Fire Resistance of Wood Structures

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Wood as a building material has the disadvantage of being combustible. Consequently wood structures are seen by many as creating an environment less safe than structures built of noncombustible materials such as steel and masonry. However, experience has shown that some wooden structures have a fire resistance comparable, or greater than that of many noncombustible alternatives. Some statistical figures are given comparing wood with other materials. The fire course and the burning mechanisms of wood are briefly discussed, as is the fire resistance of wood structures from different perspectives. Reference is also made to present research work.

IN MANY PARTS of the world, wood is one of the most commonly used building materials. There are several reasons for this, among them are availability and versatility. In heavily forested lands such as Scandinavia, Canada, and the United States, wood has been and is still readily available in many varieties, and has a long tradition of use.

Because it is a renewable resource, it has clear advantages from environmental and energy consumption perspectives. Growing forests themselves contribute positively to environmental health. Additionally, the production of wood as a building material requires only about 10 percent of the energy consumption required for the corresponding value of steel.

Wood, however, has the disadvantage of being combustible, and consequently, wood structures are seen by many as creating an environment less safe than structures built of less combustible materials such as steel and masonry. This attitude has been well noted by Swedish manufacturers of wooden houses when they attempt to put their products on the continental European market.

Reference: Kai Odeen, "Fire Resistance of Wood Structures," *Fire Technology*, Vol. 21, No. 1, February 1985, p. 34.
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Experience has shown that wooden buildings, singly or in groups, may burn with astonishing rapidity. But, on the other hand, some wooden structures have shown a fire resistance comparable to, or even greater than, that of some steel structures. It is obvious from this that the "firesafety" of wood as a building material is highly dependent upon the shape of the structure, the size of the structural members, a great number of other parameters, and the individual circumstances of the fire exposure.

In establishing that wood may be a realistic and practical material for fire-resistant structures, this paper will first comment on the essential characteristics of a modern fire scenario and present some statistical data. Then the behavior of some types of structures will be discussed, along with a brief summary of the state-of-the-art.

Finally, the fire behavior of some modern wood construction systems, including combinations of other materials such as steel will be considered. The possibility that the use of metallic joints may be the weak link in the firesafety of wood construction will be pointed out.

Fire Course

A complete room fire course can be separated into different phases according to Figure 1.

After ignition, the temperature rises slowly and, during this time, smoke and more-or-less uncombusted gases are logged in the fire room. At a certain time the conditions become "favorable" and the entire room volume is involved in the fire. This phenomenon usually described as "flash-over," is normally very dramatic and increases the risk significantly.

Today, the duration of the ignition phase of a room fire in an apartment or dwelling house is of the order of 5 to 10 minutes, whereas the corresponding values some decades ago were 25 to 30 minutes. The main reason for this difference seems to be the changes in furnishing materials with synthetic polymers (plastics) becoming dominant both for textiles and for upholstering materials. This development is clearly demonstrated in Figure 2.

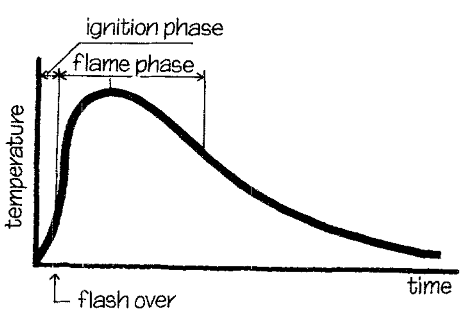

Figure 1. Characteristic phases of a fire.

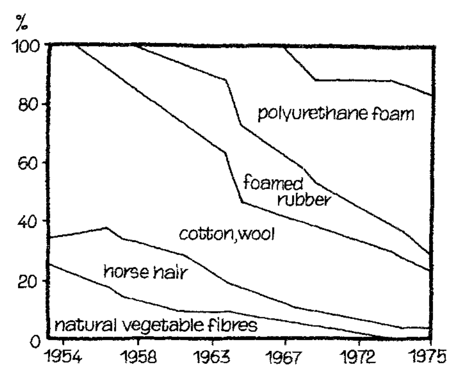

Figure 2. Typical change of materials for upholstered furniture.

Statistical data have indicated that the building's combustibility plays only a minor role in determining the degree of damage.[1] Some recently compiled statistical data shows no significant difference between combustible and noncombustible buildings as far as fatalities are concerned.[2] This can be illustrated by the following NFPA figures concerning fatal fires in one-family houses.

Type of building	*Number of fires*	*Number of fatalities*	*Fatalities per Fire*
I + II	39	68	1.74
III + IV	482	241	1.94
V	2562	4606	1.80

The type of building is characterized as follows:

I + II Load-bearing walls and noncombustible slabs with at least two hours fire rating according to ISO 834.[3]

III + IV Load-bearing walls as above but combustible floor structures.

V Wooden framed structures.

These figures, together with an approximate estimation of the number of buildings in the different classes give support to the statement that the risk of fatality is not higher in a wooden house than in a house built of noncombustible material.[4]

Some attempts have been made to estimate the influence of building class on the property loss in a fire. The existing data are not possible to interpret accurately, but there are indications of a significant difference between combustible and noncombustible buildings of about $1,000. Some figures from a Swedish insurer are given below to illustrate this:

Building class	*Number of fires*	*Frequency % of damage*	*Mean damage*
1 + 2	1511	6.9	$ 765
3 + 4	1953	6.5	$1810

Building Class 1 represents combustible buildings and Class 2, buildings with noncombustible walls. Class 4 is an entirely combustible building.

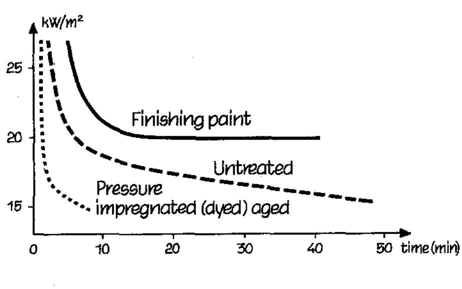

Figure 3. Time to ignition vs constant radiant intensity for variations in protective treatment and aging. Pilot flame ignition.

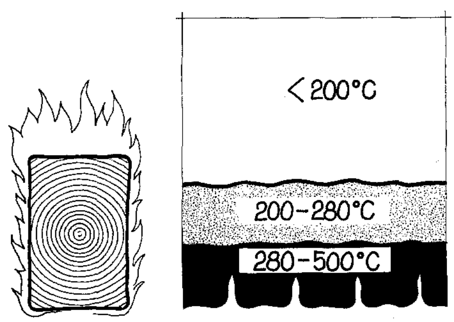

Figure 4. Characteristic zones for pyrolysis of wood.

IGNITION AND PROPAGATION

Being a combustible material, wood is ignited when exposed to sufficient heat. The time to ignition depends on a number of factors, some of which are illustrated in Figure 3, where time is given vs radiant heat intensity. The different curves correspond to different surface treatments as indicated. The values are experimentally determined using a radiant panel and a so-called pilot flame for ignition of combustible gases generated from the surface.[5]

After ignition a charcoal layer is developed on the surface. Low thermal conductivity and oxygen diffusivity make this layer a fairly good protection for underlaying unburned material. Detailed studies of this layer and of the pyrolysis of wood at elevated temperatures have shown four characteristic zones parallel to the heated surface according to Figure 4.[6]

In Zone A the pyrolysis is slow and the generated gases are not ignitable. Some exothermic oxidation may occur but fresh timber — with no rot — will not be ignited in Zone A.

In Zone B the exothermic pyrolysis and oxidation are more definite. The temperature where the net effect is clearly exothermal has been adopted as the ignition temperature for wood even if spontaneous ignition (without pilot flame) normally needs higher temperature than in this zone.

Zone C is characterized by so high a diffusion of combustible gases from interior material that the combustion takes place entirely outside the surface preventing the access of oxygen to the charcoal layer.

Finally in Zone D the charcoal layer is glowing and oxidized.

As an approximate characterization of the surface mechanisms, the border between charcoal and mechanically more-or-less undestroyed wood is assumed to follow the 300° C isotherm.

The increase of the charcoal layer is controlled by two different processes related to reaction kinetics and heat transport respectively. The thickness of the material determines which mechanism is dominant and as a rule the

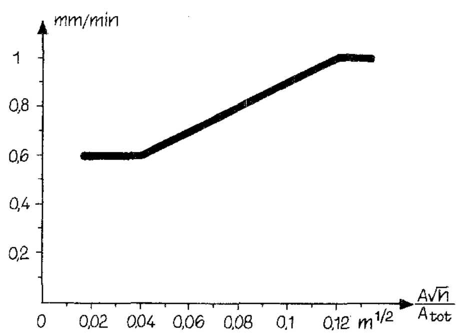

Figure 5. Approximate relation between increase rate of the charcoal layer and the opening factor of the fire room.

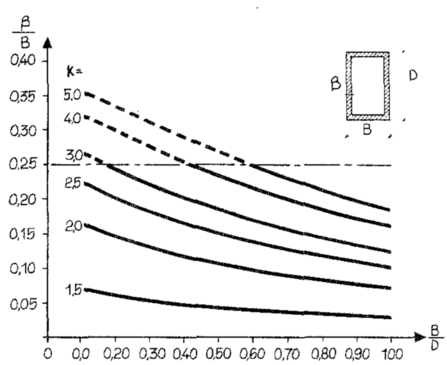

Figure 6. Relation between charcoal layer thickness at failure β, due to bending and width/height ratio for a wooden beam. K denotes the safety against failure at room temperature.

kinetic processes are most important for thin materials and the transport processes for the thick ones.

An approximate relation between the increase rate of the charcoal layer thickness and the opening factor $\frac{A \cdot \sqrt{h}}{A_{tot}}$ is shown in Figure 5.[7]

The lower value 0.6 mm per min is usually assumed to hold for a fire exposure corresponding to standard fire tests.

FIRE BEHAVIOR OF SOME TYPES OF STRUCTURES.

Several authors have presented methods for calculating the fire resistance of wooden elements subject to bending.[8,9,10] An example taken from Odeen[10] is given in Figure 6. The figure gives the value of β/B corresponding to flexural failure where β is the thickness of the charcoal layer and B is the width of the rectangular cross section. K denotes the safety against flexural failure at ambient temperature and B/D the width/height relation for the unburned cross section. In the calculations, the reduction in strength of the unburned cross section due to elevated temperatures and moisture content has been assumed to be 20 percent. For $\beta/B > 0.25$ the curves are dotted indicating insufficient experimental verification in this region.

During the fire the shape of the unburned cross section will change in such a way that the risk of lateral instability (buckling) will increase. In Fredland[11] a study of this problem is presented.

For compressed structural members, e.g. columns, a corresponding method may be applied. However, the problem is more complicated as the risk of buckling is continuously increasing during the fire due to the increasing slenderness of the unburned part. An analytical approach to this problem is given by Odeen.[10]

Applications of the methods mentioned above, show that load-bearing wooden structures of, e.g., glued laminated timber of common dimensions may have significant fire resistance and ratings of up to 90 minutes.

An interesting trend can be seen in the development of new building components especially for industrial buildings. Drastically increased insulation requirements giving large constructive heights in combination with restrictions of the allowable weight of each single element are often successfully met with composite structures of various design. Of special interest in this connection are combinations of steel, tin, and wood panels or plates. One example is shown in Figure 7.[12] The cross section is basically

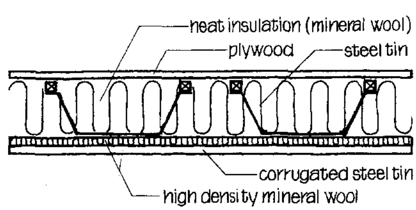

Figure 7. Modern composite industrial roof structure.

built up with a compressive flange of plywood whereas the webs and tension elements are combined in a folded steel tin structure glued and or nailed to the plywood. The construction is completed with a corrugated tin element giving a reasonably flush lower surface and mineral wool for heat insulation and noise reduction. The upper surface is covered with a sealing layer of roofing felt or PVC foil.

A roof structure of this type has a fire resistance of about 60 minutes. Perhaps more interesting is that it has been given the highest (best) class by the Swedish fire insurers putting it on the same level in this respect as entirely noncombustible constructions even if combustible material is used for a major part of the load-bearing capacity. This decision is based on extensive experimental analysis of the roof.

JOINTS

Metallic joints in timber structures must be given special attention in the fire-resistive analysis of a wooden structure. The high thermal conductivity of metal, in most cases steel, leads to a rapid, local increase of charring rate and consequently to a rapid breakdown of the joint and of the whole structure. Where fire resistance is prescribed or desirable, the metallic parts must be sufficiently protected either by the structure itself or by additional protective material. The Finnish building code requires metallic joints in direct contact with wood to be protected so that the metal temperature does not exceed 300° C.

Several authors have reported experimental work in this field. Basic studies in Finland in the early 1960s indicated the nature of the problem[12] and, subsequently, German, Norwegian, American and Swedish work has been reported.[14,15,16,17]

Analytical models at present do not exist in this field. An interesting approach towards such a model would be to extend the existing models for point set structures at room temperature to include the effect of temperature and charring. A Swedish research project attempts this.[18]

In this brief summary only some of the major fire problems related to wooden buildings have been mentioned. Additional information can be found in the literature. Recently a Swedish survey of the state of knowledge and the need for further research has been published.[18] It can, however, be stated that wood may be a realistic material for fire-resisting structures and that further research and development will widen this applicability.

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