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REPRINT

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FIRE RESISTANCE OF WOOD FRAMED WALLS

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ABSTRACT

Wood framing is traditionally used in New Zealand for residential and light commercial construction. Recent changes to the building regulations relating to fire safety have encouraged the use of wood framed construction in both loadbearing and non-loadbearing situations where fire resistance is a requirement.

A research project is currently under way at the Building Research Association of New Zealand (BRANZ) aimed at developing a rational design method for fire resisting wood framed walls based on the results of standard fire resistance tests. Initial phases of the project have involved examining the literature and gathering data from standard fire resistance tests.

The data gathered from such tests has been examined with respect to the temperatures of the wood close to the hot side of the framing, particularly noting the time when charring begins.

This paper discusses the results to date and concludes that the wood temperatures are a good indicator of the behaviour of the lining material, but are not sufficiently consistent to be used on their own as a reliable design parameter.

INTRODUCTION

Wood framed walls comprising vertical studs and horizontal noggings, lined with sheet materials, are traditionally used in New Zealand for residential and light commercial construction. The most common size of framing member is 100 x 50 mm, although sizes from 75 x 50 mm up to 150 x 75 mm may be used. The most common lining material is gypsum plasterboard, which is available in various grades and thicknesses whose use would depend on the fire, acoustic and structural performance required.

The aim of the research discussed in this paper is to examine the structural performance of such walls under fire conditions, and ultimately to develop a design procedure for fire resisting walls beyond the dimensional limits of currently available testing apparatus.

In the course of searching the literature much information has been found concerning the behaviour of wood at high temperature, some of which is directly applicable to this project. It has been found however that there are still many factors, not well understood yet, which should be taken into account in any rational design method. This paper proposes a possible design procedure (see Appendix) and discusses what information is required as input to the design procedure and some options as to how it may be acquired.

A method known as the "onset of char" method is currently available in New Zealand for predicting the fire resistance of a loadbearing wood framed wall from the results of a non-loaded test. This has met with limited success to date and the reasons for this are discussed. Some modifications are proposed to make the method more useful.

CHANGES TO FIRE SAFETY REGULATIONS

The fire safety requirements for buildings in New Zealand are contained in New Zealand Standard 1900 Chapter 5: 1984 Fire Resisting Construction and Means of Egress [19]. Prior to 1984 the regulations defined a "Fire Wall" as "a wall of concrete or masonry, having a 4 hour FRR used ... to separate two fire compartments..." [18]. In the 1984 edition this definition was changed to allow a range of fire resistance ratings (FRRs) which depend on the location and use of the building, and to eliminate the restriction on construction materials in certain areas. The effect of these changes was that for most fire walls separating residential or commercial units in the same building the use of wood framed walls became appropriate.

The definition of a "Fire Partition" within a fire compartment was also changed to eliminate restrictions on materials and also reduce the FRR required.

The overall effect of this has been that wood framed walls have been used increasingly in situations in which they were not previously allowed, and in many cases they have been used at heights beyond the 4 m limit of the BRANZ test furnace.

LITERATURE SEARCH

The structural behaviour of wood framing under fire conditions is controlled by its initial properties, i.e., at normal temperatures, and by the effects of increased temperature on these properties. The literature has been examined with a view to finding the required input to the appended design method, and has concentrated on finding information as it applies to New Zealand grown Pinus radiata as this is the species most widely used in that country for structural framing.

Normal Temperature Properties

The properties of Pinus radiata at normal temperatures have been the subject of much research in New Zealand due to its importance as a national resource, and hence the information required is relatively readily available [2], [3], [9], [20]. The accepted value for in service moisture content is 16% [19], and the average density of structural grades is about 425 kg/m^3 [20].

Wood Behaviour at High Temperature

The effects of fire or high temperature on the properties of Pinus radiata have not been studied so information has been sought from overseas research on other species. It has been assumed that the high temperature properties of Pinus radiata will follow similar trends to those of other species with similar normal temperature properties.

A number of models for the behaviour of wood exposed to fire or high temperature are available in the literature, ranging from relatively simple empirical models [14], [15] to more complex analytical [5] , [7], [8], [10] and numerical [11], [21] models. A number of these models deal only with wood exposed directly to fire, mostly the standard fire resistance test [12] or similar, and have only been validated for that situation.

Of relevance to this project are those models which predict firstly the rate of loss of section due to char, and secondly the loss of strength and stiffness in the remaining uncharred wood. Related to these is the prediction of the temperature distribution in the wood when protected from direct exposure to fire by a sheet lining of some kind. Such a model is not directly available in the literature so it is proposed to make use of the observed results and existing theory to develop a simple model for this situation.

Some relevant results from previous work are noted as follows:

(i) The charring rate of a particular species is dependent mainly on its density and moisture content. [14]

(ii) The charring rate of wood exposed directly to fire is dependent mainly on the incident radiation, although it is by convection and the concentration of oxygen in the furnace or fire gases. [8] A constant rate of 0.6 mm/minute is generally accepted to be applicable to softwoods exposed to the standard fire resistance test. [7]

(iii) The temperature at the interface between the char and the sound wood beneath is about 550 °F (288 °C). [14]

(iv) The strength and stiffness of wood decrease with increase in temperature. A simple model predicts that the decrease is a function of mass loss only for oven dry wood [6]. Gerhards [4] has surveyed the literature and concludes that temperature generally tends to have greater effects at higher moisture content, but that the data available is very limited and much more work is needed before reliable predictions can be made.

Thermal Behaviour of Linings

The literature relating to gypsum plasterboard behaviour in fire is reviewed by Alexander [1] which contains much information on its thermal and mechanical properties. An important conclusion is that the properties depend on the additives and impurities and therefore different grades of plasterboards can be expected to behave quite differently in fire.

Some literature has been found relating to the behaviour of other linings, mainly wood-based panels, but this is not discussed due to the relatively low level of use in New Zealand.

CURRENT PRACTICE

Onset of Char Method

A method has been proposed and officially approved in New Zealand [16] for prediction of the fire resistance of a loadbearing wall from data gathered from an unloaded test on a specimen construction. The method is based on the assumption that the wood remains able to carry its full design load up until the time it begins to char, at which time it immediately fails. Thus the fire resistance of a loadbearing wall is the time to "onset of char" in a non-loadbearing specimen of similar construction.

Determination of Onset of Char

The method as approved does not specify in detail the procedure for determining the onset of char, so the procedure outlined below has been developed independently by BRANZ.

Having identified from the literature that a temperature of 288 °C indicates the bottom of the char layer, and since the temperature gradient in the wood in this region is very steep, it was assumed that a temperature of 300 °C was as good as 288 °C to determine the start of charring. Since it is very difficult to measure the temperature of the surface of the wood it was decided to take the temperature 5 mm back from the exposed side as the critical value.

The temperature is measured using a stainless steel sheathed chromel-alumel (type K) thermocouple glued into a hole drilled in the side of the member. The hole is drilled horizontally a distance 25 times the diameter of the sheath, parallel to the heated side and as close as possible to 5 mm back from this face.

Results

It has been standard practice to include such thermocouples in all wood framed wall specimens tested at BRANZ for a number of years and thus a large base of data has been built up. Most of the data available have been collected from specimens lined with gypsum plasterboards of various types and thicknesses, many of them paper faced. This has not been reported in detail, but some general observations are noted below.

Gypsum plasterboard linings tend to shrink under the influence of high temperatures and pull away from the joint, exposing the wood underneath. Thus in a single layer system it is usually the wood behind a joint which chars first. In a two layer system the studs with a joint on the outer layer begin to char first. These trends are observed regardless of whether joints are plastered.

The measured times to char show wide variations. These are observed between thermocouple locations along the length of a member, between members in the same test specimen, and between similar specimens in different tests.

Charring is observed to occur mainly on the hot side which is in contact with the lining, but also on the sides of the member.

The temperature recorded by the thermocouple follows a distinctive pattern which consists of five phases as follows:

(i) Stable at initial temperature as the heat passes through the lining and 5 mm of wood.

(ii) Rapid rise to about 75 °C after the heat reaches the thermocouple until the water evaporation reaches a significant level.

(iii) Much slower temperature rise to 100 °C as water evaporates.

(iv) Rapid rise again reaching a constant rate after water has evaporated. The length of time that this phase lasts and the temperature at which the rate of rise changes vary considerably between thermocouple locations.

(v) A drop in the rate of temperature rise - sometimes to the extent that the temperature actually drops. The reason for this is not clear and the observed behaviour at this stage is not predictable.

DISCUSSION

The data required for the appended design method are not directly available from the literature. It is possible to predict the fire resistance of a wall by the onset of char method but this has a number of problems as discussed below. It is believed that this method can be modified to be more useful both for assessment of fire resistance and as input to the design method.

Behaviour of Wood

For the purposes of engineering design it is not necessary to have a detailed physical and chemical model of the behaviour of wood. It is sufficient to have a simple model which allows the structural behaviour of the wood to be predicted with reasonable accuracy.

A number of pertinent facts are well established. The temperature at the base of the char layer, the wood properties which affect the charring rate, the density distribution and the in-service moisture content of Pinus radiata are all available. The way in which gypsum plasterboard linings react to fire is reasonably well understood, particularly the chemical reactions which take place in the gypsum and the temperatures at which they occur. The general trends of strength and stiffness with temperature are clear although they cannot be accurately predicted as yet.

Using these facts we can develop a simple model using tests to evaluate the properties which are unknown. The heat transfer through the linings can be characterised by the temperature on the unheated side. Probably the temperature histories recorded by the onset of char thermocouples can be used for this input.

The rate at which protected wood chars, and the temperature distribution within the wood, will have to be established for each individual lining type. An experimental programme will have to be carried out to produce a model which relates these to the density and moisture content of the wood and to the thermal and physical characteristics of the lining.

Onset of Char Method

Although the method is officially approved it has not yet been used to determine a loadbearing FRR. There are two reasons for this. Firstly the procedure as outlined above for determining onset of char has not yet been officially approved, and secondly a pass/fail criterion has not been specified. In order for these two problems to be eliminated it is first necessary to achieve more consistency in the measured results, and then to determine a method of interpreting the results which will consistently give a conservative prediction of the loadbearing FRR.

There are a number of factors which affect the time to char, many of which have not been controlled in the tests to date. With respect to the linings, the positions of joints and fixings, the chemical composition, thermal expansion, drying shrinkage, integrity, moisture content, thickness and number of layers all have some effect.

As previously noted, the density and moisture content of the wood are known to affect the rate of charring and, since the thermocouple is 5 mm into the wood rather than at the surface, the rate of char will affect the time taken for the charring surface to reach the thermocouple. In order to make more sense of the results the density and moisture content should be known in the vicinity of the thermocouple and some correction should be made for density and moisture content differing from some standard values.

The positioning of the thermocouple may make a significant difference to the observed time to onset of char. If the thermocouple junction is closer to or further away from the hot side than its specified position then the time will be reduced or increased respectively. If the junction is closer to one side than the other then charring from the closer side may decrease the time.

The number and location of thermocouples with respect to joints and fixings in linings is a significant factor in determining whether a conservative prediction of loadbearing capacity is made. The results from a number of thermocouples within the same test specimen show that there are some types of location, which can be easily identified, which are likely to experience early onset of char. No statistical analysis has been attempted to determine how many thermocouples should be placed in any specimen, or where they should be placed to determine most accurately the time at which charring first occurs, as there are too many other variables in the experimental set-up. Consequently no attempt has been made to relate the time of first occurrence of charring to the likely time of failure if the specimen had been fully loaded, and hence to determine a reasonable pass/fail criterion.

Having enumerated some of the problems involved with the method, it must be said that there remains some merit in its continued use, with some modifications. The basis of the method is sound, and some changes in the procedures and analysis of results will improve its usefulness, both as a means of determining a loadbearing FRR and as input to the proposed design procedure. More care in the choice of location and in the placement of thermocouples should result in a reduction of scatter in results. The time to onset of char should be related to density and moisture content of the wood and, in the case of gypsum plasterboard linings at least, the unpredictable behaviour of temperature as noted above should be conservatively treated by assuming that the constant slope noted after the evaporation of water, continues until charring begins.

CONCLUSIONS

(i) The charring behaviour of wood exposed directly to fire is quite well understood.

(ii) The mechanical properties of uncharred wood at high temperature are less well understood.

(iii) The behaviour of linings varies widely. Some general predictions can be made for gypsum plasterboard linings but for design purposes each lining type must be examined individually.

(iv) The onset of char method as it is currently applied is of limited value, but procedures can be modified to produce more useful information.

(v) It should be possible to develop simple models and test methods to determine input to a rational design method based on engineering principles, using material properties modified for the effects of fire.

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APPENDIX

Possible Design Procedure

The purpose of the design procedure is to allow a prediction of the fire resistance of a range of wood framed walls from easily determined parameters. It is to be assumed that the wood will be Pinus radiata at 16% moisture content and with physical properties as for normal design, and a characteristic density, probably 425 kg/m^3.

Since safety factors are already built into design procedures, and given that fire resistance is currently determined directly from a single test on a specimen construction, it is possible that no additional safety factors would have to be applied in the design procedure.

The temperature distribution in the timber at any given time will be determined from measured thermal behaviour of the linings and empirical model for heat transfer to the wood. The strength loss with temperature will be assumed from data gained from studies of other species in other countries, or may be determined by an empirical model.

At least one full scale test on a specimen construction will still be required to determine the time at which the lining material ceases to offer any protection to the wood, i.e., when it falls off or develops large cracks. Criteria for determining this point have not been established as yet. Thermal behaviour of the linings can be characterised from thermocouples placed in this specimen.

The cross section remaining at any given time will be determined on the basis of simplified empirical charring rates on the hot face and the sides of the member. The char rate will give an "effective" loss of section, taking into account the loss of strength of the remaining uncharred section and any safety factor which is found to be necessary. The effective char rate will be calculated directly from the measured behaviour of the lining material.

Having determined the mechanical properties of the wood structural members standard engineering design principles will be used to predict the time to failure. It will be assumed that the lining on the hot side retains no structural strength at the time of failure, and the analysis will take into account the allowable defects specified by the timber grading rules.

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