In figure 4, some instances of this type of protection are presented. In membranes method (figure 4), the columns and beams are wrapped by a fireproof material and the floors are protected by an underlying ceiling which plays the role of fire barrier.

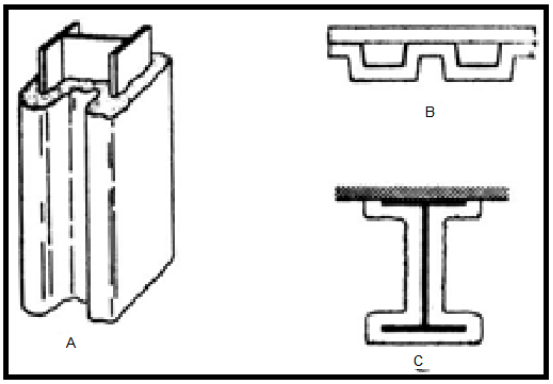

Figure 4: Contact protection (a: column, b: floor slab, c: beam)

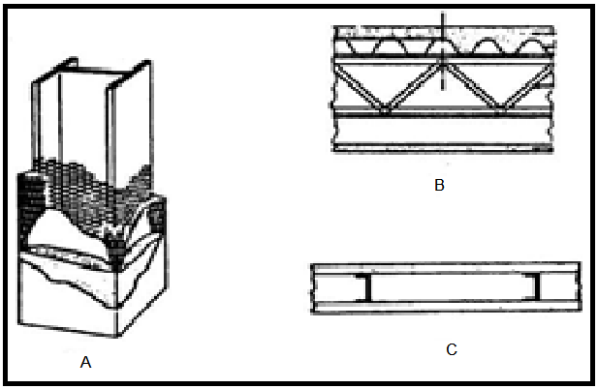

Figure 5: Membranous protection against fire (a: column, b: false ceiling, c: walls or separators)

From viewpoint of performance mechanism, there are three main types of fireproof materials: insulators, energy absorbers, and puffers. Most of the common materials act with a combined mechanism of first and second types of materials. They include certain amounts of both groups of insulators and energy absorbers.

The highest consumption level of insulators with outstanding thermal properties is related to mineral materials and expanded aggregates such as perlite and vermiculite. These materials could have cement or plaster adhesives. In addition, the existence of different amounts of other materials and additives is essential. Otherwise, performance and application of the coating cannot be properly done. These coatings are mostly known as mineral protective coatings and they have two spraying and board types. The thickness used depends on required level of fire resistance, characteristics of material, and characteristics of structure along with method of application. Keen attention to executive details is essential. In most of the cases, preparation of underlying foundation and creating a mechanical connection to underlying surface are need. The mechanical connection should be able to maintain adhesion to its underlying surface during fire.

The puffing paints are another type of protective coatings. Usually, the application of these paints as alternative for cement and plaster coatings in protection of structures against fire is due to distinctive requirements such as higher lightness, low thickness and special designs. For instance, if the visibility of structure is needed due to architectural design one can use this type of paints.

The production and application of these systems has certain complications and limitations. For example, the protective performance of these coatings is done by expansion and puffing of a layer of molten carbon layer that becomes solid as

temperature rises. For occurrence of these reactions, three components are needed namely a mineral acid catalyst, a carbon source and a puffing agent orgas production agent. The systems that include a material producing phosphoric acid, a carbon polyol, and a halogenated composition are among the most common ones. These reagents should be usually used in a resin of surficial coating and in a mixture that can offer a color of desirable quality. A puffing paint should provide a protective coating against fire and it should also provide all advantages of a common color system. Therefore, a puffing color should have coating pigments, resin adhesives, anti-bacterial materials, anti-fungus materials, fillers and anti-sagging materials among many others. In addition, these colors should have the main components of a puffing system too. The combination of all of these properties in a system is not easy and most of the commercial materials have not able to act either as a desirable fire retardant or a proper paint.

In the case of using puffing paints as fireproof coating on structural components, one should pay attention to certain points. First, these colors are mostly used for relatively low resistance against fire (i.e. less than an hour). Second, no façade such as stone layers or decorative plasters on these paints because the color cannot expand and it will become practically ineffective. Third, the protective coating should be able to offer the structure with essential resistance against fire based on the latest fire safety regulations and results of standard fire resistance test. This is also the case for other coatings but due to existence of more complicated combinations in this paints, one cannot use recommended details of the type. Fourth, the fireproof color system should be able to retain its effect in long term. To do this, the intended coating should be able to present desirable behavior during durability test in the desired environmental conditions. Fifth, the fireproof color system should be able to retain its adhesion to underlying surface in condition of fire retardation. It should effectively fulfill its tasks. Based on the project conditions, these are some other points to be noted too.

4-National Building Regulations, Protection of Buildings against Fire

Due to the fact that every building should comply with essential predictions and arrangements to secure the safety of settlers against fire, it is essential to design and construct buildings in a way that considering the application, dimension and number of floors it can resist against fire for a desirable

duration and prevents the propagation of fire to adjacent spaces or buildings. In this regard, attention to the following requirements (until reinforcement of relevant regulations) in design and construction of buildings is essential. First, the design and construction should be done in a way that if fire starts, the settlers could get themselves to a safe location inside or outside of the building through secure and predetermined ways. Second, the exits and fire escapes should be in sufficient number, based on essential capacity, and in proper locations of the building so that the individuals could get themselves to a secure place without agitation and excitement. Third, proper and adequate lighting in escape ways should be offered and all exits should be marked in a desirable manner. Fourth, the necessary equipment for prevention of flames and smoke from penetrating into exits should be prepared based on the application, dimensions and height of the building.

The essential arrangements for prevention of fire from propagating inside the house due to internal coatings and covering materials should be made. In this regard, the following issues should be noted. First, until further regulations and guidelines are codified it is better to use non-combustible or semi fire resistive materials. The coatings should be selected in a way that they show sufficient resistance against sacrificial progress of flame and if flamed they produce limited heat due to burning. The design and construction of buildings should be done in a manner that propagation of fire from a space or building to the adjacent spaces and buildings could be prevented. To do this, the following arrangements should be made. First, in the case of fire and considering the application and dimensions of the building it should maintain its resistance and stability. Second, for prevention of fire from propagation the building should offer proper internal spacing and fireproof structures based on its application and dimensions. Third, the pathways and hidden spaces such as shafts, vents for passing cables and pipes, the spaces between walls and external face of buildings should be designed and constructed in a manner that they could resist against fire propagation from one building to another. Fourth, based on application and dimensions of the building its external walls should resist against outward propagation of fire. Fifth, the roofs should be designed and constructed in a manner that considering the location of building the propagation of fire to adjacent buildings could be prevented.

In addition, all arrangements for offering firefighting forces with access to location of

fire in the building should be considered. In this regard, the following points should be noted. First, the pathways for firefighting vehicles, devices and means should be available beside of the building. Second, for access of firefighters to internal building spaces secure pathways should be devised.

Based on building dimensions and application, proper firefighting means inside the building should be available and read to be used by firefighters (National Building Regulations, 2012).

SUMMARY AND CONCLUSION

One of the most significant objectives and requirements of designing buildings is safety against fire. To supply sufficient safety and resistance against fire, one should use proper materials and systems in two parts of covering materials and building components. To evaluate the behavior and characteristics of materials and components of buildings in dealing with fire, the fire tests are used. In addition, in building regulations and other approved evidence the classification, limitation of application and assessment of performance of building materials and products the standard fire tests are used.

The evaluation of performance of building products against water is done in two primary domains of reaction of materials against fire and resistance against fire. With the help of first-category tests, the contribution of an item/product to fire propagation is determined and with the help of latter test, the ability of a product/item or structural component to continue its function and to prevent the structural collapse or propagation of fire from location of ignition to adjacent spaces is determined through fire resistance tests.

REFERENCES

[1] Bakhtiari, S & Ghasem Zadeh, M. (2003). Determination of performance expectations and methods of classification of building materials and processes from viewpoint of risk of fire, Safe Scientific-Research Journal, 34.

[2] Bakhtiari, S & Taghi Akbari, L. (2008). Experimental analysis of behavior of expanded polystyrene against fire, Science and Technology Journal of Polymer, 20 (89).

[3] Bakhtiari, S., Taghi Akbari, L & Barikani, M. (2010). Behavior of polyurethane hard foam and metal-clad polyurethane sandwich walls against fire and evaluation of their risk of participation in firing, Science and Technology Journal of Polymer, 22 (89).

[4] Bakhtiari, S., Taghi Akbari, L & Jamali Ashtiani, M. (2013). Evaluation of thermal fire hazard of 10 polymeric

building materials and proposing a classification method based on cone calorimeter results. Fire and Materials.

[5] Bakhtiari, S., Jafarpur, F & Morshedian, J. (2004). Some characteristics of fireproof colors, Publication of Research Center for Building and Housing, 379.

[6] Bakhtiari, S., Taghi Akbari, L & Jamali Ashtiani, M. (2014). Experimental study of fire risk and correlation of fire risks for a number of polymeric building materials, Modares Civil Engineering Journal, 13 (5), 29-40.

[7] Bakhtiari, S, et al. (2007). Standardization and classification of building materials from viewpoint of fire risk, Publications of Research Center of Building and Housing, National Research Program, Council of National Scientific Studies, Tehran.

[8] Bylaw of Protection of Buildings against Fire, (2014). Publication of Research Center of Roads, Housing and Urbanization, 682.

[9] National Building Regulations. (2012). Protection of buildings against fire, Chapter 3.

[10] National Standard of Iran. (2006). Fire tests standards for building materials and processes: Tests of reaction against fire (Part 1-8), No. 7271.

[11] National Standard of Iran. (2006). Reaction against fire in building materials and products: A method of classification, No. 8299.

[12] Zarin Ghalam, A & Bakhtiari, S. (2009). Principles of fire safety in organizations, Publications of Research Center of Building and Housing, 4.