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Fire propagation index of lining materials: Effect of intumescent coating

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ABSTRACT

Fire performance characteristics of lining material used in building are of considerable significance from life safety point of view. The Fire Propagation Index can be used to identify the likely fire hazard of lining materials in terms of their tendency to contribute to the growth of fire inside the buildings. A material of higher Fire Propagation Index is considered to contribute more towards the growth of fire. Thus, by comparison of the Fire Propagation Indices of different materials for the interior of a building, it is possible to identify the fire safe materials. Experimental investigations have been made to assess the Fire Propagation Index of untreated and intumescent coated particle board, plywood and fibre board. The salient results obtained during experimental investigation and the suitability of these materials from fire safety point of view are discussed.

Introduction

ONE of the prime factor governing the growth and spread of fire inside the buildings is the nature of internal linings used for both walls and ceilings. They may be of non-combustible or combu stible nature. No direct heat contribution is made to the growth and spread of fire by the materials belonging to the former class. Combustible lining materials, once ignited, can continue to burn and contribute to the growth and spread of fire. The rate at which the fire build-up takes place in an enclosure depends upon the behaviour of these materials, apart from the design, ventilation available and thermal characteristics of enclosure construction materials[1]. An obvious method of reducing the fire losses in buildings is to reduce the possibility of ignition, contributing to heat and flame spread by the combustible linings. This can be achieved by limitations on the use of materials with high contribution to fire growth. In the recent years, rapid increase in the use of new internal lining materials in buildings have contributed to enhanced fire safety problems. Since some of these materials can contribute to the rapid growth of fire in early stages, evaluation of the contribution made by these materials to the development of a compartment fire is urgently needed to establish more meaningful performance criteria of building materials.

The determination of Fire Propagation Index using 'Hot Box' is an early attempt to study and grade the materials on the basis of amount as well as rate of heat evolved when subjected to a set of standard test conditions. A material is exposed to the controlled source of heat inside a thermally insulated chamber, thus resulting in decomposition of the combustible constituents. A measure of the liberated heat provides an index of its performance.

Various natural and synthetic polymeric materials, viz. cellulose and its derivatives, plastics, etc. are finding extensive use in buildings in a variety of forms such as doors, windows, decorative walls, ceiling linings, etc. All these materials constitute a major fire load inside a building due to their combustible nature.

If these combustible materials are treated suitably for fire retardance[2] they may resist the growth and spread of fire. Thus, by making the materials fire retardant, the fire hazard can be reduced and consequently the of life and property loss in buildings can be minimised.

The present communication is concern with the results of experimental investigations carried out for determination of Fire Propagation Index of untreated and intumescent coated particle board, plywood and fibre board.

Fire retardant treatment

There are Various methods for rendering a material fire retardant such as:

(i) Impregnation (ii) Spray (iii) Surface Treatment (iv) Incorporation of chemicals during manufacturing stage.

Intumescent coating are systems which puff up to produce foams. Because of this characteristic they are used to protect the materials which are combustible in nature such as wood, wood based materials, plastics, etc. Intumescent coatings are always formulated according to the principles whether they are used as a coating or as a flame retardant. The intumescent effect is achieved by using the following components.

Acid source

These usually consist of an inorganic non-volatile acid such as boric, sulphuric or phosphoric acid.

Carbonific compounds

These are polyhydroxy compounds such as pentaerythritol, starch and phenolic or urea resins.

Spumific compounds

These includes compounds such as chloroparaffins, melamine, aquanidine etc.

Resin binders

These include compounds like chlorinated rubber etc.

Intumescent coatings act as follows:

- The effect of intense heat causes the inorganic salt to decompose to the acid (e.g. ammonium dihydrogen phosphate) :

$$NH_4H_2PO_4 \text{ --------> } NH_3 + H_3PO_4$$

- The components of the intumescent mixture start to soften. The acid esterifies the polyhydroxy compound (carbonofic compounds) to give the polyolester (e.g. pentaerythritol).

$$C_5H_8\,(OH)_4 + H_3PO_4 \text{ -----------> } C_5H_3(OH)_8H_3PO_4$$

- The mixture melts and decomposes; the polyolester breaks down to acid, water and a carbonaceous residue.

$$C_5H_8(OH)_4.\ H_3PO_4 \text{ ----------> } H_3PO_4 + H_2O + C$$

- Simultaneously, the compound supplying the blowing agent (Spumific compounds) decomposes and the gases generated expand the molten mass (e.g. Chloroparaffin) :

$$C_n\ H_{(2n+1)}\ Cl \text{ ----------> } HCl + C$$

- The softend resin binder forms a skin over the foam and prevents the gases from escaping. The viscosity of the frothy mass increases and the foam solidifies completely by cross linking and charring. The foam is 50 to 100 times as thick as the original intumescent layer resulting in good thermal insulation, thus protecting the substrate from the effect of heat and decomposition.

A few intumescent coatings have been applied and their fire performance indices determined after application on various substitute such as particle board, plywood and fibre board. Fire performance index of coated and uncoated materials is given in *Table 1*.

Experimental

The apparatus, consists essentially of a combustion chamber known as 'Hot Box'. It is made of 12.5 mm thick non-combustible board of specified properties and has internal dimensions of 190 mm x 190 mm x 90 mm. The back face of the chamber (190 mm x 190 mm) is a specimen holder designed to accommodate the samples of 225 mm x 225 mm x 50 mm. The specimen holder is held in position with compression springs and an asbestos paper gasket is used as an air tight seal. The front face has an observation window (50 mm x 50 mm) located centrally. An air-inlet (96 mm x 25 mm) is provided near the base of the chamber.

A chimney of 38 mm diameter and 190 mm height with a removable cowl having 76 mm internal diameter and 152 mm height is used at the top of the chamber for removal of flue gases. The cowl is provided with two bush holes for insertion of thermocouples. These are used for continuous monitoring of fuel gas temperature.

Energy input for combustion inside the 'Hot Box' is provided both by gas flamelets and electric heaters. Further details of the apparatus are given in the British Standard BS 476 : Part 6[6].

Methodology

A calibration run is conducted by exposing a non-combustible board of specified properties to the gas flames from 0-20 min. (the duration of the experiment) and to the radiations from electric heaters. The heaters are switched on 2 min 45 seconds after the start of the experiment to give an output of 1800 W, which is reduced to 1500 W after 5 min, and maintained constant until the end of the experimental run. During the experiment the temperature of flue gases is measured by two thermocouples inserted in the annular space between the chimney and the cowl. A multi-channel temperature recorder is used for recording the temperatures of flue gases with respect to time. A calibration curve is obtained from this time-temperature run.

Before commencing any experiment on the specimens of material, it is essential to obtain a reproducible calibration curve within specified tolerance limits. Once a consistent calibration is achieved, the experimental runs are conducted with the specimens of a material keeping the experimental conditions same as that for calibration run. The time-temperature data is now recorded continuously for the specimens and used for obtaining the time-temperature profile as well as for computation of sub indices and Fire Performance Index[5].

TABLE 1 : FIRE PROPAGATION INDEX OF UNTREATED & INTUMESCENT COATED PLYWOOD, PARTICLE BOARD & FIBRE BOARD

Material	Sub-Indices			Fire Propagation Index
	I_1	I_2	I_3	I
Plywood (4mm, 700kg/m³)	10.34	16.80	3.25	30.39
Intumescent Coated Plywood	2.20	8.00	2.60	12.80
Plastic Board (12mm, 400kg/m³)	14.21	16.81	5.50	36.52
Intumescent Coated Particle Board	4.25	13.49	4.76	22.50
Fibre Board (12mm, 235 kg/m³)	33.10	18.17	4.73	56.00
Intumescent Coated Fibre Board	4.20	11.70	3.45	19.35

Results and discussion

The Fire Propagation Index of materials can be used to identify the likely fire hazard of materials in terms of their tendency to contribute to the growth of fire inside the buildings. A material of higher fire propagation Index is considered to contribute more towards the growth of fire than the one of a lower fire propagation Index. Thus, by comparison of fire propagation Indices of different materials, it is possible to identify fire safe materials and the performance of different can be ascertained relative to each other[6].

From time-temperature data obtained during the calibration run and the experimental run with the specimens of a material, the Fire Propagation Index is computed as follows:

$$I = i_1 + i_2 + i_3$$

Where

$$i_1 = \sum_{t=0.5}^{t=3} \frac{Qm - Qc}{10t}$$

At 0.5 min interval

$$i_2 = \sum_{t=4}^{t=10} \frac{Qm - Q}{10t}$$

At 1.0 min interval

$$i_3 = \sum_{t=12}^{t=20} \frac{Qm - Qc}{10t}$$

At 2 min interval

Where I is the Fire Propagation Index.

i_1, i_2, i_3 are the sub indices for the three time components

$Ø_m$ is the temperature rise recorded for the material at time t

$Ø_c$ is the temperature rise recorded for the non-combustible standard at time t and t is the time in min from the beginning of the test.

Fire Propagation Index is the sum of three sub indices, i_1, i_2, and i_3 computed for three different intervals of experimental run. Out of these three sub indices, the first sub index i_1, which pertains to the first three minutes of the experimental run when the specimen is exposed to flames and gas burners only is relatively more important and is also taken into account while making a comparative assessment of fire hazard of different materials.

The computed sub-indices i_1, I_2, i_3 and Fire Propagation Index I for untreated and intumescent coated plywood, particle board and fibre board shown in *Table 1*.

Fig. 1 shows the time-temperature profile obtained during an experimental run on standard non combustible board. It is a calibration run obtained as per standard test condition and the time-temperature data obtained during calibration run is the basis for computation of Fire Propagation Index of a material[7].

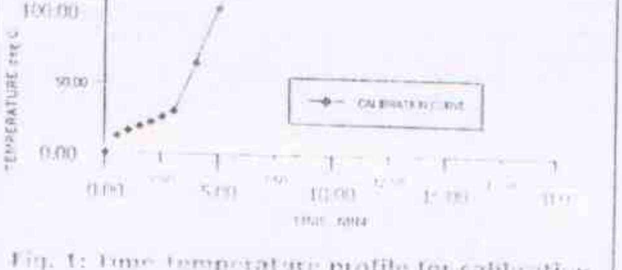

Fig. 1: Time temperature profile for calibration

The time-temperature profiles obtained during an experimental run for untreated particle board and intumescent coated particle board is shown in *Fig. 3*, while that for untreated plywood and intumescent coated plywood is shown in *Fig. 2*, and that for untreated fibre board and intumescent coated fibre board is shown in *Fig. 4*.

It is indicated from *Fig. 2* that the rise in temperatures due to exposure of the specimens of plywood (4mm thick, 700 kg/m3) is higher than that for the calibration run. The computed sub-indices I_1, I_2 and I_3 for plywood are 10.34, 16.80 and 3.25 respectively, while the Fire Propagation Index in 36.52. When the specimens of intumescent coated plywood are exposed, it is observed that the temperature rise is comparatively slower during the initial exposure period, i.e. during first 3 minutes. The computed first sub-index for intumescent coated plywood is 2.20, well within the limit of I_1 for class 0 purposes[8], which is very important for escape of people during fire, due to delay in ignition and flash-over time. Time temperature profiles for intumescent coated plywood showed promising results during the second and third phase of fire as indicated by computed sub-indices i_2

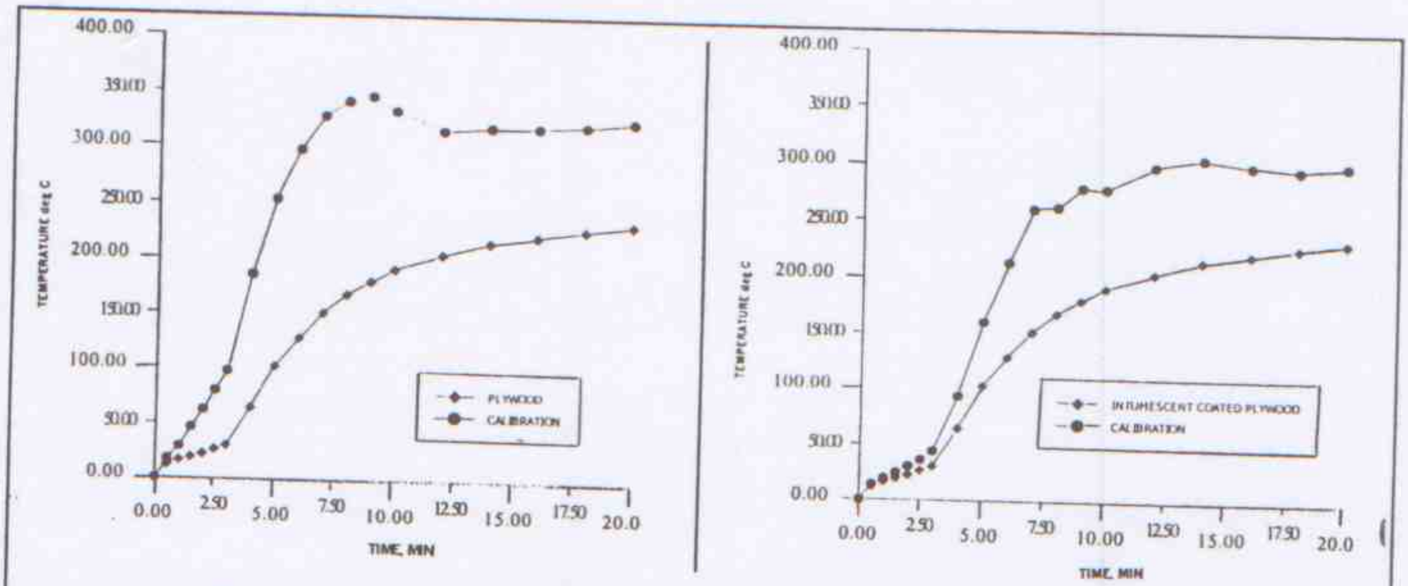

Fig. 2: Time-temperature profiles for untreated and intumescent coated plywood

and i_3 which is 8.00 and 2.60 respectively as compared to 16.80 and 2.60 respectively for untreated plywood. The computed Fire Propagation Index for intumescent coated plywood is 12.80 in comparison to 30.39 for untreated plywood, which showed an improvement in Fire Properties due to application intumescent coating.

From *Fig. 3* it is indicated that the rise in temperature due to exposure of the specimens of untreated particle board are higher than the temperature obtained during the calibration run. The computed sub index for particle board is 14.21, while the Fire Propagation Index is 36.52. When the specimen of intumescent coated particle board is exposed, it is found that the temperature rise is comparatively much slower during the initial exposure condition, i.e. during the first 3 minutes.

The computed first sub index is for particle board (I.C.) is 4.25 which is well within limits of i_1 for class Ø purposes. Though there is a substantial decreasing trend of temperature rise during the next two time intervals, the computed Fire Propagation Index for particle board (I.C.) is 22.50, which is better than that for untreated particle board.

It has been observed from *Fig. 4* that the rise in temperatures for the specimen of fibre board (12 mm, 235 kg/m³) are higher than that for the calibration run. The computed sub-indices (i_1, i_2 and i_3) for Fibre Board are 33.10, 18.17 and 4.73 respectively, while the fire propagation Index is 56.00. The time-temperature profiles for the specimens intumescent coated fibre board also

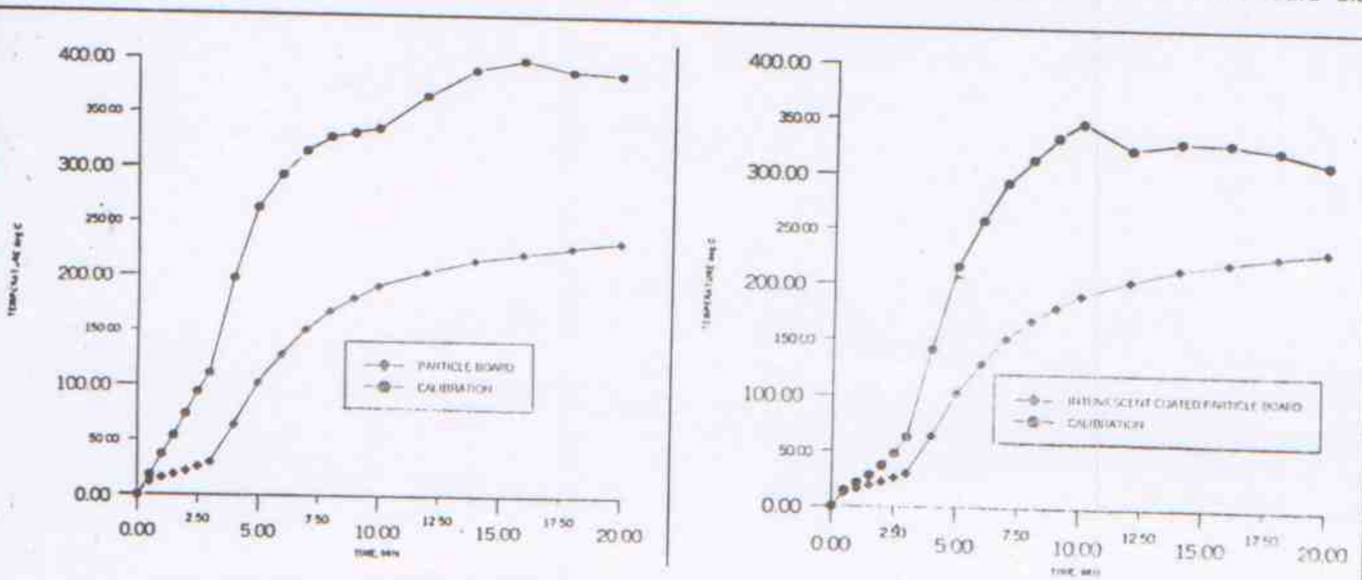

Fig. 3: Time-temperature profiles for untreated and intumescent coated particle board

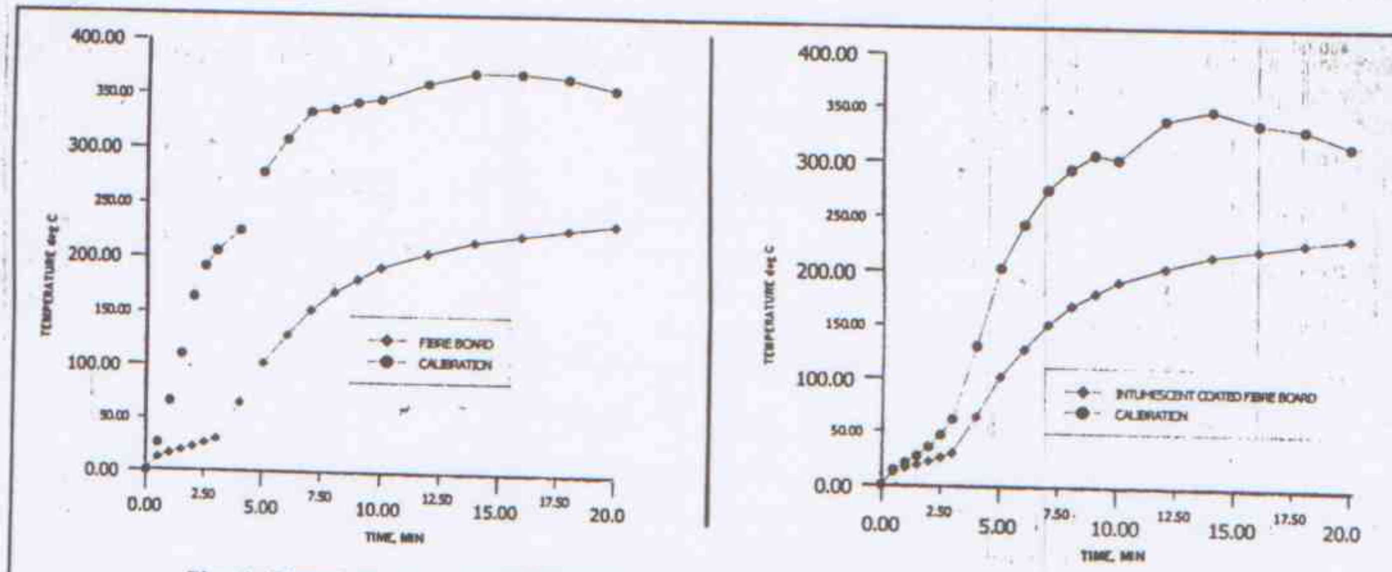

Fig. 4: Time-temperature profiles for untreated and intumescent coated fibre board

show substantial rise in temperatures over the calibration run. The first sub-index for intumescent coated fibre board is 4.20, which is much lower than that for untreated fibre board. The Fire Propagation Index for intumescent coated fibre board is 19.35 in comparison to 56.00 for untreated fibre board. The time-temperature profiles for the specimens of intumescent fibre board showed a decreasing trend in rise of temperature from initiation to decay period in comparison to that for untreated fibre board.

The Fire Propagation Index of intumescent coated plywood, intumescent coated particle board and intumescent coated fibre board is less than that for untreated ones. Hence these intumescent coated materials contribute less to the growth and spread of fire not only in the initial stage, but in the later stage of fire as well.

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