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Fire Performance of Plywood Treated With Chemical Surface Barrier

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Abstract

Generally wood and wood based materials are combustible, easily ignitable, can propagate heat and flame spread, produce dense smoke in fires. These materials can be used in buildings as lining materials in spite of their inferior behavior in fire. To render them flame retardant, we studied and prepared a new chemical surface barrier which not only improves the flame retardancy of these materials but also makes them fire safe. The paper uniquely focuses on the study of an effective chemical surface barrier after treatment and appropriate curing. It should provide better "reaction to fire" characteristics to Plywood in a building fire. Reaction to fire characteristics include: Ignitability, fire propagation index, surface spread of flame and specific optical density of smoke.

Keywords: *Ignitability, chemical surface barrier, fire propagation index, surface spread of flame, specific optical density of smoke*

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INTRODUCTION

Statistics have shown that generally between 10 to 20 fire deaths per 1,000,000 inhabitants are reported in the major industrial countries of the world. The number of severely injured people in these incidents is estimated to be ten times this figure, i.e., 100 to 200 per 1,000,000 inhabitants per year. About 80% of all fire deaths occur in residential buildings. The people most at risk are the very immature and the aged because they are least able to escape in the case of a flame.

The most prominent cause of death in fires is due to gas or fume: In UK, approximately 50% of people die this way, while 25% of deaths are due to burns and 20% are attributed to both burns and being overcome by gas or smoke. 5% of fire deaths cannot be specified. Accidental fires in the domestic place have far higher casualty levels than any other location.

A fire can fundamentally be split into three phases- the novice fire, the fully formulated fire and the depreciative fire. The fire starts with a flaming source setting up burnable material on fire. The fire disperses, heats up the environment and once the materials in the room have settled enough flammable gases and are sufficiently hot, discharge takes place and the whole room is enveloped in the fire. This is the start of the fully developed fire. The fires will later drop-off as the available fire load is used-up by the fire or if the fire happens in a totally closed room the fire can decline because of oxygen deficiency[1].

The important factors governing a fire are:

1. Combustibility: Will be a physical burn?
2. Ignitability: If it is easily ignitable, how and when will it ignite?

3. Spread of flame: Once ignited, how rapidly will the flames dispersed over the surface?
4. Heat release/Fire Propagation Index: What will be the rate and total amount of heat released or how much is contribution of heat towards development and propagation of fire in terms of Fire Propagation Index?
5. Smoke generation: Smoke development and visibility reduction which hinders escape in case of smoke filled fire.

CHEMICAL SURFACE BARRIER

Chemical surface barriers are chemicals which are added to combustible materials to render them more resistant to ignition. They are designed to minimize the risk of a fire starting in case of contact with a small ignition source. If the flame retarded material or an adjacent material has ignited, the flame retardant will slow down combustion and often prevent the fire from spreading to other items. These are necessary to ensure the fire safety of a wide range of materials including wood products. These materials are used in parts of buildings such as false ceiling, wall linings, partitions and building components.

Both our homes and offices contain an increasing potential “fire load” of combustible materials because of rising levels of comfort. Chemical surface barriers protect modern materials such as building components, from lighting and diffusing a fire. Once a fire starts in a room of a house, it can develop rapidly, if it spreads to items other than that first lighted. Once number of items burn, the temperature in the room will rise, and may reach “flash over” point, where hot burning gases cause effectively the whole room to catch light, often violently. Once this occurs, escape from the room is impossible and spread of the fire to other rooms is very likely. Chemical surface barriers act both by preventing the initial start of a fire by impeding ignition and by delaying the spread of the fire, thus, increasing escape time and perhaps preventing “flash over. Chemical surface barriers can be applied to many different combustible materials to prevent a fire or to delay its start and propagation by interrupting or hindering the combustion process. Thus, they protect lives, property and the environment.

Chemical surface barriers contribute to meet high fire safety essentials for combustible materials and polished products prescribed in regulations and tests. By chemical substance and/or physical action, flame retardation will inhibit or even suppress the burning process. They interfere with burning during a specific stage of this process e.g., during warming, decomposition reaction, flaming or flame spread[2]. The amount of flame retardation one has to add to accomplish the desired level of fire safety can range from less than one percent for highly effective flame retardant up to more than 50% for inorganic fillers[2]. Typical ranges are 5–20%by weight.

The most effective chemical action may take place by:

1. Reaction in the gas phase*:* The radical gas phase combustion process is interrupted by the flame retardant, resulting in cooling of the system, reducing and eventually suppressing the supply of flammable gases.
2. Reaction in the solid phase*:* The flame retardant builds up a char layer and protective covering the material against oxygen and provides a barrier against the heat source (flame).

The less effective physical action may take place by:

1. Cooling: Energy absorbing (Endothermic) processes triggered by cumulative and/or the chemical release of water cool the substance to a fundamental quantity below that

needful for sustaining the burning process.

2. Formation of a protective layer (coating): The material is shielded with a solid or gaseous protective layer and secure from heat and oxygen necessary for the burning process.
3. Dilution: Inert substances (fillers) and additives evolving non-combustible gases dilute the fuel in the solid and gaseous phases.

Study of Chemical Surface Barriers

Wood and wood based lining materials have a wide range of applications such as Construction material as it is or in the form of plywood, medium density fiber board, pulp board, paper board, fiber board, chip board, wood, wool board, etc .Among the wood based boards, plywood is considered to be the "combustible" boards mainly due to their low density. Untreated insulating plywood don't fulfill the requirement of minimum fire safe requirements for these boards in wall and ceiling applications[3]. The cutting edges and perforation seriously affects the flame spread classification and fire propagation index.

A chemical surface obstruction is prepared using melamine, dicyandiamide, phosphoric acid and formaldehyde solution in certain molar ratio. First of all, the formaldehyde solution was mixed with specific molar ratio in water and pH of this solution was adjusted to approximately 8 by adding NaOH solution. Then, a mixture of melamine and dicyandiamide in the required proportion was added to this mixture and the table of contents was refluxed at 80°C in a round bottom flask with a condenser fitted at its top for specific duration. Later, after refluxing, the mixture was air-cooled to room temperature and then phosphoric acid in a positive molar ratio was integrated slowly in this mixture keeping the temperature close to ambient. This solution is stored at 4°C. The solution was then diluted with water .The solution to water ratio is 65:35 and the resultant solution is our chemical surface barrier which is further stored at a temperature of 4°C. The bulk density of the solution as measured was 1.16 g/ml. The resultant solution in the mentioned ratio was found promising for treating the specimens. The specimens of 12 mm thick Plywood samples were coated by brush on the surface and cured at 60°C in an oven and finally in the sun light to characterize them for Ignitability, Fire Propagation Index, Surface Spread of Flame and Specific Optical Density of Smoke evaluations. The preparation gives a clear finish after handling and curing hence, providing radiance to surface. The dry loading after the treatment was 3.429 Kg/m^2 for 12 mm thick Plywood.

FIRE PERFORMANCE RESULTS:

Ignitability

Ignition refers to the onset of combustion. Ignitability is the tendency of materials to get involved in the process of burning. Materials when exposed to a small source of heat or flame can get ignited and contribute to burn. Materials, which get ignited easily needs to be isolated from those which do not, for fire safety considerations. The method of determining whether a material is easily ignitable or not is described in the British Standard BS 476: Part 5[4]. Exposing the specimens to a 10 mm long flame for 10 sec is used to carry out the test. If flaming does not extend to any edge during the application of the test flame or within a 10 sec following the removal of the test flame, the materials performed are designated P (not easily ignitable). Materials not satisfying the above criteria are designated as X (easily ignitable). The letter P indicates that the material has passed the test whereas the X designation indicates failure.

Table 1: *Ignitability Results for Untreated and Treated Plywood.*

Type of Sample	Ignitability Results
Untreated plywood	'P' Not easily Ignitable
Treated plywood	'P' Not easily Ignitable

Fire Propagation Index

The Fire Propagation Index of materials 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 buildings. A material of higher Fire Propagation Index is considered to contribute more towards the growth of fire than the one with lower Fire Propagation index. Thus, by comparison of Fire Propagation Indices of different materials for the interior of a building, it is possible to identify safer materials and the performance of different materials can be ascertained relative to each other.

Fire Propagation Index is determined using Fire Propagation Apparatus and by following the procedure specified in the British Standard, BS 476: Part 6[5]. A specimen of the material is exposed to radiant heat or flames and temperatures of the combustion products are recorded in the stack. From these temperatures, three sub-indices are computed for different intervals of test duration. The fire propagation index is the sum of these three sub indices and is calculated as follows:

$$I = i_1 + i_2 + i_3$$

I = Fire Propagation Index

i_1 = Sub-index calculated at 0.5 min intervals over the period 0.5–3.0 min.

i_2 = Sub-index calculated at 1 min intervals over period 4–10 min.

i_3 = Sub-index calculated at 2 min intervals over period 12–20 min.

Results are expressed as the Fire Propagation Index and the first sub-index. Higher the value of the sub-index or the Fire Propagation Index, higher is the likely contribution of the material to fire. The specimens of Untreated Plywood and Plywood treated with chemical surface barrier are exposed to fire propagation index apparatus as per standard condition including the calibration. The time-temperature curves for calibration, untreated Plywood and specimens of Plywood treated with chemical surface barrier are shown in Figure 1, while the computed mean results for Fire Propagation Indices are given in Table 2.

Table 2: *Fire Propagation Index for Untreated Plywood and Treated Plywood.*

Type of specimens		Indices		Fire Propagation index, I
	i_1	i_2	i_3	
Untreated Plywood	8.15	11.91	3.49	23.55
Treated Plywood	0.13	5.29	3.64	9.00

The time-temperature curves for calibration, untreated and treated specimens of Plywood are enclosed in Figure 1–3.

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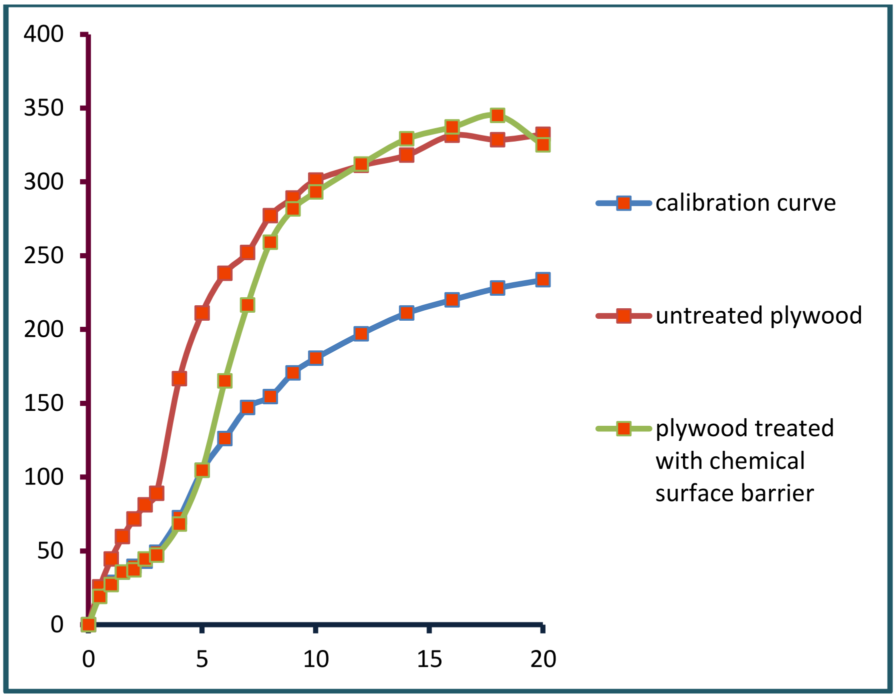

Fig. 1: *Time-Temperature Curve of Fire Propagation Index.*

Surface Spread of Flame

One of the very important fire properties of the materials in the interior of building is their tendency to spread flames over their surfaces. These materials can permit flames to travel over their surfaces to distances away from the initial outbreak. Other materials within the interior can also get successively involved in the fire, resulting in the spread of fire to different locations within the building. This property assumes considerable significance where continuous surfaces of materials are available such as for wall linings, false ceiling, insulation in air conditioning ducts, etc. For fire safety, it is necessary to restrict the use of materials based on the surface spread or flame classification.

In escape routes, for instance, only the material possessing a very low tendency to spread flames should be used. The classification of materials for surface spread of flame is determined using the apparatus described in British Standard, BS 476: Part 7[6]. The specimens of a material are exposed to right angles to vertical gas fired radiant panel to the specified radiation levels and in addition, the pilot flame is applied during the first min of the test. The distance of flame spread is recorded at the end of 1.5 min and measurement of spread against time are continued up to a total duration of 10 min unless the flame has reached the far end of the specimen in less than 10 min.

Based on the extent and the rate of flame spread observed the material is classified into one of the four classes- Class 1, Class 2, Class 3, Class 4 in descending order of merit. Thus, a selection of materials can be made depending on their surface spread of flame. The time (min) – flame spread (mm) curves obtained during surface spread of flame experiments for untreated Plywood and Plywood treated with chemical surface barrier specimens is provided in Figure 2, while the flame spread results at 1.5 min and flame spread termination results are given in Table 3. The surface spread of flame classification results are given in Table 4.

Table 3: *Flame Spread Results for Untreated and Treated Plywood.*

Type of specimens	Flame spread At 1.5 min, mm	Final Flame spread At 10 min, mm
Untreated Plywood	0	375
Plywood treated with chemical surface barrier	0	0

Table 4: *Results of Surface Spread of Flame Classification for Treated and Untreated Plywood.*

Type of specimens	Flame spread Classification
Untreated Plywood	Class-2
Plywood treated with chemical surface barrier	Class-1

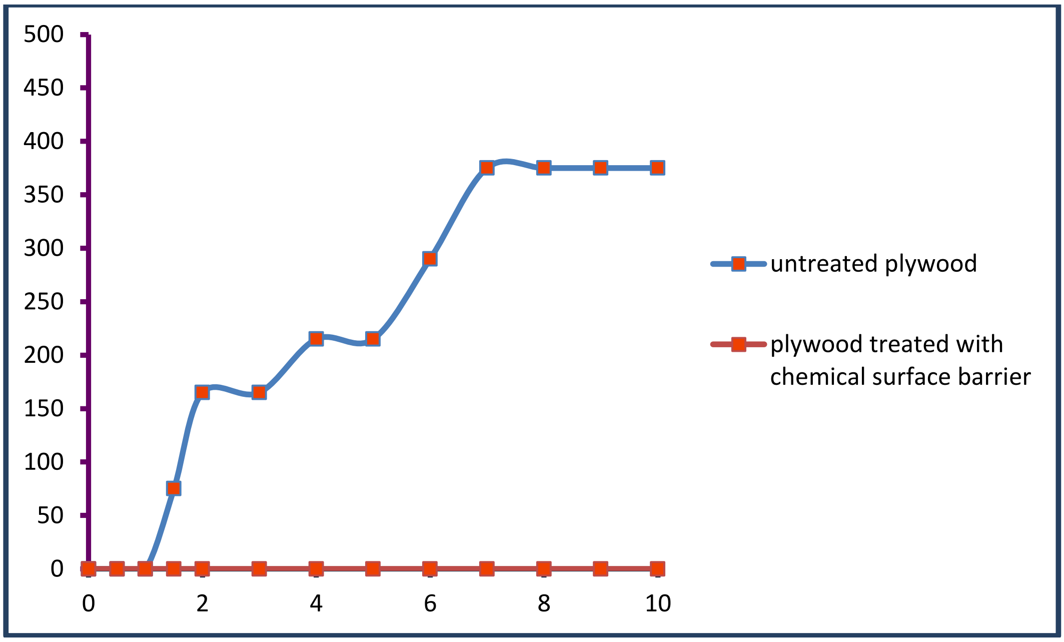

Fig 2*: Time-Flame Spread Curves for Surface Spread of Flame Experiments.*

Specific Optical Density of Smoke

Smoke generated by lining materials used in the interior of a building is known to be a major factor responsible for hampering escape and impending rescues operations. Smoke arising as a plume from burning material consists of invisible hot gases, vapors and particular matter. Immediate effect of smoke is due to the tendency of the particular matter to reduce visibility making difficult or even impossible for persons to find their way to safety from fire affected area. Direct contact and inhalation of smoke can result in irritation of the membranes incapacitation and asphyxiation. The constituent gases of smoke may be acutely toxic which may cause serious physiological disorders or impairment of mental capabilities. Proper selection of materials for the interior of a building from the point of view of their tendency to generate smoke, is therefore of great importance.

The smoke density chamber is one of the salient apparatuses employed to distinguish between the effects of smoke generation in causing a reduction in visibility. The procedure employed is specified in the ASTM E662-79[7]. During the test, two different modes of exposure of the specimen are employed. In first one, the specimen is exposed to radiant heat alone while in the other; the specimen is exposed to radiant heat as well as flames. Smoke generated by materials is expected

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to be different when paralytic decomposition takes place as compared to when a pilot flame is also applied and the materials undergo flaming combustion. In both the cases, the smoke generated by specimen of the material is allowed to accumulate inside a closed chamber and percent transmissions across a light path are measured. The result of this experiment is expressed as Maximum Specific Optical Density. Higher the maximum specific optical density, higher is effect or smoke from the material in reducing visibility.

The time-percentage transmittance curves for Plywood and Plywood treated with chemical surface barrier are shown in Figure 3 and 4 for non-flaming and flaming mode respectively. The results for maximum optical density obtained during experiment for untreated Plywood and Plywood treated with chemical surface barrier are provided in Table 5.

Table 5: *Results of Maximum Optical Density of Smoke Generated by Materials.*

Type of specimens	Maximum specific optical density; Non-flaming	Maximum specific optical density; Flaming
Untreated Plywood	15.15	56.42
Treated Plywood	9.36	85.00

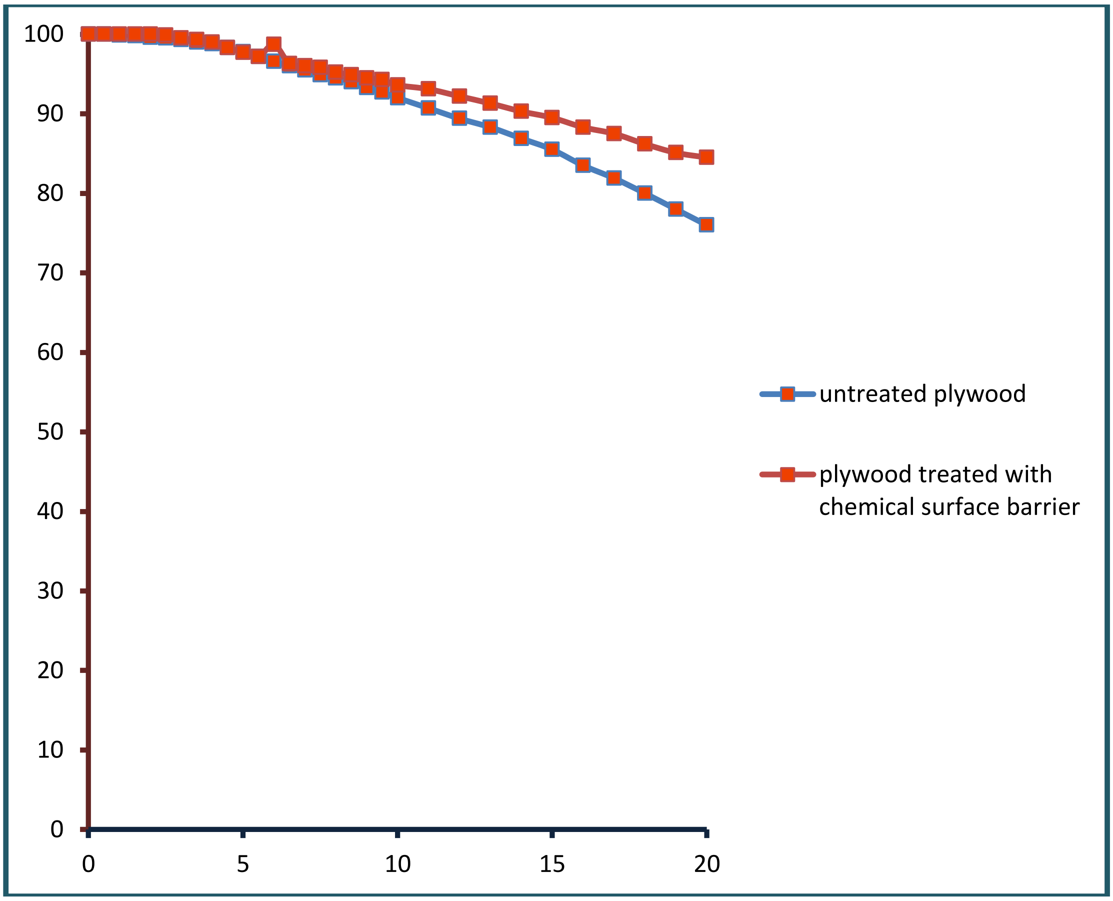

Fig 3: *Time-Percentage Transmittance Curves during Experiments on Specific Optical Density of Smoke Generated by Non- Flaming Mode.*

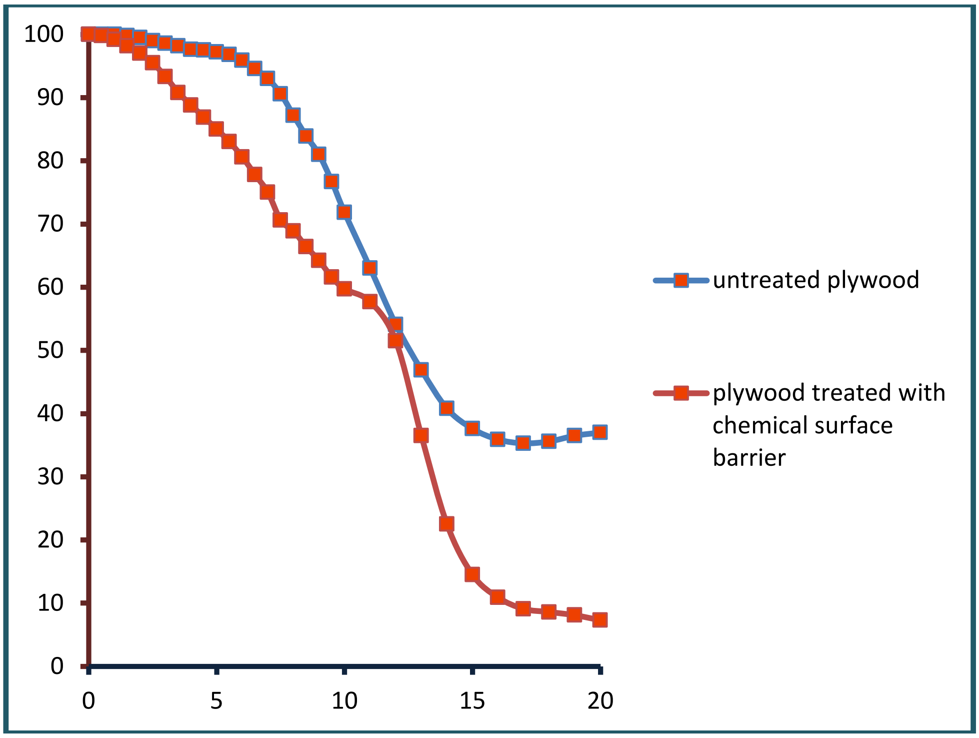

Fig 4: *Time-Percentage Transmittance Curves during Experiments on Specific Optical Density of Smoke Generated by Flaming Mode.*

RESULTS AND DISCUSSION

The results obtained during experimental investigations on Ignitability, Fire Propagation Scale, Surface Spread of Fire and specific optical density of smoke generated by Plywood and Plywood treated with chemical surface barrier are summarized in Tables 1–5.

The Ignitability performance of Plywood and Plywood treated with chemical surface barrier has been determined using BS 476: Part5. Both of them have been found to be 'not easily ignitable'.

Fire extension indices $i_{1,}$ $i_{2,}$ i_3 and I for untreated Plywood are 8.15, 11.91, 3.49 and 23.55 while for Plywood treated with chemical substance surface barrier are 0.13, 5.29, 3.64 and 9.00 severally. The first sub-index which is the measure of flammability and period to pre-flash over has come down to nearly 2%, while Fire extension index I has shown a reduction to 62%. The time-temperature curve for Untreated Plywood shows higher rate of increase in temperatures from ignition of fire to the 'flash over' then, these increases gradually in 'fully developed' fire, while it becomes steady for the 'deceased fire' period.

Plywood treated with chemical surface barrier shows very less or almost no increase in temperatures during first stage of fire and 'flash-over', hence, the result is very much promising. During fully developed fire stage, temperatures are on lower side for this composition as compared to those for untreated specimen. During the final or decay period of fire, the temperatures for all the specimens becomes steady.

Surface spread of flame study also shows significant results. The flame spread in case of untreated Plywood reached to 375 mm while there was no flame spread in case of Plywood treated with chemical surface barrier. The improvement in surface spread of flame classification from Class-2 to Class-1, which is very significant.

The maximum specific optical density of smoke generated by untreated Plywood in non-flaming and flaming mode is 15.15 and 56.42 respectively. The Plywood treated with chemical surface barrier has shown 62% reduction in non-flaming mode while it has been increased slightly by 150%. But this value of maximum specific optical density of smoke is not so high; therefore it does not poses danger to visibility.

CONCLUSIONS

Reaction to fire characteristics of materials used in building industry is of considerable significance from the life safety point of view. The concept of reaction to fire characteristics can be used to identify the likely fire hazard of materials, in terms of their tendency to ignite, to burn, to contribute to the growth of fire and spread of flame, to generate dense smoke and combustion products. Thus, by comparing 'Reaction to fire characteristics' of different materials it is possible to identify the fire safe material in order to avoid fire incidences and for maintaining desired level of fire safety in buildings.

A chemical substance surface barrier can enhance the 'reaction to fire' characteristics of lining materials used in buildings by rendering them flame retardant. The overall fire performance of Plywood treated with chemical substance surface barrier is much better than that of untreated Plywood and hence, the chemical surface barrier treatment is found to be quite effective.

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