## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

## FAIR USE POLICY

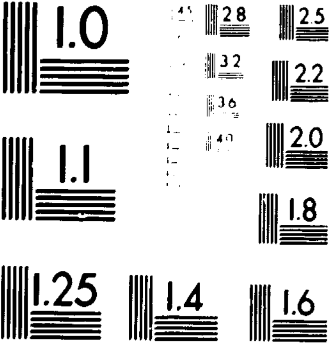
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

14427

Distr.
**LIMITED**

UNIDO/IO.608
30 January 1985

English

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

---

# TIMBER ENGINEERING
# FOR DEVELOPING COUNTRIES

## Part 3

## Durability and Fire Resistance of Timber*

John Beesley
Robert H. Leicester

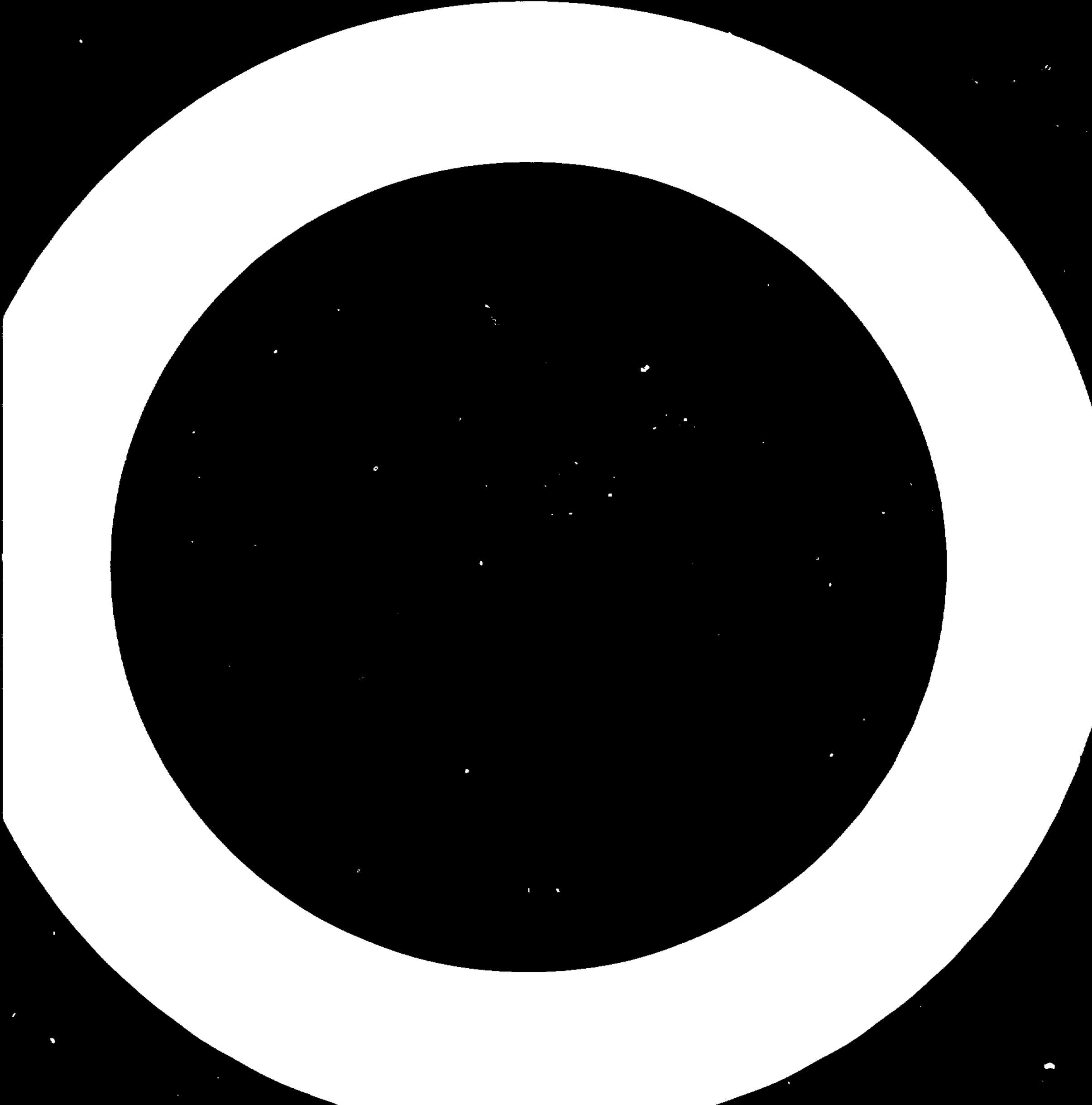
Prepared by

Agro-industries Branch,
Division of Industrial Operations

---

*The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Mention of firm names and commercial products does not imply endorsement by the United Nations Industrial Development Organization (UNIDO). This document has been reproduced without formal editing.

V 85-21827



# PREFACE

The United Nations Industrial Development Organization (UNIDO) was established in 1967 to assist developing countries in their efforts towards industrialization. Wood is a virtually universal material which is familiar to people world-wide, whether grown in their country or not. Wood is used for a great variety of purposes but principally for construction, furniture, packaging and other specialized uses such as transmission poles, railway sleepers, matches and household woodenware. UNIDO has the responsibility within the United Nations' system for assisting in the development of secondary woodworking industries, and has done so since its inception, at national, regional and interregional levels through projects both large and small. UNIDO also assists through the preparation of a range of manuals dealing with specific topics of widespread interest which are common to most countries' woodworking sectors.[1/]

The lectures comprising this set of documents are part of UNIDO's continuing efforts to help engineers and specifiers appreciate the role that wood can play as a structural material. Part 3 consists of 2 out of the 36 lectures prepared for the Timber Engineering Workshop (TEW) held 2 - 20 May 1983 in Melbourne, Australia. The TEW was organized by UNIDO with the co-operation of the Commonwealth Scientific and Industrial Research Organization (CSIRO) and funded by a contribution made under the Australian Government's aid vote to the United Nations Industrial Development Fund. Administrative support was provided by the Australian Government's Department of Industry and Commerce. The remaining lectures are reproduced as Parts 1, 2, 4 and 5 covering a wide range of subjects, including case studies, as shown in the list of contents.

---

[1/] A fuller summary of these activities is available in a brochure entitled "UNIDO for Industrialization, Wood Processing and Wood Products", PI/78.

These lectures were complemented by site and factory visits, discussion sessions and assignment work done in small groups by the participants following the pattern used in other specialized technical training courses in this sector - notably in furniture and joinery production[1] and on criteria for the selection of woodworking machinery[2].

It is hoped that publication of these lectures will contribute to greater use of timber as a structural material to help satisfy the tremendous need for buildings: domestic, agricultural, industrial and commercial as well as for particular structures, such as bridges, in the developing countries. It is also hoped that this material will be of use to teachers in training institutes as well as to engineers and architects in both public and private practice.

Readers should note that examples cited are often of Australian conditions and may not be wholly applicable to developing countries despite the widespread use of the Australian timber stress grading and strength grouping systems and the range of conditions encountered in the Australian subcontinent. Readers should also note that the lectures were usually accompanied by slides and other visual aids, together with informal comments by the lecturer, for added depth of coverage.

The views expressed are those of the individual authors and do not necessarily reflect the views of UNIDO.

---

[1] Lectures reproduced as ID/108/Rev.1.

[2] Lectures reproduced as ID/247/Rev.1.

# CONTENTS

## TIMBER ENGINEERING FOR DEVELOPING COUNTRIES

### Part 1

### Introduction to Wood and Timber Engineering

### Part 2

### Structural Timber and Products

## Part 3

### Durability and Fire Resistance of Timber

## Part 4

### Strength Characteristics and Timber Design

## Part 5

### Applications and Constructions

# INTRODUCTION

Many developing countries are fortunate in having good resources of timber but virtually all countries make considerable use of wood and wood products, whether home-grown or imported, for housing and other buildings in both structural and non-structural applications, as well as for furniture and cabinet work and specialized uses. It is a familiar material, but one that is all too often misunderstood or not fully appreciated since wood exists in a great variety of types and qualities.

There are certain well-known species that almost everyone knows of, such as teak, oak and pine, while some such as beech, eucalyptus, acacia, mahogany and rosewood are known primarily in certain regions. Others have been introduced to widespread use more recently, notably the merantis, lauans and keruing from Southeast Asia. Plantations also provide an increasing volume of wood. Very many more species exist and are known locally and usually used to good purpose by those in the business.

The use of timber for construction is not new and, in fact, has a very long tradition. This tradition has unfortunately given way in many countries to the use of other materials whose large industries have successfully supported the development of design information and teaching of engineering design methods for their materials - notably concrete, steel and brick. This has not been so much the case for timber despite considerable efforts by certain research and development institutions in countries where timber and timber-framed construction has maintained a strong position. Usually their building methods are based on the use of only a few well-known coniferous (softwood) species and a limited number of standard sizes and grades. Ample design aids exist and relatively few problems are encountered by the very many builders involved.

Recently, computer-aided design has been developed along with factory-made components and fully prefabricated houses with the accompanying improvement in quality control and decreased risk of site problems. Other modern timber engineering developments have enabled timber to be used with increasing confidence for an ever wider range of structures. This has been especially so in North America, Western Europe, Australia and New Zealand.

UNIDO feels that an important means of transferring this technology is through the organization of specialized training courses aimed at introducing engineers, architects and specifiers to the subject and especially drawing to their attention the advantages of wood (as well as disadvantages and potential problem areas) and reference sources so that for particular projects or structures, wood may be fairly considered in competition with other materials and used when appropriate. Cost comparisons, aesthetic and traditional considerations must naturally be made in the context of each country and project but it is hoped that the publication of these lectures will lead those involved to a rational approach to the use of wood in construction and remove some of the misunderstandings and misapprehensions all too often associated with this ancient yet modern material.

# DURABILITY OF TIMBER

John Beesley[1]

---

[1] Formerly an officer of CSIRO, Division of Chemical and Wood Technology, Melbourne, Australia (in conjunction with Messrs. Chen Woo Chin, O. Collett, J. Creffield, C. D. Howick and D. McCarthy).

## 1.0 INTRODUCTION

Wood preservation is the art of extending the useful life of timber in the service of mankind, with a time-scale measured in decades rather than in seasons or years. Although wood will not deteriorate with the passing of time, some changes will take place in timber in service. Further, timber in service will be exposed to a variety of detrimental hazards which may operate continuously or intermitently, consecutively or concurrently. These forces may be consistent or they may change in both nature and severity during the service life of the timber.

By classifying these hazards, and defining the various parameters which limit their effect or extension, it is possible to estimate the probable useful life of untreated timber and to assess the relative merits of substituting preservative-treated timber for untreated timber, in new structures. In the case of existing buildings, this knowledge will be useful in assessing and anticipating the costs and consequences of taking no action, instituting remedial treatments, with minor repairs and replacements or of undertaking a major reconstruction.

### Mechanical Deterioration

Timber which has split, shattered, or broken, or has been abraded and worn, is suffering from mechanical deterioration. If failure is due entirely to mechanical causes, and has not been initiated or aggravated by other causes, the remedy is simple. Repair or replace with a harder, heavier, stronger piece of wood - or use a facing to protect the piece from further wear. Do not overlook the possibility of poorly-designed fastenings inducing splitting.

### Chemical Deterioration

Wood is relatively resistant to the action of most chemicals and, in fact, is frequently used in a wide range of industries in which chemical reactions are an integral part of the process. As a rule wood is more resistant to the action of strong acids than strong alkalis. Chemical deterioration is uncommon in the structure of most buildings.

The first remedy, when chemical deterioration is suspected, is to examine the possibility of eliminating the source of the trouble. If this is not practical, it may be possible to protect the wood by some sort of barrier or coating.

## Physical Deterioration

This is best defined as deterioration due to the action of heat or moisture.

Wood is a poor conductor of heat but can be ignited and will burn when exposed to an ignition source. However, even when the wood is burning, the depth charred may not be very great (during the early stages of combustion) and the loss of strength in a structural-sized member will be small. Prolonged exposure to high temperature (above the boiling point of water) will cause embrittlement and loss of strength but such conditions would not be common in dwellings. Under most normal conditions, it is possible to protect structural timbers from undue exposure to excessive heat either by removing or modifying the heat-source or else by inserting a suitable insulating material between the heat-source and the timber.

Wood is <u>hygroscopic</u> and will absorb moisture from the atmosphere. Dry wood swells when wetted and wet wood shrinks when it dries. When, on the average, wood neither absorbs water from the atmosphere, nor loses moisture to it, it is said to be in equilibrium with the atmosphere (of that environment). For example, in Melbourne, the equilibrium moisture content for most timbers is about 14% oven-dry weight basis, for winter and about 11% for summer - depending upon the summer.

Shrinkage is not uniform either within a species or between species. In general longitudinal shrinkage is least and tangential shrinkage is greatest, with radial shrinkage usually nearer the tangential than the longitudinal shrinkage. Hence the problem of differential movement where two components meet at right-anlges to one another as, for example, with the stile and bottom rail of window joinery (Lea 1981).

Most joinery and furniture is made up from seasoned wood. If allowed to become wet, swelling will occur; this may cause joints to split. Glues are not always water-resistant and any significant increase in moisture content is almost sure to adversely affect surface finishes of paint, polish or varnish.

Prolonged exposure to conditions of high humidity could result in the growth of moulds and decay fungi.

## Weathering

Wood which is freely exposed to the weather deteriorates. This deterioration is characterised by 'silvering' of the surface, which often also becomes eroded and irregular and may split. Weathering is a complex phenomenon attributed to a combination of the effects of exposure to ultra-violet light, heating and cooling, wetting and drying, erosion by wind-blown dust and other processes which, in time, result in the bleaching and leaching of the surface fibres and the development of surface checks. In some timbers, this surface checking forms the foci from which further weathering occurs.

Paint, well-maintained, provides the best protection against weathering. Pigmented, water-repellent preservative stains are a cheaper and slightly less effective alternative. Unpigmented coatings (clear finishes) usually fail to filter out the ultra-violet light which causes bleaching and may fail to protect against water-entry after a few months. That is to say, unpigmented coatings can be expected to break down, at the coating-timber interface, after a few months service.

## Biological Deterioration

The deterioration of timber attributed to living organisms is called biological deterioration and is the form of unwanted deterioration most often encountered (and insufficiently understood) in practice. In nature, biological agencies are responsible for re-cycling most living materials - nature intended it this way. It is only when man's needs conflict with what nature intended that problems arise.

Timber is an important building material. Before man learned to make use of it as a building material, the trees grew in the forest, matured and died there. Throughout their life-cycle they were subjected to various forms of attack by insects and invasion and infection by fungi. Now, when timber may be required as a building material, it is still subject to the same hazards from insects and fungi and these invasions which occur during the growing period of the tree may affect the strength, quality or appearance of the timber obtained from the tree and exercise some restraint on the uses to which it can be put.

Fortunately, much is already known about the insects and fungi which affect the utilisation of timber as a building material. The notes which follow describe the various forms of fungal deterioration which can occur in timber and describe the remedial measures which may be taken to prevent, inhibit or reduce the extent of this deterioration by both natural and artificial methods. The success of such measures will ultimately, depend upon a thorough understanding of the conditions conducive to decay, the properties of the timbers themselves and the choice and availability of wood preservatives and preservative processes.

Measures which effectively control insect attack in building timbers in one country are likely to be equally effective in another, provided the insect pest has been correctly identified and something is known about its habits. This information is also set out in the following notes - with particular reference to Australian conditions. For example, in Australia, the common powderpost borer, *Lyctus brunneus* Steph., is readily controlled by sodium fluoride or boron-based preservatives. These treatments will be just as efficacious elsewhere, as in Australia for this purpose. What first needs to be done is to ascertain the lyctid-susceptibility of the local timbers and then to decide upon which of the several alterative treatments is the most applicable, under the prevailing circumstances.

## 2.0 THE FUNGAL DETERIORATION OF WOOD AND ITS CONTROL

### 2.1 Natural Durability and Fungal Attack

Timbers vary enormously in their natural resistance to insect and decay or other fungal attack. Some species, like ironbark, teak and redwood (Sequoia spp) are very resistant to both decay and insect attack, and are known as 'durable' species. Others, like radiata pine, coachwood and mountain ash, have very little natural resistance and are regarded as being non-durable - or even perishable. Also, it is indeed rare to find that the sapwood of a timber has any appreciable resistance to fungal attack and, for all practical purposes, sapwood must be regarded as perishable - unless it is properly treated with a wood preservative. Therefore, the natural durability of a timber species is always rated by the resistance of its mature heartwood to insect and fungal attack.

Because timbers vary so widely in the natural durability of their heartwood, it is necessary to have some form of classification for natural durability. The system most widely used throughout Australia, which was developed by CSIRO, and has been adopted by the Standards Association of Australia, recognizes four durability classes:

Durability Class 1 - Species of the highest natural durability (e.g. grey box and yellow box, grey ironbark and red ironbark, wandoo and cypress pine);

Durability Class 2 - Durable species, but not as good as Class 1 species (e.g. red gum, jarrah, yellow stringybark, western red cedar);

Durability Class 3 - Moderately durable species (e.g. southern blue gum, messmate stringybark, karri);

Durability Class 4 - Non-durable species or species of low natural resistance to fungal attack (e.g. mountain ash, manna gum, coachwood and sassafrass, radiata pine and meranti).

This classification system is limited to the relative durability values of different timbers. It would be misleading to quantify the expected service life because of the infinite variety of conditions to which wood can be exposed in service. Under severe conditions the service life achieved by the most durable species may not be much longer than that achieved by a species of moderate natural durability under conditions where the hazard is both mild and intermittent. However, under the same conditions of exposure, the higher the natural durability of a species the longer is its service life likely to be.

Unless otherwise stated, this system of classification refers to both decay resistance and resistance to attack by subterranean termites. Generally, resistance to decay (the most damaging form of fungal attack) parallels resistance to termite attack, but some Australian species, such as brush box, exhibit much higher resistance to termite attack than to decay. It should be noted too that where a parcel of timber contains mixed species, or the species is unknown, it is usually safest to regard the timbers as being of durability class 4. Also, some timbers, such as Douglas fir, which are rated at durability class 4 perform remarkably well when exposed to the weather, but without ground contact. It should be recognized, therefore, that the CSIRO system of durability classification refers to ground contact conditions where both decay and subterranean termite attack form a combined hazard.

The decay resistance of a timber is due mainly to the deposition of complex substances - the heartwood extractives - in the newly formed heartwood. Many of these are more or less toxic to fungi and insects and act as natural preservatives. Amongst the eucalypts, these substances appear to be polyphenolic compounds, which are related to the tannins. The precise chemical nature of many of these compounds has not yet been determined.

The decay resistance of timbers varies very widely, not only between different species, and between different trees of the same species, but also within individual trees. The within-tree variation is mainly in the radial direction with the other (most newly-formed) heartwood being the most durable part of the tree, and the core or pith, being relatively non-durable. The relatively low durability of this core is believed to be due in part to the lower resistance of the heartwood of a young tree and in part to the ageing of the toxic extractives in the standing tree. This core, or 'brittle heart', which exists in most eucalypts, tends to become larger as the tree grows older, and affects the recovery of useful timber from the log.

## 2.2 Facts About Fungi

Fungi are plants, but not green plants. Fungi lack chlorophyll, the substance which gives green plants their colour and enables them to synthesize sugars and starch from the carbon dioxide of the air and water from the soil - in the presence of light. Since fungi do not have the capacity of synthesizing their own nourishment from air and water they derive their food by the digestion of organic matter, living as parasites (on living matter) or as saprophytes (living on dead organic material). Thus, the fungi which cause decay in timber, live on the dead wood cells of the plant.

The fungal plant body consists of microscopic, branching thread-like tubes - called <u>hyphae</u> - with ramify through the nutrient source. Sometimes these hyphae spread over the surface of the host material to form a dense mat, which may be characteristic of the particular decay fungus present. This mat may also give rise to the 'fruiting body', the means by which these fungi sexually reproduce. With other fungi, including many wood-destroying fungi, the fruiting body may be fleshy, leathery or corky. Whether the fruiting body is a massive bracket or mushroom, or a microscopic one borne on the mycelial mat, it is capable of releasing myriads of microscopic spores, each of which can develop into a new plant.

In broad terms, fungal attack on wood can take the form of surface mould which can develop within two or three days. It is more likely to affect sapwood than heartwood but does not penetrate the timber. It may take the form of staining or discolouration which can penetrate deeply into sapwood within few hours of the falling of a tree. This may affect the heartwood, but it seldom has much effect on the strength properties of the sapwood although its appearance may be seriously degraded. When fungal attack on wood takes the form of decay, or rot, there is a significant loss of strength. Some rots develop in the standing tree while others affect timber in service.

In broad terms, all fungi which attack wood have the same basic requirements, whether they are moulds, stains or rots (fungi which produce decay, or loss of strength, in wood). Staining fungi can infect the living tree, as well as freshly felled timber. Both moulds and stains can develop on susceptible timber in a very short time, while decay develops rather more slowly. If conditions favourable to fungal development are allowed to persist for an extended period of time, the timber can be expected to decay. The presence of surface moulds or staining is indicative of conditions which are, or have been, conducive to the development of decay. However, under suitable conditions, decay can developed without any evidence of moulding or staining.

## 2.3 Conditions Necessary for Fungal Development

In general, five conditions must be satisfied before fungal development will occur and the absence of any one of these may be sufficient to prevent it. Severe staining and moulding can develop within three or four days under favourable conditions, but for severe decay to develop, suitable conditions must persist for a period of several weeks or longer.

### (a) The presence of a source of infection

Moulds, stains and decay-producing fungi spread by releasing millions of microscopic spores (fungal 'seeds') into the air. Fungal spores contaminate most of the air and nearly all unprotected surfaces. Even in almost completely enclosed cavities in a structure, there will be some air exchange and, sooner or later, fungal spores will enter.

The spores of moulds and decay-producing fungi are so widespread that susceptible materials are almost certain to be affected whenever conditions suitable for fungal development occur. Further, once wood has started to decay, the rotted wood absorbs moisture more readily, and retains it longer than does similar undecayed wood.

### (b) A supply of nutrients

Unlike green plants, which contain chlorophyll to enable them to synthesize sugars and starch from air and water in the presence of light, fungi lack chlorophyll and require an organic substrate upon which they grow through the action of enzymes such as cellulases, amylase, hemicullulase and ligninase. Moulds and stains derive their nourishment from cell contents, and not the cell walls, and therefore have little effect on strength properties. Rots, or decays, on the other hand derive their nourishment by dissolving the components of the cell wall and have a marked effect on mechanical properties. Their development can be accelerated by the presence of additional nutrients, especially nitrogenous fertilizers. Hence, decay can be usually rapid in livestock transports, fertilizer plants and in contact with fertilized soil.

### (c) A supply of air

Since oxygen diffuses only very slowly through water, wood which is completely submerged in water or in waterlogged soil (as with foundation piles driven to the water table) decays at an extremely slow rate and needs no other protection against decay. Also, logs or chips may be stored under water in log ponds or under continuous water sprays and will remain sound for long periods. The moisture content of many types of freshly felled wood is so high (especially in the sapwood) that fungal attack is confined to the surface by lack of oxygen further in, due partly to the consumption of oxygen by surface-growing fungi. The wood must therefore dry out to some extent before any appreciable decay or fungal staining can develop.

It might be thought that wood could be preserved by enclosing it completely in paint, fibre-glass or plastic to exclude oxygen, but many of these materials are relatively pervious to oxygen. It is also very difficult to ensure that no even a pinprick can develop to admit oxygen or water, and consequently this method cannot be relied on.

### (d) Suitable temperature

Atmospheric temperatures are rarely major factors in decay since fungi can operate over a wide range of ambient temperatures. The optimum temperature for decay fungi is usually between 20°C and 30°C so that decay is much more rapid in warmer localities, but most can still progress down to 5°C and can cause slow decay even in cool stores. Most fungi can tolerate short exposures to even the highest atmospheric temperatures but are killed fairly rapidly if exposed to temperatures of 40°C to 50°C. Thus it is possible to arrest decay by heating wooden articles (for instance in a kiln) long enough for the innermost parts of the wood to come to these temperatures. This will kill the fungi present, but does not protect the wood from further infection.

(e) A supply of moisture

All fungi need a supply of moisture. Without it, they die. It is well known that permanently dry wood never rots and, in fact, almost all fungi need both some free water in the cell cavity, and the 'bound' water in the cell wall. Decay normally occcurs only at moisture contents above the 'fibre saturation point' which is between 30 to 35 per cent for most timbers. There may be slow decay by some fungi (especially soft rot fungi) at lower moisture contents, so it is usually considered that any wood with a moisture content of over 25 per cent is liable to decay.

The fungus itself can produce a considerable amount of water from the chemical decomposition of the wood and this may help to keep the moisture content of the wood at a level favourable to its development.

The distribution of moisture within a piece of wood in service, or in storage, is usually very uneven. A moisture content of less than 25 per cent near the surface, or even a mean moisture content of below 25 per cent, may still leave parts of the wood quite moist enough for decay. Moreover, most decay-producing fungi will remain alive, though quite inactive, for months in air-dry wood, and will continue to grow sporadically in wood which is intermittently wet.

It is important to realize that by far the most effective means of protecting wood from fungal attack is to keep it dry. The great bulk of the timber used in buildings is never exposed to a decay hazard because it is too dry, and almost all the decay occurring in timber not in ground contact can be traced to wetting of the timber in ways which could have been easily and inexpensively avoided by thoughtful design and careful construction and maintenance.

## 2.4 Mould Growth

This type of fungal attack does not penetrate into the timber, but forms a powdery or cottony growth on the surface where the fungi have grown on the food reserves that the tree has stored in the ray cells. Like blue stain, mould tends to be most severe on sapwood, and especially on sapwood with a high starch content. Its development depends not only upon the moisture content of the wood but also on atmospheric humidity. Hence, it is most prevalent in warm, humid climates, on block-stacked timber or on moist timber held in a closed space, such as in a ship's hold. Mould does not penetrate through the cell walls and so has no effect on the strength of the wood. Since it is readily removed by brushing or, alternatively, by dressing the timber, its effect on appearance is not as serious as that of staining fungi.

Mould growth often occurs in combination with fungal stain and its presence indicates that the wood is being, or has been, kept under undesirably moist conditions. It may interfere with drying and gluing of timber and especially of veneers. Where control is desirable it may usually be achieved with the same type of solution that is used for sap stain, perhaps at a higher concentration (e.g. 1 per cent sodium pentachlorophenate plus 1 per cent borax).

### 2.5 Fungal Staining

Fungal staining is a common cause of degrade in timber. Discolouration which is usually grey or blue grey, and sometimes brown, yellow or orange, occurs as wide longitudinal bands, usually confined to the sapwood of the timber. Discolouration is associated with the presence of hyphae within the wood. The colour is due to the colour of the hyphae, to the excretion of coloured material from them, or to the production of abnormal colourations by the living cells of the tree under the stimulus of fungal attack. Although these fungi ramify through susceptible wood (as do decay fungi) they do not dissolve the wood substance but live mainly on the cell contents, especially starch. Like decay fungi, staining fungi are unable to develop in dry wood and possibly are inhibited by the lack of oxygen in water-soaked wood.

Staining is not accompanied by any pronounced loss of strength. Degrade consists almost entirely on the less attractive appearance of the wood. The discolouration caused by blue stain fungi is extremely difficult to remove by bleaching, and becomes much more conspicuous when timber is given a clear finish. Some staining fungi can cause an appreciable loss in impact resistance, so wood required to have high impact strength should be free from blue stain. Moreover, since the conditions required by the staining fungi are very similar to those favouring decay fungi, staining indicates a possibility that incipient decay may also be present and be causing loss of strength. Stained wood may be much more absorbent than sound wood and this may be detrimental in wood preservation and perhaps in gluing. Staining fungi may also affect the paint-holding qualities of the wood.

Infection of a log by staining fungi usually starts through cut ends, areas where bark has been removed, and from insect borer holes (especially those of 'pin hole borers' and of bark beetles). It also starts in sawn boards immediately after sawing. Infection is rapid under warm conditions and surface treatments applied more than 24 to 48 hours after felling or after sawing may be too late.

Protection of sawn boards is achieved by dipping the board immediately after sawing in an anti-sap stain dip, which usually contains 0.5 per cent of soidum pentachlorophenate and 1.5 per cent of borax. Recently the fungicide difolotan has become popular. Dipping can be done either by hand, or by passing the board on moving chains through a dipping trough. This should give sufficient protection to allow the boards to be air-seasoned without degrade. Protection of logs is more difficult, so it is important to extract and convert the logs as soon as possible after felling. A stronger anti-stain solution such as 2 per cent pentachlorophenol in light oil (together with an insecticide if borers are present), may be effective if it is applied to cut ends and barked areas within a few hours of felling. Another good method is to store the logs under water sprays pending conversion. (See 'Water Sprays Prevent Losses in Softwood Log Dumps'. Forest Products Newsletter No. 304, 1964).

## 2.6 Decay

The term decay is used to describe any type of fungal attack which, if allowed to continue unchecked, will eventually cause severe loss of strength in the infected wood. The fungi which cause decay growth through moist wood as a branching network of microscopic tubes, known as hyphae which somewhat resemble the root system of a plant. Within decaying wood, the individual hyphae are too small to be seen without the aid of a microscope but, with one, are readily identifiable. As the decay progresses, the hyphae often form wefts or fans of white cottony or fine silky material on the surface of the wood that is typical of that particular fungus species. The fruit body is the organ of the fungus that produces millions of microscopic spores and releases them into the atmosphere to be disseminated by air currents, and so spread the species.

Chemically, wood consists of a mixture of celluloses, hemicelluloses and lignin, all of which are insoluble. When attacked by the fungi-that cause decay, each hyphal tip within the wood secretes enzymes which dissolve the wood substance to form simpler, soluble products which can be absorbed and utilized by the fungus. Brown rot fungi attack the cellulose and hemicellulose of the cell wall but are unable to destroy the lignin which forms a major part of the wall substances. This imparts a dark brown colour to the wood. Since most of the strength of wood rests in the cellulose fibrils, a brown rot fungus will still destroy the wood. In fact, by the time wood has lost about one-half its original weight through decay by a brown rot fungus, it can usually be reduced to a fine powder by rubbing between the fingers. White rot fungi are able to attack the lignin as well as the celluloses and hemicelluloses. The removal of the lignin accounts for the bleached appearance of the decayed wood. Some white rot fungi are able to destroy wood almost completely, reducing its original weight by about 98 per cent. The mechanical strength of wood may be seriously reduced by incipient decay, with little visible sign of fungal attack. Resistance to impact is likely to be affected first so that timber required to have a high impact strength should be carefully inspected for incipient decay - or pre-tested. Decayed wood also absorbs water far more readily than similar sound wood. This fact should not be overlooked when timber is subjected to intermittent wetting for, once decay has started, this wood will progressively take up more water with each wetting.

## 2.7 Type of Decay - Detection and Appearance

Decay, especially beneath paint is often detected only at a relatively late stage, usually as a result of pronounced shrinkage or mechanical breaking of the affected wood. Where the wood surface is exposed, decay may often be detected from a localized darkening in colour, or from the development of checks in the wood on drying. Where a timber structure is being systematically examined for the occurrence or distribution of

decay, the most effective procedure is to drive a blunt-pointed instrument, such as a thin-bladed screw-driver, into the wood, when the decayed portion is readily detected by the lower resistance to penetration.

Decay may occur in the interior of a piece of wood leaving an intact shell. Such internal decay may sometimes be detected by sounding, but the best method is to drill the wood (using, for example, a 6 mm bit in a small electric drill) and detect the decayed wood by its much lower resistance to drilling. Most decay causes the wood to break with a short brash or carrotty fracture, and may be tested, especially when in its early stages, by levering up splinters with a knife blade.

Some of the terms most frequently used in describing major types of decay are as follows:

(a) Brown cubical rot

The wood has become darkened and soft and breaks with a definite brash or carrotty fracture; on drying, it shrinks abnormally and checks both along and across the grain to form cubical pieces, which can eventually be powdered in the hands. Brown cubical rot is caused by higher fungiknown as basidiomycetes such as *Serpula* (*Merulius*), *Coniophora*, and some species of *Poria*. It is a common form of decay found in flooring, weatherboards and poles, and also occurs in heart rots.

(b) White stringy rot

The wood may not change much in colur at first, but it becomes yellowish or whitish in the later stages of decay. It becomes soft but does not shrink greatly in drying and the highly decayed wood can be reduced to short stringy particles rather than to powder. It is caused by basidiomycetes such as *Fuscoporia*, *Fomes* and *Trametes*, and is found in window joinery, weatherboards, house stumps, and heart rots, particularly in hardwoods.

(c) White pocket rot

The wood shows small distinct whitish pockets separated by narrow bands of sound wood and does not change greatly in drying. It is caused by basidiomyceter such as Fomes and Hymenochaete and is usually a heart rot, though it may also occur as a rot in poles or other large timbers.

(d) Soft rot

The wood is usually darkened and shows a brash fracture but may be quite hard and show little change on drying out. Surface soft rot usually dries out to show cubical checking like brown cubical rot but on a much smaller scale, with 'cubes' 0.8 to 3 mm across. It is caused by fungi such as Chaetomium, Acremoniella and Doratomyces. Surface soft rot is common in cooling towers, on badly weathered fence rails, etc., and on durable timbers in ground contact. It is much more severe in hardwoods than in softwoods.

These are the most readily recognized forms of decay but there are other intermediate or less definite forms. A number of other terms often used in discussing decay are:

(e) Dry rot

In Europe this term is used specifically to describe the decay caused by the fungus Serpula (Merulius) lacrymans which now, also, occurs in Australia. The term 'dry rot' is misleading since it implies rotting of dry timber, which cannot occur, and should be called decay instead. In Australia, 'dry rot' is commonly used to describe decay which has occurred without an obvious source of moisture - usually condensation.

(f) Wet rot

This term which should also be avoided, is sometimes used for rot in very wet situations to distinguish it from 'dry rot'. It usually relates to decay by Coniophora spp.

(g) Heart rot

This refers to decay occurring in the standing tree, usually as a narrow central column. Heart rots may be brown cubical rots, white pocket rots or white stringy rots. Whilst they reduce the strength of the material (this reduction may extend well beyond the visible margin of the rot) they do not necessarily indicate that further trouble will occur in service. Most sawn timber is used in conditions that are too dry for decay hazard, and even where moisture is present and the conditions appear suitable, many heart rot fungi do not appear to be able to continue attack in sawn timber. Wood showing heart rots usually absorbs water much more readily than sound wood and this may increase the decay hazard in some conditions.

## 2.8 Occurrence and Control of Decay

### (a) Decay of timbers in ground contact

All timber in contact with moist soil is subject to severe decay hazard. Decay usually commences at, or slightly below, ground level, but may occur at any depth up to 2 metres or more, especially in sandy soils. When inspecting for decay, it is therefore desirable to excavate and probe well below ground level, and it may also be desirable to drill the timber since in many cases a shell of sound timber surrounds rotted wood.

The most effective means of preventing decay in timbers in ground contact is the use of highly durable or preservative-impregnated timber. However, even with preservative salt retentions in excess of 20 kg/m$^3$, soft rot attack of sapwood can occur under certain conditions. Coating of new timber with creosote, etc., has only a very short-term protective effect. Where decay is occurring in existing posts or stumps and replacement is difficult, use of a water-soluble diffusing preservative may be valuable. This could be applied around the post as a bandage below soil level with an organic or inorganic diffusing preservative on the inside and an impervious plastic film on the outside to prevent diffusion into the soil. Such bandages are now commercially available for *in situ* treatment.

### (b) Decay in building timbers above ground

Significant losses are caused each year by decay in above-ground timbers, and this has led to a reluctance to use wood for some applications. Such decay can almost always be avoided by correct building practice, but considerable use of remedial measures is required in existing buildings. The decay usually occurs either in external joinery, fascias and weatherboards or in flooring.

(i) External woodwork. External woodwork is subject to intermittent wetting and decay is likely to occur when wetting is frequent or of long duration, when the timber is relatively absorbent, or when the wood is unable to dry out rapidly after wetting. All three factors are important. It is very important to reduce the frequency and duration of the periods in which water is in contact with the wood. This cannot be done by normal painting alone, since movement at the joints will crack the paint film and allow water to seep in. With weatherboards, important means are provision of adequate roof overhang, repair of leaking or blocked guttering, and keeping shrubs and creepers away from the wall so that surface water dries off rapidly. Since water absorption is particularly rapid in the end grain, the use of cover strips over the ends of the weatherboards, or of end priming, is particularly effective. With window joinery, the design should be such that water drains off completely and does not collect in tiny pools. The top faces of all sills, horizontal sashes, rails, etc., should be sloped, and all joints should be inspected to ensure that water drains away from them. Excessive condensation on the inner side of the windows, for example, in sun rooms and bathrooms, can collect on the inner sills and sashes and lead to decay. Adequate ventilation can often prevent this.

Reduction of water absorption during the wetting period is also important. The use of highly absorbent timbers such as ramin, sassafras or pine sapwood can lead to very rapid decay in painted window joinery, its development being assisted by the fact that once decay has commenced the wood becomes even more absorbent. A most effective means of reducing water absorption is the use of water-repellent preservatives. A number of these 'light organic solvent preservatives' are now onthe market and they greatly improve the performance of external joinery and weatherboards, not only by reducing the likelihood of decay, but also by reducing paint failure near the ends of the boards. They are also effective in preserving the appearance of unpainted external woodwork in 'natural finish' construction. Although best applied by dipping the completely prefabricated assembly, they are also valuable for 'on-site' treatment of cut ends, etc., and even for remedial treatment of the joints in existing woodwork. For this last application, the preservative is brushed on liberally and allowed to seep into the joints when the woodwork is in a very dry condition.

Finally, provision for drying out of the timber after wetting is equally necessary. This is often completely neglected. It is difficult to prevent water uptake completely, so if water is absorbed, for example, by a piece of wood painted on all sides except the end through which the water is coming, drying out is extremely slow and the wood may remain wet enough for sufficient time to decay. If one face is unpainted, drying out will be much more rapid. Priming of the back face of weatherboards, though it may improve dimensional stability, slows down drying, enables water to penetrate further from the wetted ends, and so favours decay. Placing impervious sarking or reflective insulation directly under weatherboards also greatly reduces drying and is an important contributing factor to decay. In many types of external joinery such as 'window walls', it may be desirable to leave one face of each member - the underside of a horizontal rail, unpainted, or painted lightly with a 'breathing' paint to reduce decay hazards.

(ii) Flooring. Some floorings may be exposed to abnormal decay hazards due to 'wetting'. Such circumstances arise in the case of verandahs or open porches exposed to rain, and with bathroom or laundry floors subjected to plumbing leaks and condensation.

Porch floors should be of highly durable timber spaced slightly apart to prevent the accumulation of water or dirt between the boards. Water repellent preservatives should be used to protect the end grain. Bathroom floors should be of durable or preservative treated timber with provision for good thorough ventilation.

The major cause of decay in flooring is condensation of water vapour from the sub-floor space and it is important to realize just how this process occurs. The soil below a building, even if dry on top, is always moist at lower levels and there is a continuous release of water vapour into the sub-floor space. If the flooring above this is at a much lower temperature than that of the soil (as it usually is in winter) some of this water vapour will condense on the flooring and may wet it sufficiently to allow decay. If there is adequate ventilation of the sub-floor space, the water vapour may be swept out before condensation takes place, and condensate formed in exceptionally cold, still weather can readily dry out. Similarly, if the floor is bare or covered only with carpet, water vapour can readily escape through the floor to the dries room air, but if the floor is covered with vinyl tiles, rubber (which inludes underlays) linoleum or other impervious materials, this escape is impossible.

The usual method of preventing floor decay, therefore, is the provision of adequate sub-floor ventilation. This varies a great deal with climate and other factors, but as an example it is suggested that in Victoria the ventilation system should provide vents with a minimum free air space of 110 $cm^2$ for every 1.5 m run of external wall and at least that amount in every internal sub-floor walls. (Most 23 x 15 cm pressed metal wall vents now sold have around 40 per cent free air space and are much more effective than some of the older-type terracotta 'air bricks' which had less than about 6 per cent free air space.) This requirement may need to be exceeded where the minimum distance between opposite walls is over 10 m. It is also important that the free movement of air through the ventilators should not be obstructed by joists or mortar drippings, or by shrubs, garden plantings or soil.

Provision of adequate ventilation is usually easy in residences but may be difficult in shops, where the sides may have party walls with adjoining buildings and where the floor is at pavement level. In these cases normal cross-ventilation is impossible and floor vents appear to have little value. Use of vertical flues 15 to 20 cm in diameter from below the floor to above roof level at the 'closed' end of the building, with liberal provision for air intake through sub-floor ventilators or floor vents at the opposite end, appears to be a promising method. Blowing warm air into the sub-floor space, e.g. from store heating systems, is often suggested but has many drawbacks. Apart from the cost of continuous operation and maintenance for many years, careful design would be necessary to ensure that the warm air does not absorb moisture from one part of the space and deposit it in some colder area further on. In new buildings where concrete terraces or bathroom floors on solid fill would block normal ventilation it may be desirable to lay 10 to 15 cm diameter ventilating pipes through the obstruction.

In all cases where difficulty arises in providing sub-floor ventilation, full use should be made of the American system of soil cover. This involves laying over the soil below the floor a sheet of polyethylene film, bituminous felt or other impervious and durable material, so that the movement of the water vapour from the soil to the sub-floor space is greatly reduced or practically eliminated. Such soil cover can easily and cheaply be installed in new constructions. In existing buildings, it should often be possible to roll the sheet out, even under a low floor. (There is no need for complete sealing of joints or edges in the cover and it is often of value if only a part of the soil is covered.) The reduced amounts of water vapour coming through can then be coped with by a lesser amount of ventilation.

Wooden floors on concrete slabs may also present some decay hazards. Even if the concrete has been 'waterproofed' water vapour will move up through it and even if the concrete contains or overlies an impervious plastic film, moisture can often seep in the edges, and the slab itself will release water vapour for many months. Such floors should always be givn some ventilation, and it may be necessary to cover the concrete with plastic film, bitumen or vapour-impermeable paint between joists or nailing strips. (Any nailing strips set in the concrete should be of preservative-treated wood.)

These requirements for ventilation or soil cover where wooden floors are used over either soil or concrete should be carefully followed. Although use of treated floor will eliminate the decay hazard, some measures may still be necessary to reduce undesirable cupping or movement of the floor boards.

(iii) <u>Miscellaneous building timbers</u>. Decay can, of course, occur in parts of buildings other than external woodwork and flooring.

Decay in beams and joists may occur because of condensation as described for flooring. More usually it is caused by seepage of water from masonry due to the failure or omission of a damp-proof course, or from rain penetration through solid masonry walls or old buildings. In new structures, this can be prevented by waterproofing walls, by installing complete and permanent dampcourses, and by isolating timber from masonry by plastic sheet, galvanized iron or bitumen. In existing buildings, it may be possible to restrict water ingress by waterproofing, or to insert a moisture barrier between timber and masonry. Helping the joists to dry out by improved ventilation or by removing paint from them may be helpful. Where decay is sufficiently advanced to cause risk of failure, strengthening with treated timber or metal plates may be preferable to removal.

Decay in cold stores is often a serious problem and is usually due to water vapour coming from warm moist outside air and condensing within the insulated walls. It can often be prevented by placing a vapour barrier on the outside of the wall. On no account should vapour barriers be placed near the inside face of the wall. This would prevent evaporation of water vapour into the drier air of the cold room, which usually has a low absolute water vapour content even if the relative humidity is high.

Decay in wood used as decking under flat membrane roofs may be caused either by leakage or by condensation within the roof structure, especially where the use of the room involves humid conditions. Because of the high costs of repairs in such a position, it is desirable to use treated timber, although incorporation of a vapour barrier between room and decking, plus ventilation within the roof may giveadequate protection.

(c) Decay in boats

Decay in wooden boats has become an increasingly serious problem in recent years. There has been a spectacular increase in the use of power boats for pleasure and many of these are now used on inland rivers, lakes and reservoirs, rather than in salt water. This tends to increase decay hazards partly because sea water acts as a mild preservative and inhibits many fungi, and partly because inland waters, being small and landlocked, are prone to still, damp days which render ventilation and drying out of boats difficult.

Decay may occur in any part of the craft - in the outer planking or plywood skin, in major structural members such as ribs or stern posts, and in cabin linings. It is caused by dampness due to rainwater seepage, condensation, shipping of (fresh) water, or by seepage from the bilges.

Preventative measures include the use of preservative-impregnated timber and plywood wherever possible (especially for structural members where replacement costs would be high), the liberal use of water-repellent light organic solvent preservatives, especially on end grain of wood and edges of plywood, adequate ventilation of all cavities within the boat, and designing of decks, wheel-houses, etc., so that rainwater drains off completely and cannot seep into joints. It is important to assist wood to dry out by refraining from painting any interior timber unless it is essential to do so. Timber or plywood coated on all exposed faces with red lead or marine varnish can scarcely be expected to dry out.

An important control measure is the regular and systematic inspection of all parts of the boat for the first signs of decay, using a thin-bladed screwdriver as a probe. If decay is detected early it can usually be remedied without much trouble. Remedial measures include the replacement of decayed wood, preventing rainwater seepage, improving ventilation, removing paint, linings, etc., to provide better drying conditions, and in fresh water, using some diffusing preservatives, e.g. borax, in the bilges.

### (d) Decay in cooling towers

Industrial development and the progress of air conditioning is leading to a great increase in the use of cooling towers, but many wooden cooling towers have been severely affected by decay, and there is a tendency to use other methods of cooling. Decay is usually in the form of surface soft rot, especially in the filling slats, but also in other parts of the tower. However, brown rots can still occur. Pre-treatment of the timber with a highly fixed copper-chrome-arsenic preservative is the method now preferred for prolonging the life of cooling tower timbers in Australia. Where soft rot has occurred in large existing towers, there are commercially available in-situ treatments which deposit insoluble salts in the wood and appear to give a considerable increase in service life.

## FURTHER READING

Nicholas, D.D. (1973). Wood Deterioration and its Prevention by Preservative Treatments (2 Volumes). Syracuse University Press.

Richardson, B.A. (1978). Wood Preservation. Construction Press, Longman Group Ltd, London.

Walters, N.E.M. (1973). Australian House Fungi. Forest Products Technical Note No. 13, CSIRO Division of Building Research, Melbourne.

Wilkinson, J.G. (1979). Industrial Timber Preservation. The Rentokil Library, Associated Business Press, London.

## 3.0 WOOD DESTROYING INSECTS - WOOD BORERS

### 3.1 General Characteristics

Various timbers under certain conditions may be attacked by wood borers or different types, and when dealing with timbers, it is important to be aware of the existence and habits of these pests. With some species of wood borer, an infestation can result in serious damage necessitating treatment and repair or replacement. With other species, little weakening is likely to occur and, unless a good appearance must be maintained, remedial action is unncessary.

Most wood borers are beetles which at some stage of their development bore into wood for food or shelter. Beetles have complete metamorphosis, passing through four distinct stages of development: egg, larva, pupa and adult. The larvae of the majority of wood borers actively tunnel in wood and derive their nourishment from it. With some exceptions, the only damage they cause as <u>adult beeltes</u> is the flight hole made through the surface of the infested timber as they emerge. After emergence and mating, the female may lay eggs in the timber from which they emerged. Usually, the adults live for only a few weeks.

Some borers lay their eggs beneath the surface of the wood, others lay them in cracks and crevices or where one piece of timber abuts another. Some borers introduce the spores of a wood-rotting or wood-softening fungus with their eggs, others do not. Some species attack only green timber, although they can often complete their life cycle and emerge after the timber has dried out. Other species attack only seasoned timber. A knowledge of these characteristics and habits can assist in recognition of the type of borer responsible for damage. When necessary, appropriate action can then be taken.

Significant differences in a number of common borers and in their habits are shown in Table 3.1. For simplicity, a division has been made between those species attacking standing trees and green timber, and those which attack dry wood. Information is also given on methods of control, including a discussion of quarantine requirements in Australia.

## TABLE 3.1 CHARACTERISTICS OF THE MORE COMMON BORERS

| | | BORERS ATTACKING STANDING TREES AND GREEN TIMBER | | | | BORERS ATTACKING DRY WOOD | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pinhole | Longicorn | Bostrychid | Siricid | *Lyctus brunneus* | *Anobium punctatum* | *Calymmaderus incisis* | *Ernobius mollis* | *Hylotrupes bajulus* | *Ambeodontus tristis* | *Anobium australiense* |
| TIMBER | TYPE | In Victoria mainly Hardwoods | In Victoria mainly Hardwoods | In Victoria mainly Hardwoods | Softwoods mainly Pine | Hardwoods | Mainly Softwoods | Softwoods In Queensland especially Hoop Pine | Softwoods with Bark | Mainly Softwoods | N.Z. Rimu some Pines | Softwoods and Hardwoods usually with decay |
| | ZONE | Sapwood and Heartwood | Sapwood and Heartwood | Sapwood only | Mainly Sapwood | Sapwood only | Mainly Sapwood | Sapwood and Heartwood | Mainly Bark some Sapwood | Mainly Sapwood | Sapwood and Heartwood | Sapwood and Heartwood |
| LARVAL GALLERIES | DIRECTION IN TIMBER | Straight Across Grain | Meandering Along Grain | Meandering Along Grain | Curved Random | Meandering Along Grain | Meandering Honeycombed | Meandering Honeycombed | Cambial Zone only | Meandering Random | Meandering Random | Meandering mainly Along Grain |
| | DISCOLORATION | Present | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent |
| FRASS (BORER DUST) | QUANTITY | Slight | Slight | Copious | Tightly Packed | Copious | Copious | Copious | Moderate | Copious | Moderate | Moderate |
| | DESCRIPTION | Strands or Powdery | Coarse and Stringy | Fine and Powdery | Coarse | Fine and Powdery | Granular like salt | Granular | Granular and speckled | Granular to Powdery | Coarse and Compacted | Powdery Compacted |
| FLIGHT HOLES | SHAPE | Round | Oval | Round | Round | Round | Round | Round | Oval | Oval | Oval | Round |
| | DIAMETER | 2 mm or less | 6-10 mm (long axis) | 1-6 mm | 3-6 mm | 1-2 mm | 2 mm | 2 mm | 2 mm | up to 6 mm (long axis) | about 6 mm (long axis) | 2-5 mm |

* NOTE: It is important to distinguish between the coniferous timbers, or softwoods, such as the pines, firs and spruces, and the hardwoods, such as the eucalypts, and the lightweight soft brushwoods of the rain forests.

## 3.2 Borers Attacking Standing Trees and Green Timber

### (a) The pinhole borers

Pin hole borers are forest insects belonging to the families Platypodidae, Scolytidae or Lymexylonidae. They are capable of attacking both standing trees and freshly felled logs, but they do not and cannot initiate attack in dry timber. Attack may occur in a tree which has suffered external damage, but it is more likely to occur in felled logs, often shortly after felling. Most pinhole attacks occur in hardwoods, but softwoods are not immune from attack.

The members of the families Platypodidae and Scolytidae are often known as ambrosia beetles. Their attack is initiated by adult beetles boring into the timber, excavating tunnels, and placing eggs within the timber at the termination of the various branches of the tunnels. These pinhole borers may thus be regarded as a distinct group among the wood-boring beetles, as it is the adult beetle, and not the larva, or grub, which causes damage to infested timber. After hatching from the eggs, larvae live and grow in the galleries constructed by the parent, until they reach maturity, in from one to four months. They feed not on wood, but on a fungal or mould growth, termed '<u>ambrosia</u>' which is introduced into the galleries by the parents prior to egg-laying. Because this ambrosia requires moisture for its development, it will die out as the timber dries, and consequently the larvae will not survive. This is why pinhole borers attack only green timber and will not infest or re-infest once the wood has dried. With these species, the 'frass' or borer dust takes the form of a loose powder which is ejected on the surface of the log where it may lie in piles before falling off.

The larvae of the third family, Lymeylonidae, do not appear to depend on fungal material for nourishment, although their galleries are often discoloured. These larvae actively bore into the timber, ejecting compacted strands of frass. Lymexylids are not commonly found in Eastern States, but are of considerable importance in Western Australia.

The galleries made in timber by species of Platypodidae and some species of Scolytidae are discoloured by the growth of the ambrosia fungus, and this dark staining may extend along the grain in the vicinity of the gallery or hole. For this reason, pinhole attack can affect the merchantable value of timber. If the original attack occurred in the standing tree through a surface scar or wound, it will probably cease as the wound heals over, but when the apparently 'clean' log is peeled for veneers, the stained punctures will be revealed. Some loss of quality must be expected in all timber infested by pinhole borers. However, where the timber is to be used as ordinary building scantling, pinhole attack is unlikely to cause significant degrade or loss of strength and may be equated with a similar number of small nail holes. In a load of scantling timber, very heavily infested pieces may have to be culled out, but the remainder will be quite satisfactory for ordinary building purposes. A piece of scantling timber attacked by pinhole borers will not constitute a hazard to other timbers in the structure as these will be at least partially dry, and therefore immune from pinhole borer attack.

### (b) The longicorn borers

The Cerambycidae is a family of beetles widely distributed throughout the world, and popularly known as the longicorns or longhorns because of the length of their antennae (feelers). Although certain species of logicorn occur in sufficient numbers in various parts of the world to be of economic importance, they are essentially a forest pest, since all but a few species can initiate attack other than on living trees and green timber. Because of this, they can affect the amount of merchantable timber obtained from the tree, but they do not greatly detract from the performance of building timbers.

The actual wood boring is done during the larval period, which is usually from one to three years in the living tree. Adult beetles occasionally emerge from structural timbers or furniture. This may be explained by the fact that although most longicorns attack only green timber, they are able to complete their development in dry wood. In seasoned timber, where moisture contents are necessarily lower, and the amount of starch present may be much less than in green wood, larvae obtain less nourishment and thus the life cycle may be extended greatly. Periods in excess of 20 years have been recorded. However, if timber which has been attacked when green is subsequently kiln dried, no larvae will emerge from it, as the temperatures normally used in kiln-drying schedules are sufficiently high to kill all stages. Most adult longicorns are medium to large beetles (20 to 50 mm in length), and are characterized by the antennae which are generally as long as or longer than the body.

Although many hundreds of species regularly breed in Australia, only a limited number of species occur in sufficient quantities to be of any importance to timber users. In Australia, the majority of longicorn attacks occur in green hardwoods although in other countries, some species readily infest softwoods. Attack is not necessarily confined to sapwood, as larvae may tunnel deep into the heartwood as they prepare to pupate.

The structural weakening of framing timbers by longicorn borers is unlikely. Most longicorns do not excavate timber extensively and although the galleries are large, they do not 'honeycomb' the wood. As it is unusual to find more than one or two larvae in a piece of framing-sized timber, emergence is unlikely to be any more than sparse. Except for a very few species, longicorns cannot re-infest the dry timber from which they have emerged and thus further damage is improbable. In emerging from studs or other framing timbers, longicorns may cut through lining materials such as plaster or fibre walls. This does not mean that they are attacking the wall, but merely that the lining was impeding their egress. The flight hole disfigures the timber, but it can be filled and the surface finish restored. Emergence holes are usually isolated and scattered and are an oval shape 6 to 10 mm in diameter, and the margins are unstained. The galleries are usually across the grain and the frass is often coarse and stringy.

### (c) The Bostrychid borers

Auger beetles which belong to the family Bostrychidae do not initiate attack in living trees, but can and do attack freshly felled logs and green timber. Timber is frequently attacked by Bostrychids during seasoning, but usually not after the wood approaches Fibre Saturation Point (i.e. about 30 per cent moisture content). These borers do not attack dry timber and because of this, it is unusual for more than one generation to breed in any one piece of commercial timber. Like the longicorn borers, Bostrychids can complete their life-cycle in, and subsequently emerge from, dry wood. Only the sapwood of hardwoods is susceptible to Bostrychid attack. The eggs are laid by the female beetle at the ends of short tunnels bored into susceptible sapwood, and after hatching, the larvae tunnel in the sapwood, obtaining nourishment from the starch in the timber and subsequently emerging as adult beetles. The frass produced by the larvae is coarse grained and often lumpy.

There are a large number of species of Bostrychids. The adults range in size from 3 to 20 mm in length. Apart from one species, Bostrychopsis jesuita which is up to 20 mm in length, most common Bostrychids such as Mesoxylion collaris are small beetles up to 6 mm long. The round emergence hole made by these more common species is usually about 2 mm in diameter, but flight holes made by other Bostrychids vary from 1 to 6 mm in diameter according to the species. It is not unusual to find M. collaris emerging from scantlings during the first summer after a house has been constructed. In ordinary scantling timber they do not constitute a serious hazard, as they can infest only sapwood, and cannot re-infest dry timber. However, they cause considerable degrade to decorative timber and their presence is nearly always indicative of timber susceptible to attack by Lyctidae (the powder post beetle) which attacks similar timber, but at a lower moisture content.

### (d) The Sirex wood wasp

Sirex is not a beetle, but a wood wasp belonging to the family Siricidae. It was originally a European timber pest, but has been introduced into many other countries.

Sirex attack is limited to softwoods, predominantly pine. All trees attacked by the Siricid wasps in Europe are confiers, and include the pines, the firs and spruces. In North America there are several species of Siricid each attacking a range of pines and some attacking firs, including oregon. Since Siricid wood wasps only attack living trees, freshly felled logs and green timber, they are essentially a forest pest and as such, their attacks often result in the killing of trees in the forest. As with other green timber pests, it is impossible for Siricid to comlete its life cycle in dry timber and subsequently emerge. Experience has indicated that the most serious attack occurs on suppressed, damaged or burnt trees, but once infestation has become well established, the population build-up may result in attack to apparently healthy trees.

Although Sirex is a wasp its life-cycle resembles that of the wood-boring beetles. The female wasp lays her eggs in the tree by inserting her 'ovipositor' or egg-laying apparatus which operates like a thin tubular drill through the bark and into the wood. At the same time, she introduces the spores of a wood-rotting fungus, probably to soften the wood around the egg. It is believed that these fungal spores are always injected whenever the ovipositor is inserted into the tree, and it is this fungus which kills the tree after it is taken up into the sap. After about two weeks, the eggs hatch into larvae which initially feed near the surface and then bore into the tree towards the heart. The tunnels may be as much as 450 mm in length and increase in thickness as the larvae grow. Larvel galleries are circular and meandering and usually tightly packed with rather coarse frass. Towards the end of the larval period, the larvae return to a point near the surface and after pupation, the adult wasp chews its way out of the timber leaving a round emergence hole up to 6 mm in diameter. It is interesting to record that Siricid females are capable of parthenogenesis. In other words, females can lay unfertilized eggs which subsequently hatch out, although always into males. The eggs of a fertilized female, however, will usually produce about equal numbers of males and females.

Although limited degrade is caused by Siricid attack, the insect can be responsible for enormous economic loss by killing living trees. In Australia, strict quarantine control is exercised on the movement of timber from areas where Siricids are known to be active. The restrictions require that if any pine timber leaves the area to be milled, it must be either fumigated under quarantine supervision or kiln-dried. The only exception to this rule is timber to be milled to a thickness of 6 mm or less, as it is unlikely that any larvae would survive this milling process.

(e) Other borers

Although there are many other borers capable of attacking standing trees and green timber, they are unlikely to have the commercial significance of the four types described above. The majority of the other groups of borers are exclusively forest insects whose damage does not greatly affect the merchantable value of the timber or end product. Certain bark beetles and weevils sometimes attack the sapwood or the wood immediately under the bark of the tree and weevils often attack decayed wood. There are species of jewel beetles and wood-boring moths which occasionally bore through into heartwood. None of these insects are very common, however, and although evidence of their work is sometimes apparent, a detailed knowledge of their habits is not considered essential for people other than foresters.

## 3.3 Borers Attacking Dry Wood

### (a) The powder post borers

The powder post borers are classified in the order Coleoptera and the families Lyctidae and in some rare cases, Bostrychidae. The Lyctids are the most common borers attacking seasoned hardwood in Victoria, so much so that the majority of unprotected susceptible timber is attacked in the first two or three years of service.

The most important fact to remember concerning these borers is that they attack only the sapwood of certain hardwoods. Because heartwood is never attacked, their attack can only cause serious structural weakening in timbers which have a large sapwood content. Two factors determine the susceptibility of sapwood of the various species of hardwood to Lyctid attack. These are the diameter of the pores of the timber and its starch content. Attack is initiated by the female beetle laying her eggs in the pores of susceptible sapwood. Therefore if the texture of any species is such that the pores are too small to accommodate the ovipositor, then that species will be immune from attack. One or two weeks after oviposition, the eggs hatch into tiny larvae which bore into and through the sapwood, usually parallel with the grain of the timber, extracting starch for nourishment. If the timber contains insufficient starch, there will be no larval development and such timber could be regarded as immune. The larvae grow as they tunnel, and the galleries become packed with flour-like powdery frass. In hot climates and artificially heated buildings, the larval period may be as short as three or four months, but in southern States the normal period of development is nine to 12 months. At the end of this time, the fully developed larvae pupate and subsequently emerge from the wood as adult beetles. In emerging, the beetles cut their way out of the wood, leaving a round unstained emergence hole from 1 to 3 mm in diameter. This may be the first indication of Lyctid infestation, as the naked eye cannot see where eggs have been laid in the pores, and all damage is done by the larvae boring below the surface. The powdery frass is often ejected through emergence holes and it may then collect in small piles on underlying surfaces. In house framing, frass may continue to be vibrated from old flight holes long after Lyctid attack has died out.

If infested timber has been used in house framing, an adult emerging from a stud or nogging is quite likely to puncture lining materials, while doing so. Thus, plaster, hardboard, wallboard or timber lining placed hard against the sapwood of a stud may have small holes made in them by adult Lyctid borers emerging from the framing beneath. This does not mean, of course, that these linings are susceptible to these or any other borer, but merely that being hard against the sapwood of a stud, they block the path of emergence unless they are cut through by the adult beetle. As emergence holes in lining materials may be unsightly it is good building practice to install studs, noggings and ceiling joists with the sapwood edge away from the lining.

Adults are small, dark brown beetles about 2 to 6 mm in length. Susceptible sapwood may be attacked by Lyctid borers once the timber dries out to a moisture content of about 25 to 20 per cent. The attack thus often ocurrs at about the moisture content where that of the Bostrychid Mesoxylion ceases (see 2.2(c)).

In Queensland and New South Wales, where rain forest timbers, often with very wide sapwoods, are commonly used, State legislation regulates the sale of timber susceptible to attack by the Lyctid borer, and controls the type of treatment which may be used to immunize such timber from attack. However, the sale of untreated Lyctid susceptible scantling timber is permitted by the Timber Users' Protection Act in Queensland and the Timber Marketing Act in New South Wales provided not more than one-quarter of the perimeter of the piece is in susceptible sapwood. Destruction of this fraction of cross-section is not likely to cause any serious weakening in structural timbers.

Victorian hardwoods have a comparatively narrow sapwood band and it is rare for scantlings of Victorian hardwood to contain more than this amount of sapwood. Lyctid attack in framing timbers in Victoria is therefore unlikely to cause structural weakening of any practical importance in a building, and thus legislation similar to that operating in New South Wales and Queensland is not currently prescribed in Victoria.

Because Lyctid eggs are laid in the pores of the timber and not in cracks, crevices, etc., timber which has been sealed on exposed surfaces and ends by paint, varnish, polish or waxes cannot be attacked, because the pores will be blocked. However, if the timber is already infested prior to the application of the finish, adult borers will have no difficulty in emerging through the coating. Once this has occurred, subsequent infestation may occur by re-entry through old emergence holes.

In common with many other borers, Lyctids cannot survive the temperatures used in kiln-drying processes. However, this should not be taken to indicate that kiln-dried hardwood is immune from Lyctid attack as this is not the case. Kiln-drying will not alter the pore size or the starch-content of the timber and therefore it cannot affect its susceptibility.

### (b) The Anobiid borers

There are many different species of Anobiid borer, but only four are important enough to warrant some details being provided. As their habits vary considerably, they will be described separately.

Anobium punctatum - Although this beetle is commonly known in its native England as the Furniture Borer, it attacks not only furniture, but also flooring, structural timbers and decorative woodwork. It shows a preference for old, well-seasoned timber and in Australia, its attack is most common is softwoods such as Baltic pine or New Zealand white pine. It is known that A. punctatum will also attack some hardwoods such as blackwood, and particular imported hardwoods such as English oak. Australian eucalypts appear to be virtually immune from this destructive insect. Old furniture is frequently attacked, particulary pieces such as pianos, large cupboards, etc. Although a high moisture content is not essential for this borer, it does show a preference for rather damp, humid conditions and flooring attack is often found to be most severe in those areas of a house where the sub-floor ventilation is inadequate. Probably the most common incidence of domestic A. punctatum attack in Australia is Baltic pine flooring in older houses with poor sub-floor ventilation and in cupboards and shelving of New Zealand white pine.

Eggs are laid by the female beetle in cracks and crevices in susceptible timber and also on the rough surface of unprotected end-grain. After some two to five weeks, the eggs hatch into larvae, which bore into the timber in a fairly random manner, not necessarily along the grain, attacking both sapwood and heartwood. They produce a granular frass of similar consistency to table salt, although the granules tend to be a flattened oval shape.

In Australia, the larval period lasts about 1 to 3 years. After pupation, the adult beetle emerges from the timber, leaving a round unstained emergence hole similar to that caused by the Lyctid borer. It can be appreciated, that Anobiid infestation, which often results in structural weakening, can be far more serious than Lyctid attack. Once attack is initiated it is unlikely to cease or die out of its own accord without some sort of eradicative treatment. Old furniture that has been in store or has been obtained from auction rooms may be infested, and if taken to a house where there is susceptible softwood timber, the infestation may well spread. However, because it spreads slowly, it can be controlled in furniture before damage is too serious.

The adult is a small, dark brown to charcoal coloured beetle usually about 3 to 5 mm in length.

Calymmaderus incisus - The Queensland pine bettle, as this insect is commonly known, is an Anobiid which is frequently found in Queensland attacking softwood timbers, predominantly Hoop pine and less frequently Bunya pine and New Zealand white pine. It has not been recorded as occurring in other States but this may be because it has very similar habits to A. punctatum, has a similar life-cycle, causes similar damage and both larvae and adults are very similar in appearance to those of the furniture beetle. Experience in Queensland has found that C. incisus attack is generally initiated in the darker sub-floor areas and that it subsequently spreads by the re-infestation of later generations.

Ernobius mollis - This species of Anobiid is a cambium borer of softwoods and as such, its damage is rarely of any significant importance. However, it is often mistaken for the furniture beetle A. punctatum and therefore some details of its habits and pecularities may help to avoid confusion.

The female beetle lays her eggs in the bark of softwoods. The larvae can breed only if bark is present although damage may spread into the outer sapwood. Because E. mollis does not attack living trees and green timber, is not a forest insect and because it can only attack dry timber which still has bark on it, the borer is not a particularly common pest. In localities where softwood building scantlings are in general use, the possibility of dry softwood with some bark present is very real and this timber is susceptible to E. mollis attack. The frass produced by this borer is gritty but because the insect attacks both bark and cambium, the frass is usually speckled, as some grains are from the bark and others from the lighter cambium or sapwood.

A more common source of E. mollis attack is the bark around knots in softwood. The insect can be present and subsequently emerge from wood surrounding the knot.

Eradicative treatment is not usually necessary apart from stripping the bark from the timber, after which attack will cease. If nothing is done at all, attack will often die out within a few years either because the food supply has run out or because bark has simply fallen off.

Anobium australiense - A. Autraliense attacks both softwoods and hardwoods, only when conditions are conducive to decay. The adult beetle is similar in form to the furniture beetle Anobium punctatum, but is about twice the size (about 7 to 8 mm) and rather darker, being almost black. The emergence holes are round and unstained like those of the furniture borer, but are appreciably larger. Attack is often confined to sapwood, but when heartwood has been softened by decay, attack will spread to it also.The frass produced by the larvae is powdery with the appearance of being dirty, and tends to be packed in the tunnels by the moisture which is usually associated with the decay. Once the moist conditions conducive to decay have been removed and the decay arrested, the attack will cease.

(c) The dry wood longicorns (Cerambycids)

Normally, longicorn or Cerambycid beetles initiate attack in green timber and, although they may complete their life-cycle in, and emerge from timber which has been allowed to dry naturally, they cannot re-infest dry timber. There are, however, a very few beetles of this family which are able to initiate attack in dry wood and to cause serious damage to it. Fortunately, none of these exceptions occur naturally in Australia although there have been instances of them being imported into Australia in timber from abroad.

Hylotrupes bajulus - This Cerambycid beetle is very common in many parts of Europe, the USA, and South Africa. In Britain it is known as the 'House Longhorn Beetle', in Germany the 'Hausbock', in France 'Capricorne des maisons', in the USA the 'Old House Borer', and generally throughout the world as the 'European House Borer'. All these names imply that housing timbers are frequently attacked by this pest, and indeed this is so. Because it can attack and infest seasoned softwood, it has become a pest of major importance in those countries where it has successfully become established. It attacks softwoods such as pine, fir and spruce and so thoroughly excavates the timber that it causes severe structural damage. Hardwoods are not attacked by H. bajulus.

Although the average life-cycle in Europe is from three to six years, it can be as long as ten years or more. Some softwood timbers, infested in Europe and subsequently imported into Australia, have had adult H. bajulus emerge from them more than ten years after their arrival here. Many hundreds of pre-fabricated houses imported by various government departments shortly after the war have been thoroughly inspected and, where necessary, fumigated with methyl bromide. As far as we know, this has prevented this most dangerous of all longicorns from becoming established in Australia.

The adult beetle may vary in size from 6 to 25 mm in length. Its overall colour is greyish-brown to black, with light patches on the wing covers.

Ambeodontus tristis - The Two-Toothed Longicorn, as this beetle is frequently called, is a native of New Zealand. It attacks dry New Zealand rimu and some pines. Like the European House Borer, it has been found in imported timber in Australia but it has not become established here.

The adult beetle may vary in size from 6 to 25 mm in length and is a uniform brown colour.

## 3.4 Methods of Control

### (a) Predators and parasites

In nature, most insects pests are limited in number either by birds or by other insects, and wood borers are no exception to this. Adults of forest borers such as those attacking standing trees and green timber are frequently eaten by birds and sometimes the larvae may be extracted from the tree by birds pecking through bark to reach them. However, there are other insects whose primary function is to parasitise various stages of certain wood-boring species.

In Australia, the most common and active predators of wood-boring beetles are those of the family Cleridae. The various Clerid species are predatory in both larval and adult forms and some of them attack most of the borers previously mentioned in this chapter, including Pinholes, Longicorns and Bostrychids in the forest, and Lyctids in dry wood. A very common species, Paratillus carus, lays its eggs in the sapwood of hardwood that has already been infested by Lyctids. After hatching, the long, thin larvae move around in the wood, using galleries made by Lyctid larvae and when one of these is encountered, it is killed and devoured. The adults of P. carus are larger than those of Lyctids being up to 8 mm in length and are easily distinguished by a white band across the wing covers, giving this species the common name of the White-Banded Clerid. These adults are predacious on the adults of Lyctid beetles and often decapitate them.

Another familiar predator is the Yellow Horned Clerid - Trogodendron fasciculatum adult of which may be seen flying during daytime or resting on trees or timber in the open. This species is predacious on both the larvae and adults of many species of longicorn, larvae killing longicorn larvae and adults killing longicorn adults. The adult Trogodendron is often up to 25 mm or more in length and will fearlessly attack longicorn adults much larger than itself. If picked up in the hand, it may also bite the finger and be rather hard to dislodge.

In addition to the Clerids there are a number of wasps which are predators of wood borers at the larval stage. Two such wasps have recently been imported into Victoria, Rhyssa spp. and ibalia spp., because they are predators upon the larvae of the Sirex wood wasp.

Other parasites of the Sirex spp. include the Nematodes which can breed in the gut, and therefore parasitise larvae and adults. Also, various species of mites (particularly the hay-itch mite Pyemotes ventriculosis) obtain their nourishment from the larvae of both Lyctid and Anobiid borers in dry wood.

While predatory parasites do have some control over the wood-boring population, they are not sufficiently numerous to prevent borer infestation in susceptible timbers. It is therefore necessary to use other methods of control, either by chemical means or by the selection of non-susceptible timber species.

### (b) Treatment before use

Numerous insecticidal formulations have been used to protect logs and green sawn timber from borer attack - with various degrees of success and persistence. Seasoned timber may be 'immunized' (permanently protected) against borer attack by fully impregnating the susceptible wood with a preservative which will not deteriorate, or be lost from the wood, during its service life.

It is often economical to prevent Lyc'id attack by removing susceptible sapwood from the timber.

### (c) Treatment of Lyctid borers

For building timbers, either pressure impregnation or, more frequently, either hot immersion or steam and cold quench treatments are used. The boron or fluorine compounds which are commonly used in these treatments are very effective in preventing Lyctid attack, but do not 'fix' in the wood like the metal-chrome-arsenic waterborne preservatives and can therefore be leached out if subjected to wetting.

Spraying hardwood house frames against Lyctid attack is of no value. In general, all unprotected susceptible sapwood is likely to become infested with Lyctid borer within the first few summers of service and any timbers not attacked after about five years are, in all probability, immune from attack. Spraying is a surface treatment only and will have little or no effect on any larvae inside the wood and, once the house is completed, effective retreatment of all timbers is virtually impossible.

The fact that woodwork has been attacked by borers is usually not apparent until after the building is completed. Where only limited sapwood is present, treatment against Lyctid attack is rarely necessary for struct-ural reasons, but unless treatment is given as soon as the holes first appear, attack in finishing timbers may mar a decorative appearance.

(d) Treatment of Anobiid borers

Anobiid attack does require treatment. Insecticides, such as aldrin, dieldrin, chlordane, heptachlor, DDT, etc., in a light oil solvent such as mineral terpentine or kerosene can be used against borers in seasoned timber. It may be applied by syringe through finished surfaces into emergence holes and forced in until the timber is saturated. Penetration is improved by removing loose frass from galleries with a vacuum cleaner before treatment. Once the insecticide has dried, the holes may be plugged and the surface finish restored. On timbers with unfinished surfaces, the insecticide should be liberally applied with a brush so as to get as much into the timber as possible. This applies particularly to the underside of softwood flooring which has been infested with Anobiids.

(e) Fumigation

Fumigation is a treatment used only in special cases, usually for individual packages of timber or pieces of furniture. It involves placing the items in an air-tight compartment, e.g. a cylinder, a special room or under polythene tarpaulins, and pumping a liquid fumigant into the area. The fumigant - often methyl bromide - vapourizes and the resultant gas has the property of permeating through timber and destroying any adults, pupae, larvae or eggs which may be present. Although fumigation kills any pest in the timber at the time of fumigation, it cannot be described as a preservative treatment, as it confers no immunity from subsequent attack. It is commonly used for treatment of imported timber known to contain foreign pests, for treatment of individual pieces of infested furniture and occasionally for entire houses where they are known to contain timber infested with borers which are subject to quarantine regulations. This operation, however, is a very expensive one and is used only in exceptional circumstances.

(f) Quarantine control

The Commonwealth Department of Health administers Plant Quarantine in Australia and its duties are carried out in the various States by special officers of the local Department of Agriculture.

All timber entering Australia is subject to quarantine inspection and control. This timber arrives in the form of green logs, sawn timber, furniture and other manufactured articles as well as packaging timbers and dunnage. Quarantine regulations are such that if any evidence of borer attack is present in imported timber, such timber is either compulsorily fumigated at the expense of the consignee or else it is destroyed. Importation of bark or timber containing bark is prohibited. The more quarantine-conscious timber importers and timber users become, the more successful will be the task of keeping the country free from overseas pests and the more sound will be the future of the Australian timber trade.

It may be argued that except where absolute prohibitions are rigidly enforced, or where there is climatic control, a quarantine system cannot expect to succeed indefinitely, and that gradually many of its barriers must be penetrated. This may be partly true, but it does not alter the fact that as long as there are diseases or pests which can be excluded, a quarantine service is of immense value, and that it is the obligation of every person to abide by its regulations.

As a matter of strict principle, it must also be realized by the timber trade and timber-using industries that no quarantine system can function effectively if avoidable risks are taken. Vested interests must not be allowed to affect policy or influence the setting of standards of safety. The need for an uncompromising attitude in quarantine matters is not always appreciated, though on reflection it should be obvious that a risk taken only once or a single mistake made, may cause irreparable harm on a national level and nullify all the vigilance of the past. Because of this there are good reasons - technical, economic and psychological - why regulations and decisions, which, if regarded individually, may seem unduly stringent or arbitrary, in some cases may be invoked on suspicion alone.

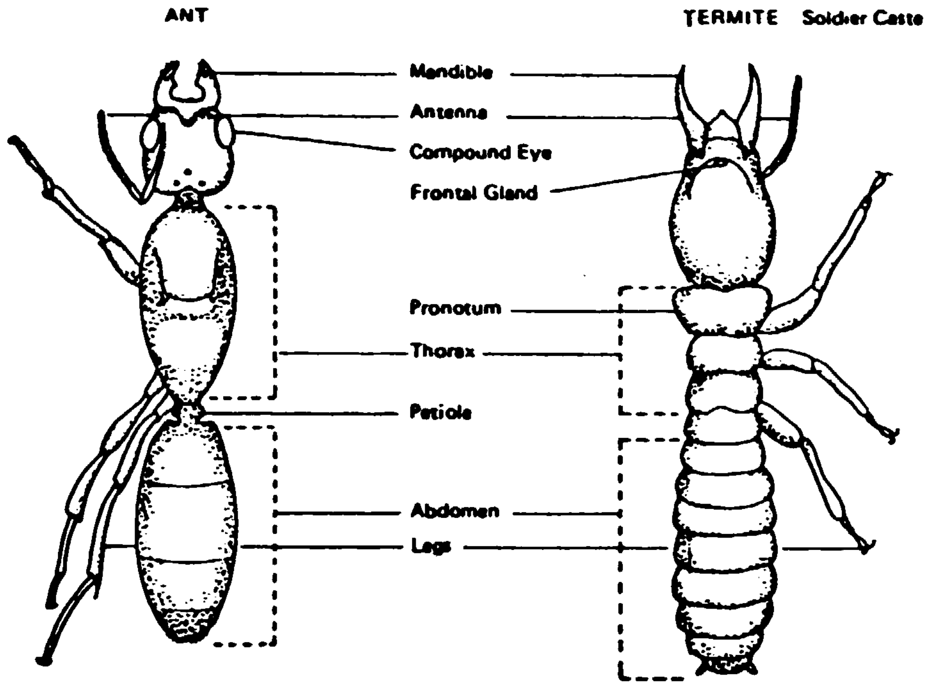
## 4.0 WOOD DESTROYING INSECTS - TERMITES

### 4.1 Occurrence and Distribution

Termites and 'white ants' are to be found in most tropical countries and are quite widely distributed in temperate regions. Australia contains its fair share of these insects and, with over 300 different species recognized and described, few parts of the continent or surrounding islands are without them.

Termites are among the few insects capable of utilizing cellulose as a source of food. Since cellulose is the major constituent of most plant tissues it follows that the majority of plants and plant products are likely to be susceptible to termite damage. Under natural conditions termites of one sort or another feed upon the roots of grasses, living trees, dry wood or decaying vegetable matter. However, when given the opportunity, they may also damage or destroy paper, building boards, linoleums, leather and bone. Even buried telephone cables, plastic waterpipes and the lagging around steam pipes have been known to suffer from termite attack. Thus, whenever they occur, some termite species are likely to damage or destroy articles useful to man, and precautions must be taken to minimize the losses they might cause.

The old adage that 'prevention is better (and cheapter) than cure' applies to termite attack as much as to anything else. New buildings can be given permanent protection against termite attack by the inclusion of suitable barriers into the structure during construction while timbers of low natural resistance can be given immunity from attack by means of preservative treatments. The cost of such precautions generally represents only a very small fraction of the total cost of the structures which they protect. To take precautions is good insurance; to ignore them in areas of unknown or high hazard is seldom wise.



## 4.2 Ants and Termites - Identification

Ants - Hymenoptera and termites, or 'white ants' as they are commonly called - Isoptera are two groups of insects which have many characteristics in common. Both contain a large number of species and live in colonies or organized communities whose members are divided into a number of castes of more or less specialized individuals. The differences between the two groups of insects are numerous, obvious and fairly consistent but, because of variations due to species or castes within a species, it may be necessary to examine and compare several individuals before making an identification. In the generalized diagram (Fig. 3.1) and notes (Table 4.1), the differences between ants and soldier caste termites have been emphasized.

## 4.3 Termite Classification

Correct identification of the different species of termites requires considerable skill and experience. Fortunately, such a detailed identification is seldom necessary when dealing with species of economic importance to wood-using industries. Within broad limits and with the clear understanding that some species might be correctly placed in more than one class, Table 4.2 is a simple classification based upon habits. This system of classification serves to segregate the different classes or groups of species which are of economic importance and defines the characteristics of the few species which are of direct concern to the timber user.

Of these several different classes, only the tree-dwelling species and the subterranean termites are of major economic importance to the timber industry.

Ratcliffe, Gay and Greaves (1952) suggest that the term subterranean termite should be reserved for those forms which nest underground or near ground level in a tree stump, log or post should not include those forms which construct an exposed nest or mound. For the purposes of this discussion the difference is immaterial and the term subterranean will be used to include both forms.

## 4.4 Important Termite Species

### (a) Damp-wood species

Always associated with rotting wood - usually in the form of fallen logs in the forest but may sometimes be found in decayed wood in buildings, fences etc. Usually the decay precedes the termite attack.

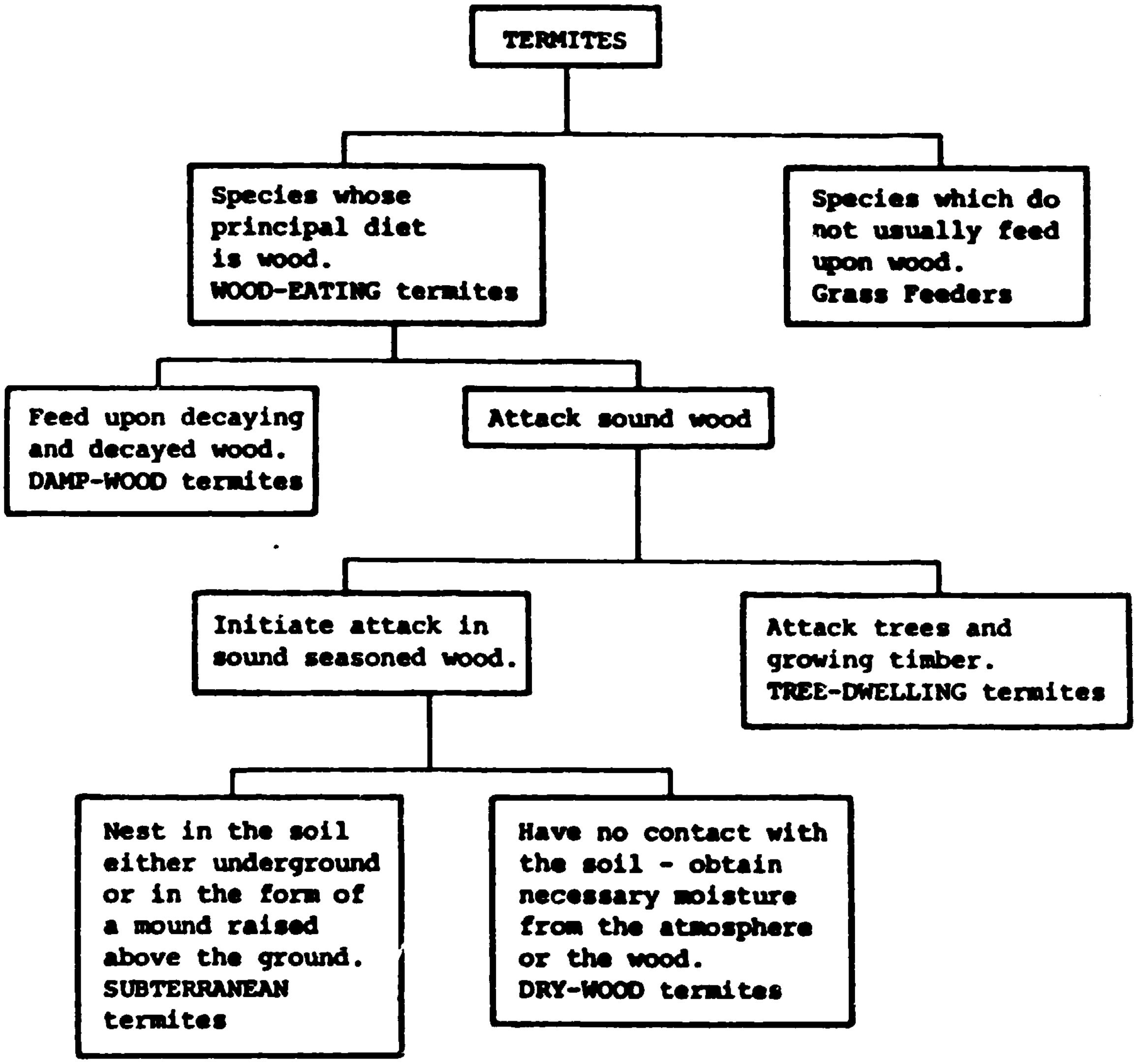
(i) Stolotermes victoriensis. A termite of variable size which is sometimes mistaken for Neotermes insularis or Porotermes adamsoni because of its size.

Recognition - The soldiers which are fairly numerous in the colonies are 6 to 11 mm long and are easily recognized by their extremely flattened heads and their pointed leaf-like mandibles which show neither a marked upward nor a downward curve when seen in profile. The pronotum is very much narrower than the head. Small but distinct eyes are usually present in the soldiers.

## TABLE 4.1

| | | |
|---|---|---|
| An ANT has:<br>"Elbowed," first segment always long, about as long as head. | Antenna | A TERMITE has:<br>Never elbowed; 11 to 15 segments long like a string of beads. |
| Terminates in "cutting edge," never pointed. | Mandible | If visible, terminates in a point. |
| Always present, obvious | Compound eye | Absent - except in winged forms. (Simple *ocelli* - eyes - sometimes present. |
| Distinct and thin. | Neck | Not obvious. |
| Distinct, large, often equal to or larger than abdomen. | Thorax | Inconspicuous; three distinct segments; seldom bigger than the head, never so large as abdomen. |
| Long, usually able to reach past head and tail. | Legs | Short - incapable of reaching to end of abdomen. |
| Always present; 1, 2 or 3 segments forming "waist." | Petiole | Never present. |
| Often small, compact and globular; carried well off ground. Generally 3 to 5 indistinct segments. | Abdomen | Large, usually more than half total length of body; soft, usually rests on ground. Always seven or more segments, fairly distinct. |
| Always ends in a point - may have sting. | Anal end | Blunt or obtuse. Never has a sting. |
| Usually heavily pigmented dark, reddish-brown to black; sometimes lighter, orangy thorax. Head usually about as dark as body. | Colour | Always light, creamy or pearly but stomach contents may give some species a smoky colour. Head may be same as body or, in solder caste, pigmented yellow, orange to dark brown with darker mandibles. |
| Strong-bodied, well adapted to foraging in open. | Toughness | Soft-bodied, easily squashed, ill-adapted to survive in the open. |
| Brisk, often run faster than 1.5 m. per minute. | Speed in the open | Comparatively sluggish, do not run - approximate speed 0.5 m. per minute. |
| ANTS<br>May follow trails in the open - do not build covered shelter-tubes but may invade and occupy tunnels excavated by other insects. Commonly found foraging freely in the open. | Runways or trails | TERMITES<br>Never found foraging freely outside their galleries or runway systems but do move freely within the enclosed galleries of the system. |
| Scurry frantically in all directions, making no attempt to hide. Many species bite or sting viciously. | When disturbed | Immediately attempt to escape and find shelter away from bright lights, heat or draughts. Do not sting - bite (if any) is barely perceptible on the thin skin between fingers. |
| Generally have strong pungent odour when crushed. | Odour | Practically odourless when crushed. |
| Never eject "milky fluid" from head but may have poison gland associated with sting in the tail. | "Poison" | Soldiers of certain species may eject droplet of "milky fluid" from head. |
| Do not attack wood. May establish temporary nests in wall cavities, between pairs of studs or in other narrow spaces. | DAMAGE CAUSED in wood | Attack may not be detected until extensive damage has occurred. In later stages of attack, interior of wood is eaten away to leave only a paper-thin surface veneer. |

TABLE 4.2


TERMITES
Species whose principal diet is wood. WOOD-EATING termites
Species which do not usually feed upon wood. Grass Feeders
Feed upon decaying and decayed wood. DAMP-WOOD termites
Attack sound wood
Initiate attack in sound seasoned wood.
Attack trees and growing timber. TREE-DWELLING termites
Nest in the soil either underground or in the form of a mound raised above the ground. SUBTERRANEAN termites
Have no contact with the soil - obtain necessary moisture from the atmosphere or the wood. DRY-WOOD termites

(ii) Porotermes adamsoni. This termite is most commonly found as a forest pest. It causes considerable damage to standing trees, particularly in cooler localities. Found in fallen logs in an advanced state of decay, it is probable that the attack originated in the standing tree indicating that the colony and, perhaps, some of the individuals of the colony, are very long-lived. Porotermes, although primarily a forest pest, does attack timber in service and has been found in a variety of situations attacking hardwood timbers of many species, including some of the more durable species used for house stumps but, in all such cases, the termite attack can be traced back to decayed wood.

(b) Tree-dwelling species

Attack by tree-dwelling termites may be of considerable concern to the forester, the timber-getter or the sawmiller but is seldom of much importance to the timber-user. In general, timber damaged by tree-dwelling termites is discarded during conversion and very little evidence of the damage caused should reach the consumer. Occasionally small pockets of termite-damaged wood containing a few live insects might be present in freshly sawn scantlings. These few insects will soon die without causing further damage because they are isolated from their supply of moisture and their parent colony.

Neotermes insularis. Essentially a forest pest which shows a marked tendency to attack growing trees through wounds at some distance above ground. It may then work downward through the centre of the log. Attack may continue in the sound wood of fallen logs but it is believed that this would have been initiated when the tree was standing.

Recognition - On the basis of the soldier caste it is the largest termite, with soldiers from 9 mm to 15 mm long. Soldiers of N. insularis may be distinguished from those of Porotermes by the following characteristics:

1. The pronotum is as wide as the head;
2. The head is not noticeably flattened; and
3. The mandibles are long and, seen in profile, have an upward curve.

Soldiers of N. insularis vary very greatly in size and in the size and profile of their mandibles.

(c) Subterranean species

In addition to the obvious damage to timber in service, subterranean species may also attack growing trees and cause a significant reduction in the volume of millable wood which can be recovered from their trunks. They are both a forest pest and a pest of seasoned timber.

(i) Coptotermes - Three species, C. acinaciformis, C. frenchi and C. lacteus, are common. Since it is not easy to distinguish between these species and since they have similar habits, they may be treated collectively as the most economically important group of termites in the country.

Coptotermes attack both trees and seasoned timber. Their nests may be completely underground, in an old stump or a living tree or in the form of a domed or rounded conical mound, which may rise several feet above ground.

Recognition - Soldiers smallish, up to about 6 mm long with rounded, rather pear-shaped yellowish heads and dark slender tapering mandibles without visible teeth. Their habit of exuding a drop of milky fluid from the frontal gland when disturbed or annoyed offers a sure means of identifying them in life. Soldiers are relatively numerous in the colonies and when the galleries are broken open will usually appear after a short interval.

(ii) Nasutitermes exitiosus. It attacks seasoned timber, poles, posts and sawn timber. It is a mould-building species which adopts its nesting habits to local conditions. Under natural conditions its mound may be built around or over a stump or piece of wood in which, presumably, the colony was originally founded. When it attacks buildings, the nest is likely to conform to the shape of the cavity of the wall, or the sub-floor space available.

## 4.5 Termite Biology

### (a) Ancestry

Fossil records show that the progenitors of modern termites date back more than 50 million years and that termites and cockroaches have a common ancestry. In fact, the wing structure of the most primitive living termite, Mastotermes darwiniensis - the giant termite of tropical Australia - is similar to that of the roaches and its egg mass resembles the egg-capsule of the roaches. As further evidence of a common ancestry of roaches and termites, one roach burrows into the sounder wood of decaying logs for food and shelter and like Mastotermes and many other groups of termites, has a rich protozoan or bacterial fauna in its gut to aid in the digestion of its food.

### (b) Biological limitations

The biology of the termites is interesting and complex; but only those aspects of termite biology which are relevant to the control of attack by subterranean termites will be discussed here. Although the observations will be in general terms, this limitation should not be overlooked.

(i) Life span. The life span of the individuals of a termite colony is believed to be as much as 25 years for the reproductive castes but considerably less for the other castes. Certainly, there is no difficulty in maintaining a laboratory colony of sterile workers and soldiers for a period of four years or so.

The life span of the colony varies with the species assuming, in each case, no untoward accident to interrupt its development. With some species it is believed that the original pair of reproductives which founded the colony are never replaced or supplanted. If this is so, the life span of the colony is limited to that of the founding pair, plus the limited period for which the remaining members of the colony will survive without further replacements. With those species capable of producing supplementary reproductives which either supplement the original queen or, if she suffers an accident or dies, replace her, the life of the colony is indefinite and might well exceed a century or two.

(ii) Industry. Termites are industrious. It is virtually impossible to observe them under natural conditions without disturbing or disrupting the colony. In laboratory colonies the constant activity of these insects is amazing and there is no reason to support that they are less active under natural conditions. It should be recognized, however, that activity tends to be reduced in cold weather and that foraging may cease altogether during spells of hot dry weather.

(iii) Moisture and light. There is a common believe that subterranean termites must return to water once in every 24 hours. It is possible that this is true for some species but it is certainly not universally so.

Apart from the reproductive castes when making their 'colonizing flight', subterranean termites spend the whole of their existence in the galleries and tunnels associated with their nest.

Conditions in these galleries and tunnels, and the nest, are uniform and fairly constant. Total darkness prevails at all times, humidities are high and diurnal temperature fluctuations are minimized. Termites have become so specialized that these are virtually the only conditions they can now tolerate. Since their activities are confined to a gallery system in which the relative humidity is always high, their integument (outer covering or 'skin') does not need to be a good moisture barrier. In fact, it is very permeable, so that when termites are exposed to a dry atmosphere they lose moisture and soon die from desiccation. Also, the surface of their bodies is normally moist; consequently any dry dust particles with which they might come in contact adhere only to be removed when the insects clean or 'groom' each other.

Living in total darkness, they have largely lost the faculty of sight and most termites are either blind or almost so. Being perpetually sheltered from normal light and radiation, termites have little need of pigmentation as a filter against ultra-violet light. Hence, their integument is either translucent or very poorly pigmented, except for the head and jaws of the soldier caste which tend to be hard and horny with a corresponding amount of pigmentation.

(iv) Protein conservation. The plant tissues upon which termites feed contain very little protein. Hence it is reasonable to assume that a termite colony needs some mechanism for the conservation of protein. It has been suggested that termites conserve their protein by (i) cannibalism and (ii) 'grooming'.

There is a considerable amount of evidence to support the contention that termites dispose of dead and diseased members of the colony by cannibalism and some evidence to suggest that surplus or unwanted members may suffer a similar fate. Certainly such a procedure would be a convenient and efficient method of protein conservation.

It is well known that termites 'groom' one another. This may be because their bodies lack the flexibility necessary for them to be able to clean themselves and this duty must be delegated to other members of the colony, but it is quite evident that their body secretions are attractive to other members of the colony and are eagerly sought after. This habit of grooming is of prime importance in termite control work. If a poison dust, such as finely divided white arsenic powder, is blown into occupied termite galleries it will be fairly widely distributed by the initial blast; it will also adhere to the rather moist bodies of any insects which come in contact with it. This will aid and extend its distribution. Since termites habitually groom each other, the particles of poison will be ingested along with other body secretions with the inevitable result. The poison remains active in the dead bodies and, if these are eaten, continues to kill.

(v) Digestion and food preferences. Termites show considerble preference in their choice of food. If subterranean termites, which normally feed upon wood, are given a free choice between two timbers, they will consume the more susceptible of the two for preference. Several timbers are seldom attacked by termites under natural conditions, but in compulsion tests, where the termites have the choice between eating the resistant species or starving, few timbers are totally immune from their attack.

In Victoria, subterranean termites normally feed upon hardwoods. The Nasutitermes species found in this State practically never attack softwoods, but the Coptotermes species show no such discrimination.

(c) Social organization

Termites are social insects which usually live in large, populous colonies which may contain over a million individuals. Activities within the colony appear to be divided between groups of specialized members, refered to as castes. The population of a mature colony of subterranean termites will consist of three principal castes and juvenile forms. The three major castes are the reproductives, the soldiers and the workers. For various reasons, classification of the various species is based upon the morphology of the soldier caste.

(i) Reproductives. The only members of the colony to be complete with appendages (including eyes and wings) and functional reproductive parts. Once their colonizing flight is completed these shed their wings and as 'first form reproductives' - or first form kings and queens - set about founding a new colony. First form queens can practically always be recognized by their wing-stubs and their distended abdomen which, in Nasutitermes, for example, may become so enlarged that the queen is several hundred times the size of a soldier or a worker.

Some species produce additional reproductives to help populate the colony and to replace the original queen, if she is injured. These remain permanently in the mother colony, though not necessarily in the central nest. In fact, they may found a new colony by a process of 'budding off'. As the strength of the daughter colony increases communication with the parent colony may be lost and the new colony become independent.

As a colony matures, it produces reproductives which, when weather conditions are suitable, leave the parent colony in swarms in an attempt to found new ones. These swarms of 'flying ants' usually emerge from close to the parent colony and may be some help in finding the site of the nest.

The reproductives are the only termites which leave the shelter of the gallery system: this happens only during their brief colonizing flight, after which they seek a suitable site in which to found new colony. Fortunately, of the millions which set out, only an occassional pair succeeds.

The juvenile reproductives or nymphs may be recognized by the presence of wing buds and, sometimes, their larger size.

(ii) Soldiers. Apparently their main function is to defend the colony against ants - one of the termites' principal enemies.

The soldiers are most useful in termite classification and should always be procured if a species is to be identified. Soldiers may be recognized by their dark-coloured heads and, if closely examined, well-developed mandibles - except in Nasutitermes which has a pear-shaped head.

(iii) Workers. In nearly all species, workers constitute the great majority of the inhabitants of a colony. They are uniformly pale-coloured, with rounded heads and soft bodies, and are blind and sterile.

### 4.6 Prevention of Termite Attack

Whenever doubt exists as to the adequacy of the precautions proposed for the prevention of termite attack in buildings or other structures in whih wood has been used, the proposals should be checked by specialists before any work commences so that modifications can be made with a minimum of inconvenience.

It should be noted that the precautions described apply to Victorian conditions, where subterranean termites are responsible for practically all the damage of economic consequence to timber in service. In other States, alternative methods may be more acceptable.

(a) Timber in the ground

When timber is used in the ground, as poles, posts, railway sleepers or house foundations, soil-dwelling termites have direct access to it. Commonly, their foraging galleries lie from 100 to 200 mm below the surface of the soil and attck is usually initiated at about this level. However, in dry soils it is by no means rare for attack to be initiated at a much greater depth.

(i) Resistant timbers. The heartwood of a number of eucalypt timbers is very resistant to termite attack without any form of preservative treatment. Resistant timbers in Victoria, Australia, include:

TABLE 4.3

| Durability Class | Standard Trade Common Name | Botanical Name |
|---|---|---|
| 1 | Box, grey<br>Box, grey, coast<br>Ironbark, red | *E. microcarpa (Maid.)*<br>*E. bosistoana F. Muell.*<br>*E. sideroxylon A. Cunn.* |
| 2 | Gum, red forest<br>Gum, red, river<br>Gum, yellow<br>Stringybark, white<br>Stringybark, yellow | *E. tereticornis Sm.*<br>*E. camaldulensis Dehnh.*<br>*E. leucoxylon F. Muell.*<br>*E. eugenioides Sieb.*<br>*E. muelleriana Howitt.* |

(ii) Impregnated timber. Only the sapwood of most hardwood timbers can be impregnated with wood preservatives by conventional methods. Therefore, unless the species is one of those listed as resistant, the benefits of preservation will be lost unless all the sapwood is intact. With softwood timbers, particularly P. radiata, which normally have a comparatively wide sapwood band, at least 80 per cent of the cross-section should be fully and uniformly penetrated.

The Australian Standard AS 1604-1974: Preservative-treated sawn timber, veneer and plywood, and AS 2209-1979: Timber poles for overhead lines, both deal with the preservative treatmemt of timber used in ground contact.

AS 1604, relates the penetration and retention of wood preservative to the natural durability of the timber species and to the anticipated hazards of service. Appendices to this Standard deal with the composition of commercial wood preservatives available in Australia, the sampling and testing of preservatives and preservative-treated wood, the natural durability of Australian commercial timbers and similar matters. This Standard should be consulted for the recommended retentions of commercial preservatives in various classes of timber for any particular end-use.

(iii) Soil puddling. Sawn heartwood and other impermeable timbers can be given a useful measure of protection against subterranean termite attack by surrounding them with an annulus or 'collar' of soil thoroughly mixed with a persistent insecticide. To be effective this collar must be in direct contact with the timber to be protected, not less than 50 mm wide (measured radially from the surface of the wood) and extending for at least 0.5 m below groundline. In dry soils it may be necessary to carry the collar down deeper.

The persistent insecticides allowed in the Australian Standard, AS 2057-1977 will also be found effective for protecting timber in ground contact against termite attack - but not against decay. They are usually pruchased as emulsifiable concentrates and applied as diluted emulsions at the rate of about 150 $1/m^3$ of soil.

(b) Timber in buildings

With buildings, it is necessary to protect the contents of a building from damage by termites as much as to preserve the structure itself. In fact, the contents of a shop or warehouse often exceed the value of the building. Therefore, protection against termite attack is just as necessary in a building in which all the materials of construction are immune from termite damage as in one built entirely of timber. Normally termites forage in concealed tunnels beneath the surface of the soil, or in galleries in the timber they attack. However, they will build mud-covered shelter tubes over materials they cannot penetrate in order to reach susceptible timber at some distance above ground. It is by means of these shelter tbes that they gain access to the superstructure of a building or its contents.

Buildings are usually protected against termite attack by mechanical barriers (termite shields, ant caps) placed on top of the foundations or by barriers of chemically treated soil at ground level. In either case the barriers must be continuous and complete so that all possible routes of entry to the building from the soil are intercepted by a barrier. Even then, under some circumstances, termites will raise a mound or a free-standing shelter tube to by-pass the barriers. Hence, in areas of established termite hazard, periodic sub-floor inspections are a necessary part of termite protection.

(i) Mechanical termite barriers. When set into continuous foundations these are known as 'strip shields' but when set over stumps or piers, as 'caps' or 'ant-caps'. Collectively they may be referred to as either 'capping' or 'shielding'. Both are made from galvanized iron of heavier gauge than 26-gauge or from copper.

Correctly made, they should project beyond the foundation they protect before turning downwards. All joints should be carefully mitred and well soldered or spot-welded at close intervals. Detailed instructions for the correct method of fitting shields to buildings are set out and illustrated in Australian Standard AS 1694-1974. Because of the need for periodic inspections and because it is very rare to find all the joints and corners properly made, shields are practically never recommended for use in buildings with continuous foundation walls. Hence, their use is more or less restricted to the 'capping' of stumps or piers in timber-framed houses under which inspection presents no difficulty. For ease of inspection the edges of the shields should stand clear of all obstructions by at least 50 mm.

(ii) Treated soil barriers. These may be referred to as 'chemical barriers.' The Australian Standard AS 2057-1977 is a code of practice for forming barriers of chemically-treated soil as a protection for buildings against subterranean termite attack. This code describes the correct method of forming these barriers, nominates chemicals and concentrations and suggests building modifications which can simplify and reduce the cost of termite prevention. The common chemicals recommended for these barriers are aldrin, dieldrin, chlordane and heptachlor. They are usually used in the form of water emulsions. The treating solution should be applied to the whole of the sub-floor area, after it has been cleared of all debris and reasonably levelled. Special attention must be given to areas of fill under concrete slabs raised to the same level as suspended timber floors.

Treated soil barriers are the preferred treatment for concrete raft (slab-on-ground) construction.

## 4.7 Eradication of Termite Attack

(See Australian Standard AS 2178-1978: The Treatment of Subterranean Termite Infestation in Existing Buildings).

In the event of active termite attack being discovered in an existing building, THE INSECTS SHOULD BE LEFT UNDISTURBED UNTIL ALL THE MATERIALS NECESSARY FOR TREATMENT HAVE BEEN ASSEMBLED OR ARRANGEMENTS HAVE BEEN COMPLETED FOR TREATMENT BY A SPECIALIST.

One of the most effective treatments for an active termite infestation is dusting with arsenic dust. Government regulations make it difficult for ordinary householders to obtain this poison so it is now usual to employ professionals who are licensed to handle poisons. The success of this method depends upon the termites continuing to occupy treated galleries after the dust has been blown in. It is for this reason that a warning is given against disturbing the termites until arrangements for treatment have been completed.

As an alternative to the poison dust treatment as recommended in the Standard, the superstructure of the building can be isolated by a barrier of treated soil. If it is formed correctly, and it completely surrounds all the foundations, it will protect the building from further attack but may not be effective in eliminating the nest or colony from which the attack originated. Care must also be taken to avoid encircling the termite colony within the treated soil barrier and isolating it from alternative sources of food. This is most likely to happen when the treated soil barrier is formed around a concrete slab which is part of the house.

## LITERATURE FOR REFERENCE

Ratcliffe, F.M., Gay, F.J., and Greaves, T. (1952). Australian Termites. CSIRO, Melbourne.

CSIRO Division of Building Research,

INFORMATION SHEETS

10-66 Prevention and Control of Termite Attack
10-69 Porotermes adamsoni (Froggatt) - A Dampwood Termite
10-71 The Troublesome Termite (White ant)

Information Sheet No. 10-66 outlines the contents of the following Australian Stndards, which are quoted (variously) in the texts:

STANDARDS ASSOCIATION OF AUSTRALIA

Australian Technical Standards Nos:
AS 1694-1974: Physical barriers used in the protection of buildings against subterranean termites
AS 2057-1977: Soil treatment for the protection of buildings against subterranean termites
AS 2178-1978: The treatment of subterranean termite infestation in existing buildings
**AS 1604-1974: Preservative-treated sawn timber, veneer and plywood

## 5.0 WOOD PRESERVATIVES

### INTRODUCTION

Wood has many advantages over competing materials for both structural and ornamental uses. Timber does not deteriorate as a result of ageing alone: any failure is invariably the result of attack by some external agency and if adequately protected against dampness, insects, fungal infection and fire, it will (unless exposed to severe mechanical wear) last almost indefinitely.

To some extent the reputation of timber has suffered due to deterioration resulting from attack by fungi or insects. Such biological attack can now be almost entirely prevented, but the preservative measures require a clear understanding of the nature of the organisms concerned; the factors governing their development; the different properties of various timber species and the principles upon which scientific control is based.

Conventionally, timbers have been classified into four durability classes according to the relative natural resistance of their heartwood to biological attack when the service conditions involve contact with the ground. It will be realized however, that in countless uses of timber which do not involve contact with the ground, for example weatherboards, joinery and furniture, these ratings have much less significance. There are numerous instances where timber, in favourable, protected situations, has remained sound and serviceable for generations without any special preservative treatment. However, to ensure long life under conditions of high hazard, it is necessary to use either the more highly durable species or timber of lower natural durability which has been given the recommended preservative treatment.

Decay increases the susceptibility of wood to attack by termites and other wood-boring insects. Indeed, there are many insects which cannot initiate attack in sound, seasoned wood but which can be very destructive to wood in which some decay is present. The damage caused by insects which initiate attack in sound, seasoned wood can be controlled, or entirely prevented, by the use of appropriate preservative treatments or other suitable precautions.

Almost invariably, the sapwood of a timber is less resistant to decay and insect attack than the heartwood. Conversely, the sapwood is nearly always more amenable to preservative treatment than the heartwood. Species vary widely in the natural resistance of their timber to fungal and insect attack. With appropriate preservative treatment, sapwood (of practically all species) and the heartwood of permeable species can be rendered highly resistant to both insect and fungal attack. Thus, with proper preservative treatment, species of low natural resistance may be substituted for timbers of the highest natural durability and may even out-perform them.

The prime purpose of any wood preservation process is to extend the useful life of timber in service. This may be achieved by increasing its resistance to damage by invading organisms (fungi, insects or marine animals) or by increasing its resistance to deterioration caused by 'weathering' and other physical forces.

To be effective, preservation processes need to place an adequate quantity of an appropriate preservative far enough into the timber to ensure that no unprotected (or any insufficiently-treated wood) becomes accessible to the invading organism or is exposed to other destructive forces.

Numerous methods of treatment have been developed to protect timber against unwanted deterioration. The simplest have required only the application of surface barriers (e.g. paint, coatings of other materials, metal sheathing, etc.) which are intended to deny moisture, and other destructive agencies, access to the wood. Other, more sophisticated methods of treatment are designed to distribute through the wood preservative chemicals which are toxic to wood-destroying organisms. Current worldwide research aims at refining these treatment methods and improving the environmental acceptability and other properties of the preservatives to the point where there is a satisfactory preservative and treatment process for practically every normal requirement.

Numerous chemicals, and mixtures of chemicals can be used as wood preservatives. Some, like creosote oil, and the copper-chrome-arsenic (CCA) salts are general purpose preservatives. Others, such as boric acid, and sodium fluoride, have specific, limited uses. Hence the choice of preservative will depend upon the agencies of deterioration (biological, mechanical, etc.) against which protection is required, and the conditions to which the timber will be exposed in service. In choosing a preservative, consideration should be given to the possibility that the nature or level of the hazard might change, in the course of time.

## 5.1 General Requirements

The biodeterioration of wood (i.e. the deterioration of wood caused by living organisms) and some forms of mechanical breakdown can be greatly reduced or retarded by the correct use of certain oils and toxic chemicals that, collectively, can be called 'wood preservatives'. These preservatives may be applied to the green log to prevent fungal or insect damage for a few weeks before conversion; to veneer or sawn timber for short-term protection during drying, shipping or storage; or to the final product to confer resistance for many years to decay, termites, borers, marine organisms and such mechanical agencies as weathering, splitting, or water obsorption. Fire-retardant compounds are sometimes grouped with wood preservatives and some proprietary products contain a mixture of fire-retardant and wood-preserving chemicals. Because of these varied uses there are many different preservative formulations, though in general, all comply with the following main requirements.

### (a) Toxicity

The first requirement is toxicity or repellency to the organism(s) to be controlled. Few chemical compounds are equally effective against both fungi and insects and within any group there are often some organisms which have unusual tolerance. In most cases, therefore, preservatives based on a single toxic compound are best restricted to specific uses, such as borax for Lyctid and Anobiid control, while mixtures are preferably used as general purpose preservatives.

### (b) Permanence

Although a high degree of permanence is not essential for all uses, premature failure can be expected if a preservative does not withstand the conditions of service for the period required. When selecting a preservative the conditions of service must always be considered in conjunction with the required period of service. The more volatile preservatives are unsuitable where long-term protection is required, particularly if the rate of evaporation is increased by exposure to high temperatures. Preservatives which can be leached easily from the wood are unsuitable for use under wet conditions though they may give protection for a lifetime if the timber is kept dry.

### (c) Penetration

However toxic or permanent a preservative may be, its effectiveness over any long period is dependent to an important extent on the type of penetration obtained in the wood. Superficial coatings or shallow or erratic penetration cannot be expected to give protection for as long as deep uniform treatment. Such treatment is dependent on the method of application, the penetration properties of the preservative, and the permeability (or 'treatability') of the timber. The latter is of major importance although when sufficiently dry the sapwood of most timbers is fairly readily penetrated. The heartwood is much more difficult to treat and many timbers including the eucalypts, are in the 'very difficult' class. In practical terms this means that to obtain deep, uniform penetration in sawn timber, it is necessary to select the timber species, the preservative and the treatment method with considerable care.

### (d) Other requirements

There are various other properties of a preservative which are either essential or desirable depending on the particular use. These include:

- safety in use;
- low toxicity to people;
- low fire hazard;
- cleanliness and absence of objectionable or persistent odour and colour;
- environmental acceptability (for both the treated wood and wastes);
- negligible corrosive action on common metals
- readily identifiable or detectable in treated wood;
- minimal interference with gluing, painting or other finishing;
- cheapness and ready availability.

As there is no ideal preservative it is necessary to select one which meets essential requirements and then to adjust the methods of treating and handling the timber to minimize any inherent disadvantages.

## 5.2 Classification of Preservatives

There is no universally accepted system of classifying wood preservatives but Table 5.1 draws the main practical distinctions.

TABLE 5.1 TYPES OF WOOD PRESERVATIVES

| Type | Usual Treatment Methods | Examples of each type |
|---|---|---|
| A. Permanent oils | Pressure or open-tank (thermal process) | Creosote oils, mixtures of creosote with tar or mineral oils, oil solutions of pentachlorophenol, creosote-pentachlorophenol mixtures. |
| B. Fixed waterbone preservatives (CCA) | Pressure, sap replacement | Metal-chrome-arsenic mixtures such as "Boliden," "Celcure" and "Tanalith" salts. |
| C. Unfixed diffusion preservatives | Steeping, dip-diffusion, pressure-diffusion | Boron compounds, sodium fluoride, multisalt diffusion mixtures. |
| D. Aqueous dipping and spraying preservatives | Spraying or dipping to give superficial or envelope treatments | Log sprays, anti-satin dips, timber stack sprays, termite soil poisons, etc. |
| E. Light organic solvent preservatives (LOSP) | Brushing, spraying or dipping to give superficial or envelope treatments | Water repellent dipping preservatives, metallic naphthenates, various organic fungicides and insecticides. |
| F. Glue line additives for plywood | For addition to glues used for bonding plywood | Arsenic, chlorinated hydrocarbon insecticides, etc. |

## 5.3 Fixed Oil Preservatives

(a) Creosote oil

Creosote oil is probably the best known and most widely used preservative in the world. It is generally regarded as setting the standard of permanence and reliability for a general-purpose wood preservative for outdoor construction timbers such as sleepers, poles, marine piling, etc. Almost all the creosote oil currently used in Australia for wood preservation conforms to the Australian Standard AS 1143-1973. It is produced by blending distillate fractions from coke-oven tar. The production closely follows the specification used in America for the production of high temperature creosotes but, due to subtle differences in composition, the Australian creosote produces an undesirable deposit ('crud') on the surface of treated wood. Transmission-line poles, when so treated require a long period of 'weathering' before becoming acceptable to linesmen who must work on them. In an effort to overcome this objection, Government and industry are working together to develop an emulsified pigmented creosote (PECC). Test results so far obtained with this material are promising but additional field and laboratory testing is still necessary to confirm the preservative effectiveness of treatments made with this modified product and to ensure the acceptability of the treated timber to the work force.

### (b) Creosote mixtures

Mixtures of creosote oil withtar or mineral oil have been used to a considerable extent in the US mainly for sleeper treatments. They have not been used commercially in Australia although, in experimental tests of pressure-treated radiata pine sleepers in South Australia, a mixture of creosote and furnace oil (60:40) has shown a slight superiority over creosote alone because of a small improvement in the mechanical life of the sleepers. This result, due to better weather protection, is common with heavy mineral oils and must be set against their tendency to cause formation of troublesome sludge when mixed with creosote.

### (b) Tar

Tar used alone is not a good wood preservative because it is less toxic than creosote and usually is less able to penetrate wood. Its use as a surface coating to improve service life of timber in ground contact is of doubtful value.

### (d) Pentachlorophenol and arsenic in creosote

The addition of about two per cent pentachlorophenol to creosote oil to increase its toxicity to fungi has gained favour in the US for some pole treatments. It is not commercially used in Australia but it may be an advantage for some round eucalypt timbers where it is difficult to obtain the desired minimum creosote retention.

Addition of arsenic trioxoide to creosote to improve termite resistance is also possible and may in the future find application in areas of high termite hazard.

### (e) Pentachlorophenol in mineral oil

A five per cent (by weight) solution of pentachlorophenol in a non-volatile mineral oil such as furnace oil may be considered as approximately equivalent to creosote oil for the treatment of sleepers, poles, etc. Compared to creosote oil, this solution is:

- more resistant to weathering;
- ineffective against marine borers;
- often dirtier to handle, and more likely to cause skin irritation. (Because of this problem, its use is restricted in some countries.) Although a five per cent solution of penetachlorophenol in heavy oil has given good results under a wide variety of conditions, it is not a good insecticide and needs to be reinforced with a persistent insecticide if required for use where there is a hazard from both decay and insects - particularly termites.

## 5.4 Fixed Waterborne Preservatives

### (a) Metal chrome-arsenic salts

There have been many attempts to devise mixtures of inorganic compounds which will dissolve in water to produce stable solutions but which will react or 'fix' in the wood after treatment to form more or less insoluble toxic compounds. Probably the most successful of these fixed waterborne preservatives have been the metal-chrome-arsenic salts which are now widely used as general-purpose preservatives. As used commercially in Australia today these are all products of the copper-chrome-arsenic (CCA) type. These preservatives should be referred to by their trade names in specifications so that equivalent retentions can be set.

Preservatives of unkown or confidential composition can rarely be recommenaed. The user should not be asked to trust secret formulations which may vary in composition without his knowledge and which he cannot assess by an quick practical test. Premature failure of treated wood is often disastrous but, as it may not occur for several years, it is more likely to damage the reputation of the wooden product than that of the preservative which is easily changed in name and composition.

The composition of the majority of the CCA preservatives currently available commercially in Australia is listed in an Appendix to AS 1604. A summary of their elemental compositin is presented in Table 5.2

TABLE 5.2 COPPER-CHROME-ARSENIC PRESERVATIVE

| Preservative | Type of Formulation | Elemental Composition (per cent) | | | | |
|---|---|---|---|---|---|---|
| | | Copper (Cu) | Chromium (Cr) | Arsenic (As) | Zinc (Zn) | Phosphorous (P) |
| Boliden K.33 | oxide | 11.8 | 13.8 | 22.3 | * | * |
| Celcure A<br>Celcure AP | salt | 8.1 | 14.1 | 14.8 | * | * |
| Tanalith C | salt | 8.9 | 15.9 | 11.3 | * | * |
| Sarmix 3 | salt | 8.9 | 15.9 | 11.3 | * | * |
| Tanalith CA | salt | 8.9 | 15.5 | 21.0 | * | * |
| CSIRO 3S | salt | 7.3 | 10.9 | 10.3 | 3.9 | 4.6 |
| CSIRO 30 | oxide | 10.4 | 15.5 | 14.6 | 5.6 | 6.5 |

*Some of these preservatives are now being produced with lower water content by using some anhydrous salts. The above is, however, still their nominal elemental composition.*

The toxicity of these preservatives to insects is dependent almost entirely on the arsenic content while both copper and arsenic are toxic components for fungi. The chromium is relatively non-toxic, its function being mainly to control solubility and fixation and to prevent corrosion of metals.

It should be noted that differences in the toxic content of these preservatives do not indicate that one is superior to another, but only that different amounts (or 'retentions') in the wood may be necessary to secure the same result.

The difference between oxide and salt type formulations should be understood. In the latter, some sodium or potassium sulphate is formed as a by-product of the fixation reaction and this may crystallize on the surface of the wood as a faint white bloom during drying of the treated timber. It is not poisonous or deleterious to the preservative and it readily washes off. In oxide formulations this by-product is not formed. It is claimed that, for this reason, wood treated with an oxide formulation has higher practical importance even in electric transmission poles, is controversial.

(b) Zinc or copper pentachlorophenate

These compounds, which have low solubility in water and high toxicity to fungi, are used to a limited extent in wood preservation. Zinc pentachlorophenate has been used commercially in Australia for treatment of plywood by dipping the veneer in two different aqueous solutions to form the insoluble toxic compound in the wood. Copper pentachlorophenate is generally more toxic to fungi but being strongly coloured has more limited use. The addition of arsenic or other insecticides to both these preservatives seems desirable where there is a termite hazard.

(c) Other fixed preservatives

There are several other well-known preservatives which form more or less insoluble compounds in the wood. These include -

Celcure non-arsenical
- acid copper chromate

Chemonite
- Ammoniacal copper arsenate
- Ammoniacal copper caprylate
- Ammoniacal copper pentachlorophenate
- Solubilized organo-tin compounds

Several Wolman salts
- fluor-chrome
- fluor-chrome-arsenic
- chrome-arsenic
- copper-chrome-boron

Some of these preservatives confer high resistance to both decay and insects, and are well fixed. Others are relatively inferior in one or other aspect or have other disadvantages. All, however, are potentially usable under some conditions.

## 5.5 Non-Fixed Diffusion Preservatives

### (a) Penetrability

With fixed waterborne preservatives such as copper-chrome-arsenic salts, which are usually applied by pressure treatment, initial penetration occurs only where the solution can be forced into the wood. Fixation within the wood is usually rapid and these preservatives soon become insoluble and incapable of further movement. The penetration pattern is thus fairly sharply defined and any areas which resisted treatment during the pressure injection remain untreated.

Diffusion preservatives are also water soluble but differ from fixed salts because they do not form insoluble compounds in the wood, or at most, do so only very slowly. They thus retain their ability to move (or diffuse) in the wood over long periods if conditions are suitable. This diffusion is not a quick mass movement of solution as occurs during pressure treatment but is the slow passage of molecules or ions of the preservative from cell to cell through the water in the wood. Provided the wood is green or semi-green, this movement will continue in both sapwood and heartwood irrespective of whether the latter can be penetrated in pressure treatments. It will also continue in wood which has been previously dried but which has become wet again. Although diffusion is a relatively slow process, considerable penetration in green wood can generally be obtained from a concentrated surface application of preservative, provided the wood is prevented from drying out for a few weeks after treatment.

### (b) Application

Where more rapid treatment is required, the methods commonly used for Lyctid immunization of sawn timber in Australia may be used. These are hot treatments in which the timber is either steamed or is heated in the solution and is then allowed to cool down for several hours while still immersed. Since the timber is usually either green or semi-green when treated, these methods combine open-tank method with diffusion treatment, i.e. the volume of solution in the tank decreases because of solution absorption and its concentration also decreases because of diffusion of preservative into the wood. As relatively weak solutions are used and as the open-tank effect is considerable, the sapwood is usually much more heavily treated than the heartwood. In Lyctid immunization this is a desirable economy.

It should be clearly understood that most diffusion preservatives will leach out of wood used in ground contact or exposed to wetting for any considerable period. Diffusion preservatives are therefore suitable mainly for timber or plywood and used indoors or protected from wetting by a well-maintained paint system.

As there are large differences in the rates of diffusion of different preservatives, those used in diffusion treatments should be selected as far as possible from compounds in which the toxic ions are relatively fast moving.

### (c) Diffusion preservatives

The main diffusion preservatives used or available in Australia are Boron Compounds, the effectiveness of which, in preventing Lyctid borer attack, has been demonstrated for more than 30 years. These compounds have found wide use in Australia for this purpose and more recently in New Zealand for prevention of both Lyctid and Anobiid borer damage. Also, it is now known that boron compounds have considerble toxicity to most wood-destroying fungi and useful toxicity to termites. Because of fast diffusion rate, low chemical cost and clean, colourless treatment, they are particularly suitable for diffusion treatments of building timbers.

### (d) Boron compounds

The main boron compounds of value in wood preservation are listed below. The toxic content has been expressed as per cent boron (B) in the pure compound.

(i) Boric acid ($H_3BO_3$) - 17.48% (B). Boric acid is usually more costly per toxic unit than borax. It also has the disadvantage that solutions used for treating wood should be kept from contact with iron which causes inky discolouration due to formation of iron tannate. Solubility at 20°C is about 4.6% mass/mass (4.6 g Boric Acid in 100 g water).

(ii) Borax decahydrate ($Na_2B_4O_7.10H_2O$) - 11.34% (B). Because of high water content (about 47%) and bulk, this compound is usually less economical to use than borax pentahydrate, though otherwise it is quite suitable. Solubility at 20°C is about 4.9% m/m. Unlike boric acid, it does not react with ferrous metals in a treatment plant.

(iii) Borax pentahydrate ($Na_2B_4O_7.5H_2O$) - 14.85% (B). This is widely used in Australia for *Lyctid* immunization of sawn timber and veneer. Because of lower water content (about 31%) and less bulk than borax decahydrate, its price per toxic unit is generally lower. In common with other borate solutions for treating wood, it can be used in iron tanks without causing danger of discolouration from formation of iron tannate.

(iv) Borax anhydrous ($Na_2B_4O_7$) - 21.49% (B). Contains no water of crystallization and is more difficult to dissolve than the hydrated forms.

(v) Sodium 1:5 borate ($Na_2B_{10}O_{16}.10H_2O$) - 18.32% (B). The compound, often called sodium pentaborate, is much more soluble in cold or warm water than boric acid or borax and is hence suitable for dip-diffusion treatments where a cold or warm, concentrated solution is required. It can be purchased as pentaborate or can be made by mixing 100 parts (by mass) of boric acid ($H_3BO_3$) with 78.5 parts of borax pentahydrate ($Na_2B_4O_7.5H_2O$). This mixture contains about 16.32% B.

(vi) Sodium 1:4 borate (approx. $Na_2B_8O_{13}.4H_2O$) - 20.97% (B). This compound, sometimes called sodium octaborate, is higly soluble in warm water and is commonly usedin dip-diffusion treatments of sawn timber in New Zealand. Up to about 20°C it is not highly soluble but thereafter its solubility increases more rapidly until it becomes suitable for dip-diffusion treatments requiring concentrated solutios at temperatures of about 30 to 55°C. It can be made by mixing 100 parts (by mass) of boric acid ($H_3BO_3$) with 117.5 parts of borax pentahydrate ($Na_2B_4O_7.5H_2O$). This mixture contains about 16.06% B. Its solubility at 20°C is approximately 10% m/m.

(vii) Sodium borofluorides. A highly soluble complex is formed when boric acid ($H_3BO_3$) and sodium fluoride (NaF) are dissolved together in the ratio of four parts (by mass) of $H_3BO_4$ to one part NaF. This mixture contains about 13.99% (B) and 9.05% (F) and is more soluble in cold water than the boron compounds previously described. Its solubility at 20°C is approximately 27% m/m and it is particularly suitable for cold dip-diffusion treatments.

## (e) Fluorine compounds

Sodium Fluoride (NaF) - Sodium fluoride is used as an alternative to boron compounds for Lyctid immunization of plywood by dip-diffusion treatment of the green veneer. Unlike boron compounds, which do affect the water resistance of some phenolic glues, sodium fluoride does not seem to cause any gluing problems. However, as a lycticide its cost is higher per toxic unit and more care is necessary to avoid health hazards. It is not a good termiticide.

## (f) Complex diffusion preservatives

(i) BLUE 7 diffusion preservative. This preservative is particularly suitable for the *in situ* treatment of any partially decayed wooden member which still retains sufficient mechanical strength to be useful. Applied as a brush coating or surface spray (with slight dilution) it will penetrate damp and/or decayed wood and prevent further decay. When used in the repair of window sills, and similar building timbers, pockets of bodly decayed wood should be scraped reasonably clean prior to the application of the BLUE 7.

BLUE 7 was developed for the treatment of centre rots in power poles but it has proved to have much wider application. Recently, it has been released for general use and is now available in small lots for domestic purposes and in larger lots for industrial uses. It is supplied as a concentrate, consisting almost entirely of toxic components and, as supplied, contains 10.4% copper, 13.1% fluoride, 6.8% boron and some ammonia. It is safe to handle and presents minimal pollution problems either in service (when it may be covered with paint) or in the subsequent disposal of any unwanted treated wood. The recommended rate of usage is about 8 to 10 kg/m$^3$.

BLUE 7 should not be used where direct and continuous leaching is likely to occur. It is not intended for use in ground contact and, above ground, may need replenishment every 5 to 7 years unless protected by paint.

(ii) Dip-diffusion preservative. Variously known as CSIRO's patent preservative, BFCA (borofluoride-chrome-arsenic), and dry-mix, the components of this preservative can be prepared in several forms including a dry powder (hence 'dry-mix'), as a one-pack mix, a two-pack mix or as separate components. All forms are highly soluble in cold water and will readily form solutions in excess of 30% (m/m) concentration. According to the actual formulation use, the preservative will contain 10 to 13% elemental boron, 6 to 8% elemental fluorine, 3 to 4% elemental chromium and between 6% and 8% elemental arsenic.

Among its many advantages, the dip-diffusion process requires no monitoring of treatment solution concentrations or composition - provided that the several components are supplied and used in their correct proportions. Immersion in the treating solution is only momentary and contact between the green wood and the treatment solution is too brief for any differential absorption to occur. Penetration of the preservative takes place away from the treatment solution in diffusion stacks (or sweat boxes).

The preservative treatment has been successfully used in Papua New Guinea for over 20 years for the control of insect attack and decay in building timbers, including exterior joinery. In spite of this satisfactory service record in tropical climates, and although some fixation may occur, this preservative is regarded as being leachable and is not recommended for use in ground contact. Best results will be obtained when it is protected from the weather by painting or when used indoors.

(g) Aqueous dipping and spraying preservatives

Wood preservatives in this category are used mainly in superficial treatments such as spraying of logs, anti-stain dipping or sawn timber, etc., where long term protection is usually not required. However, some are used as termite soil poisons and in this case much higher permanence can be expected provided the application is not superficial.

Some of the main compounds and their uses are:

(i) Sodium pentachlorophenate. This compound has very high toxicity to almost all fungi including common moulds many of which are not deterred by treatments effective against wood-destroying fungi. It is water soluble while the solution remains alkaline, but will precipitate out as the water insoluble pentachlorophenol if the solution becomes even faintly acid (i.e. when the pH falls below 7). For this reason solutions used for dipping timbers often contain borax to supply an alkaline reserve or 'buffer' against the acidity of the wood.

As sodium pentachlorophenate is a much better fungicide than insecticide, its use in log sprays is almost always in mixture with an insecticide intended to control borers.

Typical formulations for a log spray or an anti-stain dip for sawn timber are:

Log spray (% m/m)

| | |
|---|---|
| - Sodium pentachlorophenate | 2.0% |
| - Emulsifiable insecticide (as pure lindane, dialdrin, etc.) | 0.8% |
| - Water | 97.2% |

(A colour may be added if required).

Anti-strain dip or spray (sawn timber)

| | |
|---|---|
| - Sodium pentachlorophenate* | 0.5% |
| - Borax Pentahydrate ($Na_2B_4O_7.5H_2O$) | 1.5% |
| - Water | 98.0% |

(* Under difficult conditions 1% sodium pentachlorophenate may be necessary).

(ii) Sodium orthophenylphenate. As an alternative to sodium pentachlorophenate this water soluble compound is more pleasant to use and is less toxic to people. In general, somewhat higher concentrations are desirable.

(iii) Sodium salicylanilide. As the toxicity to people is very low for this odourless compound, it can be used for mould control in food stores or near foodstuffs where most other preservatives would be objectionable.

(iv) Copper-8-quinolinate. Water-soluble formulations of copper-8-quinolinate (Copper-8) have been tested at the New Zealand Forest Research Institute and have been shown to be suitable for application by spray or dip. Adequate control of moulds, stains and decay has been achieved with concentrations as low as 0.025% active ingredient. Copper-8 is not compatible with boron salts but may be used in conjunction with emulsifiable concentrates of the chlorinated hydrocarbon insecticides. It is somewhat corrosive to iron treatment vessels and solutions of this preservative tend to be unstable.

(h) Emulsions and suspensions

Most modern insecticides are organic compounds which will not dissolve in water but which are widely available as emulsifiable concentrates or as water dispersible powders. Purchased in these forms they can be readily diluted with water to form emulsions or suspensions. Many organic fungicides can be similarly prepared if required. Some current uses are:

(i) Termite soil poisons. Emulsifiable concentrates of aldrin, chlordane, dieldrin, heptachlor, etc. may be diluted with water and used as termite soil poisons. Some of these compounds are widely used in Australia for this purpose and if applied in accordance with the provisions of AS 2057 are effective for many years.

(ii) Timber stack sprays. The above insecticides, either as emulsifiable concentrates or as wettable powders, may be used for temporary insect protection of sticks of sawn timber. Spraying with lindane or dieldrin at a concentration of 0.5% (m/m calculated as pure active compound) would be a typical application. It should be noted that, with pinhole borers, this type of treatment may not prevent damage entirely in freshly sawn green timber as the beetles can drill holes for egg-laying so rapidly that some disfigurement may occur before the insecticide can take effect.

(iii) House frame timber spraying. The most persistent insecticides, both oil solutions and emul-sions, have been used apparently for the control of powderpost beetle attack in newly erected eucalypt hardwood house frames.

Applied as an overall spray coating, to the completed timber frame, such treatments may retard the rate at which these borers destroy susceptible sapwood but there is no evidence to indicate that the end result is any different from what happens in houses which are not sprayed - it just takes a little longer. Such treatments are not recommended by CSIRO.

## 5.6 Light Organic Solvent Preservatives

Light organic solvent preservatives (LOSP) are solutions of fungicides and insecticides either singly or in combination in non-swelling (non-aqueous) solvents. These solutions may also contain wax and resin additives intended to repel water or impede its absorption thus contributing to the dimensional stability of the treated wood. Originally, they were intended to give short-term protection to exterior joinery during the period between delivery to a building site and completion of the structure. In more recent times, there has been a tendency to expect longer-term protection from them.

### (a) Penetration

These preservatives were once mainly applied by spraying, brushing or short-term dipping but, more recently have been used in increasing amounts in vacuum/pressure systems. With most timbers the penetrations obtained from surface applications or short-term dipping is only superficial and, on the side grain, the protective envelope can be very thin indeed. End-grain penetration is usually deeper but varies greatly with the timber species and with the presence of sapwood. With relatively impermeable timbers, such as eucalypt heartwood, the end-grain penetration obtained from a 3 minute dip may amount to only a few millimetres while, with absorbent timbers or sapwood, it may exceed 250 mm. With the modern vacuum/pressure cycles sometimes used, the penetration is dependent upon both the treatment schedule and the permeability of the wood. In any case, and for best results, light organic solvent preservatives should be applied only to seasoned wood after all machining and fitting has been completed.

### (b) Application

As a general rule, superficial treatments do not give effective protection to timber used in ground contact or fully exposed to the weather. Their main use is for timbers in service above ground, where the hazard is moderate and intermittent and where they are given some additional protection by painting or are otherwise sheltered, as by a roof overhang. Typically, they are used to protect exterior joinery by inhibiting water absorption at the joints and by providing protective envelope against decay and insect attack. When timber so treated is cut or machined subsequent to treatment, the freshly exposed surfaces should be given a saturating application of the preservative solution to restore the protective envelope.

Light organic solvent preservatives are now being offered for many purposes for which they were not originally intended and some of these uses may involve high hazards, or even soil contact. Under such conditions of exposure, they cannot be expected to give as much protection as conventional pressure impregnation treatments with fixed preservatives or with creosote oil and other preservatives in a heavy, non-volatile oil.

### (c) LOSP Components

(i) Copper naphthenate. A solution of copper napthenate in mineral turpentine or white spirit, containing at least 2% metallic copper, has been used as a coating or dipping preservative for many years. It is durable, has a reasonable measure of water repellency and is quite effective against both decay and insects. It has also been used on wooden boats, inside for protection against decay and outside for protection against marine borers, prior to painting. After the solvent has evaporated, it has low toxicity to green plants and can, therefore, be used for the treatment of seed boxes.

Copper naphthenate has a persistent and rather unpleasant odour and is usually slow to dry, but if allowed to dry for long enough, can be painted over. It has a strong, persistent green colour.

(ii) Pentachlorophenol. Pentachlorophenol (PCP) is very toxic to fungi but it is not particulary effective against insects. When used in modern, general purpose preservative formulations, it is usually reinforced by the addition of a persistent insecticide such as aldrin, chlordane, dieldrin or heptachlor. It may also be fortified with tributyl tin oxide (TBTO) in some of the formulations used in vacuum and/or pressure treatment of joinery, etc. The formulations may also contain timber stabilizing and water repellent compounds. If treated timber is cut, the protective envelope should be restored by saturating the freshly exposed surfaces with preservative.

Pentachlorophenol is toxic to people and is liable to cause dermatitis. It has been banned in some countries. In spite of its disadvantages, it has been widely used and, no doubt, will continue to be used for some time but with considerbly more care and attention to sensible precautions.

(iii) Tributyl tin oxide. Tributyl tin oxide (TBTO) is the principal toxicant in many solvent-based preservatives and, particularly, in those used for the vacuum/pressure impregnation of exterior joinery.

Although TBTO has insecticidal properties, most proprietary formulations contain insecticides as well as resins and waxes. TBTO is particularly effective against brown rots and, when used in conjunction with other fungicides, such as pentachlorophenol, or quaternary ammonium compounds, can be a very effective preservative.

## 5.7 Glue Line Additives

Borer and termite attack on plywood can be controlled effectively by the addition of suitable insecticides to the glue. This simple treatment can be used with most glues but has special application to phenolic resins used for exterior and marine grade plywoods. With these grades of plywood neither boron compounds nor sodium fluoride, both of which are readily leachable, can be recommended for a product that is sold as waterproof. Insecticides which are not readily leached and which give good control of borers and termites when incorporated into the glue are, therefore, attractive. The recommended glue-line additives are amply described and provided for in AS 1604.

So far, the addition of preservatives to the glue line has not been accepted by Australian research workers as a suitable process for increasing the decay resistance of plywood.

## 6.0 EXTENDING THE SERVICE LIFE OF TIMBER (TIMBER PRESERVATION)

### INTRODUCTION

Having chosen a preservative suitable to the anticipated hazard and service condition, the quantity or retention of the preservative and its distribution or penetration into the wood can be greatly affected by the treatment process. The choice of process will depend upon many factors, including the condition of the wood at the time of treatment (e.g. its moisture content); the timber species (some species are more permeable than others); whether the sections to be treated are natural rounds, or sawn (sapwood is always more permeble than heartwood of the same species); the hazard and degree of exposure to which the treated timber will be subjected in service (e.g. the hazard to building timber protected from the weather is generally lower than that to which exterior joinery is exposed and timber used in ground contact is at higher risk than timber used under groud, etc.).

A wide range of treatment processes is available to the modern practitioner of wood preservation. These range from simple surface applications and diffusion treatments requiring little capital expenditure to sophisticated commercial operations using high autoclaves (or cylinders) with automatic control of treatment variables such as vacuum and pressure, time and temperature, coupled to capacious storage tanks and backed up by modern laboratory facilities for quality assurance. In commercial ventures the scale of the operation will be related to the capitalisation of the treatment plant.

The Australian Standard AS 1604 attempts to equate preservative penetration and retentions to the natural durability of the heartwood of the treated wood and the severity of the hazard to which it is likely to be exposed in service. It also lists the major commercial preservatives available in Australia. It does not place any restriction on treatment process but indicates results to be attained.

### 6.1 Pressure Treatment

When pressure is applied to the liquid in which permeable timber is immersed, the rate and depth of penetration are increased. This is the basis of all pressure treatment. Vacuum pressure is a term used to cover most forms of such commercial treatments as these employ a vacuum in the treatment cycles.

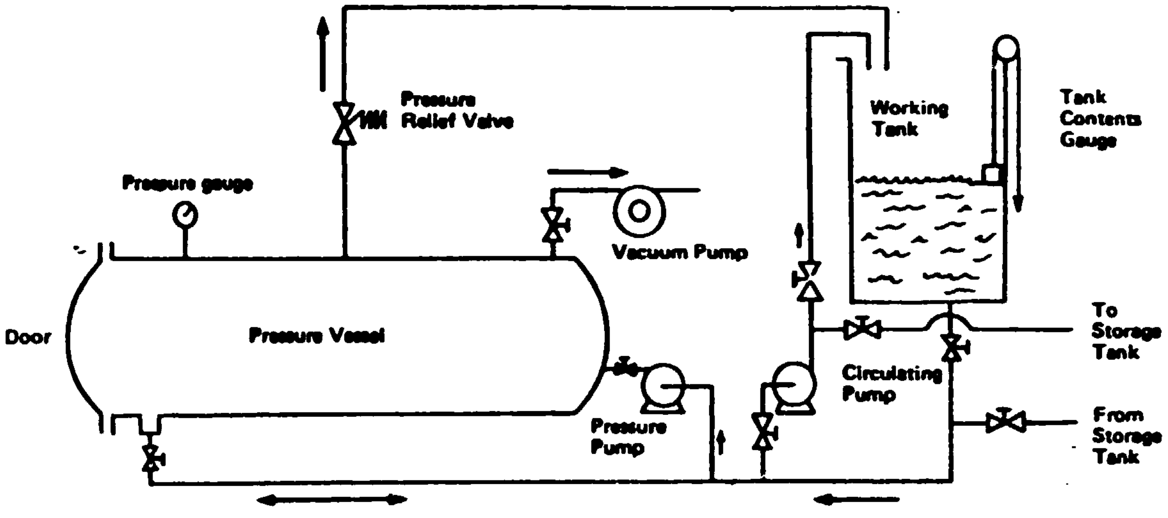


Figure 6.1 Basic pressure treatment plant design

The first requirement for the process is a steel pressure vessel or autoclave, with a pressure-tight door. The door can be held by bolts, but quick locking doors with hydraulic seals have obvious advantages.

The basic plant, represented diagrammatically above, requires a working tank with a contents gauge; a pressure pump for applying pressure to the liquid in the pressure cylinder; and a vacuum pump to fill it and to remove surplus preservative from the surface of the timber and the necessary ancilliary piping and valves. In addition, a circulating pump may be provided for pumping preservative between cylinder and tank or for mixing by re-circulation.

The pressure cyclinder must be protected by safety valves. A pressure or pressure/vacuum gauge is essential. Plants using heat have a pressure/ temperature recorder on the cylinder and a thermometer on the working tank. A storage tank for reserve supplies is necessary in a plant using oil and a mixing tank with mechanical stirrer or other means of agitation for a plant using waterborne salts. Pressure vessels are usually required to withstand vacuum and hydraulic pressure of 140 kPa (gauge) for low pressure treatment and up to 7000 kPa (gauge) for high pressure.

To facilitate manipulation, some types of preservative require heating to reduce viscosity before they are pumped into the pressure cylinder. This is accomplished usually by heating with steam coils or by employing a heat exchanger, although in small plants electrical heaters can be used. When heat is applied, both the cylinder and the tank must be adequately insulated.

Cylinder sizes vary from 1.8 metres long x 1 meter diameter (for the treatment of fence posts) to more than 25 metres long (for poles). Some cylinders are made large enough to accept packs of sawn timber already stripped for drying to avoid the extra handling costs, but such large cylinders require much more liquid to fill them and, in some instances, it is cheaper to treat more charges in a smaller cylinder, in spite of the extra handling costs.

Timber is loaded on steel bogies which run into the cylinder on rails over a movable bridge which is removed to operate the door. These rails can connect with tracks to other parts of the plant. Light timbers must be restrained and the bogies held down to prevent them floating off the rails when the cylinder is flooded.

## 6.2 Types of Pressure Treatment

Different sequences of cycles of vacuum, air pressure and liquid pressure are used to obtain treatment retentions with various timbers and preservatives. The different types of treatment and their purpose are as follows:

(a) <u>Full-cell treatment</u> (Bethell process)
As its name implies, this treatment leaves the cells in permeable timber full of liquid. Vacuum is first applied to the cylinder to remove as much air as possible from the timber (see Fig. 2). The same vacuum is maintained while the cylinder is filled with preservative solution and

pressure is then applied until refusal* is reached. The pressure is related and the cylinder emptied after which a short final vacuum is applied to recover 'drip' or waste that would otherwise occur; finally the vacuum is released.

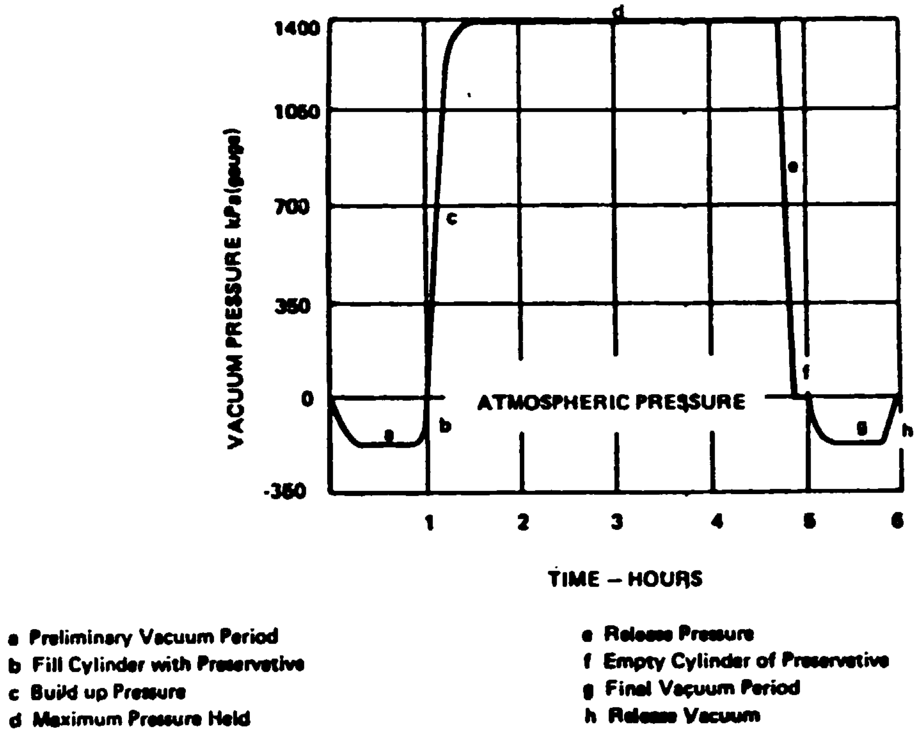


Figure 6.2 Full-cell treatment (Bethell)

Commonly, two or three hours of treatment (and this includes initial and final vacuum of 30 minutes each) are required for a permeable timber such as Pinus radiata sapwood. Much longer vacuum and pressure periods may be needed with semi-permeable timbers (such as the heartwood of Western hemlock, Tsuga heterophylla) to obtain sufficient retention and penetration of the preservative. Total treatment times of 12 hours or even longer are costly, but may be inexpensive when compared with the cost of premature failure in service of imperfectly treated material.

Full-cell treatment is also used for the treatment of semi-permeable or refractory heartwood with preservative oils. Hardwood rail sleepers are usually treated in this way to obtain maximum retentions.

---

* Refusal may be defined as the stage in the treatment when the quantity of preservative absorbed in any two consecutive 15 minute periods will not exceed 1% of the amount already absorbed.

(b) Empty-cell treatments

These treatments depend on the expansion of air trapped in the timber during treatment to expel excess preservative from the cells after pressure has been released. Their use is essential when maximum penetration without excessive retention of preservative oils is required in more permeable timbers.

(i) The Lowry process (Fig.3) is the simplest and most commonly used form of empty-cell treatment. In it the preservative is admitted to the cylinder without drawing an initial vacuum and atmospheric air is released from the top of the cylinder as it fills with liquid. When pressure is applied the air in the timber is compressed as the liquid is forced into the timber. After the desired gross absorption of liquid has been achieved, preferably at refusal, the pressure is released and a short final vacuum is applied during which time a proportion of the liquid, known as the kick-back, is forced out by expansion of the air compressed in the cell cavities.

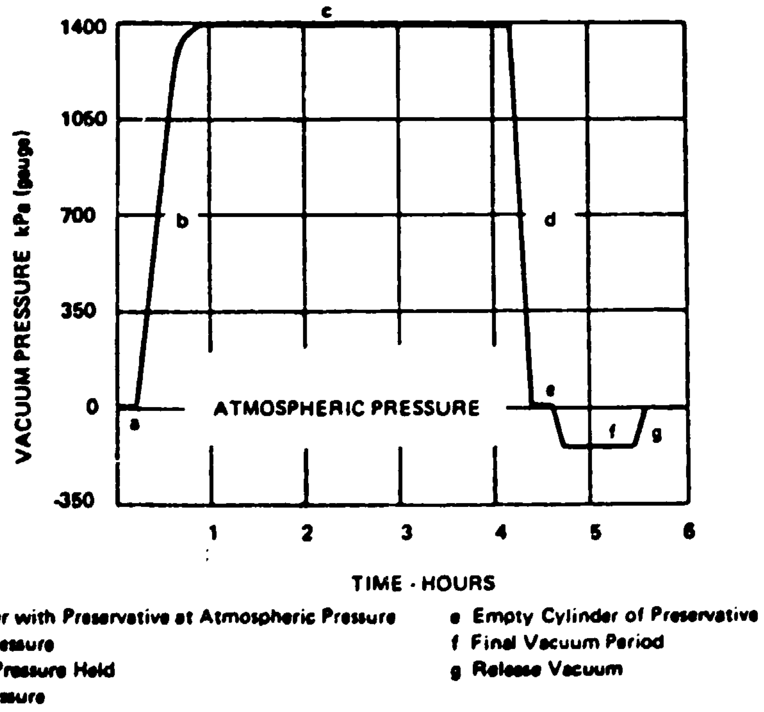


Figure 6.3 Lowry 'Empty Cell' treatment

(ii) In the Rueping process (Fig. 4), the charge is sealed in the cylinder which is then filled with compressed air to a predetermined pressure. Preservative is then pumped in against this pressure which is prevented from rising by bleeding air from the top of the cylinder as the cylinder fills. When the cylinder is full hydraulic pressure is applied followed by a final vacuum. Kick-back is greater with this process than with the Lowry cycle and it is mainly used for every permeable lightweight timbers. In Australia it has been used for treating radiata pine with creosote for poles, posts and rail sleepers where control of final retention is essential for economy and to prevent bleeding.

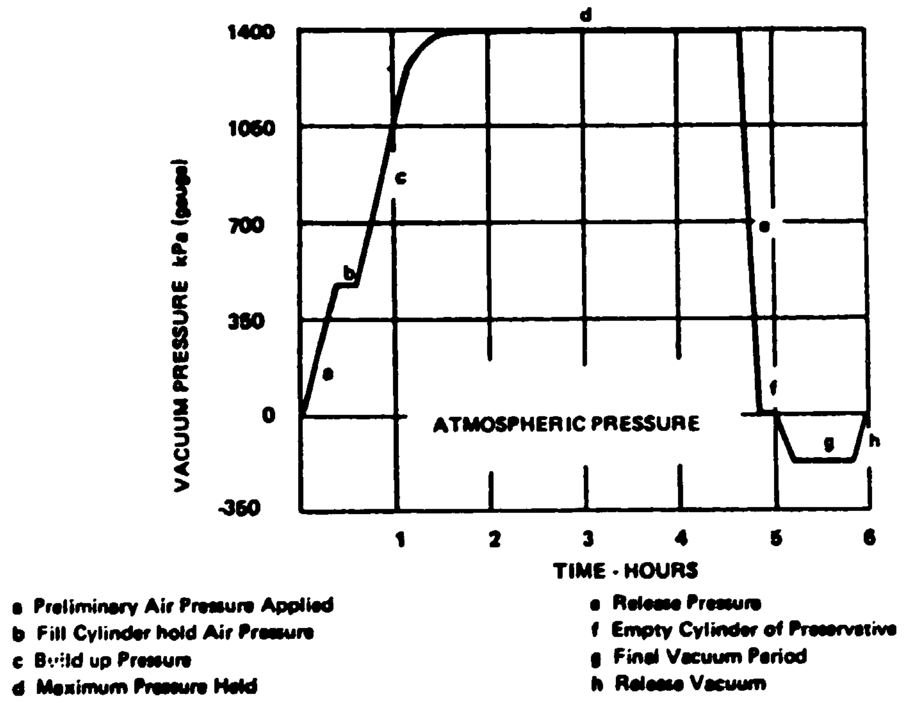


Figure 6.4 Rueping 'Empty Cell' treatment

(c) Oscillating pressure process

The oscillating pressure method (Fig. 5) is a variation of the full-cell process for the treatment of softwoods of high moisture content with waterborne preservatives. By the use of rapidly alternating cycles of vacuum and hydraulic pressure it replaces some of the free water ('sap') in the timber with preservative solution. An automatic controller is used to apply vacuum pressure cycles to the pressure cylinder.

Research in New Zealand has shown that Pinus radiata can be successfully treated by this method provided that it is partly air dried first and that the repeated application and release of pressure is sufficient without the use of vacuum. the process in use in New Zealand uses boron compounds as the preservative. With CCA preservatives the process requires careful control of solution strength and chemical balance as these may alter during treatment.

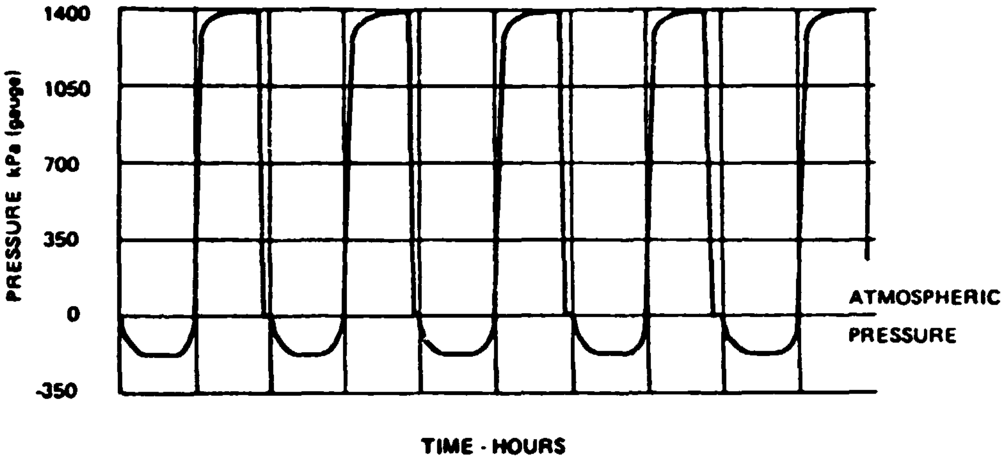


Figure 6.5 Oscillating-pressure treatment

(d) Double vacuum

This process depends primarily on creating a vacuum inside the timber and then using this to draw preservative fluid into the timber; the impregnation period is usually at atmospheric pressure, although in some variations it may still be under vacuum. With semi-permeable timbers, or to obtain high preservative loading, a positive pressure may also be used when it is necessary.

A final vacuum serves to remove excess preservative from within the wood, Complete penetration of permeable sapwood is achieved, but retentions are controlled at a low level since the double vacuum technique is used with organic solvent preservatives for treatment of window frames and other building timbers which are to be painted.

(e) Liquified gas process

This process utilises a gas such as Butane which can be liquified by cooling or by compression and used as a solvent for organic preservatives. The treatment is a pressure process which has the advantage that nearly all excess solvent evaporates from the wood at the conclusion of the treatment cycle, and renders the wood ready for immediate use.

The wood is placed in a treatment cylinder and an initial vacuum applied. The cylinder is then purged with an inert gas until safe conmitions have been achieved and a second vacuum is applied. The preservative solution is then run into the cylinder and the pressure is increased by applying heat. At the conclusion of the pressure phase, excess liquid is returned to storage and the pressure in the treatment cylinder slowly reduced down to vacuum conditions. A second inert gas purge is then applied and when safe conditions have been achieved the wood may be removed from the cylinder.

The process possesses the advantage that penetration into some semi-permeable species can be achieved and the wood is immediately ready for finishing due to the absence of solvent.

## 6.3 Non-Pressure Treatment

Although pressure treatment is generally regarded as the basis of commercial preservation, the method described below are important for particular purposes and in some instances are the only means of treating a particular type of timber or of treating timber _in situ_.

### 6.3.1 _Surface treatments_

### (a) _Surface coatings_

(i) _Brushing_. Brushing is the simplest and most readily available method of applying a wood preservative, and is particularly useful to the general public and for on-site treatments in building, particularly where working of pre-treated timber exposes a fresh surface. It is mostly associated with organic solvent type wood preservatives or with lower viscosity grade of creosote.

Preservatives should be brushed on to clean and dry timber in flood coats, with the second and any subsequent coats being applied after the previous coat has soaked in but before it has dried. The preservative should not be brushed out to cover a large area, but sufficient flood application must be given to achieve the application rate recommended for the preservative being used; this usually necessitates two or three applications.

The preservative should be applied at the appropriate rate to all sides of the wood and must be flooded on to the end grain. When treating made-up components (e.g. furniture), the preservative should be flooded into joints. When used for woodworm eradication, it is beneficial to flood into old flight holes.

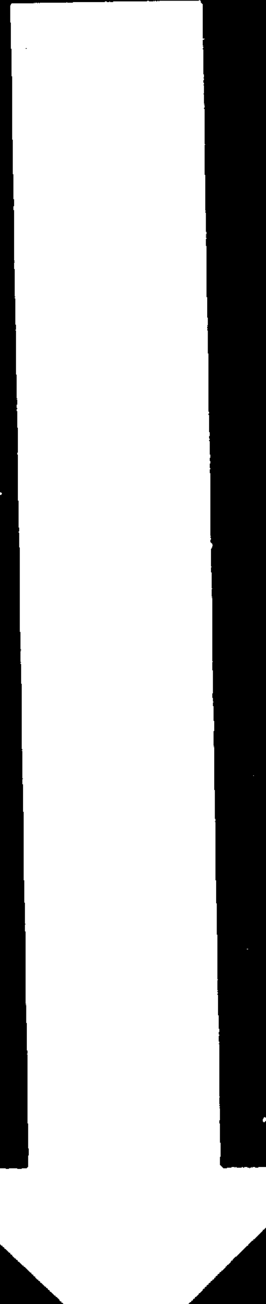
The life of superstructures, such as fencing and huts and sheds, will be extended by several years by brush application of a suitable preservative and may be prolonged almost indefinitely by applications of wood preservative at intervals of three or four years. Care must be taken to ensure the preservative enters all joints where water might lodge.

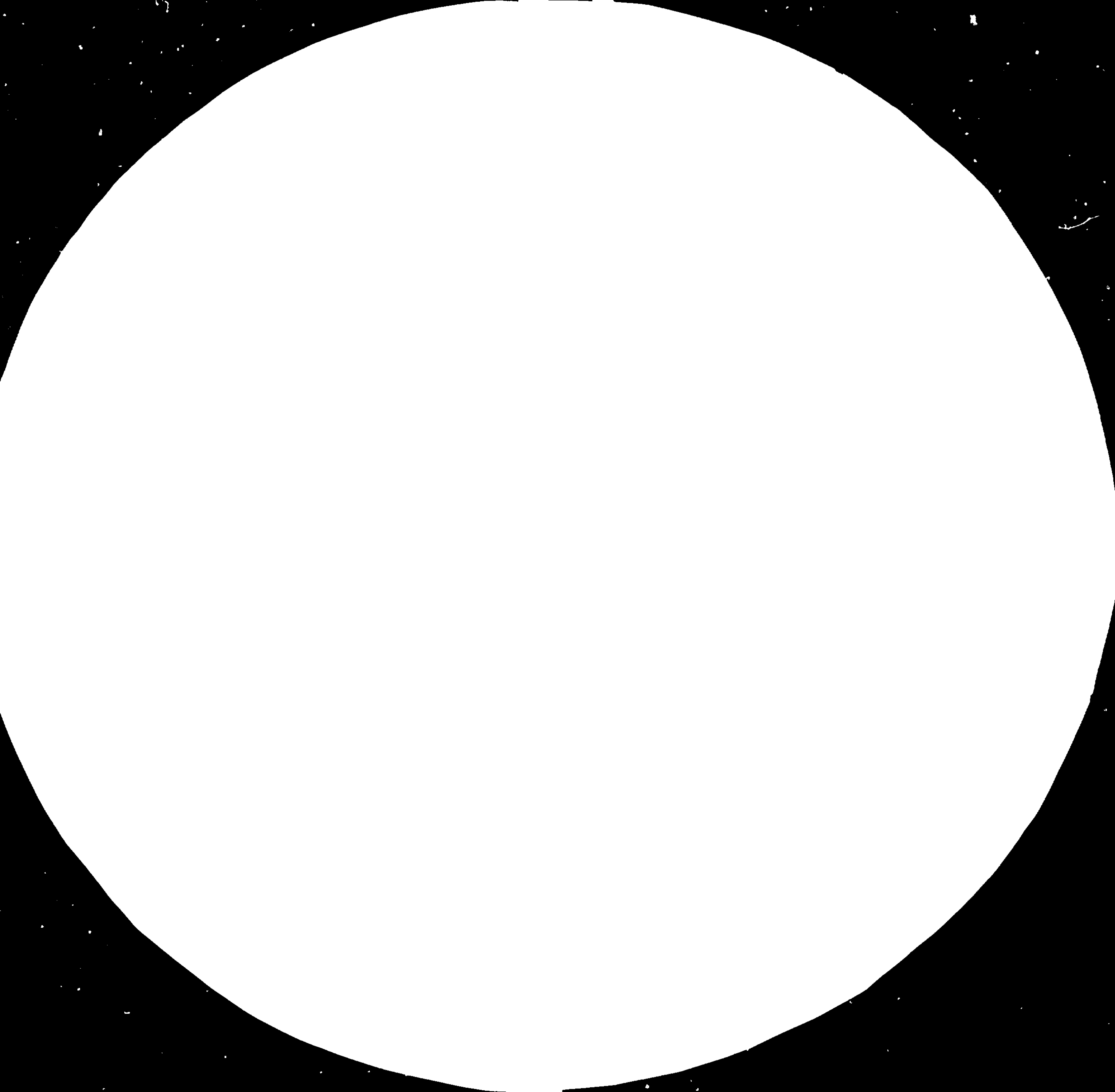
(ii) Spraying. Spray application of wood preservatives is generally comparable in its results to brush application, and can be carried out as an alternative to brush treatment under appropriate circumstances. Spray treatment is the most common and widely-used method of application of wood preservatives in the in situ erdication of woodworm.

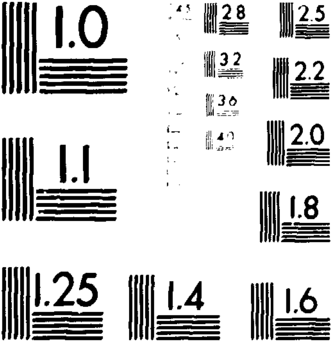
The preservative should be flooded on to the surface until a slight run-off occurs. If the resultant absorption is less than that recommended for the preservative being used, further applications should be made after the initial treatment has soaked in but before it has dried.

For pre-treatment, the preservative should be applied to all sides of the timber, and for in situ eradication to all accessible sides. Particular regard should be paid to end grain and joints which should be thoroughly flooded.

(iii) Deluging. In deluging, the timber is passed through an enclosed tunnel in which preservative is applied to it from various types of jet; in different makes of deluge tunnels these vary from spray







MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

jets similar to those used in normal spray application to a number of small jets or a single jet from a large diameter pipe.

Deluging is mostly used for application or organic solvent preservatives, but tar oils, creosote and certain types of waterborne preservatives may also be applied by this method.

Deluge treatments can be used for the pre-treatment of timber in situations where a brush or spray treatment could also be considered, but they offer greater through-put and more uniform application for industrial use.

### (b) Bandage applications

Bandage treatments are useful in prolonging the life of pole which are partly decayed. A porous medium or an emulsion containing a diffusable preservative is applied to the surface of the pole at the groundline. Diffusion of the preservative outwards into the soil at, and below, the groundline is prevented by a waterproof membrane.

CSIRO has developed a bandage system in which polyurethane foam has been pre-impregnated with diffusable fungitoxic chemicals contained within an outer protective sheath of polyethylene. The bandage is applied to the pole at groundline and is heat-shrunk into place to ensure a close fit.

### (c) The oxy-char process

This process is an effective maintenance treatment used on standing desapped durable poles showing partial decay. Checks and decay pockets at groundline are scraped free of soil and scoured with a very hot flame which burns all the decayed wood and sterilizes that adjacent to it. The surface of the pole is then charred and while still hot is sprayed with creosote. The disadvantage of the treatment is the small loss of cross-section that occurs each time it is repeated, usually every 3 to 6 years.

### 6.3.2 Cold soaking

The effectiveness of this treatment is related to the time for which the timber is immersed. With many of the preservatives prepared for these treatments, recommended immersion times range from three minutes (dip treatment) for many building timbers to several hours for fence posts in ground contact or other hazardous situations.

The clean and dry timbers are totally immersed in a tank of preservative fluid. Immersion treatment is used for all types of wood preservatives but it is most usual with organic solvent preservatives or low viscosity creosote. The treatment is normally carried out in ambient temperatures.

An exception to total immersion is the butt treatment of fence and other posts where an effective economical treatment can be given by soaking the butt-end only, to about 300 mm above ground level, in preservative for several hours and treating the remainder by a much shorter immersion or by brush or spray.

### 6.3.3 The hot and cold bath process

This process involves heating the dry timber in steam, hot water or liquid preservative to drive out most of the air, followed by cooling in preservative, when atmospheric pressure assists capillary forces in moving the liquid to replace the air driven out. Heating is best done close to boiling point (100°C) or higher if oil or steam are used. Heating time is approximately proportional to thickness. As a general rule one hour at the maximum temperature is required for each 25 mm of thickness, but where poles or round timbers require treatment of a narrow sapwood only, this time may be reduced. Where time is not critical, e.g. in an overnight treatment, it may be expedient to reheat the preservative next day to drive off surplus liquid and improve surface cleanliness: this is known as an expansion bath.

Hot and cold bath treatment can be done very simply in a drum over an open fire but for effective control and safety the preservative is usually heated by steam coils or low-temperature electric elements in an insulated tank. Poles and posts can be treated full length in the horizontal position or butt treated in the vertical position, to save heat and preservative where protection of the sapwood above ground is not essential. In either case, adequate lifting gear is needed. Hot and cold bath treatment is not used with the 'fixed' CCA preservatives, as solutions are not stable at high temperatures. It is a very satisfactory method of treatment if using creosote and other oily preservatives, or solutions of single waterborne salts.

### 6.3.4 Sapwood replacement methods

This term covers a variety of similar treatments of green round timber in which some of the free water or sap is removed from the sapwood and replaced by a waterborne preservative solution. One method, the Boucherie process, in which solution under pressure is applied to one end of the freshly cut log or pole, has been in use in Europe for over 100 years. Modern variations of this include the application of vacuum to one end of the log or even immersing the log in liquid under pressure at the same time.

A simple form of sap-replacement can be used to treat round hardwood fence posts and small poles. Freshly cut green posts are barked and their butts immersed in a 3.5% concentration of copper-chrome-arsenic solution. As the sap evaporates from the exposed surfaces, solution is drawn up to replace it. Before all the solution is used, the posts are inverted to treat the top ends. In good drying weather, posts can be treated in about one week. Although the distribution of preservative in the sapwood is not uniform the treatment has proved both cheap and effective. In remote areas where impregnation facilities are lacking, for those wanting a few posts for their own use, this process is very cheap and simple.

The sap replacement process is recommended for treating sound, green hardwood posts with waterborne preservatives. The hot and cold bath method is used to treat dry timber with oils and oily preservatives, e.g. creosote. CSIRO however, experimentally treated some Victorian green pine posts using a variation of this process. Freshly cut posts were substantially, but not completely, immersed (vertically or inclined) in hot creosote for about six hours at 90 to 100°C and were then allowed to cool to 50°C (usually overnight). A very thorough treatment of the softwood posts resulted.

### 6.3.5 Diffusion processes

These processes are based on the fact that chemicals in solution will move from zones of high concentration into zones of low concentration through a permeable material such as wood. This principle operates when treating green timber with chemical preservatives in aqueous solution. The molecules or ions of the dissolved preservative move from the zone of high concentration in the solution to the zone of lower concentration in the wood.

The rate of movement of chemicals into wet wood is governed by factors such as the density of the timber, solution concentration and temperature. It has been established that:

(i) Concentration of preservative at a given depth in the timber after a given time, is proportional to the solution concentration.

(ii) Depth of penetration of a required concentration is directly proportional to the square root of the time of immersion for any solution concentration.

(iii) The rate of diffusion is approximately doubled for each 20°C rise in temperature.

These relationships are used to determine approximate treatment schedules with different forms of diffusion treatment, but because of variation between and within species they must be checked by frequent chemical analyses.

(a) Simple diffusion

Simple diffusion involves water-soluble single salts dissolved in water. Green timber is immersed in the solution for hours or days, depending on species, size, concentration and temperature of the solution, to allow sufficient salt to move into the timber. This process is principally used for immunisation of sapwood. The preservative in the wood is not 'fixed', and will leach out.

(b) Dip-diffusion

Dip-diffusion was developed by CSIRO. After sawing, the green timber is immersed in a strong solution of a multi-salt diffusion preservative, e.g. a combination of boron, fluorine, chromium and arsenic compounds (BFCA) which is a patented preservative. After momentary immersion, the timber is then close-piled under cover to restrict drying for several weeks while the preservative diffuses into the wood. The process is widely used in Papua New Guinea for the treatment of building timber of mixed species.

Timber treated by the above two processes is unsuitable for use under wet conditions such as ground contact or for external use unless protected by paint, as the preservative salts remain water-soluble.

(c) Double diffusion

The purpose of the double-diffusion method is to form a preservative salt which is resistant to leaching within the wood, by reaction between suitable chemicals. This can be accomplished, for example, by first soaking green posts in a solution of copper sulphate long enough for sufficient chemical to diffuse into the wood, and then by immersing them in a second solution containing sodium chromate with or without sodium arsenate. As the second solution diffuses into the wood a precipitate is formed, which is toxic to fungi and very resistant to leaching. The solution concentrations must be carefully checked before each treatment to ensure satisfactory fixation of the chemicals. Full-length treatment by this procedure has given excellent results with fence posts, and the method is also used for treatment (in place) of the wood in water cooling towers, usually by spraying the first solution on the wood and, after a suitable interval, spraying on the second solution.

## 6.4 Factor Affecting Preservative Treatment

### 6.4.1 Inherent factors

(a) Timber species

While some treatment plants deal with only one species, such as *Pinus radiata*, most must treat a variety of timbers. Plants treating sawn timber will have very mixed results if impermeable timber is included in lots of treatment. Proper identification and segregation of species is essential if consistently satisfactory treatments are to be obtained.

Problems can occur at commercial pressure plants which treat eucalypt poles if the species are not properly identified by the pole cutter. Many species are difficult to tell apart after they have been barked, so there is always a risk of including refractory species in a charge of mixed species.

### (b) Density

Density is a major factor in determining the depth of penetration and amount of liquid preservative that any timber will absorb. In general, lighter timbers can be penetrated more readily and will absorb more liquid than denser ones, but for anatomical and structural reasons there are many exceptions to this rule, for example, Douglas fir, Baltic spruce and balsa. Pit aspiration and blockage of vessels in heartwood by tyloses are typical anatomical factors which can affect penetration.

The user or timber treater must be aware of the maximum preservative retention that can be obtained in a timber of any given density. Knowing that he can decide what type of treatment and what concentration of solution to use.

## 6.4.2 Factors which can be controlled or modified

### (a) Moisture content

The most important factor, after inherent treatability, which affects preservative penetration and retention is moisture content. Many techniques, mainly non-pressure processes, are being developed to treat timber with waterborne and oil preservatives, at moisture contents above fibre saturation (25 to 30 per cent). General practice in Australia is to dry all treatable timber to a point below this figure for pressure treatment. Retention and penetration are further improved in the sapwood of eycalypt poles if these are fully dried to equilibrium moisture content (12 to 15 per cent in southern Australia) before treatment.

Timber can be dried in the treatment cylinder by boultonizing (boiling under vacuum in creosote or preservative oil before applying a pressure treatment process). The technique is well established in Australia as a commercial treatment for hardwood railway sleepers.

### (b) Pre-fabrication

As a general rule it is desirable that all machining be done on timber before treatment. This is particularly important with refractory timbers, in whch end-grain penetration is usually all that is obtained. In fact, most pre-fabrication or machining is done before treatment because it is more convenient. For example, rail sleepers are adzed and bored, poles are machined for cross arms and caps, bolt holes are drilled, cross arms are bored for bolts and insulation pines, and timber for log cabins and cooling tower components are fully machined.

(i) Incising is a form of pre-fabrication specifically designed to improve penetration particularly into refractory heartwood through side-grain surfaces. Machines for this purpose make a regular pattern of incisions with sharp knives at intervals of about 50 mm along the grain and 25 mm across, usually to a depth of 18 mm. Incising is used overseas on rail sleepers and poles of refractory timbers such as Douglas fir, and, in Australia, for the impregnation of eucalypt rail sleepers with creosote or oily preservatives. Incising may also give more uniform drying when done on green material so reducing the risk of splitting.

(ii) Bark must be removed as it will retard drying and, in softwoods, it will prevent radial penetration. Any bark is a nuisance in a treatment plant where it can come loose and obstruct valves or strainers.

## 6.5 Preservative Penetration and Retention

No matter how good the preservative, a treatment will not be effective unless the retention or amount of preservative present in the treated wood is sufficient to repel or destroy the invading organisms and the penetration or distribution of preservative in the treated wood is such that no improperly treated wood is accessible to invading organisms.

Usually, shallow penetrations will be indicative of low retentions and deep penetration will result in high retentions. However, when retentions are expressed in terms of volumes of treated wood - as opposed to total volume of wood treated - preservative retention need not be related to depth of penetration.

Current Australian Standards and specifications tend to require treated timbers to satisfy penetration requirements before being tested for compliance with retention requirements. Fortunately, with most preservatives, penetration is more readily determined than is retention.

### 6.5.1 Penetration

Penetration is usually checked by boring treated wood at the conclusion of the treatment.

With poles and other round timber an increment borer (hollow-core borer) is commonly used to extract a radial plug from the side of the pole or post - usually at about mid-length. Such a plug or core can be split, penetration can be accurately measured and, if necessary, retained for reference.

With waterborne preservatives, colour of the treated wood may be indicative of preservative penetration but most commercial operators rely upon specific chemical indicators. For example, tumeric is used todetect boron compounds, while chrome-asural S and rubeanic acid are indicators for CCA-type preservatives.

With creosote and other oily preservatives, chilling the plug before splitting will retard the 'bleeding' (creeping or smearing) of the oil and so allow more time for an accurate measurement.

### 6.5.2 Preservative retention

According to the type of commodity being treated, preservative retentions will be based on average or charge* retentions or on the retention of preservative in individual pieces. Furthermore, a distinction must be made between retentions expressed in terms of total volume and those referring only to treated wood volume.

For example, with fence posts of P. radiata, which has a wide, permeable sapwood, practically the whole of the post will be treatable and there will be little difference between 'treated volume' and 'total volume'. With eucalypt hardwood posts, only a narrow, outer annulus of sapwood will be treatable and the treated volume is likely to be much less than one-third of the total volume.

---

* One charge is a single load of timber in a pressure cylinder.

Waterborne preservative salts retentions are expressed as either

1. the amount of active ingredient as a percentage of the oven-dry weight of the wood, or

2. net dry salt retention (NDSR) which is measured in kilograms of dry salt per cubic metre (kg/m³).

With these preservatives, the solution concentration can be varied to control uptake - a small volume of concentrated solution delivers as much chemical as a larger volume of a dilute solution.

The retention of creosote and oil-borne preservatives is generally expressed as total preservative uptake (e.g. kg/m³ of 5% solution of preservative in oil).

Retentions determined from charge volumes apply to the charge as a whole. Where the variation or scatter of retentions between pieces in a charge is required, individual retentions can be found by weigh in the pieces before and after treatement. Analysis of samples such as borings taken from individual pieces, by chemical or other means can be used but because of variations in loading which can occur within the piece itself, this method does not necessarily give the same result. However, it is usually all that is practicable.

In the case of round timbers with a relatively narrow band of treatable sapwood, such as the eucalypts, the volume of treatable timber in a charge must be estimated, before treatment, from measurements of mean girth and mean sapwood thickness for each pole. This in turn depends on a clear definition of the sapwood-heartwood boundary which often requires the use of a chemical indicator. Di-methyl-yellow in alcohol and water is effective with many eucalypts.

Accurate determination of the average charge retention requires:

1. Measurement of volume of liquid preservative used from the difference between initial and final tank gauge readings with proper allowance for drip, leads, evaporation and corrections for changes in volume due to changes in temperature.

2. Determination of the volume of timber treated. With round timbers this may be calculated from the girth, length and sapwood thickness of the individual rounds - but penetration should be checked against sapwood thickness for a representative sample.

3. That the concentration of salt in aqueous preservatives be checked by chemical analyses or by measurement of specific gravity. Waterborne preservatives can vary in concentration as a result of imperfect mixing, precipitation, or selective absorption by the timber of individual components from a mixture.

The determination of preservative retention is unreliable with those treatment processes in which green wood is used and where the timber can lose water during treatment. This applies to certain types of diffusion treatment and to processes where green (unseasoned) timber is strongly heated.

## 6.6 After Treatment

Removal of timber from the treatment plant does not necessarily complete the treatment process.

Oil treatments may require a period of air drying to make the timber clean enough to handle. Heavy petroleum oils and coal tar rarely dry out completely and are therefore reserved for purposes where resistance to weathering or leaching is more important than a clean surface such as rail sleepers and marine piling. Creosote and the lighter oils require different drying times depending on the timber, retention and weather conditions.

With appropriate protective clothing, timber impregnated with waterborne preservative may be handled soon after treatment. However, as it is to be used for mouldings or for any other purpose where properly dried timber is essential. Surface drying is not enough and the cost of complete re-drying must be allowed for.

In spite of their poisonous nature, preservative oils and waterborne preservatives are generally safe to handle if normal precautions are observed.

Most preservative oils have irritant properties with distinctive odours which combine to ensure that they are handled carefully. Copper-chrome-arsenic preservatives, once impregnated into the timber, are insoluble, which minimises hazard to health.

Skin irritations can occur when plant operators handle either type of preservative, but they are more likely if handlers are careless about washing or wearing gloves and aprons.

The disposal of waste from treatment plants requires some care. Creosote and preservative oils will contaminate streams so that plant effluent should have some form of trap to retain as much as possible. CCA waterborne preservatives are toxic in solution and should <u>never</u> be released into streams. Discharges are subject to strict EPA controls.

Small quantities of waste timber treated with CCA preservatives may be burnt in an open space, but should <u>never</u> be used for cooking, or in a barbecue. The remaining ash will contain some soluble arsenic and should be buried in a safe place away from streams and ground water. It has been found to kill garden plants.

## 6.7 Quality Control of Treated Timber

At the present time no single authority is responsible for specifying the maintaining standards of preservative treatment in Australia.

The Forest Departments of Queensland and New South Wales control preservative treatment by State legislation. In Victoria the Forests Commission has been given similar authority, but does not exercise it. The Standards Association of Australia has produced standard specifications covering items such as preservative treated transmission poles and building timbers. Various electricity supply authorities and Telecom Australia have their own specifications for treated poles and cross arms, and maintain their own inspection services at treatment plants. The Timber Preservers' Association of Australia is concerned with maintaining high standards of treatment within the industry.

Defective treatments of timber may be caused by one, or a combination of, the following factors - insufficient drying; poor plant control;

poor quality and incorrect concentration of preservatives; insufficient treatment time, pressure or temperature; treating mixed charges; incorrect processes, etc. When faulty treatment is detected its cause should be traced and eliminated with the help of preservative suppliers, State Forest Departments and other authorities.

Major items such as transmission poles are usually labelled with information such as the timber species, treater's name and date of treatment. Sawn timber and plywood can only be identified as treated by branding or colour coding each piece. Despite some objections to extra cost and complications in production, branding must eventually be accepted. Without it there is considerable risk that untreated timber may be sold as treated or timber treated for a low exposure rating may be sold or used for situations where much more severe hazards exist. In New Zealand this risk has been recognized and all treated timber is required to be branded and colourless preservatives identified by a dye. Branding of immunized timber is required by law in Queensland and New South Wales.

## 6.8 Plywood, Particleboard and Hardboard Preservation

While the same processes can be used to treat plywood as are used to treat solid timber, there are some important differences.

Unless plywood is specifically made wholly of sapwood or permeable heartwood veneers, it cannot be effectively pressure-treated in made-up form if complete penetration is required. Also re-drying of plywood pressure-treated with waterborne preservatives becomes increasingly difficult as the thickness increases.

In spite of this, large amounts of waterproof plywood, pre-cut to finished size, are treated with high loadings of CCA salts for use in cooling towers, where it is proving very satisfactory and re-drying is not needed. The simplest way to preserve plywood is by pre-treatment of the veneers. This can be done by dip-diffusion of green veneers and pressure treatment of dry veneers.

A large proportion of Australian plywood production is alredy immunized against lyctid attack, usually by momentary dip-diffusion treatment of veneers, but some is immunized by adding insecticide to the glue line.

The latter method is very effective against termites and offers some possibilities for protection against decay when thin veneers are used.

Reconstituted boards can be treated by adding preservatives or insecticides during manufacture or in special cases by soaking the finished board in preservative oils. Treatment is rarely specified but some hardboards are treated to prevent termite attack.

## BIBLIOGRAPHY

In addition to the literature specifically mentioned in the body of this part, the following references may prove useful:

Hadlington and Cooney (1974). A Guide to Pest Control in Australia. NSW University Press, Sydney.

Hickin, N.E. (1971). Termites - A World Problem. Rentokil Library, Hutchinson, London.

Hunt and Garratt (1953). Wood Preservation. McGraw-Hill, New York.

Nicholas, D.D. (1973). Wood Deterioration and its Prevention by Preservative Treatments. Syracuse University Press, New York.

Ratcliffe, Gay and Greaves (1952). Australian Termites. CSIRO, Melbourne.

Richardson, B.A. (1978). Wood Preservation. The Construction Press, Lancaster, UK.

US Department of Agriculture (19755). Wood Handbook - Agriculture Handbook No. 72. US Govt Printing Office, Washington DC.

Walters, N.E. (1973). Australian House Fungi. Forest Products Tech. Note No.13, CSIRO Division of Building Research, Melbourne.

Wilkinson, J.G. (1979). Industrial Timber Preservation. Associated Business Press, London.

AUSTRALIAN STANDARD SPECIFICATIONS concerned with wood preservation include:

AS K55-1964: Creosote oil for the preservation of timber.

AS 1143-1973: High temperature creosote oil for the preservation of timber.

AS 1144-1973: Arsenical creosote for the preservation of timber.

AS 1604-1974: Preservative-treated sawn timber, veneer and plywood.

AS 1605-1974: Sampling and analysis of wood preservatives and preservatives-treated wood.

AS 1606- and 1607-1974: Water-repellent treatment of timber and joinery.

AS 1608-1974: Preservative-treated farm fencing timber.

AS 1694-1974: Physical barriers used in the protection of buildings against subterranean termites.

AS 2057-1977: Soil treatment for the protection of buildings against subterranean termites.

AS 2178-1978: The treatment of subterranean termite infestation in existing buildings.

AS 2209-1979: Timber poles for overhead lines.

CSIRO DIVISION OF BUILDING RESEARCH: Information sheets, various.

# FIRE RESISTANCE OF TIMBER

Robert H. Leicester[1]

---

[1] Officer of CSIRO, Division of Building Research, Melbourne, Australia.

# FIRE RESISTANCE OF TIMBER

## PART 1 – PERFORMANCE OF TIMBER STRUCTURES IN A FIRE

### 1. INTRODUCTION

Because fire resistance is frequently and misleadingly associated with non-combustibility, the excellent potential of timber as a fire resistant structural material is seldom appreciated.

All building materials under suitable conditions are combustible. The significant aspect is the degree to which these materials spread fire and contribute to the total fuel load of a building. Typically, timber structures contribute less than 20 per cent of the fuel load available in a building, and thus the use of these structures does not significantly add to the fire hazard.

Furthermore, in a fully developed fire situation, structural timber exhibits remarkable fire resistance. Although the timber chars at a rate of 30 to 40 mm per hour, the low thermmal diffusivity of both the timber and the char protects the unburnt wood which thereby retains most of its original strength. By contrast many incombustible structural materials do not perform as well. For example, at a temperature of 800°C, a situstion reached within half an hour in a fully involved fire, steel structures have less than 10 per cent of their initial strength.

The characteristics of building fires, and the behaviour of structures therein, are the results of very complex processes. Because of this, much of the current design procedures for fire resistance is related to the measurement of index properties. The following is a discussion on the basic processes involved, the index properties currently used in fire resistant design, and the basis of a rational fire resistant design approach. Part 2 of this report will give a model for a code of fire resistant structural design in timber.

The following references provide a useful source of information for an overview on the fire resistance of timber structures:

*Proceedings of Symposium No. 3. Fire and Structural Use of Timber in Buildings*. Fire Research Station, Boreham Wood, Herts., UK, 1967.

Ashton, L.A. *Fire and timber in Modern Building Design*. TRADA, High Wycombe, UK, 1970.

*Wood and Fiber*. Vol.9, No.2, 1977.

*Behaviour of Wood Products in Fire*. Proc. of Seminar, Timber Committee, UN Economic Commission for Europe, Oxford, UK. Pergamon Press, 1977.

Pearson, R.G. The Fire Resistance of Timber. Parts I, II, III, IV, V. *CSIRO Forest Products Newsletter*. No.280, Nov. 1961; No.281, Dec. 1961; No. 282, Jan.-Feb. 1962; No.283, March 1962; No.284, April 1962.

## 2. NOTATION

$A_T$ = total room surface area
$A_W$ = area of window opening
$b$ = width of beam
$C_p$ = specific heat
$C_T$ = heat transfer coefficient
$d$ = depth of beam
$F$ = ultimate stress capacity of unburnt timber
$h$ = charred depth
$h_{clad}$ = thickness of protective cladding
$h_{eff}$ = effective depth of charring
$H_W$ = window depth
$k$ = thermal conductivity
$L$ = total fire load
$M$ = mass rate of combustion
$Q_c$ = rate of heat loss through convection
$Q_e$ = rate of heat loss through radiation via openings

$Q_F$ = rate of heat generated through combustion
$Q_S$ = rate of heat loss through radiation to room surfaces
$r$ = radiation
$r_B$ = black body radiation
$t$ = time
$t_{clad}$ = time for penetration of cladding material
$t_D$ = duration of fully developed fire
$t_{FS}$ = fire severity
$T$ = temperature
$T_{max}$ = temperature at base of char
$T_o$ = room temperature (23°C)
$v$ = $dh/dT$ = charring rate
$W_D$ = dead load
$W_L$ = live load
$x,y$ = cartesian coordinates
$\alpha$ = thermal diffusivity
$\xi$ = distance from edge of char
$\rho$ = air-dry density
$\sigma_f$ = ultimate stress capacity of burning wood
$\sigma_i$ = ultimate stress capacity of unburnt wood
$\phi$ = $A_W H_W^{0.5}/A_T$ = opening factor

## 3. CHARACTERISTICS OF BUILDING FIRES

### 3.1 The Fire Scenario

The scenario of building fires has been discussed in detail in numerous papers and texts. Some examples are those referenced herein by the American Iron and Steel Institute (1979), Gross (1977), Harmathy (1977), and Lie (1972, 1974).

Figure 1 shows the stages of development in a tyical building fire. Ignition usually occurs in a very localised area and if this should grow, an 'incipient' fire situation is reached. During this stage, hot smokey gases accumulate near the ceiling and radiate heat downwards on the furnishings to encourage further and more vigorous fire growth. This is illustrated schematically in Figure 2. When this radiation reaches approximately 20 $kw/m^2$, the temperature of the gases will be roughly 500°C and they will ignite, creating a condition known as 'flashover'.

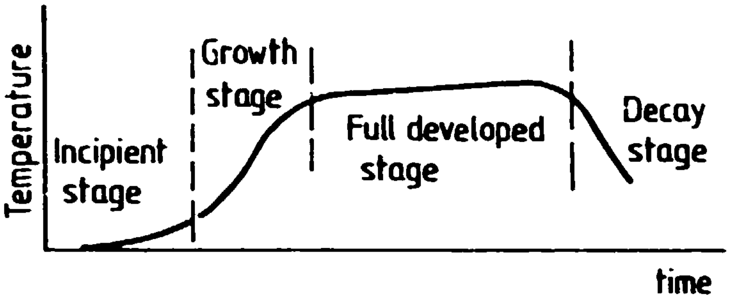


Figure 1 Stages of a typical fire

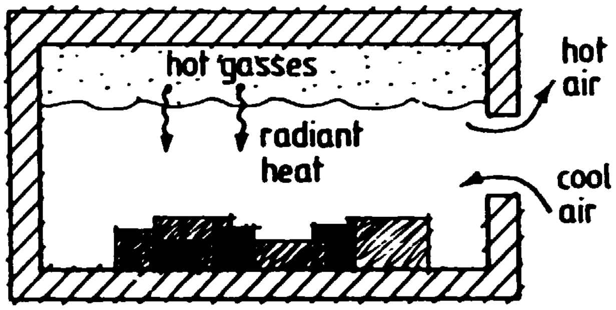


Figure 2 Incipient stage of a room fire

After flashover occurs, the fire develops rapidly and soon involves all furnishings in the room. When most of the fuel is consumed, a decay period with reducing temperatures sets in, sustained to some extent by the residual heat in the walls and ceiling of the room.

The time to flashover is typically 5 to 20 minutes after the ignition of a large furnishing object. This time is important as it is the time available for the escape of the building occupants. In fact, the primary purpose of a sprinkler system is to extend this period of incipient growth and if possible to prevent the occurrence of a flashover. After the flashover, the growth period is associated with the release of both smoke and toxic gases. Most deaths that occur in building fires are due to the inhaling of toxic gases rather than due to the effects of heat. The toxic gas most responsible for death is carbon monoxide, although there are indications that hydrogen cyanide, hydrogen chloride, nitrogen dioxide and sulphur dioxide may also cause deaths.

The fire in the fully developed stage represents the most serious hazard to building structures. Accordingly it will be discussed in some detail in the following section.

## 3.2 The Fully Developed Fire

A useful review of the literature on this topic has been given by Gross (1977). The characteristics of a fully developed fire are the result of a complex interaction of many factors such as the quantity and disposition of the fuel available, the geometry of the room and ventilation openings, and the thermal properties of the enclosing surfaces.

The fuel load of the furnishings in a room is usually stated in terms of the weight of wood that would have the same calorific value, the calorific value of wood being taken to be 4,700 kcal/kg. An example of data obtained in fire load surveys is given in Table 1. The large differences observed between countries is to be noted.

TABLE 1
FIRE LOADS
(After Gross 1977)

| Building type | Fire load (kg/m²) | |
|---|---|---|
| | 50 percentile | 80 percentile |
| <u>Office buildings</u> | | |
| Holland | 10 | 24 |
| UK | 20 | 32 |
| Sweden | 28 | 38 |
| USA | 35 | 50 |
| W. Germany | 43 | 60 |
| <u>Swedish Buildings</u> | | |
| Hotels | 18 | 22 |
| Schools | 22 | 26 |
| Offices | 28 | 38 |
| Hospitals | 33 | 35 |
| Residences | 40 | 45 |

Once the room furnishings ignite there are basically two types of fires that can develop. For the case of low fuel loads and large openings, adequate air will be available for rapid combustion and hence the development of the fire will be determined largely by the characteristics of the combustible contents, such as their surface area, geometrical disposition and material type. The characteristics of such a fire are highly variable and difficult to predict. However, most structural design situations are concerned with heavy fire loads and rooms with limited openings; for this case the characteristics of the fire are controlled by ventilation conditions, and some useful predictions on the effects of the fire can be made.

In discussing fire characteristics it will be useful to make use of the two reference conditions. The first is the temperature-time relationship that is specified for index tests of structural elements. The current proposal by ISO, which also is to be used in Australia, is the following:

$$T = T_o + 345 \log_{10} (8t + 1) \qquad (1)$$

where T is the furnace temperature ($^oC$), $T_o$ is the initial room temperature (usually taken to be $23^oC$) and t is the time from the commencement of the tests (min.). Equation (1) is intended to be representative of the situation in a fully developed ventilation-controlled fire where there is considerable fuel. Some typical time-temperature values shown graphically in Figure 3 are as follows:

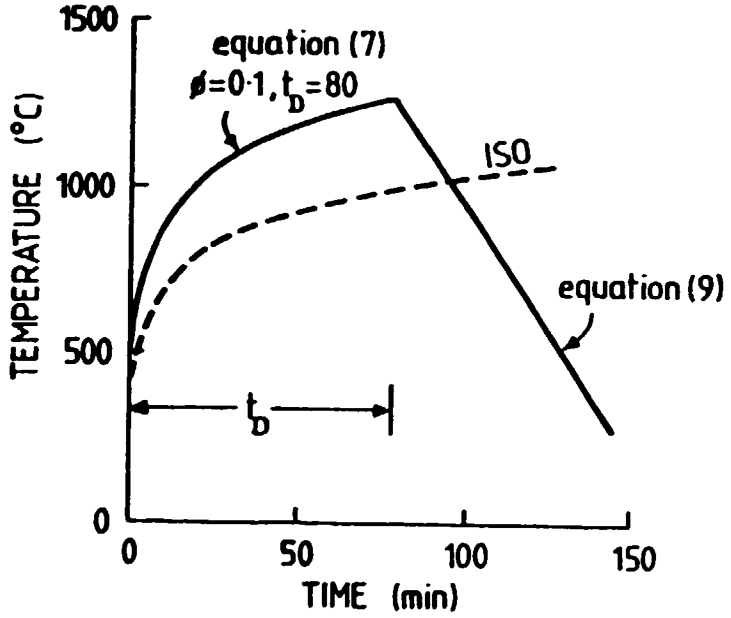
| Time (min.) | Temperature ($^oC$) |
|---|---|
| 0 | 23 |
| 5 | 579 |
| 20 | 784 |
| 60 | 948 |
| 180 | 1113 |

The second reference condition is the relationship between temperature and radiation for ideal black bodies. For this case the radiation intensity $r_B$ is given by the equation

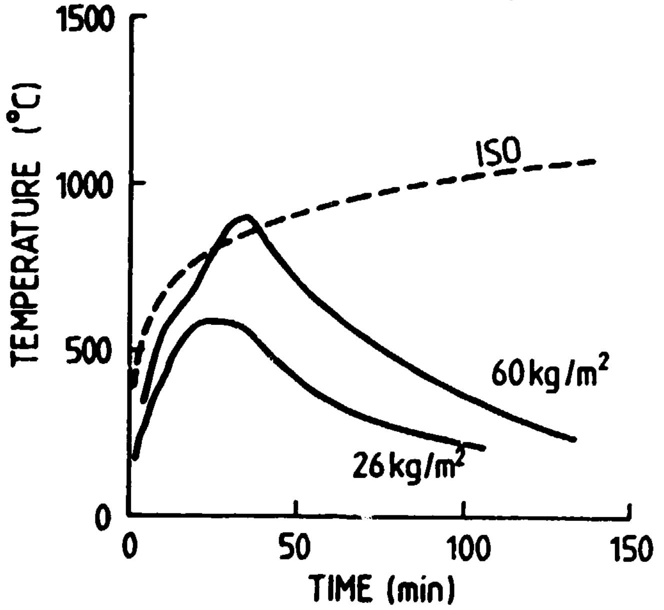
$$r_B = 57 \{(T + 273)/1000\}^4 \qquad (2)$$

where $r_B$ is in kw/m$^2$ units. Some values given by equation (2) are as follows:

| Temperature ($^oC$) | Radiation intensity (kw/m$^2$) |
|---|---|
| 500 | 20 |
| 1000 | 150 |
| 1500 | 560 |



(a) Theoretical temperature



(b) Experimentally measured temperature (after Gross 1977)

**Figure 3 Time-temperature relationships**

For the case of ventilation controlled fires, Kawagoe and Sekine (1963) have derived the following simple expression for the rate of combustion during a fully developed fire in an idealised room such as that shown in Figure 4(a)

$$M = 5.5 A_W H_W^{0.5} \qquad (3)$$

where M is the mass rate of combustion of the fire load (kg/min), $A_W$ is the total area of all window openings ($m^2$), and $H_W$ is the height of the windows (m). Equation (3) is derived from a simple theory in whch the room is taken to be at a temperature of 800 to 1000°C, the fuel is assumed to be equivalent to wood which burns incompletely and is therefore only 60 per cent efficient, and the coefficient of contraction of the window openings is taken to be 0.7.

From equation (3), the duration of active combustion, denoted by $t_D$ (min), can be estimated by

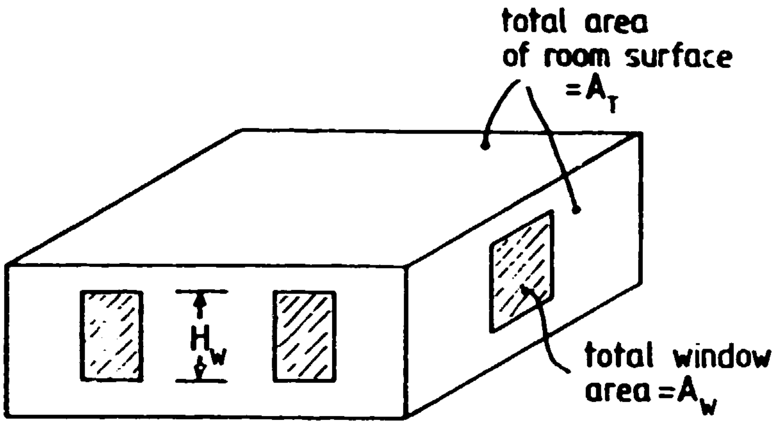
$$t_D = L/M \qquad (4)$$

where L is the total fuel load (kg) in the compartment.

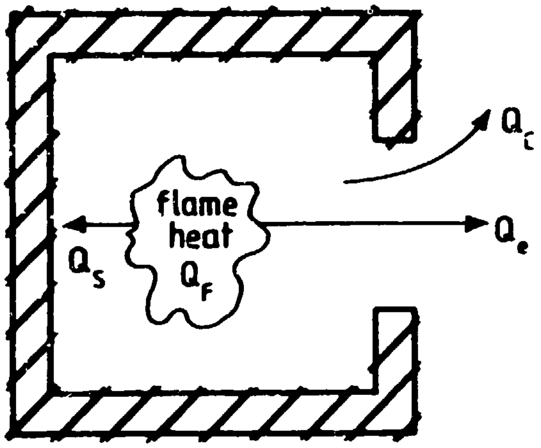
The estimate of the time-temperature relationship requires the solution of a set of dynamic equations related by the heat-balance equation illustrated in Figure 4(b)

$$Q_F = Q_s + Q_e + Q_c \qquad (5)$$

where $Q_F$ is the rate of heat generated by combustion of the compartment contents, $Q_s$ is the nett rate of heat lost by radiation to the surface of the compartment, $Q_e$ is the nett rate of heat radiated out through the open windows, and $Q_c$ is the heat loss through convection processes.



(a) Idealised room



(b) Dispersion of heat generated

Figure 4 Notations used in describing a developed fire

Obviously an important factor in the rate of temperature rise is the ratio of the rate of heat generation to the total room surface area. This ratio is proportional to an opening factor $\phi$ which will be defined by

$$\phi = (A_W/A_T)\, H_W^{0.5} \qquad (6)$$

where $A_T$ is the total area of the internal surface, i.e. walls, ceiling and floor.

Temperature-time curves for walls having typical values of thermal conductivity have been computed by numerous researchers such as Kawagoe and Sekine (1963), and Lie (1974). For typical situations the solutions of Kawagoe and Sekine can be fitted to the following modification of the standard time-temperature curve

$$T = T_o + \boldsymbol{\phi}\ 345 \log_{10} (8t + 1) \qquad (7)$$

where

$$\boldsymbol{\phi} = 1.0 + 1.1\ (\phi - 0.03)^{0.5} \qquad (8)$$

in which the opening factor $\phi$ is stated in $m^{0.5}$ units.

After the compartment temperature has reached its peak value at a time $t_D$ given by equation (4), the temperature T can be assumed to decay at a rate defined by

$$\partial T/\partial t = -10 \qquad (9a)$$

for $t_D < 60$ minutes, and

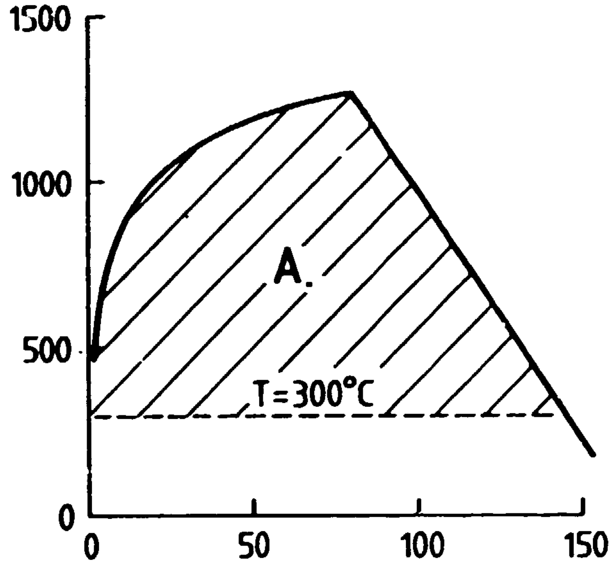
$$\partial T/\partial t = -7 \qquad (9b)$$

for $t_D \geq 60$ minutes. The term $\partial T/\partial t$ is the rate of decay stated in $^{o}C$/min. units.

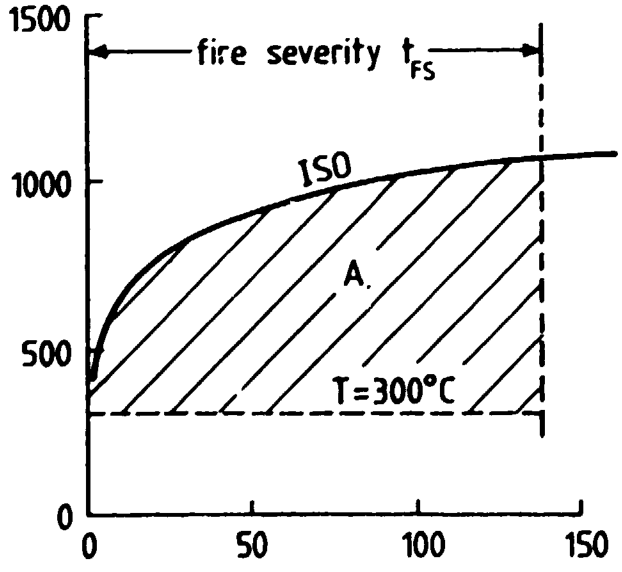
The application of equations (3), (4) and (7) is illustrated in Figure 3(a).

In the above, the fire behaviour has been characterised by the use of a single temperature that is representative of conditions at the hottest part of the room. Through the use of more sophisticated analyses it is possible to estimate the spatial characteristics of a fire, and thus to design fire resistance in a more realistic manner. An example of this is given in the design guide prepared by the American Iron and Steel Institute (1979).

In order to use a single figure to define the effect of a fire, the term fire severity is sometimes used. This concept, illustrated in Figure 5, is based on a definition related to the effective duration of a fire; this duration is the duration on the standard time-temperature curve defined by equation (1), for which the area between the time-temperature curve and some specified datum such as T = 300°C, is the same as that of the real fire.



(a) Theoretical fire



(b) Idealised fire

Figure 5 Definition of fire severity

# 4. EFFECTS OF FIRE ON TIMBER

## 4.1 Combustibility

Combustibility is a relative term. For example, many building materials such as aluminium which are normally considered incombustible, will burn easily if finely powdered and assisted by an adequate supply of oxygen. In addition, combustibility is not by itself a relevant parameter for defining the fire resistance of structures. However, the permission to use particular building materials in particular situations is sometimes related to their combustibility, and for this reason the factor of combustibility must be considered.

Most specified tests for the combustibility of building materials are similar to one given in the Australian Standard AS 1530, Part 1 (Standards Association of Australia 1976); this standard specifies a test in which a 45 mm diameter cylinder of the test material is subjected to a temperature of 850$^{\circ}$C for 20 minutes. The material is deemed to be combustible if it flames or if its temperature rises above 900$^{\circ}$C. Under these criteria all timber is combustible, and there is no chemical treatment that will render it otherwise.

## 4.2 Ignition and Flame Spread

Like combustibility, ignition and flame spread are relative terms and are not directly related to structural fire resistance. However, again like combustibility, these properties are relevant because they may be used as criteria for the acceptance of timber as a building material.

In theory wood can decompose at a temperature as low as 20$^{\circ}$C (at the rate of about one per cent per century). At 93$^{\circ}$C, the wood will become charred in five years. The time to ignition of heated wood is given in Figure 6. Spontaneous ignition will occur if wood is subjected to a radiant heat level of 25 kw/m$^2$, and ignition by pilot flame will occur for half this level of radiation. Mention should also be made of the fact that a ball of sawdust with diameter in excess of 50 m can develop ignition temperatures internally due to the heat of decomposition.

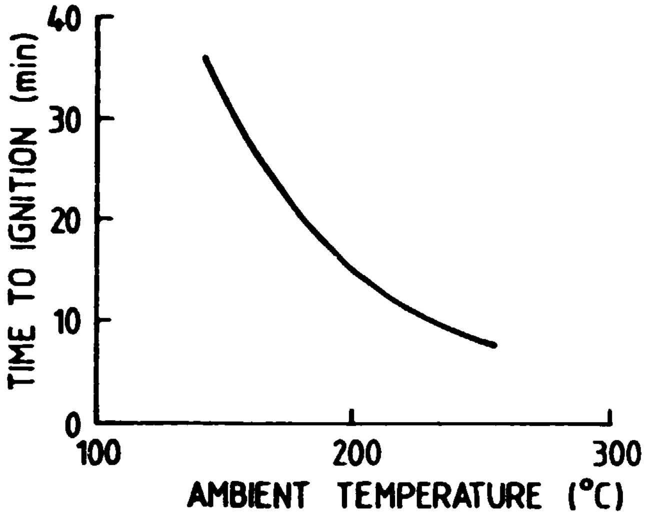


Figure 6   Time to ignition for heated wood (after Odeen 1967)

Once ignited, timber cannot continue to burn without aid from an external source of heat unless it is in a size less than 70 mm thick. Vertical surfaces burn more easily than horizontal ones.

For purposes of material classification, an index test is used to measure various properties related to the early fire hazard. A typical example of such a test is the Australian Standard AS 1530 (Standards Association of Australia 1982). In this test, illustrated in Figure 7, a 300 x 300 mm heat panel radiating at a rate of 240 kw/m$^2$ is moved towards a 600 x 600 mm panel of the test material located 15 mm behind a pilot flame. The radiant panel is moved from a distance of 850 mm from the test panel to a distance of 175 mm over a period of 20 minutes. The movement is stopped if the panel ignites. Then the heat radiation and optical density of the smoke from the test panel is monitored. From this information the following four indices are derived:

- ignition index (0 to 20)
- flame spread index (0 to 10)
- heat evolved index (0 to 10)
- smoke developed index (0 to 10)

The numbers in brackets indicate the possible range of each index, with larger values denoting a more serious hazard.

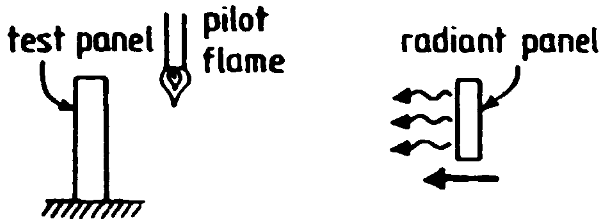


Figure 7 The test for early fire hazard properties

The early hazard properties of a large number of timber species have been evaluated by Moulen and Grubits (1980). A linear regression with respect to density has been fitted to this data and the values for densities of 400 and 900 kg/m$^3$ are given in Table 2. For comparison purposes, Table 2 also shows early fire hazard properties of some other materials to be found in buildings. It is seen that untreated timber lies within the range of values relevant to these other materials.

TABLE 2
EARLY FIRE HAZARD PROPERTIES

| Material | Hazard index* | | | |
|---|---|---|---|---|
| | Ignition | Flame spread | Heat evolved | Smoke developed |
| <u>Timber</u>** | | | | |
| Density = 900 kg/m$^3$ | 13 | 5 | 5 | 2 |
| Density = 400 kg/m$^3$ | 14 | 9 | 9 | 4 |
| <u>Building material</u>* | | | | |
| Asbestos cellulose board | 0 | 0 | 0 | 0 |
| Plasterboard | 12 | 0 | 2 | 3 |
| Wool carpet | 16 | 0 | 0 | 4 |
| Acrylic sheet | 14 | 7 | 8 | 4 |
| Linoleum | 16 | 8 | 9 | 6 |
| Acrylic carpet | 16 | 8 | 9 | 6 |

* Standards Association of Australia (1982)
** Moulen and Grubits (1980)

## 4.3 Pyrolysis of Timber

The burning of timber has been described in many papers such as those by Browne (1958), Wardle (1966), and Schaffer (1973). In fact timber itself does not burn unless subjected to heat radiation of an intensity considerably higher than normally occurs in building fires. The usual process is for it to decompose, or <u>pyrolyse</u>, under the influence of heat. The decomposition products include gases, tar and charcoal which will burn if sufficient heat and oxygen is supplied. Once a layer of char has formed, the char protects the unburnt wood.

Due to the excellent insulating properties of the wood and the char, pyrolysis develops in narrow bands parallel to the timber surface as indicated in Figure 8. The following is a rough classification of these bands:

<u>Zone A</u> - 95°C to 200°C ... water vapour is given off and wood eventually becomes charred.

<u>Zone B</u> - 200°C to 280°C ... water vapour, formic and acetic acids and glyoxal given off, ignition is possible but difficult.

<u>Zone C</u> - 280°C to 500°C ... combustible gases (carbon monoxide, methane, formaldehyde, formic and acetic acids, methanol, hydrogen) diluted with carbon dioxide and water vapour. Residue is black fibrous char. Normally vigorous flaming occurs. If however the temperature is held below 500°C a thick layer of char builds up and because the thermal conductivity of char is only 0.25 that of wood, it retards the penetration of heat and thus reduces the flaming.

<u>Zone D</u> - 500°C to 1000°C ... in this zone the char develops the crystalline structure of graphite, glowing occurs and the char is gradually consumed.

<u>Zone E</u> - above 1000°C ... at these temperatures the char is consumed as fast as it is formed.

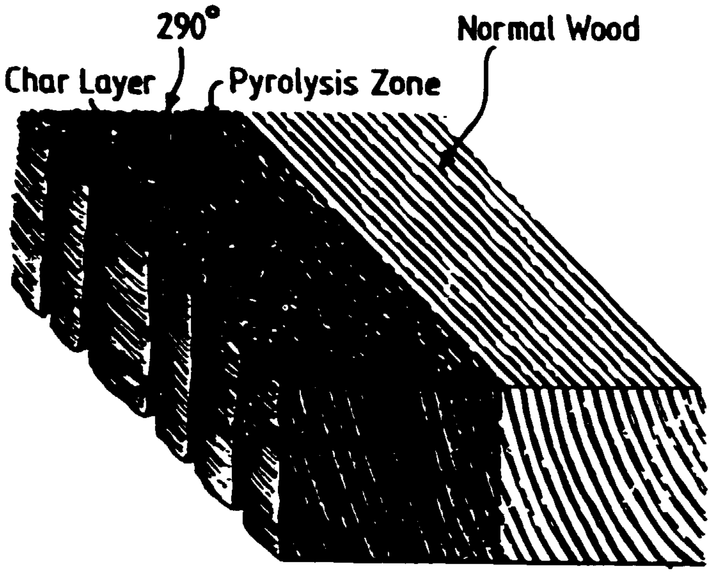


Figure 8 Degradation zones during burning

Wood comprises essentially the three components cellulose, hemicellulose and lignin, bound together in a complex network. The effect of heat on the structural properties of these constituents can be summarised as follows:

60°C ... hemicelluloses soften
120°C ... lignins soften
140°C ... bound water is freed
160°C ... lignin has melted and commences to reharden
210°C ... lignin is hard and celluloses soften

The varied behaviour of the wood constituents leads to very complex relationships between temperature and the physical characteristics of wood (Hillis and Rozsa 1978).

## 4.4 The Charring Rate of Wood

Various scientists, such as Schaffer (1967), have studied theoretical models to predict the charring rate of wood. However these models are usually too complex for practical application, and only empirical relationships will be presented herein.

Unburnt wood exposed to radiation can char at a fast rate. From a survey by Butcher (1976) of the available data, this rate of char is given by

$$dh/dt = 0.022\ r \qquad (10)$$

where

dh/dt = rate of char (mm/min)

r = radiation

In terms of black body radiation, equations (2; and (10) lead to the following char rates:

| Temperature | Radiation | Char rate |
|---|---|---|
| $500^{\circ}C$ | $20\ kw/m^2$ | 0.4 mm/min. |
| $1000^{\circ}C$ | $150\ kw/m^2$ | 3.3 mm/min. |

This rapid char rate is considerably reduced once a layer of char roughly 5 mm thick has formed to insulate the unburnt wood. The 'dwell time' phenomenon illustrated by the example shown in Figure 9, indicates the insulating character of a well developed char layer.

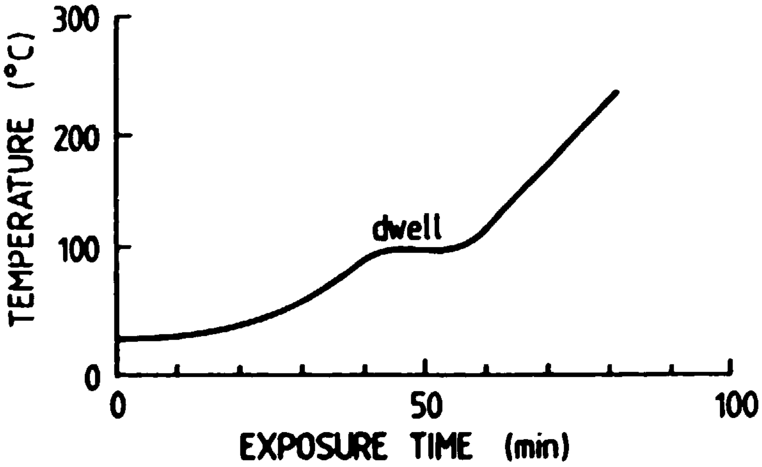


Figure 9 Temperature for a thermocouple located in burning wood (After Schaffer 1967)

Figure 10 shows measurements of the char depth for Douglas fir subjected to constant temperature conditions, and to the ISO time-temperatur curve given by equation (1). It is of interest to note that for the standard time-temperature conditions the rate of charring is essentially a constant. This constant charring rate is related to density and as a rough guide may be taken to be given by

$$dh/dt = 360/\rho \qquad (11)$$

where

$dh/dt$ = charring rate (mm/min.)

$\rho$ = density (kg/m$^3$)

One further aspect of note is that corners tend to burn to rounded arises as shown in Figure 11.

More detailed information on charring rates has been given by Schaffer (1976).

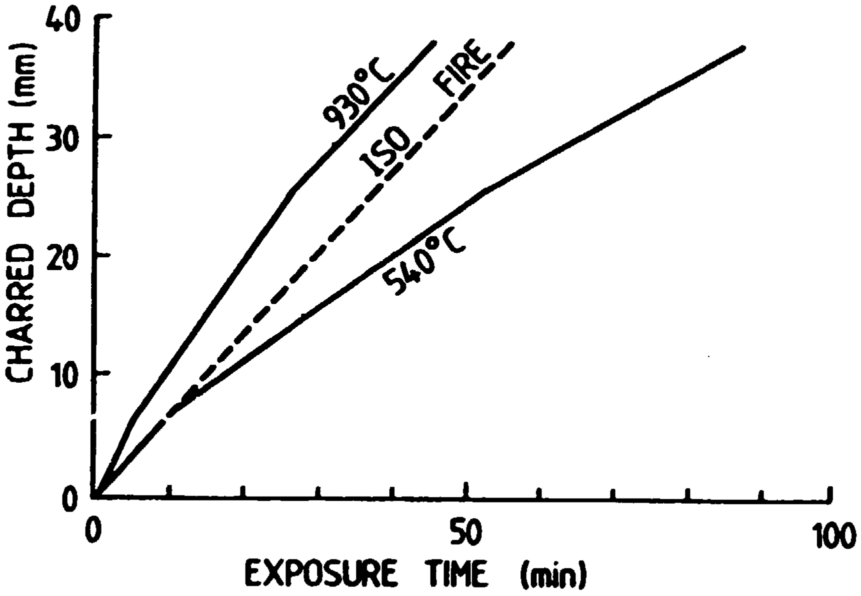


Figure 10 Measured charred depth for Douglas fir (After Schaffer 1967)

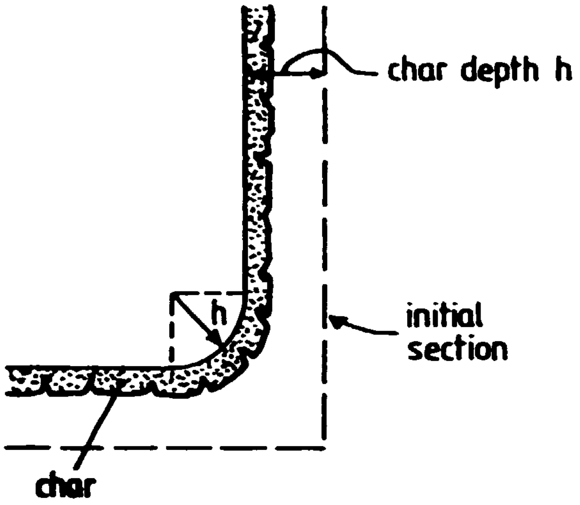


Figure 11 Dimensions of a rounded arris

## 4.5 Internal Temperatures of Burning Wood

Knudson and Schniewind (1975) have described a sophisticated method of computing the internal temperatures of burning wood. Essentially the method is based on a numerical solution of the heat diffusion equation

$$\partial T/\partial t = \alpha \nabla^2 T + Q/\rho C_p \quad (12)$$

where

$\alpha$ = $k/\rho C_p$ = thermal diffusivity

k = thermal conductivity

$C_p$ = specific heat

$\rho$ = density

Q = heat generation rate per unit volume

The parameters used by Knudson and Schniewind for unburnt wood may be summarised as follows:

$k = 0.15$ [J/(sec. m. $^{\circ}$C)]

$C_p = 1700$ [J/(kg. $^{\circ}$C)]

The char is taken to be 20 per cent the density of unburnt wood with the following properties

$$k = 0.15\ [\mathrm{J/(sec.\ m.\ ^{o}C)}]$$
$$C_p = 700\ [\mathrm{J/(kg.\ ^{o}C)}]$$

In addition, the exothermic heat developed at the boundary of the solid wood and char is taken to be 200 J/kg, and the heat transfer coefficient at the external surface is taken to be given by

$$C_T = 350\ (T/1000)^{1.5} \tag{13}$$

where

$C_T$ = heat transfer coefficient, $[\mathrm{J/(sec.\ m^2\ ^{o}C)}]$

$T$ = temperature of the wood surface, $[^{o}\mathrm{C}]$

The one dimensional form of equation (12) is useful for providing a qualitative picture of the temperature distribution. The heat diffusion equation for this case is

$$\partial T/\partial t = \alpha\ \partial^2 T/\partial x^2 \tag{14}$$

If it is assumed that the internal edge of the char boundary moves inwards at a constant velocity $v = dh/dt$, then a coordinate $\xi$ measured from the char edge as shown in Figure 12 is given by

$$\xi = x - vt \tag{15}$$

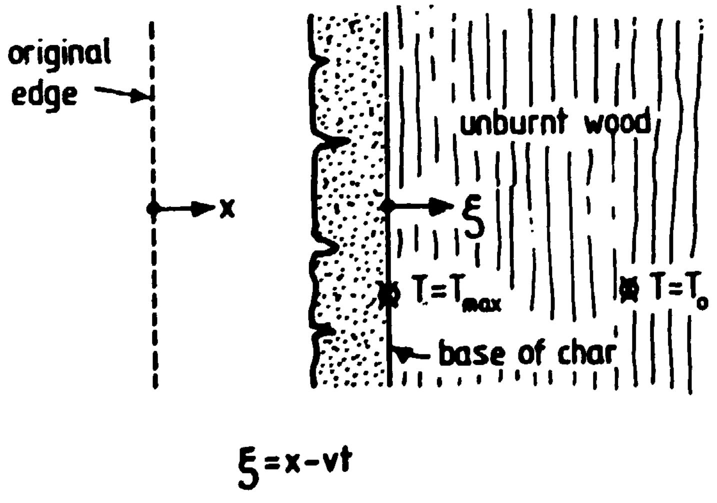


Figure 12 Coordinate system for burning wood

Using equation (15) to transform the reference coordinate from x to $\xi$ leads to the following form of equation (14)

$$\partial T/\partial t - v\ \partial t/\partial \xi = \alpha\ \partial^2 T/\partial \xi^2 \qquad (16)$$

A quasi-stationary solution of equation (16) is

$$T = T_o + (T_o - T_{max}) \exp\{-(v\xi/\alpha)\} \qquad (17)$$

where

$T_o$ = initial temperature of the timber

$T_{max}$ = temperature of the timber at the char edge.

As an example, for the case of a timber with density 500 kg/m$^3$, rough estimates from data given earlier lead to the following,

$\rho$ = 500 kg/m$^3$

v = $1.2 \times 10^{-5}$ m/sec

$C_p$ = 1700 J/(kg. $^o$C)

k = 0.15 J/(sec. m. $^o$C)

$T_o$ = 23$^o$C

$T_{max}$ = 290$^o$C

Substitution of these values into equation (17) leads to

$$T = 23 + 267 \exp\{-70\xi\} \qquad (18)$$

A graph of equation (18) is shown in Figure 13.

Schaffer (1965) has demonstrated that equation (17) is a good predictor of the temperature distribution within the unburnt wood. The rapid attenuation of the temperature with distance from the char edge is to be noted.

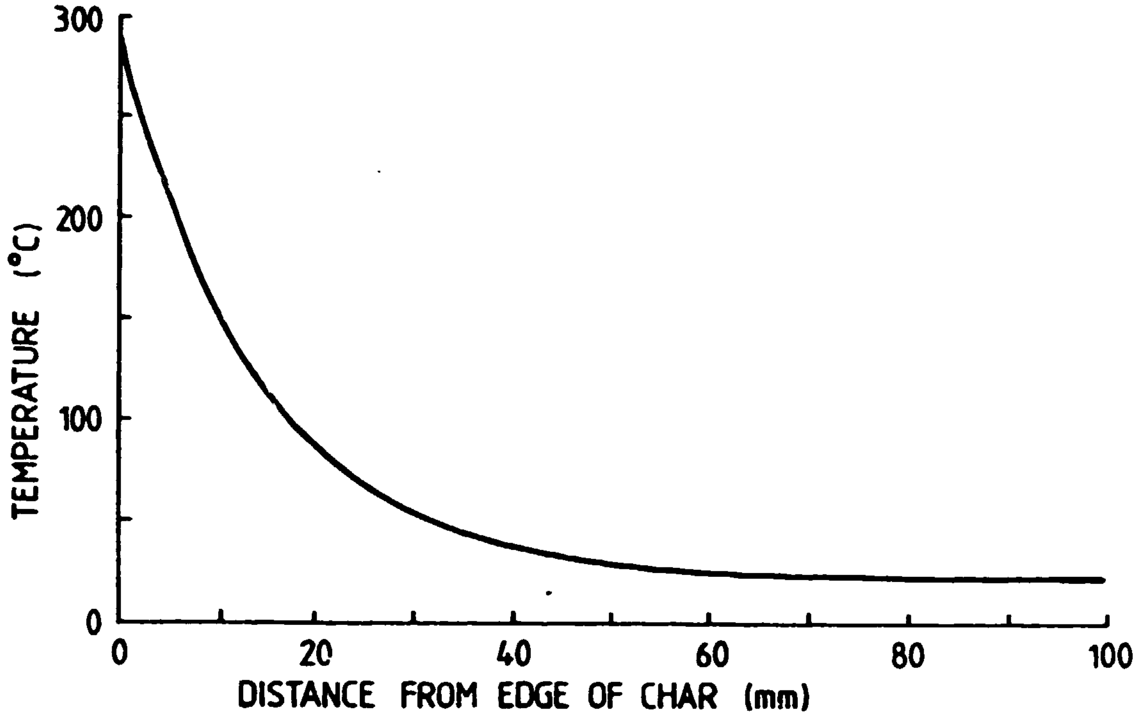
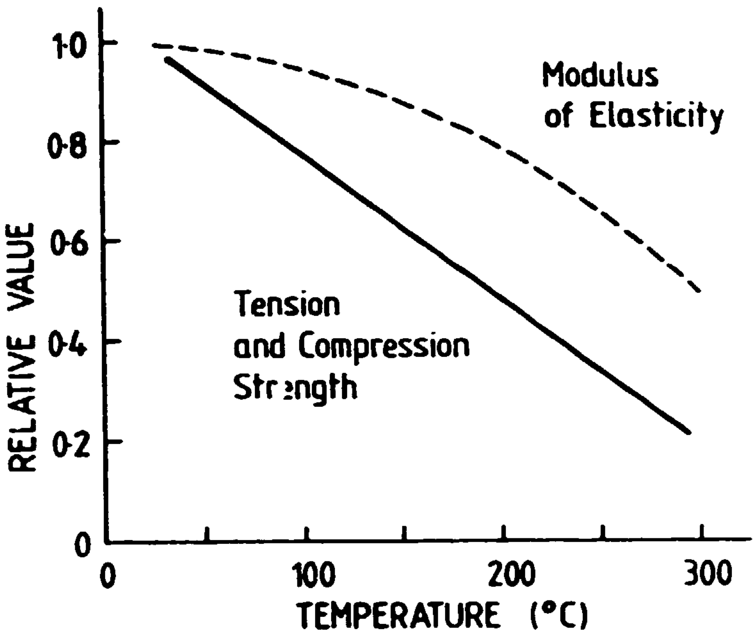


Figure 13 Computed temperature distribution in a burning wood member

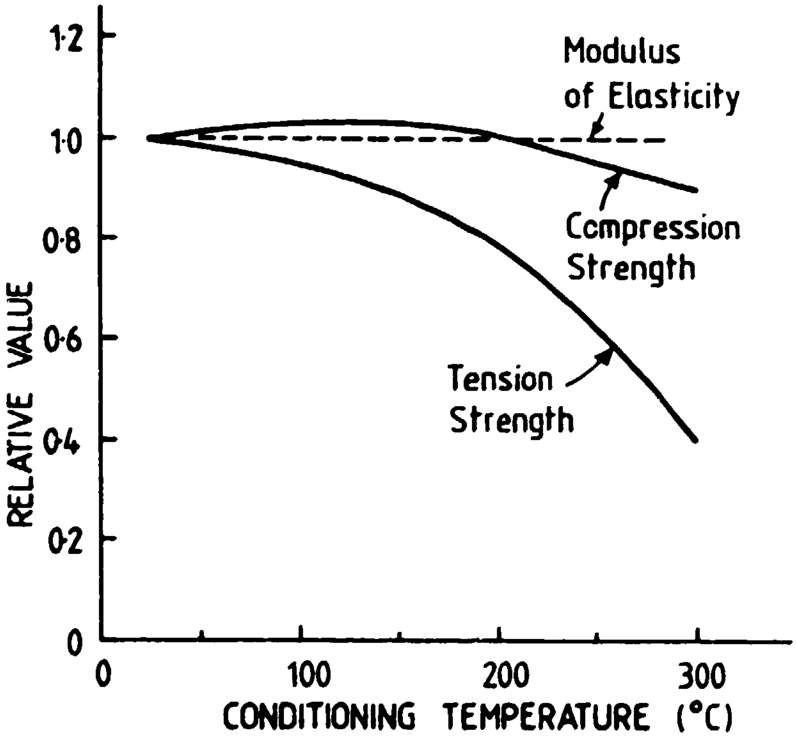
### 4.6 Strength of Timber

The effect of heat on the strength of clear wood has been examined by Sulzberger (1953), Schaffer (1973), Knudson and Schniewind (1975), and Beall (1982).

The characteristics of clear wood, after heating at various temperatures for a period of one hour are shown in Figure 14(a). The corresponding characteristics after the wood has been reconditioned to room temperature are shown in Figure 14(b). By combining this information with the temperature distribution shown in Figure 13, it is possible to estimate the structural characteristics of timber members during a fully developed fire and also when reconditioned to room temperature. This is shown in Figure 15.

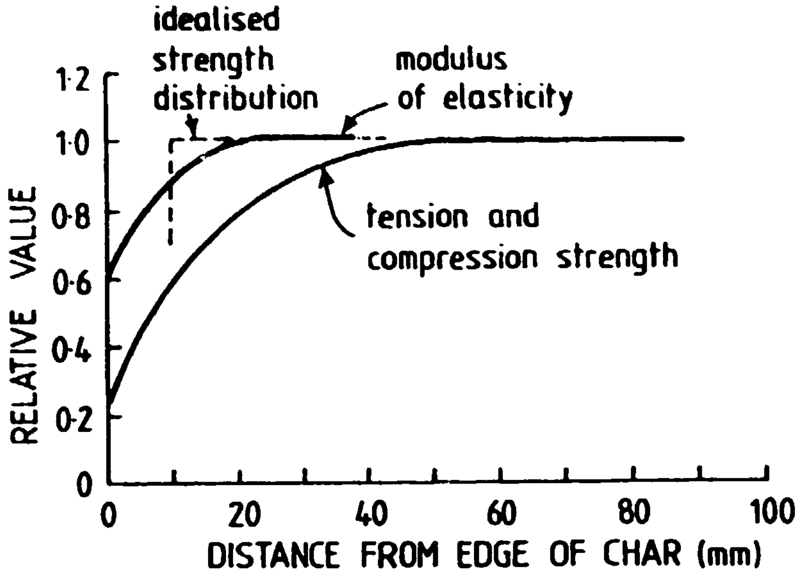


(a) At heated temperature

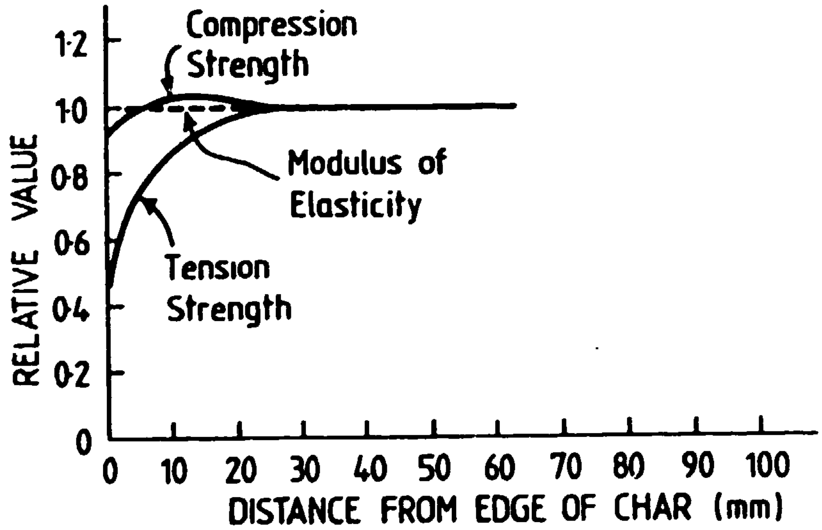


(b) Reconditioned to room temperature

Figure 14 Properties of heated wood
(After Knudson and Schniewind)



(a) Properties during fire



(b) Reconditioned at room temperature

Figure 15 Distribution of structural properties

The relationship between the initial stress capacity $\sigma_i$ and the strength during a fire $\sigma_f$ can be written

$$\sigma_f = \beta\sigma_i \tag{19}$$

where the parameter $\beta$ is a function of numerous factors such as the specimen geometry, fire history and temperature-strength relationships.

From the analysis of data obtained in numerous fire tests (Dorn and Egner 1961, Lawson et al. 1952, Lie 1977, Malhotra and Rogowski 1970, Odeen 1970, Schaffer 1977, Wardle 1966, Woeste and Schaffer 1979, 1981), it would appear that $\beta$ at failure is typically about 0.8 for large structural members and about 0.6 for small sections. An examination of the strength distribution shown in Figure 15(a) indicates that the loss of strength during fully developed fire conditions is equivalent to a loss of about 10 mm from each face of the timber section. Thus equation (11) may be modified to produce the following estimate of the effective final depth of the char as follows,

$$h_{eff} = (360\ t_{FS}/\rho) + 1.5\ \sqrt{t_{FS}} \qquad (20a)$$

but not greater than

$$h_{eff} = (360\ t_{FS}/\rho) + 10 \qquad (20b)$$

where

$h_{eff}$ = effective final depth of char (mm)
$t_{FS}$ = duration of fire above 300°C (min)
$\rho$ = timber dry density (kg/m$^3$)

The residual section obtained after the effective char depth $h_{eff}$ has been removed is assumed to have the same strength as that which it had before the fire. Figure 16 shows an example of the effect of fire severity on the strength of a glulam beam computed with these assumptions.

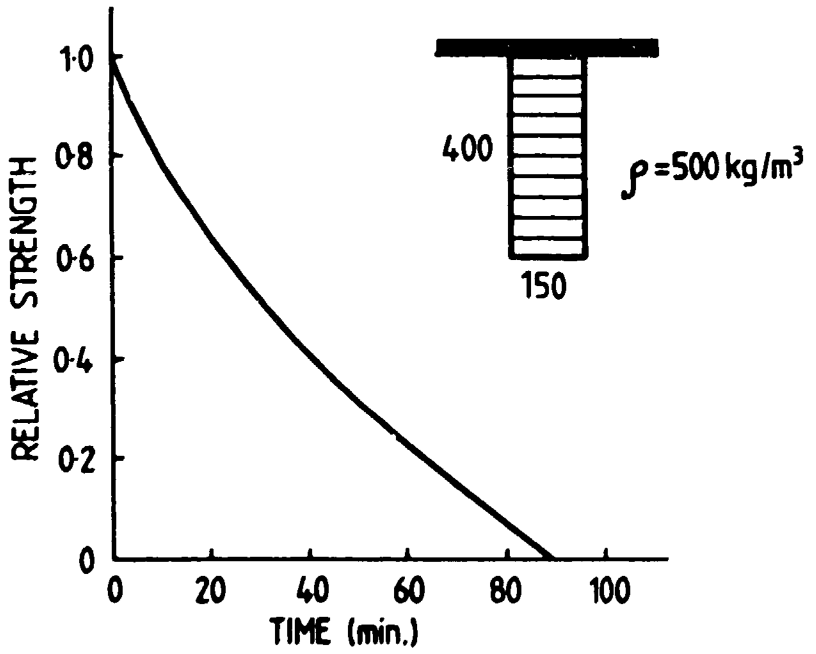


Figure 16 Example of effect of fire duration on strength

Some further matters that have been noted in the analysis of the test data are the following:

(a) Surprisingly the variability of strength in fire conditions is less than the initial value (Woeste and Schaffer 1981).

(b) The effect of a fire does not appear to be related to the defect size associated with the specific stress grade of timber tested (Malhotra and Rogowski 1967).

(c) The burning of a member frequently leads to a change in shape of the cross-section, and the possible effect of this change on buckling strength must be considered.

(d) If a member of solid timber contains deep checks or kino veins, these will be penetrated rapidly by the heat and the resultant charring may lead to a significant increase in the loss of strength.

## 4.7 Performance of Gluelines

In general gluelines have little effect on the overall charring rate, although the char does tend to penetrate the gluelines more deeply than the wood. However, gluelines fabricated with urea glue may have adverse effects when heated; for example the outermost laminate of a glulam beam may delaminate, or a finger joint in solid timber member may fail prematurely. Both phenolic and resorcinal adhesives have excellent stability in high temperature conditions.

## 4.8 Effect of Additives

Timber can be impregnated with numerous additives, and these may have an effect on both strength and fire characteristics. Their effect on strength is usually small and will not be considered herein.

Numerous chemicals are used as fire retardants; these include monoamonium phosphate, diamonium phosphate, amonium sulphate, borax, boric acid and zinc chloride. They operate in numerous ways such as by raising the ignition temperature, providing a barrier to either oxygen or flame, or by modifying the form of the char. In general they reduce the early fire hazard properties of the timber (Table 3). They can also cause a slight reduction in the charring rate, but the total effect on structural fire resistance is negligible (Malhotra and Rogowski 1967).

The preservative CCA (copper-chrome-arsenic) has a slightly beneficial effect on the early fire hazard properties as shown in Table 3, but can encourage an after-glow behaviour, wherein the timber will continue to burn ater the external source of heat has been removed (Beesley et al. 1974). However, the use of zinc and phosphorus additives to CCA to form the patented preservative 3S (McCarthy et al. 1972) has been found effective in controlling after-glow, with a negligible effect on the early fire hazard as shown in Table 3 (Beesley et al. 1974).

TABLE 3
EFFECT OF ADDITIVES ON THE EARLY FIRE HAZARD OF RADIATA PINE
(After Beesley et al. 1974)

| Additive | Hazard index* | | | |
|---|---|---|---|---|
| | Ignition | Flame spread | Heat evolved | Smoke developed |
| Untreated | 15 | 7 | 6 | 3 |
| Fire retardant | 0 | 0 | 0 | 2 |
| CCA | 14 | 6 | 5 | 3 |
| 3S | 15 | 7 | 6 | 3 |

Timber impregnated with creosote tends to ignite easily and initiallly it will smoke heavily, particularly if the treatment is fresh. However the dense smoke and the thick char reduces the accessability of oxygen to the unburnt timber, and hence the wood will self-extinguish if the exposure to fire is limited. Under prolonged exposure to fire, timber impregnated with creosote probably has the same fire resistance as untreated timber.

## 4.9 Surface Coatings and Cladding

Timber structures my be protected by the application of surface coatings or claddings. These increase fire resistance by delaying the onset of heating of the structural member.

Intumescent coatings are usually proprietary products; some delay the heat by only a few minutes, while others can delay the arrival of heat for several hours.

The following data on the protection provided by claddings has been collated by Schaffer (1977);

For solid timber panels

$$t_{clad} = \rho\, h_{clad}^{2}/15000$$

(21a)

For particleboard and plywood (presumably softwood plywood)

$$t_{clad} = 0.06\, h_{clad}^{2} \qquad (21b)$$

For gypsum plasterboards with glass fibre additive

$$t_{clad} = 0.15\, h_{clad}^{2} \qquad (21c)$$

where

$t_{clad}$ = time for penetration of the cladding when one side is subjected to the ISO standard time-temperature curve (min)

$\rho$ = timber density (kg/m$^3$)

$h_{clad}$ = thickness of cladding material (mm).

(Note that there appears to be some discrepancy between the data for solid timber and for plywood.)

## 5. EFFECTS OF FIRE ON METAL CONNECTORS

Figure 17 shows a set of joints investigated by Leicester <u>et al.</u> (1979). These joints were loaded to their design load (about 0.25 of their short term ultimate strength) and then subjected to a standard fire according to equation (1). The performance of these joint is shown in Figure 18.

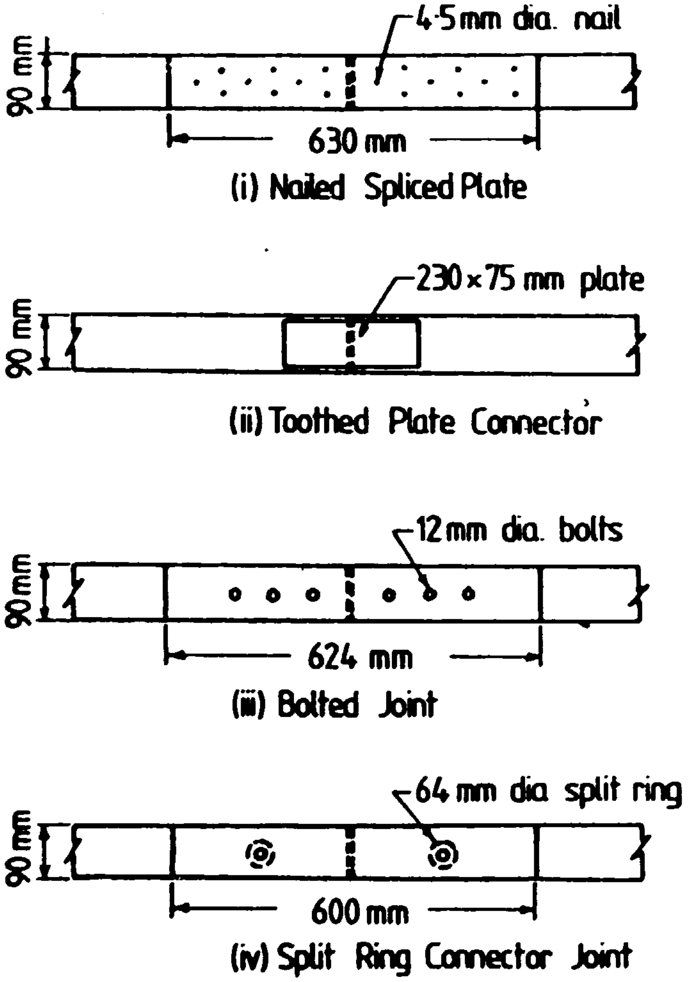


Figure 17 Dimensions of joints tested

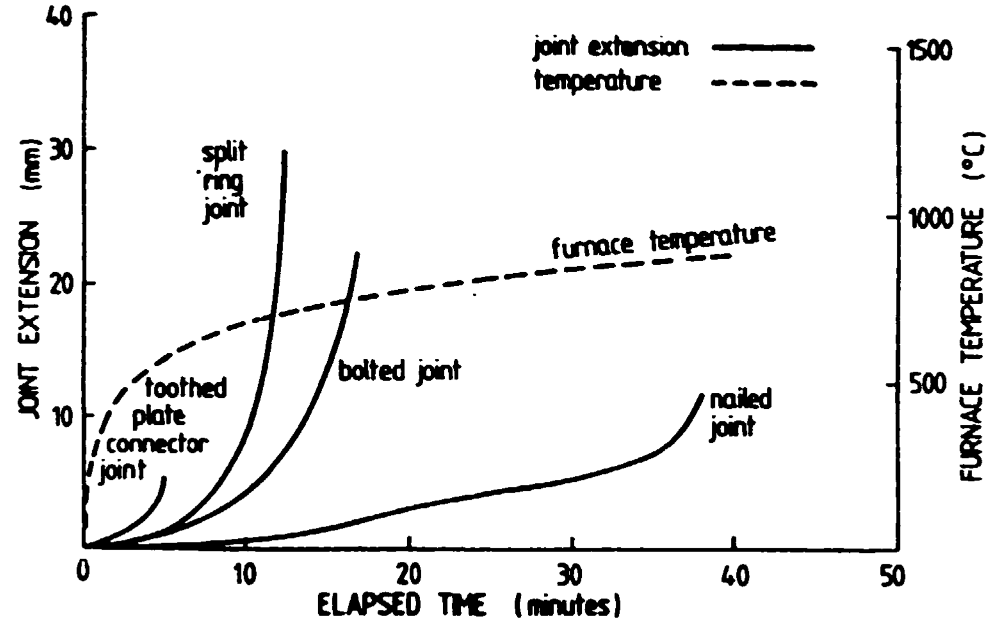
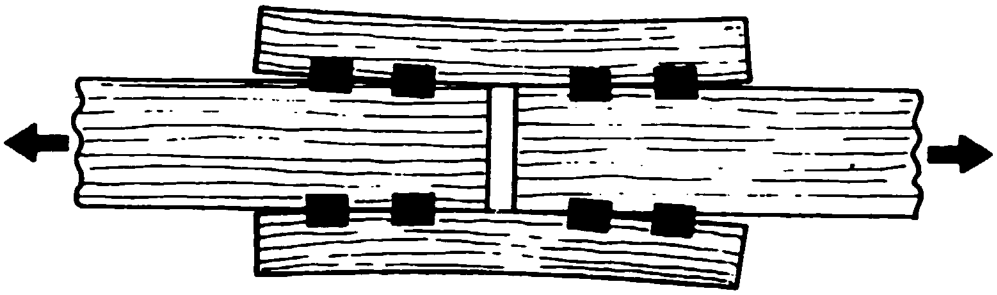


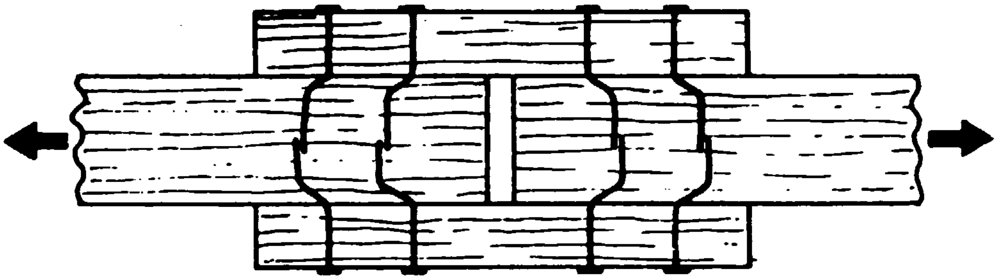
Figure 18 Performance of metal connector joints in a standard fire (After Leicester et al. 1979)

Except for the nailed joint, the performance of these joints were all poorer than may have been anticipated.

Figure 20 illustrates an aspect of joint deformation that is critical to fire resistance. Split rings are rigid relative to the wood; therefore they rotate under load, causing the ends of the splice plates to separate from the main member and thereby permitting the access of heat to the split ring and adjacent timber. By contrast nails yield under load; this causes the interface between the splice plates and the main member to close tight under load, thereby protecting the highly stressed wood at the interface. The characteristics of bolts lies somewhere between those of nails and split ring connectors.



(a) Split ring connector



(b) Nailed joint

Figure 20 Schematic illustration of distortion of joints under load

The understanding of the failure mechanism outlined above has led to the development by CSIRO of a fire resistant connector. This connector, shown schematically in Figure 21, is used by sandwiching it between the two pieces of timber to be connected, and then using an hydraulic jack to press the nails into the wood. Tests to date have shown that this connector performs well with softwoods.

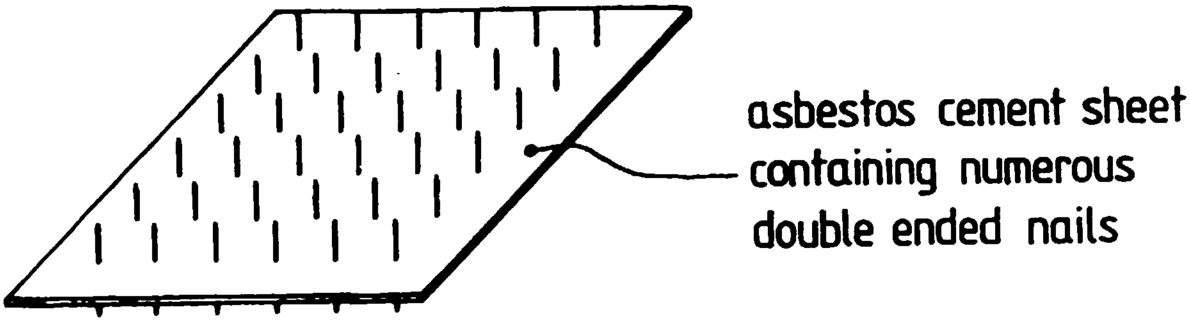


Figure 21 A fire resistant connector

## 6. DESIGN FOR FIRE RESISTANCE

### 6.1 Building Regulations

Most building regulations do not encourage rational design for the fire resistance of timber structures. At the least sophisticated level, the regulations categorise structures into those that are constructed wih combustible and with non-combustible materials. Structures of combustible materials, such as timber, are limited in application to particular classes of buildings, and for these classes no required fire resistance is specified.

In the following, two further types of building regulations will be discussed.

### 6.2 Design by Fire Resistance Rating

A semi-rational approach to the design of timber structures is possible where building regulations waive the requirement of non-combustibility and focus on the specification of fire resistance in terms of a performance criterion.

For this purpose the definition of fire resistance is specified in standards such as the Australian Standard AS 1530, Part 4 (Standards Association of Australia 1975). In this standard the term fire resistance is defined essentially as the time that a structure will carry its design load, while being subjected to the standard time-temperature regime described by equation (1).

The rationale of specifying fire resistance ratings relates to the strategy of compartmentation. Fire risk areas are divided into compartments which may be rooms, buildings or even city zones; the building regulations are then framed so that the effects of any severe fire will be contained completely in its compartment. In this scenario, the requirement of a structure is to continue to function and survive the complete burn-out of the contents of the compartment.

The required fire resistance ratings are usually specified in the appropriate building regulations, and tend to vary considerably from one location to another. A typical set of required ratings is shown Table 4.

TABLE 4
TYPICAL FIRE RESISTANCE REQUIREMENTS

| Building type | Required fire rating (min.) |
|---|---|
| House | 0 |
| Flat | 90 |
| Hotel | 90 |
| Office | 120 |
| Shop | 360 |
| Warehouse | 480 |

Because of the considerable time and expense involved in undertaking fire tests to demonstrate fire resistace, deemed-to-comply criteria are used wherever possible. As an example, the New Zealand Model Building Bylaw (Wardle 1966) accepts the following as minimum sizes that will qualify for a 30 minute fire rating:

For roof loads,

| | |
|---|---|
| beams | ... 150 x 100 mm |
| colums | ... 200 x 150 mm |
| truss members | ... 150 x 100 mm |

and for floor loads,

| | |
|---|---|
| beams | ... 250 x 150 mm |
| columns | ... 200 x 200 mm |
| truss members | ... 200 x 200 mm |

## 6.3 Design for Reliability

Design for structural reliability is now well accepted in principal and is often used as a basis for deriving design recommendations for structural codes. There have been some attempts such as those by Woeste and Schaffer (1979, 1981) to do this for the fire resistance of timber structures, but the results have not been completely satisfactory.

Structural reliability is related to the probability of failure in-service. As an example of the theory presented herein, the probability of failure during a fire of the beam shown in Figure 16 can be written

$$p_F = \Pr((b - 2h_{eff})(d - h_{eff})^2 (F/6) < W_L + W_D) \qquad (22)$$

where

$h_{eff} = f\ (L,\ A_W,\ A_T,\ H_W,\ r)$

and where

F = ultimate stress capacity of the timber where there is no fire involvement

$W_L$ = live load effect

$W_D$ = dead load effect

f() = function of the parameters in brackets

Similarly the design criterion for the beam is

$$(b - 2h^*_{eff})(d - h^*_{eff})^2 (F^*/6) = W^*_L + W^*_D \qquad (23)$$

where $h^*_{eff}$ is given by the lesser of the following

$$h^*_{eff} = (360/\rho)\ t^*_{FS} + 1.5 \sqrt{t^*_{FS}} \qquad (24a)$$

$$h^*_{eff} = (360/\rho)\ t^*_{FS} + 10 \qquad (24b)$$

and $t^*_{FS}$ is the effective fire duration defined as shown in Figure 5 and computed from the use of equations (7) and (9). The asterisks are used to denote the design values of the associated parameter. The relationship between the design values and the components of uncertainty are illustrated schematically in Figure 22.

It is outside the scope of this paper to discuss the details of the uncertainties and the computation of the probability of failure. The second Part of this paper will contain a model design code for which the recommendations have been derived through an analysis of the type described here. The analysis used also took into consideration the fact that during a fire the floor live loads are arbitrary-point-in-time rather than peak lifetime values, that the probability of occurrence of a fire is small, and that the socially acceptable risk of structural failure in a fire is greater than for normal loads.

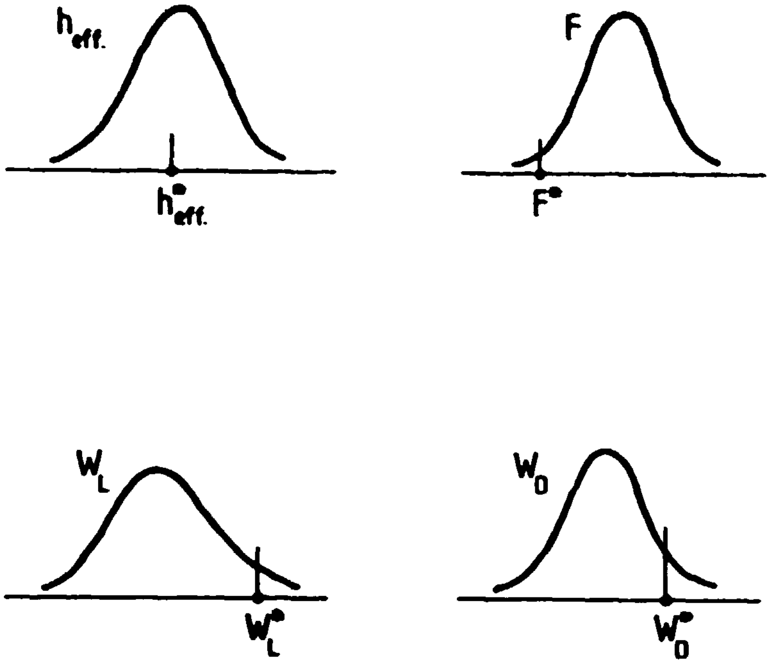


Figure 22 Components of uncertainty in the reliability analysis

## 6.4 Details of Design

Design and construction details are important in fire resistant construction. Fire readily attacks sharp corners, and thin sections, and flames readily enter any cracks and gaps. Points of high local stress such as can occur at supports and load points should be well protected as timber in these areas will tend to plasticise on heating; the use of metal plates to apply these localised loads will lead to a loss of fire resistance. Useful design details are given in the papers by the Canadian Wood Council (undated) and Wardle (1966).

## 7. REFERENCES

American Iron and Steel Institute (1979). Fire-safe structural steel. A design guide. Washington, USA, March.

American Society for the Testing of Materials (1974). Standard Method of Fire Tests of Building Construction and Materials. ASTM, E119-73.

Anon. (1972). Watery Lane Project. Timber Research and Development Association, Bucks., UK.

Babrauskas, V. (1976). Fire endurance in buildings. UCB FRG 76-16. Univerity of California, Berkley, USA.

Beall, F.C. (1982). Effect of temperature on the structural uses of wood and wood products. Structural Use of Wood in Adverse Environments. Van Nostrand.

Beesley, J., Keough, J.J., and Moulen, A.W. (1974). Early burning properties of Australian timbers. Technical Paper (Second Series) No.6, CSIRO Division of Building Research, Melbourne, pp.1-14.

Browne, F.L. (1958). Theories of the combustion of wood and its control. FPL Report No. 2136, USDA Forest Products Laboratory, Madison, Wisconsin, USA, December.

Butcher, E.G. (1976). The yule log - do we know how fast it burns? Fire Surveyor, December, pp.29-33.

Canadian Wood Council (Undated). Fire protective design - types. Commentary on NBCC 1970, Subsection 3.1.4. CWC Datafile FP-2.

Dorn, H., and Egner, K. (1961). Fire tests on glued laminated structural members. Holz-Zentralblatt Stuttgart, Vol.28, pp.435-438. Also, Technical-Translation 1131, National Research Council of Canada, Ottawa, 1964.

Gross, D. (1977). Measurements of fire loads and calculations of fire severity. Wood and Fiber, Vol.9, No.1, pp.72-85.

Harmathy, T.Z. (1977). Building design and the fire hazard. Wood and Fiber, Vol.9, No.2, pp.127-144.

Hillis, W.E., and Rozsa, A.N. (1978). The softening temperatures of wood. Holzforschung, Vol.32, No.2, pp.68-73.

Imaizumi, K. (1962). Stability in fire of protected and unprotected glued laminated beams. Norsk Skogindustri, Vol.16, No.4, pp.140-151. Reprinted as Information Series No. 47, New Zealand Forest Service, 1963.

Ingberg, S.H. (1928). Tests on the severity of building fires. Quarterly Report of the National Fire Protection Association, Vol.22, pp.43-61.

Kawagoe, K., and Sekine, T. (1963). Estimation of fire temperature-time curves in rooms. Occasional Report No.11, Building Research Institute, Ministry of Construction, Japan.

Knudsen, R.M., and Schniewind, A.P. (1975). Performance of structural wood members exposed to fire. Forest Products Journal, Vol.25, No.2, February, pp.23-32.

Lawson, D.I., Webster, C.T., and Ashton, L.A. (1952). The fire endurance of timber beams and floors. The Structural Engineer, February, pp.27-33.

Leicester, R.H., Seath, C.A., and Pham, L. (1979). The fire resistance of metal connectors. Proc. of 19th Forest Products Research Conference, Melbourne, Australia. Topic 2/12.

Lie, T.T. (1972). Fire and Buildings. Applied Science Publishers, Ltd., Ripple Road, Barking, Essex, UK, p.276.

Lie, T.T. (1974). Characteristic temperature curves for various fire severities. Fire Technology, Vol.10, No.4, November, pp.315-326.

McCarthy, D.F., Seaman, W.G., Da Costa, E.W.B., and Bezemer, L.D. (1972). Development and evaluation of a leach resistant fire retardant preservative for pine fence posts. Journal of the Institute of Wood Science, Vol.6, No.1, June, pp.24-31.

Malhotra, H.L., and Rogowski, B.F.W. (1970). Fire-resistance of laminated timber columns. Proceedings of Symposium No.3, Fire and Structural Use of Timber in Buildings. Fire Research Station, Boreham Wood, Herts., UK, 1967, HMSO, UK, pp.16-51.

Meyer-Ottens, C. (1970). The behaviour of load-bearing and non-loadbearing internal and external walls of wood-based materials under fire conditions. Proceedings of Symposium No.3, Fire and Structural Use of Timber in Buildings. Fire Research Station, Boreham Wood, Herts., UK, 1967, HMSO, UK, pp.78-90.

Moulen, A.W., and Grub, S.J. (1980). The early fire hazard properties of timbers. Technical Study No. 50, Experimental Building Station, Department of Housing and Construction. Australian Government Publishing Service, Canberra, Australia.

Odeen, K. (1970). Fire resistance of glued, laminated timber structures. Proceedings of Symposium No.3, Fire and Structural Use of Timber in Buildings. Fire Research Station, Boreham Wood, Herts., UK, 1967, HMSO, UK, pp.7-15.

Rogowski, B.F.W. (1970). Charring of Timber in Fire Tests. Proceedings of Symposium No.3, Fire and Structural Use of Timber in Buildings. Fire Research Station, Boreham Wood, Herts., UK, 1967, HMSO, UK, pp.52-59.

Schaffer, E.L. (1965). An approach to the mathematical prediction of temperature rise within a semi-infinite wood slab subjected to high temperature conditions. Pyrodynamics, Vol.2, pp.117-132.

Schaffer, E.L. (1966). Review of information related to the charring rate of wood. Research Note FPL-145. USDA Forest Products Laboratory, Madison, Wisconsin, USA, November.

Schaffer, E.L. (1967). Charring rate of selected woods - transverse to grain. Research Paper FPL-69. USDA Forest Products Laboratory, Madison, Wisconsin, USA, April.

Schaffer, E.L. (1973). Effect of pyrolytic temperatures on the longitudinal strength of dry Douglas-fir. Journal of Testing and Evaluation, Vol.1, No.4, July, pp.319-329.

Schaffer, E. (1977). State of structural timber fire endurance. Wood and Fiber, Vol.9, No.2, pp.145-170.

Standards Association of Australia (1975). Australian Standard 1530, Part 4-1975, Fire Tests on Building Materials and Structures. Part 4 - Fire Resistance Test of Structures. Sydney, Australia.

Standards Association of Australia (1976). Australian Standard 1530, Part 1-1976. Fire Tests on Building Materials and Structures. Part 1 - Combustibility Test for Materials. Sydney, Australia.

Standards Association of Australia (1982). Australian Standard 1530, Part 3-1982. Methods for Fire Tests on Building Materials and Structures. Part 3 - Tests for Early Fire Hazard Properties of Materials. Sydney, Australia.

Sulzberger, P.H. (1953). The effect of temperature on the strength of wood, plywood and glued joints. Report ACA-46, Department of Supply, Aeronautical Research Consultative Committee, Melbourne, Australia, December.

Thomas, P.H., Heselden, A.J.M., and Law, M. (1967). Fully developed compartment fires - two kinds of behaviour. Fire Research Technical Paper No.18, HMSO, London, UK.

Wardle, T.M. (1966). Notes on the fire resistance of heavy timber construction. New Zealand Forest Service, Wellington.

Woeste, F.E., and Schaffer, E.L. (1979). Second moment reliability analysis of fire exposed wood, joist floor assemblies. Fire and Materials, Vol.3, No.3, pp.126-131.

Woeste, F.E., and Schaffer, E.L. (1981). Reliability analysis of fire-exposed light-frame wood floor assemblies. Research Paper FPL 386. USDA Forest Products Laboratory, Madison, Wisconsin, USA, January.

# FIRE RESISTANCE OF TIMBER

## PART 2 - A CODE FOR FIRE RESISTANT DESIGN

based on

DRAFT No. 1 AUSTRALIAN STANDARD (December 1982)

RULES FOR

USE OF TIMBER IN STRUCTURES

known as the

SSA TIMBER ENGINEERING CODE

PART 4 - FIRE RESISTANCE OF TIMBER STRUCTURES

AS 1720, Part 4-1983

# 1. GENERAL

## 1.1 SCOPE

This Part of the code gives methods of assessing the fire resistance of flexural, tension and compression members of solid and of glued laminated timber, and also of the resistance of their joints. The methods are intended to provide assessments that are in accord with the requirements of the Australian Standard AS 1530, Part 4, Fire-Resistance Tests of Structures.

## 1.2 METHOD

For solid and glued laminated timber, the assessment method is based on computing the strength of the residual section after an allowance has been made for the loss of timber due to charring.

For joints fabricated with metal fasteners, the criterion for failure is related to a rise in temperature at the timber-to-metal load-bearing interface.

# 2. DEFINITIONS

<u>Standard Fire</u>. Standard fire conditions refer to the furnace conditions specified in AS 1530, Part 4-1975 for fire-resistance tests of structures or structural elements. These conditions are intended to simulate the temperature and radiation of fully developed fires.

<u>Fire Resistance</u>. Fire resistance is stated in terms of a duration which corresponds to the time for which the member can perform its required function when subjected to standard fire conditions. For structural members, the required function is to carry the design load.

**Fire Resistant Cladding**. This refers to cladding which will protect a structural element from the effects of the standard fire conditions for a stated duration.

**Fire Proof Barrier**. This is a barrier that has a fire resistance in excess of that of the building element that it is protecting.

**Notional Charring Rate**. This is a theoretical charring rate that is used in the assessment of fire resistance. It is intended to correspond roughly to the charring rate that is observed in standard fire conditions.

## 3. SOLID TIMBER

### 3.1 CHARRING

### 3.1.1 General

The assessment of the fire resistance of solid timber is based on the concept of a loss in timber section due to an idealised or notional charring of any wood surfaces that are exposed to fire as shown in Figure 1. The notional charring rate in a standard fire situation may be taken to be given by

$$c = 360/\delta \qquad (3.1)$$

where

$c$ = charring rate, mm/min

$\delta$ = dry timber density, kg/m$^3$.

Note. Dry timber density refers to a density measured at a moisture content of 12 per cent.

The notional charring rate defined by equation (3.1) is applicable to dry, untreated timber. If the timber is treated with a preservative or fire retardant, then due account shall be taken of the effect of this treatment on the charring rate.

Note. Some preservatives not only modify the charring rate, but also cause an 'after-glow' effect. This after-glow effect refers to the phenomenon wherein the burning of timber persists after the external source of heat has been removed; usually this burning continues until all the treated timber has been consumed.

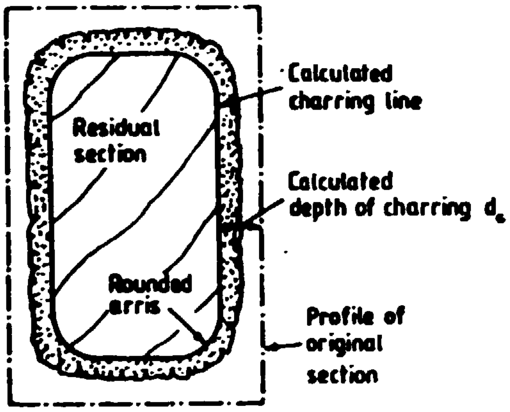


Fig. 1 Loss of Section due to Charring

### 3.1.3 Depth of Char

The total depth of the notional charring for exposed flat surfaces of timber shall be computed from

$$d_c = ct \quad (3.2)$$

where

$c$ = charring rate defined by equation (3.1), mm/min.

$d_c$ = depth of charring, mm

$t$ = design fire resistance time that the timber is considered to be exposed to a standard fire, mm.

For timber surfaces that are protected by a fire resistant cladding, the time t shall refer to the time for which the timber surface is exposed to temperatures above 280°C. Furthermore, it shall be assumed that once the cladding is breached by the fire, the charring rate c shall be 1.1 times the value given in equation (3.1).

### 3.1.4 Exposed Arrises

Exposed arrises will burn to a rounded profile as shown in Figure 1. Details of the geometry of this profile are given in Figure 2. The radius of an arris, denoted by $r_a$, may be taken to be equal to $d_c$, the depth of char.

### 3.1.5 Barrier Junctions

If the timber member is built into a fire proof barrier, then the detail of the notional charring that occurs at the junction of the member with the barrier may be taken to be as shown in Figure 3.

## 3.2 DESIGN CRITERIA

### 3.2.1 Strength

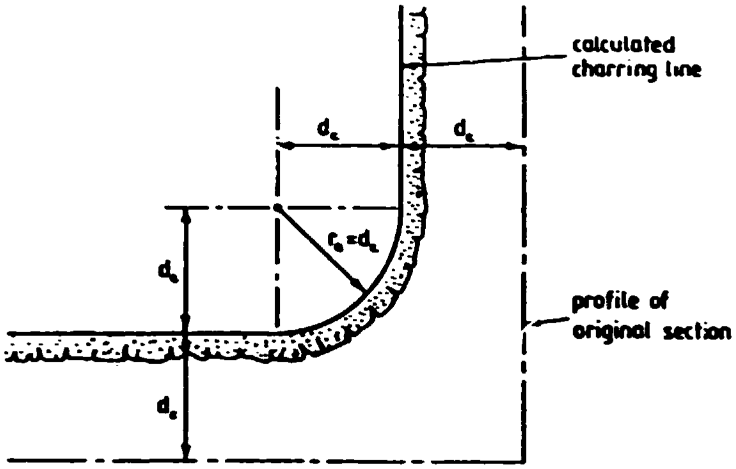
In order to assess the strength capacity of a structural timber member during fire, a residual section shall be obtained by subtracting from the original section an area that is notionally charred as described in Rule 3.1. Then a check is to be made to ensure that the residual section has adequate design strength for an applied load defined by

$$W = 0.8\,W_D + 0.4\,W_L \qquad (3.3)$$

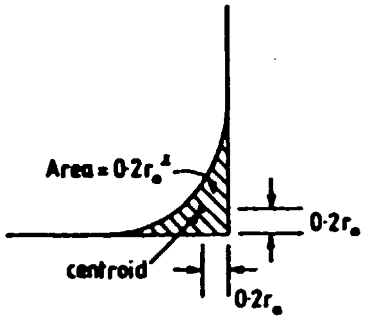
where

$W_D$ = dead load

$W_L$ = floor and/or roof live loads as specified in AS 1170, Part 1.



(a) Radius of rounded arris



(b) Geometry of burnt section

Fig. 2 Rounding of Arris due to Charring

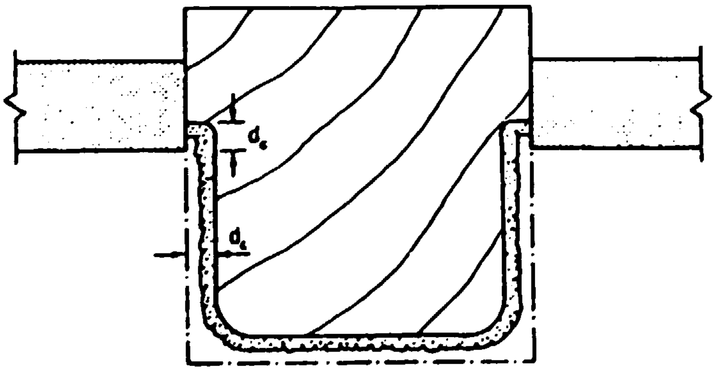


Fig. 3 Details of Charring at Junction with Fire Proof Barrier

The design strength of the residual section is to be derived according to the Australian Standard AS 1720, Part 1; in this check the effect of the fire on the residual section is ignored and all the normal requirements such as buckling strength are considered.

Note. The recommendations for the design check have been derived through a consideration of many factors such as the loss of section, the fact that the load will not be at its peak design value, the loss in strength due to heat and the low probability of occurrence of a fully developed fire.

### 3.2.2 Stiffness

The design criteria for stiffness may be chosen at the discretion of the design engineer. However, in no case shall the stiffness of beams be such that the notional application of a load W as defined by equation (3.3) to the residual section leads to deflections greater than span/50.

### 3.2.3 Design Details

The details of construction must be such as to ensure that the assumptions used in the assessment of fire resistance are valid. For example protective fire proof barriers, lateral restraints against buckling and end supports must all have a fire resistance at least equal to that of the structural member assessed; fire resistant cladding must be fixed so that it remains in place when subjected to the combined effects of heat and structural member deformation. In addition, the timber must not split when subjected to fire. If there is a possibility that the timber will split, then due allowance shall be made for the increased charring rate and loss of structural stability in assessing fire resistance.

Note. One common cause of splitting is the occurrence of large kino veins in hardwood species.

## 4. GLUED LAMINATED TIMBER

The fire resistance of glued laminated timber, fabricated in accordance with the Australian Standard AS 1328 may be assessed according to the procedure recommended in Rule 3 for solid timber. The effect of gluelines on the notional charring rate may be neglected.

Note. If gluelines are inadequately bonded, then they will open up under fire conditions and the caution given in Rule 3.2.3 concerning splitting should be applied.

## 5. FINGER JOINTS

Finger jointed softwood timber, fabricated with casein and phenolic glues, may be considered equivalent to solid timber in assessing its fire resistance. For other types of finger jointed material, the fire resistance must be established in accordance with the Australian Standard AS 1530, Part 4.

## 6. METAL CONNECTORS

### 6.1 UNPROTECTED CONNECTORS

The fire resistance of joints fabricated with unprotected metal connectors should be established in accordance with the requirements of the Australian Standard AS 1530, Part 4. A guide to the likely performance of such joints is given in Appendix B. In the absence of adequate test information, it should be assumed that the fire resistance of joints fabricated with unprotected fasteners is negligible.

## 6.2 PROTECTED CONNECTORS

Metal connectors may be protected by embedding them within a structural member to a depth equal to the notional charring depth as illustrated in Figure 4. The residual holes resulting from such a fabrication are to be plugged by timber glued into place.

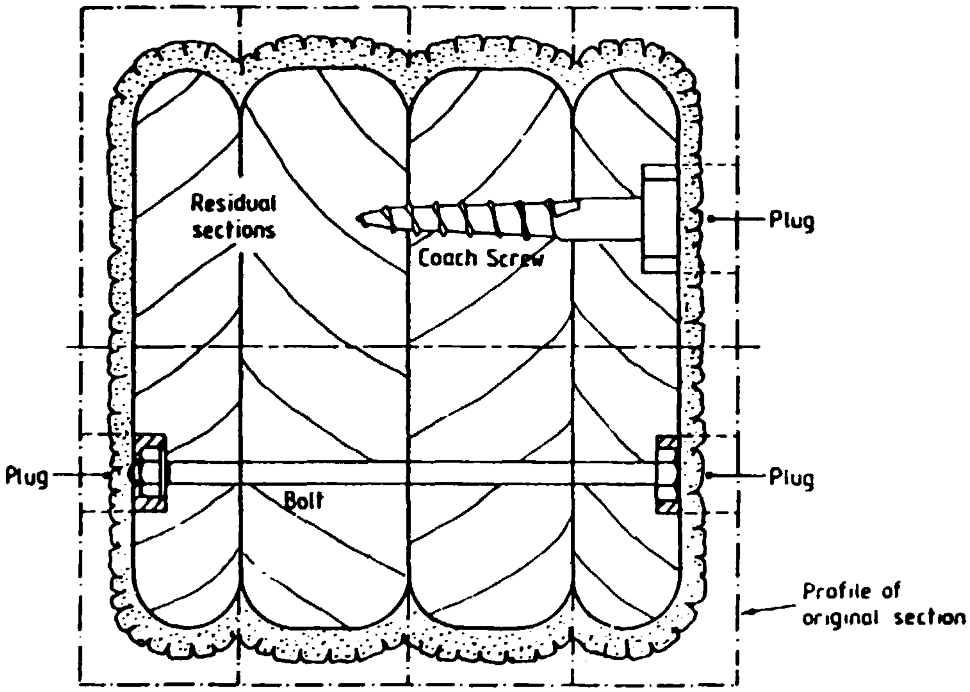


Fig. 4 A Method of Protecting Metal Connectors

Note. In such a construction, care must be taken to ensure that the contacts between the interfaces of the timber members remain tight on appliction of the load. When rigid connector systems such as shear plates are used, the joint opens up under load and the metal connectors are then directly exposed to the heat of any fire that occurs.

An alternative method of obtaining a fire resistance for for joints fabricated with metal connectors is to protect the connectors by fire resistant claddings such as board material or subliming coatings. Structural failure of such joints will be deemed to occur when the temperature of the timber-to-metal load-bearing interface reaches 120°C.

Note. At a temperature of 120°C wood softens and loses bearing strength.

Note. Protective cladding must be fixed to joints in such a manner that they do not separate off due under the combined effects of joint deformation and fire.

## APPENDIX A

### STANDARDS AND OTHER SPECIFICATIONS RELEVANT TO THE FIRE RESISTANCE OF TIMBER STRUCTURES

| | |
|---|---|
| 1328-1972 | Glued-Laminated Structural Timber |
| 1720, Part 1-1983 | SAA Timber Engineering Code. Part 1 - Design Methods |
| 1720, Part 3-1985 | SAA Timber Engineering Code. Part 3 - Design Loads for Non-Standard Fasteners |
| 1170, Part 1-1971 | SAA Loading Code. Part 1 - Dead and Live Loads |
| 1530, Part 4-1975 | Fire Tests on Building Materials and Structures. Part 4 - Fire-Resistance Test of Structures |

# APPENDIX B

## FIRE RESISTANCE OF METAL CONNECTORS

The fire resistance of joints depends on the joint geometry, the species of timber and the applied load. In the absence of reliable test information, the values shown in Table B1 may be used as a rough guide to estimate the fire resistance of unprotected joints fabricated with metal connectors and load with the design loads as specified in AS 1720, Parts 1 and 3. As noted in Section 6, the failure of unprotected joints occurs when the temperature of the timber-to-metal load-bearing interface reaches 120°C.

TABLE B1
TYPICAL FIRE RESISTANCE VALUES FOR
UNPROTECTED METAL CONNECTOR JOINTS

| Type of connector | Typical fire resistance (min.) |
|---|---|
| Toothed plate | 5 |
| Split ring and shear plate | 10 |
| Bolts | 20 |
| Nails* | 30 |

* Except when thin wood members are used, nailed joints have the same fire resistance as solid wood