EFFECT OF DENSITY ON RATE OF BURNING OF WOOD USED IN FRAME OF FIRE RATED DOORS

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Abstract: **During designing of fire rated doors more importance is given to the door shutter as compared to door frame for achieve given fire rating. On the contrary, it is observed in various events that, even if the fire rated door resists fire, the failure occurs in frame because of wrong selection of wood, resulting in non-conformity or failure of door set for achieving the desired fire rating. This study is carried out to correlate the density of wood used in frames of door shutter assemblies with its rate of burning. Some of the widely used species for frames of fire rated door were selected for the study viz. Red meranti (*Shorea acuminata*), Sal (*Shorea robusta*), Birch (*Betula pendula*), Padauk (*Pterocarpus spp.)*, White Meranti (*Shorea spp.*). Samples of different densities ranging from density of 412 to 849 Kg/m^3 were tested for rate of burning as per Indian standard IS 1734 (1983). The correlation of fire performance/ rate of burning was drawn with respect to density of wood. From the results of the study it is observed that lower rate of burning of wood is observed with denser wood, hence it can be said that fire resistance of wood increases with density.**

Keywords: **fire rating, density, selection criteria, optimization, wood species.**

1. INTRODUCTION

Wood is one of the most used natural building materials. A number of valuable properties such as low heat conductivity, low bulk density, relatively high strength, amenability to mechanical working etc. makes wood as a famous building material. The often inevitable hazards of fire make wood a very desirable material for further investigation. It is necessary to take great care to adequately reduce the risk of fire. The use of wood as an interior material is strictly controlled by building codes, so it is necessary in the design stage to thoroughly consider the resistance of these materials to fire.

Fire Resistance means the ability of a building component to resist fire, while still performing its function. Fire resistance in form of a fire rating, can be applied to a total building element incorporating plywood e.g. fire rated door, wall or roof system. Fire retardant plywood (IS: 5509, 2004) is quite acceptable material used in fire resistance components or structures. While timber is indeed a combustible material, in construction it has significant insulating properties and burns in a slow, predictable and measurable way. These factors see timber perform strongly against fire and give designers the ability to confidently create strong, durable, fire resistant timber constructions. When exposed to the heat of a fire, timber goes through a process of thermal breakdown into combustible gases. During the process, a layer of charcoal forms on the burning surface of the timber and it is this charred layer that is the key contributing factor in timber's fire resistance. The layer acts as an insulator protecting the inner core of the timber, making it resist heat penetration and thus burn more slowly ; while the temperature of inner, un-charred core remains low, enabling it to continue to carry its load. Initially the rate of charring is fast but as the char depth increases it provides a stronger protective layer to the timber, slowing the overall combustion rate. The rate at which timber chars varies between species and is predominately dependent on density and moisture content.

Since density has a great relationship with the other physical properties of wood, this study focuses on density, the most widely used physical index of wood, to correlate with fire resistance of wood.

A fire rated door is a door with a fire-resistance rating used as part of a passive fire protection system to reduce the spread of fire between compartments and to enable safe egress from a building or structure. Fire rating has to be specified prior to the installation of a timber door in any high-rise buildings, shopping complexes, hotels and condominiums. Fire doors are "rated" by time (in minutes or hours) that a door can withstand when exposed to fire test conditions. Fire ratings include 30, 60, 90, 120 minutes etc., with the maximum rating required of any swinging type fire door being 180 minutes. Fire doors may be made of a combination of materials, such as timber, steel, gypsum (as an endothermic fill), vermiculite-boards, glass sections. The door frame includes the fire or smoke seals, door hardware, and the structure that holds the fire door assembly in place. Together, these components form an assembly, typically called a "door-set" which holds a numerical rating, quantified in hours of resistance to a test fire. It is reasonable to assume that all fire doors and frames manufactured to the same specification as the two specimen doors and frames will achieve the same fire resisting properties. During fire rating tests the failure of the door is analyzed by Impermeability /Integrity (fire visible on unexposed face) and Insulation (unexposed surface temperature increases specified limits).

During designing of fire rated door more importance is given to designing of door to achieve said fire rating and selection of high density wooden species for use in frames. However, there is a lot of literature available for designing of fire rated door but no literature is available for selection of frames for use in fire rated doors.

White (2000) reviewed the fire performance characteristics and fire safety engineering of wood products and results on the fire performance of hardwood species were presented. He identified two broad areas of fire safety engineering of materials as Fire initiation and growth and Fire containment. The flame spread during combustion may depend on density, thickness, chemical composition, and surface characteristics. Finishes on the wood may affect the flame spread index depending on the thickness and composition of the finish. Fire-retardant treatments can be used to reduce the flame spread index of wood. Although timber is classified as combustible material, a properly designed timber structure has been recognized as performing very well in fire. Light timber construction is normally protected from fire by fire resistant cladding materials, while heavy timber construction has good inherent fire resistance because a char layer is formed that retards the heat penetration. When heavy timber members are exposed to a fire, the temperature of the fire exposed surface of the members is close to fire temperature. When the outer layer of wood reaches its burning point (about 300°C), the wood ignites and burns rapidly. The burned wood becomes a layer of char which loses all strength but retains a role as an insulating layer preventing excessive temperature rise in the core.

The low conductivity of char will cause a steep thermal gradient across the char layer. Underneath the char layer, there is a layer of heated wood with a temperature of above 200°C, which is known as the pyrolysis zone. This part of wood is undergoing irreversible chemical decomposition caused solely by a rise in temperature, accompanied by loss of weight and discolouration. The inner core wood is slightly temperature affected with some loss of strength and stiffness properties, mainly due to the moisture evaporation in the wood. The charring rate is more or less constant and depends on the density and moisture content of the wood and heat exposure (Buchanan 2001; Purkiss 1996). The fire performance of timber is dependent on the charring rate and the loss in strength and modulus of elasticity. Strength and stiffness properties depend on temperature and moisture content.

Various standards and codes throughout the world describe fire resistance of materials in different ways.

These codes give that uniform set of technical provisions for the design and construction of buildings and other structures. The BCA includes a section on Fire Resistance, and designers and builders must ensure that their constructions satisfy this section.

Various types of tests methods are available for evaluating fire resistance of wood and panel products internationally. The Indian standard IS: 1734 (Part 3)- 1983 describes the test method for determination of fire resistance of plywood by conducting three tests viz. flammability, flame penetration and rate of burning. Whereas, the performance of timber doors is judged by subjecting them to the standard test procedure specified in BS 476: Part 22 (1987), BS EN: 1634-1 (2000), IS: 3614 (1992), ISO: 3008 (2007), ISO 834-1 (1999) etc. Tests are made on complete door assemblies, the fire door and frame with all the necessary hardware.

When heated, wood undergoes thermal degradation and combustion to produce gases, vapors, tars and char. In order to understand and alter the fire behaviour of wood, it is necessary to know in as much detail as possible about its processes of decomposition. Various thermal analysis and flammability assessment techniques are utilized for this purpose, including thermo-gravimetric analysis, cone calorimetry and the single burning item test. The results of such tests are often highly dependent on various parameters including changes to the gas composition, temperature, heating rate, and sample shape size (Laura et.al., 2013). Heat transfer through the insulation is considered to be a combination of gas-phase conduction, solid-phase conduction and radiation (Kumaran et.al. 1988).

ISO 834 -1 (1999) gives the general requirement for fire resistance tests for elements of building construction.

The Indian standard IS 1734 (Part 3)- 1983 describes the test method for determination of fire resistance of plywood by conducting three tests viz. flammability, flame penetration and rate of burning. Objective of this study is to find the effect of dimensions, density and species of wooden frames used in fire rated doors to resist fire.

2. MATERIALS

The most commonly used species for use in Frames of fire rated doors used in India were identified. The samples of different species of various densities species were collected for the sttudy as given below:

i. Red meranti (*Shorea acuminata*)

ii. Sal (*Shorea robusta*),

iii. Birch (*Betula pendula*)

iv. Padauk (*Pterocarpus spp.)*

v. White Meranti (*Shorea spp.*)

3. METHODOLOGY

Since during testing of fire rated doors as per BS 476 -Part 20&22 (1987), the burning of the door takes place from Inside furnace to outside furnace direction resulting in charring of frame along thickness, which is similar to the burning of samples subjected to rate of burning test as per IS 1734 -Part 3 (1983). Typical failure pattern of fire rated door during testing as per BS 476 (Part 20 & 22) is shown in Fig. 1. Specimens were prepared for evaluation of properties viz. density and rate of burning. Samples were subjected to rate of burning test as per IS: 1734 -Part 3 (1983) to simulate the conditions of burning of door frame at a smaller scale.

Three number of specimen from each samples of size 100 mm x 12.5 mm x 12 mm were prepared for testing fire resistance (rate of burning test) as specified in IS:1734 -Part 3 (1983), in which the test specimen is suspended in a fire tube and adjusted at a height of 30 mm from the flame of the burner. The test specimen is ignited by a blue flame and the time taken from 30 to 70 percent loss in mass of sample was recorded. The average value of three specimens was reported after rounded to the nearest minute. The test setup for 'Rate of burning test' is shown in Fig. 2. Three number of specimen from each samples of size 50 mm x 50 mm x 150 mm were prepared for determining density as per IS 1708 (1986). The specimens were preconditioned to a constant mass at a relative humidity of 65 $\pm$ 5% and at a temperature of 27 $\pm$ 2ºC

4. RESULTS AND DISCUSSION

The density and rate of burning of wooden samples are given in Table 1. It is observed that the fire resistance increases with increase in density of wood and also from the correlation (Figure 3) it is observed that the fire resistance of wood increases with increase in density. Although timber is said to be a combustible material, a properly designed timber structure performs very well in fire. Heavy timber has good inherent fire resistance because a char layer is formed that retards the heat penetration. When heavy timber members are exposed to a fire, the temperature of the fire exposed surface of the members is close to fire temperature. When the outer layer of wood reaches its burning point, the wood ignites and burns rapidly. The burned wood becomes a layer of char which loses all strength but retains a role as an insulating layer preventing excessive temperature rise in the core.

The time for rate of burning of 3 minutes was observed for sample G (*Shorea acuminate*) having density of 412 Kg/m^3, whereas highest rate of burning of 9 minutes was observed for sample D (*Shorea robusta*) having density of 849 Kg/m^3. The average density of 13 samples taken for the study was computed as 665 Kg/m^3.

The low conductivity of char will cause a steep thermal gradient across the char layer. Underneath the char layer, there is a layer of heated wood with a temperature of above 200°C, which is known as the pyrolysis zone as shown in Figure 1b. This part of wood is undergoing irreversible chemical decomposition caused solely by a rise in temperature, accompanied by loss of weight and discolouration.

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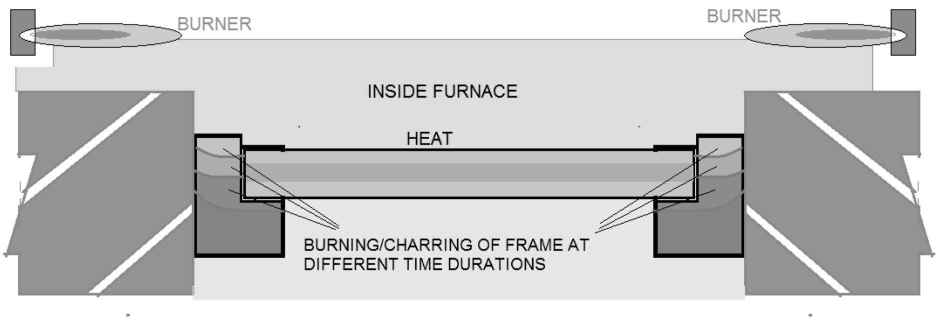
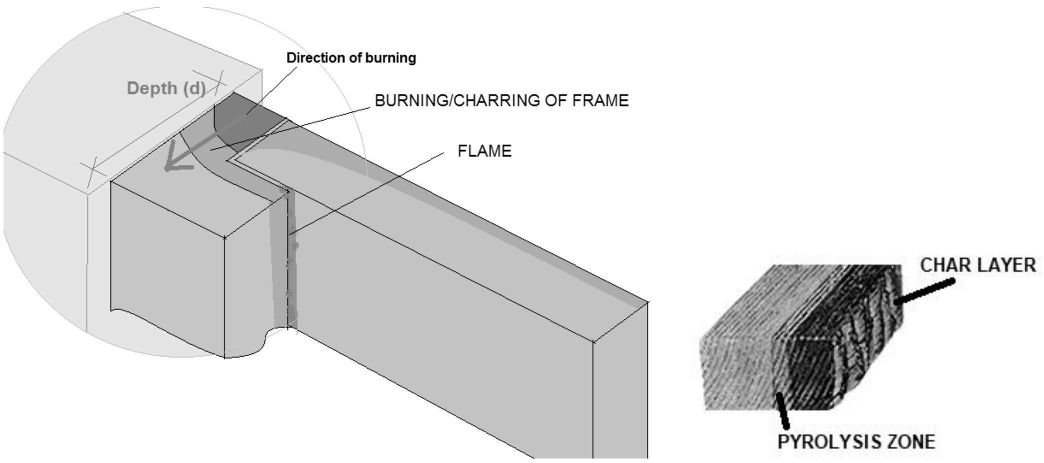
From the study it can be said that for lower density species, by providing higher dimensions/ cross-section resulting in more travel length of flame the given rating can be achieved. The charring rate is more or less constant and mainly depends on the wood properties viz. density and moisture content.



a. Typical view of door under testing



b. Burning pattern of wood used in door during test

Fig. 1: Failure pattern of fire rated door during testing as per BS 476 (Part 20 & 22)

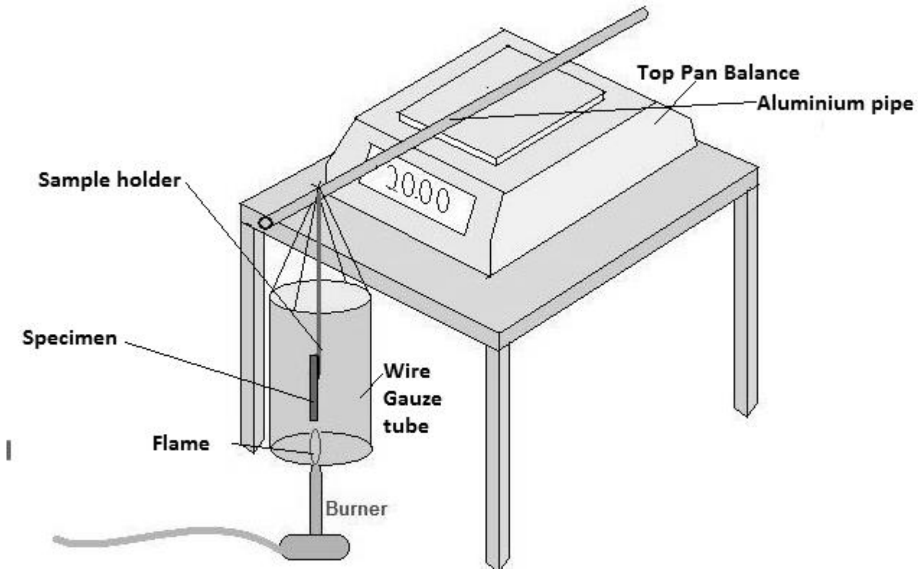


Fig. 2: Setup for rate of burning test

TABLE 1: Results of Rate of burning tests of samples drawn from frames

Sl. No.	*Species*	*Avg. Density, Kg/m³*	*Rate of burning (average), minutes*
A.	*Shorea robusta*	785	7
B.	*Shorea robusta*	800	7
C.	*Shorea robusta*	804	8
D.	*Shorea robusta*	849	9
E.	*Betula pendula*	518	4
F.	*Betula pendula*	590	6
G.	*Shorea acuminata*	412	3
H.	*Shorea acuminata*	456	4
I.	*Shorea spp.*	544	5
J.	*Shorea acuminata*	794	9
K.	*Pterocarpus spp.*	654	6
L.	*Pterocarpus spp.*	660	6
M.	*Pterocarpus spp.*	774	9

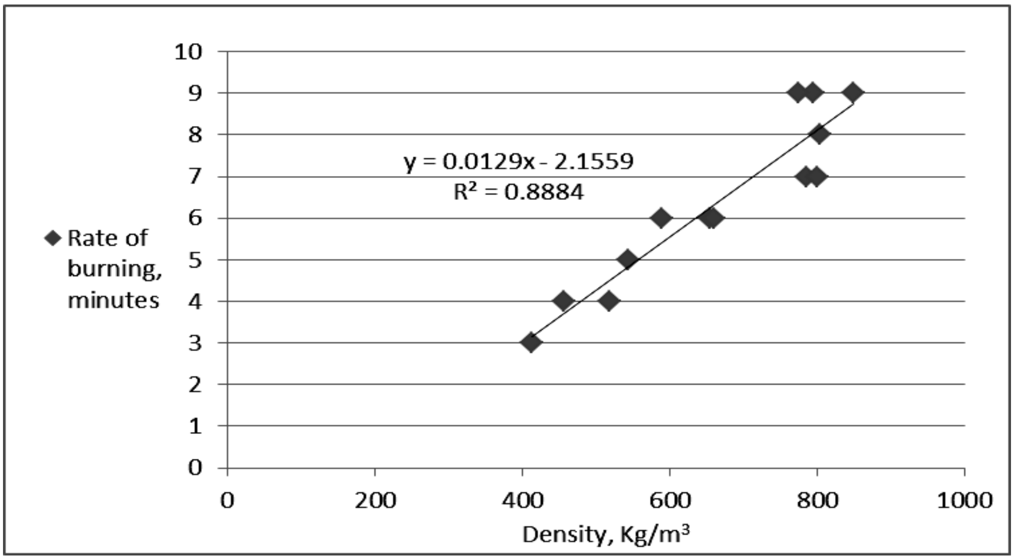


Fig. 3: Correlation between density (Kg/m^3) and rate of burning (Minutes) of wood samples

5. CONCLUSION

From the study it is concluded that density wood plays an important role in selecting frames for fire rated door shutters. High rate of burning is observed for *Shorea acuminata* sample having density of 412 Kg/m^3, whereas lowest rate of burning was observed for *Shorea robusta* sample having density of 849 Kg/m^3. The average density of 13 samples taken for the study was computed as 665 Kg/m^3. This indicates the resistance to burning increases with density of wood. The fire rating increases with density of wood used in fire rated door shutters. Also, the depth of door frame and area of cross section also plays an important role in achieving desired fire rating.

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