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Flame Spread in Wood and its Control

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ABSTRACT

Wood has been recognised as a good building material and has been popularly used in variety of forms. However, it is an intrinsically combustible material and poses fire hazard and also permits rapid spread of flame on its surface. There are several factors which influence surface spread of flame like moisture content, ventilation, surface texture and size of specimen etc.

To study the control of flame spread, chemical, coating, thermal and gas theories have been discussed. To reduce the fire hazards posed by wooden materials several fire retardant treatments have been proposed, such as impregnation, spray, surface treatment and incorporation method.

Fire prevention always must take precedence over fire extinguishing. Thus suitably treated wood based materials will no more be dangerous from the flame spread point of view.

1. INTRODUCTION

Wood has long been recognised as a good building material and has been popularly used in a variety of forms for diverse applications in buildings such as for doors, windows, frames and as partitions and floorings etc. However, it is an intrinsically combustible material and poses fire hazard. It has low fire resistance and also permits rapid spread of flame on its surface.

When wood is heated in the range of 190°C to 360°C combustion occurs with evolution of hydrogen, carbon monoxide and other organic gaseous compounds which are highly flammable and catch fire and burn producing large flames and flying brands. If a piece of furniture situated in a room catches fire flames spread across the wood block flooring to a wall or another piece of furniture, which will also become involved. At this stage of flame spread, the rise in temperature in the room will be relatively slow and it will remain so until it builds up to such a level that any flammable objects in the room are at a pyrolysis temperature. At this time any or all of these flammable objects will be evolving flammable gases and flames will no longer propagate progressively along surfaces, but will jump from one solid object to another. The condition of flashover, akin to a slow explosion occurs. Beyond this point, control of the fire is very difficult and the fire resistance properties of the walls, ceiling and floor become important for containing the fire within the room. It will continue in its fully developed state until extinguished or its supply of fuel or oxygen becomes exhausted.

To enable wood to be used without the reservation imposed by its combustibility and to lesson the fire potential and hazard posed by it, its fire retardant treatment becomes of prime importance. Fire retardant treatments can be applied to wood and its products to make these materials fire retardant and to retard the spread of flame across their surfaces. If these materials are rendered fire retardant, fire hazards would be reduced, cause of fire safety would be assisted and loss of property and life especially in buildings where people assemble in large number would be minimised.

2. FACTORS INFLUENCING SURFACE SPREAD OF FLAME

Flame propagation begins when a surface is subjected to an energy input from some external source by radiation, conduction or conviction. As a result of this energy input, the temperature of the surface is raised such that volatiles are emitted. Ignition of these flammable volatiles evolves more heat which is transfered to the surface and starts the process again. Flame spread is a series of ignitions and radiations of heat[1] taking place at the surface where the contact between fuel and air is at its greatest. The factors controlling flame propagation are related to the external heat source that start and aids the process throughout, the nature of the surface across which the flame spread (its roughness as well as its density and material composition) and the access of the fuel to oxygen.

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2.1 Moisture Content

It is logical to assume that the presence of moisture in wood will delay its ignition and slow down flame spread. Gross[2] evaluated this with A.S.T.M. (American Society for Testing and Materials) Radiant Panel Flame Test on a wood based fibre board and obtained the results as follows

Moisture content (per cent) :	→ 1	7	12
Flame Spread Index :	→ 353	276	156

2.2 Ventilation and Other Factors

Oxygen concentration in the atmosphere, movement of air across the burning specimen and ambient temperature are important factors affecting flame spread.

2.3 Surface Texture

The effect of having a rough surface is that of dividing a smooth surface up into a large number of element, each of which behave as a small specimen from the stand point of ignition. Access of oxygen to each element is high, heat transfer into the bulk of the material is limited. by the diameter of the projecting element and so temperatures increase rapidly. Ignition is aided by these conditions so surface spread of flame is much more rapid over rough surfaces than over smooth ones.

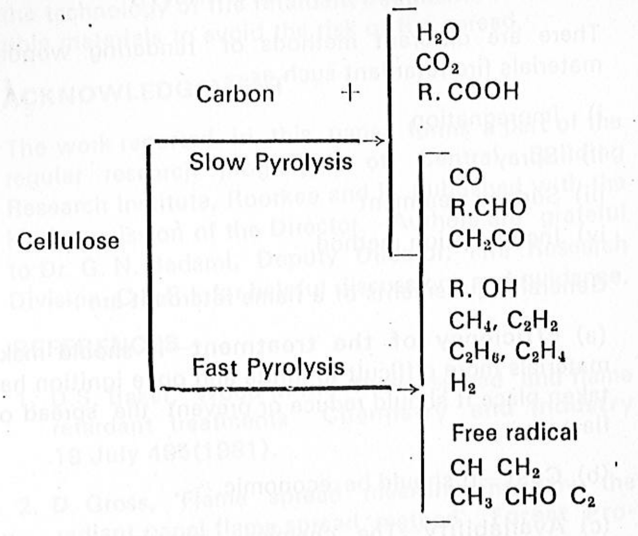
2.4 Size of Specimen

Ignition and flame spread are affected by a heat energy balance between incident energy from an external source the energies associated with the chemical reactions of combustion and the energy dissipated by conduction into the fuel by radiation and by convection from the flames. Heat dissipation into the fuel is limited by area and thickness. In a thin material, the amount of heat that may be conducted away from the surface to the interior is limited, so surface temperatures increase rapidly favouring ignition and rapid flame spread[1].

3. CONTROL OF FLAME SPREAD—THEORIES OF FLAME RETARDANT

Wood and its products can be treated with chemicals in such a way that their ignitibility decreases and propagation of flame ceases.

The pyrolytic reactions of wooden materials is a two way process. From an initial temperature of 250°C to a final temperature of 400°C at different rates and pressures. The slow and fast reactions of pyrolysis for cellulose have been represented schematically[3] as follows :



Thus slow pyrolysis yields charcoal and oxygenated gases whereas rapid pyrolysis yields little or no carbon and forms hydrogenated gases.

3.1 Chemical Theory

The chemical theory is based on changing the pyrolysis mechanism from that of fast pyrolysis to that of slow pyrolysis[1]. If the pyrolysis of cellulose could be directed to complete dehydration according to the equation

$$\underset{\text{Cellulose}}{(C_6H_{10}O_5)n} = \underset{\text{Carbon}}{6nC} + \underset{\text{Water}}{5nH_2O}$$

there would be no flammable gases from the major component of wood until temperatures were high enough for the water gas reaction to set in by which time most of the water would escape.

3.2 Coating Theory

The fire retardant coatings contain retardant ingredients that may function as the barrier between air and material to prevent access to oxygen and to hamper the escape of combustible gases. The foam[4] which forms on heating, serves as a barrier to air and flame providing thermal insulation and entraps volatile tars.

3.3 Thermal Theory

There are two alternative concepts i.e. the heat supplied may be absorbed[5] by exothermic process during transformation of the flame retardants or the heat may be removed by conduction along the fibres.

3.4. Gas Theory

The retardant decomposes to give non-flammable gases[6] which hinder propagation of the flame by combating the oxygen present.

There are different methods of rendering wooden materials fire retardant such as—

i) Impregnation

ii) Spray

iii) Surface treatment

iv) Incorporation method.

General requirements of a flame retardant are :—

(a) **Efficiency of the treatment**—It should make materials more difficult to ignite and once ignition has taken place it should reduce or prevent the spread of flame.

(b) **Cost**—It should be economic.

(c) **Availability**—The chemical should be easily available.

(d) **Non corrosive nature**—It should be non-corrosive to other constructional materials and should not interact with other finishes and commonly encountered substances.

(e) **Non toxicity**—It should be preferably be non-toxic to humans.

(f) **Environment**—In a fire situation it should not evolve toxic decomposition products or dense smoke that will pollute the environment and make escape more hazardous.

(g) **Strength**—It should not reduce the strength of material.

(h) **Handling**—It should be easy to apply.

A number of chemical formulations have been developed keeping in view the above characteristics.

4.1 Impregnation Method

Historically this is the first method to have been used for the control of flame spread in wooden materials. Many chemicals have a fire retardant effect when material is impregnated with them. Such chemicals are ammonium chloride, ammonium sulphate, zinc chloride etc. A solution of cyanamide and phosphoric acid[7] is a very good fire retardant for cellulosic materials. Optimum results are obtained when the solution contains three moles of cyanamide to one mole of phosphoric acid but there is a loss of strength of about 35 per cent while employing the above process.

An aqueous solution of different concentrations with ammonium phosphate, sodium tetraborate and boric acid as chemical constituents were used to render wooden material fire retardant.

The process of impregnation known as the full-cell process is fairly simple and involves preliminary de-aeration of the wood by application of vacuum followed subsequently by immersion of the de-aerated wood under the solution of the mixture of salts. 11 to 13 % retention has been found suitable for satisfactory fire retardance. At this retention no flaming and no after glow has been found. Char area was only 12 to 14 cm². Cellulosic absorbing materials such as celotex boards, thermal insulating boards and acoustical boards etc. were immersed in the fire retardant solution for about 50 to 60 minutes to get the required retention of about 11 to 13 per cent.

4.2 Spray Method

For employing the spray method a chemical solution of 10 per cent concentration in an aqueous medium was prepared and specimen were treated by a spray gun. An optimum retention of 12 per cent is quite adequate to render materials fire retardant. On fire test it was found that at this retention neither there was any surface spread of flame nor glow, char area was minimum in the range of 12 to 14 cm². After the removal of flame, samples remain unaffected except for the charred portions where flame had been in direct contact. The specimens were also tested as per B.S. 476 Part 7 (Test for surface spread of flame) to confirm the results.

4.3 Surface Treatment

There are two types of coating

a) Intumescent

b) Non-intumescent.

4.3 (a) Intumescent Coating

When heat is applied to paint film, combustion produces a residue which is puffed up by escaping gases. It is however possible to puff up combustion residues in such a way as to produce a tough insulating foam which will protect materials over which it is formed in a very efficient manner. Such technique has been refined for use in fire retardant paints.

Intumescent paint on heating should produce

—Incombustible residue

—Residue must be expanded to cellular foam

—Foam must be tough

—Foam should be adherent to surface

—It should resist violent draft and other forces arising from fire.

Intumescent coatings have certain basic ingredients, additional to those of pigments, resins, plasticizers, thickners etc. which give them their individual characteristic as paint. These basic ingredients[8] are, a source of carbon, blowing agent and a catalyst.

4.3 (b) Non Intumescent Coating

These are invariably opaque for the necessity include white antimony trioxide in the formulation makes it impossible to produce a clear colourless product. The binder may, therefore, be a polyvinyl acetate, copolymer or an alkyd type as appropriate. Antimony trioxide is more effective in presence of halogen compounds an example of synergism. Halogen compound is usually either a chlorinated hydrocarbon wax or an acid with a number of chlorine atoms forming the acid part of alkyd binder. The mechanism of their action as flame retardants has been discussed by Pitts[9]. Evidence is advanced that volatile reaction products like antimony trichloride are formed in situ in the burning process and these become flame suppressants by acting as chain stopper in the gas phase combustion mechanism.

4.4 Incorporation of Flame Retardants

Building materials can be rendered fire retardant by adding the fire proofing agents during manufacturing stage. Addition of dry chemicals to the raw materials is advantageous over the impregnation method, because not all chemicals most effective as flame retardants are readily soluble in water or solvents. The addition of borax, ammonium borate and the less soluble antimony halogen or phosphorous compounds are some of the possible dry constituents of a chipboard or hard board furnish, for rendering them fire retardant.

5. CONCLUSION

It has been shown that suitably treated wood based materials are no more dangerous from the flame spread point of view. There are several satisfactory treatments available for wood to render them fire retardant. The builders should thus plan either to avoid extensive use of highly combustible materials or should apply the technology of fire retardant treatments of combustible materials to avoid the risk of fire spread.

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REFERENCES

1. D.S. Baker, 'Wood in fire flame spread and flame retardant treatments' **Chemistry and Industry** 18 July 485(1981).
2. D. Gross, 'Flame spread measurements by the radiant panel flame spread method', **Forest Products J.** 10(1), 33(1960).
3. S. Martin, 'The mechanisms of ignition of cellulosic materials by intense radiation', Research and Devement Technical Report, U. SNR DL-TR-102 N.S. 081-001(1956).
4. F.L. Browne, 'Theories of the combustion of wood and its control', Forest service U.S. Dept. of Agriculture, Dec. (1958). Inf. Rev. and Reaffirmed (1963).
5. P. Thiery, 'Fire Proofing' Elsevier Pub. Company Ltd., New York (1970).
6. D.S. Baker, 'Flame retarding wood and timber products', **Chemistry and Industry**, 15 Jan. (1977).
7. K. Loader, **Fire Prevention**, 132, Sept. 18-21 (1979).
8. J.W. Lyons, 'Chemistry and uses of fire retardants' Wiley-Interscience N.Y.C. (1970).
9. J.J. Pitts, 'Incrganic flame-retardants and thei mode of action', Flame Retardancy of polymeri materials 2, 133-94 (1973).