CHAPTER 9

Environmental deterioration of timber

S. Mindess
Department of Civil Engineering, University of British Columbia, Canada.

1 Introduction

Timber structures can be remarkably durable if they are properly designed, constructed and maintained. However, wood is a naturally occurring biological material. Thus, timber structures are also subject to decay due to a number of biological factors such as bacteria, fungi, insects and molluscs, and due to such non-biological factors as weathering, wetting and drying, chemical exposure and atmospheric contaminants. Timber is as well susceptible to fire. Here, the environmental deterioration of timber structures is discussed, as well as the available preventative measures that may be taken to preserve timber. Finally, some of the economic considerations involved in timber preservation are considered.

Wood is the oldest and one of the most widely used construction materials. It combines a high strength-to-weight ratio, appealing aesthetic properties, ease of construction, the ability to be repaired, and cost effectiveness. It is also a renewable resource, and its production is much less energy intensive than that of other construction materials, such as steel, aluminium or concrete. Currently, the annual production of wood is about $10^9$ tonnes, about equal to the world production of iron and steel, and about one-tenth of the world production of concrete (about 10 billion tonnes).

The terms wood and timber are often used interchangeably, but we will distinguish between them here. Wood will be used to refer to the basic material that we obtain from trees. Timber (or lumber) will refer to the sawn structural members (beams, planks or boards) which are used in construction. Timber will, in general, contain a large number of macroscopic defects, such as knots and cracks; the properties of timber are governed both by these macroscopic features and the underlying structure of the wood itself.
Fig. 1 shows one of the oldest timber structures in China: a Liao dynasty temple constructed in 984 A.D. The oldest existing wood-frame structure in the United States (Fig. 2) is a home built in 1636. And, on a totally different scale, some of the violins (Fig. 3) produced in Cremona, Italy, as far back as the 17th century are still in use today. On the other hand, there are all too many cases in which wood-frame structures have had to be rebuilt after only three to five years in service.

2 Wood as a material

The macrostructure of wood is shown schematically in Fig. 4. Briefly, the outer bark is a dense layer that protects the interior of the tree. The inner bark transports sap from the leaves to the growing parts of the tree. The cambium is a layer of tissue, one-cell thick, between the bark and the wood. Its repeated subdivision forms both new wood and new bark. Sapwood is the wood near the outside of the tree trunk; it conducts moisture up from the roots and stores food (carbohydrates) needed for further growth. Heartwood is the inner core of the trunk and is composed of non-living cells; it is drier and harder than sapwood, and is more resistant to decay. The annual rings are formed as the cells of cambium grow and divide during a growing season. During the period of rapid growth in the spring, the cells are relatively large with thin walls, and are referred to as springwood; the summerwood forms later in the growing season, with smaller cavities and thicker walls than the springwood. Finally, the pith is a small cylinder of primary tissue at the centre of the tree around which the annual rings form.
Figure 2: Fairbanks House, 1636-40, Dedham, Massachusetts (Photograph courtesy of Dr. Jeffery Howe, Boston College, Boston, MA).

Figure 3: Amati violin, 1677.
Environmental Deterioration of Materials

Figure 4: Schematic illustration of the parts of a tree and of the structure of wood.

On a microstructural level, wood may crudely be modelled as consisting of bundles of aligned, thin-walled tubes (fibres) glued together. Typically, about 90% of the volume of the wood consists of longitudinally oriented cells (tracheids), as shown in Fig. 5 for two different species, birch and Douglas fir. These tracheids are responsible for the mechanical support of the tree, and for vertical conduction of water and sap. The remaining 10% consists mostly of transversely oriented cells (Fig. 6), whose function it is to store the food for the tree and transport it horizontally.

Wood is an organic material. On a molecular level, wood consists mainly of cellulose, hemicellulose, lignin and extractives (a variety of chemical substances responsible for properties such as colour, odour, taste, resistance to decay, flammability and hygroscopicity); there are also very minor quantities of inorganic materials. The elemental composition of dry wood is approximately 50% carbon, 44% oxygen, 6% hydrogen and 0.1% nitrogen. Its general chemical composition may be approximated as C_{6}H_{9}O_{4}.

Finally, since wood can exchange moisture with the atmosphere quite easily, it will eventually reach moisture equilibrium with its surroundings. Moisture can exist in wood as free water within the hollow cell cavities, and as bound water physically adsorbed in the cell walls. The point at which the free water has completely evaporated while the cell walls are still fully saturated is known as the fibre saturation point, which occurs at a water content of approximately 27%. If wood is dried below this point, it will begin to shrink, which may lead to cracking and warping as described later. Kiln drying typically reduces the moisture content of timber to about 16%. In equilibrium with exterior air, wood generally has a moisture
content of about 12% to 18%. In a heated building, this will be reduced to about 4% to 10%. The effect of moisture content on deterioration will also be discussed later.

Like other naturally occurring biological materials, wood is subject to deterioration over time. The factors that cause deterioration may be divided into two groups: biological factors and weathering. (It should be noted that this review deals only with the deterioration of timber in construction; biological attack on living trees will not be considered here).

3 Biological factors which cause deterioration

Though different species of wood have different degrees of resistance to biological attack, all will deteriorate under the appropriate conditions. Wood may be attacked by a number of different organisms. To thrive, these organisms require food, oxygen, moisture and warmth. The food, of course, comes from the wood itself. There is generally enough oxygen present in wood to promote the growth of these wood-eating organisms. Even fully submerged wood can be attacked by marine organisms.
Environmental Deterioration of Materials

Figure 6: Douglas fir, tangential plane. (Photograph courtesy of Ms. Mary Mager, Department of Metals and Materials Engineering, University of British Columbia.)

(The British warship, the Mary Rose, which was raised from the seabed in 1982 after having been sunk in a naval engagement in 1545, must be sprayed continuously with cold, fresh water to prevent further biological attack on her timbers). While keeping wood dry will prevent attack from fungi, some insects will attack dry wood. As well, most wood-eating organisms do well at the moderate temperatures which generally promote plant growth. Thus, preventing wood deterioration is generally not a simple procedure, and clearly different types of preservation treatment are required for different types of exposure. However, in general, if wood can be kept very dry and is not exposed to wood-eating insects, it may survive for a very long time, as wooden artefacts recovered from the tomb in Egypt of Tutankhamen, who died in 1352 B.C., attest (Fig. 7).

3.1 Fungi

Fungi are a class of non-flowering plants that contain no chlorophyll. They cannot manufacture their own food, and therefore can grow only on dead or living organic material. They reproduce through the production of microscopic spores that may be spread in various ways. These spores develop into thread-like hyphae which spread through the wood. They secrete an enzyme which de-polymerises the long-chain...
cellulose molecules and the lignin structure, eventually softening and weakening the wood. Fungi grow best at temperatures in the range of about 20°C to 35°C. At low temperatures, fungi remain inactive, but will not die. They also become inactive at temperatures above about 45°C, but will not die until the temperature reaches at least 60°C. There are a number of different types of fungi that may attack wood, and that may cause different types of deterioration. They can often be detected visually, as they sometimes produce fruiting bodies, such as toadstools and even some types of mushrooms.

3.1.1 Brown rot fungi
Brown rot fungi cause the most damage to wood, particularly softwoods, in temperate climates. They attack primarily the cellulose (though they also modify the lignins), and the wood takes on a brown colour. Cracking across the grain, abnormal surface shrinkage and eventual collapse accompany this attack, and there is a rapid loss of strength in the affected wood. For instance, it has been reported that Douglas fir heartwood, which is fairly durable, can lose as much as 25% of its compressive strength perpendicular to the grain, and 15% of its compressive strength parallel to the grain, after only one week of exposure in conditions ideal for fungal growth. Even greater losses would occur in the less durable sapwood.

3.1.2 White rot fungi
White rot fungi, which attack primarily hardwoods, remove both cellulose and lignin from the wood. They cause the wood to lose colour, thus making it appear paler or ‘whiter’. Unlike wood attacked by brown rot fungi, white rot fungi do not
normally cause much cracking or shrinkage; strength loss occurs at a relatively slow rate.

3.1.3 Soft rot fungi
Soft rot fungi attack the lignocellulose in wood. They attack wood that is permanently saturated with water, such as in cooling towers, or in permanent contact with moist soil. They may also attack wood that undergoes cyclic wetting and drying over a long period of time. Soft rot generally attacks only a thin surface layer of the wood. Hardwoods are more susceptible than softwood to soft rot. This type of rot is generally less serious than either brown or white rot.

3.1.4 ‘Dry rot’ fungi
The term ‘dry rot’ is a misnomer, since all wood must be damp in order for rotting to begin (Fig. 8). These fungi have water-conducting strands that can carry water (usually from the soil) to wood that would normally be dry, so that it becomes moist and subject to rotting.

Figure 8: Fungus bloom and dry rot. (Photograph courtesy of Steve Lay, Trinity Termite and Pest Control, Redding CA.)
3.1.5 Mould and stain fungi

Mould and stain fungi live on the carbohydrates stored mostly in the sapwood, and thus have little or no effect on the strength properties of the wood. They thus cause mostly aesthetic damage to the wood. (It should be noted, however, that some moulds may pose a health hazard in some cases to humans, particularly if there is a high level of mould present in a home). The stains produced by these fungi can take on a variety of colours; black, blue and grey are most common, but brighter colours such as various shade of yellow, red, green and orange also occur. On softwoods, the resulting stains can often be brushed off or surfaced off. On hardwoods, however, the stains generally penetrate too deeply to be removed easily.

3.1.6 Control of fungi

For most wood-destroying fungi, the moisture content must be above the fibre saturation point (i.e. above 25%–30%). Since kiln-dried or even properly air-dried woods have moisture contents less than about 20%, they should not be subject to rot if they remain dry in service. However, due to improper construction techniques, the amount of water held in homes or commercial buildings may be excessive, and condensation may occur. This can readily and rapidly lead to severe rotting damage, as in the ‘leaky condominium’ problems that have occurred in British Columbia and elsewhere (Figs 9 and 10). Thus, control of the moisture content of the wood is the best and easiest method of controlling fungi. This may involve proper ventilation, ensuring that no plumbing or other leaks occur, and sealing the wood with paint or other waterproofing materials. Chemical treatments of the wood for this purpose will be discussed later.

Figure 9: Damage to leaky condominium in Vancouver, Canada, due to rotting wood. (Photograph courtesy of Levelton Engineering Ltd., Richmond, BC.)
3.2 Bacteria

Bacterial growth may occur in wood that has a high moisture content – freshly cut, in contact with damp soil, or stored in water or under a water spray. While bacterial decay is not generally a major problem, it may cause a significant loss in strength over long periods of times (decades). Some bacteria may increase the permeability, or the absorptivity, of wood.

3.3 Insects

There are a number of different wood-destroying insects that may infest wood, including termites and some species of beetles and ants. Collectively, they are responsible for a great deal of damage.

3.3.1 Termites

Termites are social insects that live in large colonies (Fig. 11). There are three main classes of termites: subterranean termites, dampwood termites and drywood termites.

Subterranean termites are responsible for most of the serious wood damage. They live in underground nests in damp soil, and will infest wood either directly in contact with the nest, or which they can reach through mud tubes (up to 100-m long) that they construct. The ‘worker’ termites excavate tunnels and chambers through the wood; it is the formation of these galleries that weakens the wood.
One-celled protozoa in the digestive tracts of the termites then break down the wood cellulose from the wood so removed into suitable ‘food’.

**Dampwood termites** generally nest above ground in damp or decaying wood. They require a high moisture content in their nesting area, but can invade adjacent dry wood as well. Compared to subterranean termites, they are of minor economic significance.

**Drywood termites** can live in dry wood, without contact either with the soil or other sources of moisture. They multiply less rapidly than subterranean termites, and do not destroy wood as rapidly. However, over time they too can do a great deal of damage.

### 3.3.2 Control of termites
Apart from chemical treatments, which are discussed later, the best protection against termites is to prevent them from gaining access to the structure. This may involve ensuring that the timber parts of a structure are not in contact with damp soil, preventing cracks in concrete slabs, providing proper ventilation, and so on. Proper painting will generally prevent the ingress of drywood termites.

### 3.3.3 Carpenter ants
Unlike termites, carpenter ants do not use wood as a food source. Rather, they burrow into wood in order to create nesting sites. They may also nest in insulation adjacent to the wood. If left unchecked, they can cause serious damage in structural members as the colonies grow or move to different parts of the structure. As with other insects, carpenter ants prefer to locate close to a source of food. Thus, the best means of prevention is to maintain a sanitary environment, avoid moisture
problems around or within the structure, and prevent vegetation from coming into contact with the structure.

### 3.3.4 Wood-boring beetles

There are a number of beetles (and a few other wasps, bees and weevils) that may infest wood. While most of these attack live trees (and are thus outside of the scope of this chapter), there are some that attack structural timber. For most of these, it is the larvae that cause the damage as they burrow through the wood. In some cases, the damage due to these insects is mostly cosmetic, but in other cases more significant damage may occur. For instance, beetles of the *Lyctus* family infest only hardwoods and are most commonly found in flooring and wood trim. On the other hand, some powder-post beetles of the *Anobiid* type may infest both hardwoods and softwoods and are most commonly found in moist substructures, such as damp crawl spaces. On the whole, however, these insects make relatively little economic impact.

### 3.4 Marine borers

Various kinds of marine borers will attack wood in saltwater or in brackish water. They are found in all of the seas and oceans, but are most active at temperatures of about 10°C.

#### 3.4.1 Shipworms

Shipworms are wormlike molluscs, related to clams and oysters, the most destructive of which are the *teredos*. They are a particular problem in wharves and harbours, where they attack pilings, docks and so on; in extreme cases, they can destroy structural timbers within a year. They tunnel into the wood, creating tunnels up to 12 mm in diameter and up to 1 m in length. They live on the wood borings and the organic material contained in seawater.

#### 3.4.2 Wood lice

Wood lice (Fig. 12) are crustaceans related to crabs and lobsters. They too bore into the wood, but unlike teredos, they confine themselves to the region just below the wood surface. The damage is greatest in the intertidal zone, particularly as the regions weakened by the small burrows are further damaged by wave action, and by abrasion from floating debris.

### 4 Non-biological factors that cause deterioration

#### 4.1 Weathering

The weathering of wood is a complex process, involving drying and wetting effects, exposure to light, freezing and thawing, and exposure to chemicals. Weathering is primarily a surface effect, and so does not particularly affect the mechanical
properties of wood. It is thus mainly of concern with regard to the appearance of the wood.

When freshly cut wood is exposed to the atmosphere, the first noticeable effect is a change in colour, first to yellow or brown, and then to the commonly observed grey due to some chemical breakdown of the cellulose. Beyond this point, in the absence of biological attack, the colour will remain largely unchanged. Exposure to light, particularly ultraviolet light, will increase the severity of the chemical changes. Due to cycles of shrinking and swelling as the wood is dried and rewetted, and sometimes to cyclic freezing and thawing, the surface fibres may loosen and wear away, leading to a very slow surface erosion (estimated to be perhaps 6 to 12 mm/century).

In addition, because of non-uniform moisture changes, the surface will roughen, the wood may tend to warp, and cracks may develop. Weathered wood may also be rather more susceptible to biological attack.

4.2 Exposure to chemicals and other environmental factors

In general, wood is quite resistant to chemical attack. However, wood may be affected, sometimes seriously, by exposure to certain chemicals. Above the fibre saturation point, changes in moisture content have little effect on wood properties. However, below this point, most mechanical properties of wood are related to the moisture content, as indicated by the following empirical relationship:

$$\log P = \log P_{12} + [(M - 12)/(M_p - 12)] \log \left(\frac{P_g}{P_{12}}\right),$$

where $P = $ property of interest, $P_{12} = $ value of property at 12% moisture content, $M = $ moisture content, $M_p = $ moisture content at fibre saturation point (often taken as 25%), $P_g = $ value of property for moisture contents above $M_p$, i.e. for green timber. Thus water, alcohol and certain other organic liquids that cause the wood to swell, but which do not otherwise alter the wood structure, may bring about completely reversible changes in wood properties, in accordance with the
above equation. (It should be noted that this empirical relationship does not hold well for impact, bending, toughness or tension perpendicular to the grain). That is, when these liquids are removed, the wood will return to its original state.

Other chemicals, however, may cause irreversible changes to the wood structure, and degrade its mechanical properties. Thus, while wood is quite resistant to weak acids, it will be attacked by strong acids, which may attack the cellulose or hemicellulose. Highly acidic salts will also attack wood. On the other hand, alkalis and alkali salts will react with the cellulose and the lignins, thus weakening the wood. In general, hardwoods are more susceptible than softwoods to both acid and alkali attack. Iron salts, from the corrosion of iron fittings such as tie plates, bolts and so on, may degrade damp wood, leading to both the commonly observed discolouration around such fittings, accompanied by a softening of the wood. Of course, since different chemicals will have different effects on different species of wood, it is not possible to make more sweeping generalisations about the resistance of wood to chemicals.

High levels of nuclear radiation are known to degrade the strength of wood by decreasing the degree of polymerisation of the cellulose molecules, but this is unlikely to be much of a problem in practice, since nuclear reactor vessels would never be constructed of wood.

Thermal effects on wood properties are more significant. Below approximately 200°C, the mechanical properties of wood increase in an essentially linear fashion as the temperature decreases. If wood is heated or cooled below about 65°C fairly rapidly, the changes in properties with temperature are reversible. However, if wood is exposed to higher temperatures than that for long periods of time, the wood itself will degrade, probably due to acid hydrolysis of the cellulose. There will be a loss not only in strength, but also in mass. This effect is more marked in hardwoods than in softwoods. The loss in properties is also greater at higher moisture contents. Thermal effects can be quite dramatic. For instance, keeping wood at 115°C for 250 days will reduce its strength by about 35%; at 135°C, this change will occur in about 50 days; and at 175°C, it will occur in less than one day.

5 Fire

Wood is obviously a highly flammable material; it has been used as a source of fuel for at least 500,000 years. However, because of the way in which wood burns, timber structures may have a remarkable degree of fire resistance, sometimes even better than that of steel structures. The fire resistance of large sections of wood depends on temperature, moisture content, duration of heating and specimen geometry.

The ignition temperature for wood is not a well-defined property; it depends both on the way in which it is measured, and on the type of wood. The value of 200°C is often taken as the temperature at which wood will ignite in the presence of an open flame (which will ignite the combustible gases given off as the wood is heated), but this depends on the duration of exposure to that temperature. For instance, after about 30 minutes of exposure, many woods will ignite at about 180°C; at 300°C they will ignite in about 2 minutes; and at 400°C, in 30 seconds or less. If wood
Environmental Deterioration of Timber

Fire

Char base (T = 288°C)

Pyrolysis zone base

Pyrolysis zone

Char layer

Normal wood

Figure 13: Degradation of wood exposed to fire on one surface.

is simply heated in hot air (in the absence of a flame), ignition may occur at temperatures as low as 330°C in less than one hour.

The particular way in which wood burns is the reason that large wood timbers are remarkably fire-resistant. Fig. 13 shows schematically the degradation zones in a large wood member exposed to fire on one face only. When burning begins, a char layer develops on the surface, which slowly progresses into the wood. At the base of this layer, the temperature is about 288°C. However, since wood is an excellent insulator, the temperature falls off rapidly beyond the char base; for Douglas fir, the temperature would be only about 93°C, 13 mm in from the char base. In the pyrolysis zone, the wood begins to decompose at a temperature of about 66°C, emitting water vapour, smoke, and both flammable and non-flammable gases. The char zone itself is also a very good insulator, and this helps to prevent strength loss in the interior of the timber section. The rate at which the char base moves into the wood depends upon the species, the density and the moisture content. It is slower at higher moisture contents and densities, and for more impermeable species of wood. For dry Douglas fir, the charring rate is only about 0.6 mm per minute in large sections.

Of course, the spread of a fire through a structure depends on much more than the properties of the wood itself; the entire structural system must be properly designed to provide fire protection. This would include proper fire separations both horizontally and vertically, properly protected openings for stairs and doors, avoidance of combustible finishes and furniture, proper protection for light framing and so on. A detailed discussion of design procedures for fire is well beyond the scope of this chapter.

6 Techniques for preserving wood

Over the years, many different techniques have been developed for wood preservation, depending on the type of wood, the nature of the problem, the exposure conditions and costs. Often, this may consist only of regular painting and maintenance. However, there are many instances in which chemical preservatives must
be applied in order to protect the wood from the types of deterioration discussed earlier.

Both the amount of preservative that is impregnated into the wood and the depth of penetration must be considered when assessing the relative effectiveness of the different types of treatments. These factors will depend, in turn, on the method by which the preservative is applied. If non-pressure methods of application are used, such as brushing, spraying or dipping, there will not be much absorption or penetration of the preservative into the wood. Much more effective treatment can be obtained by the application of pressure (sometimes in conjunction with the application of a vacuum) to force a larger quantity of the preservative deeper into the wood. The chemical preservatives that are used may be dissolved either in water or oil. In all cases, however, the preservatives must not be unduly flammable or harmful to people or animals, and they must be economical to use.

6.1 Waterborne preservatives

Waterborne preservatives consist of salts that are dissolved in water. They are used largely for timber and plywood in general residential and commercial structures. They are becoming increasingly popular because they are essentially odourless and because they leave a clean wood surface that may be painted or stained. In North America, the most common of these is chromated copper arsenate (CCA) that is available in three different combinations of chromium trioxide, copper oxide and arsenic pentoxide, depending on the specific application. It is now often used for poles, posts, pilings and foundation timbers as it provides protection against fungi and termites. Some environmental concerns have, however, been raised about its use. It has been found that in some areas, the CCA may drain off freshly treated wood, or leach out of treated wood into the soil, groundwater or nearby rivers and streams, leading to elevated concentrations of arsenic.

Several other waterborne preservatives are also recommended by ASTM. Acid copper chromate (ACC) is a combination of copper sulphate and sodium dichromate with some chromic acid, and makes wood more resistant to termites and decay. Ammoniacal copper arsenite (ACA) is often used for timber and plywood intended for house foundations. It consists of copper and arsenic salts in an aqueous ammonia solution. Chromated zinc chloride (CZC) can provide protection not only against insects and decay, but also against fire. It consists of a combination of zinc chloride and sodium dichromate. It is best used in dry conditions, as it can be leached out of wood in a moist environment. Fluorochrome arsenate phenol (FCAP) consists of fluoride (either sodium or potassium), sodium dichromate, sodium arsenate and dinitrophenol. It, too, performs best above ground as, like CZC, it is subject to leaching.

6.2 Oilborne preservatives

By far the most widely used of the oilborne preservatives is creosote, produced mostly from the distillation of coal tar. It is highly toxic to the fungi and insects.
that attack wood, is insoluble in water and has great permanence because of its low volatility. It is also relatively inexpensive and can easily be applied. It is particularly effective on large timbers, such as railroad ties (sleepers) and bridge timbers. Unfortunately, it has an unpleasant odour and leaves an oily surface that prevents the wood from being painted. It is thus unsuitable for most residential construction. Creosotes can also be manufactured from other organic materials, but such creosotes tend to be less effective than those made from coal tar.

Coal tar creosote may be mixed with coal tar or petroleum to produce creosote solutions, mostly in order to reduce the cost of the preservative. They are used in the same way as creosote and are generally almost as effective. Indeed, they are better than creosote in providing protection against checking and weathering of the wood.

Pentachlorophenol (C₆Cl₅OH), often referred to simply as ‘Penta’, can be dissolved in various mineral spirits and petroleum oils. It is then toxic to wood-destroying organisms. It too leaves a surface that cannot generally be painted.

Copper naphthalene and tributyltin oxide have been found to offer reasonable protection against marine borers.

Copper-8-quinolinolate is recommended where the treated wood is to be used for harvesting, storage or transportation of foods.

### 6.3 Weather-resistant coatings

In order to protect wood against weathering, a large number of surface coatings are available. These include everything from water-repellent treatments to pigmented stains, varnishes and paint. Of these, paints are most effective and are generally used not only for preservation but also for aesthetic reasons. Of course (as any homeowner knows), all of these surface treatments have a relatively short effective life, and so the wood must be refinished on a regular basis for them to retain their preservative qualities.

### 7 Fire retardants

As noted in Section 5, a properly designed and constructed timber structure can be remarkably fire-resistant. In addition, to satisfy most fire codes, the wood should also be chemically treated with one of the many available fire retardants. While none of the chemical treatments can render wood truly ‘fire-proof’, they can considerably improve its fire-retarding capacity. The mechanisms by which fire retardants act are still not fully understood. It is believed that some retardants provide a coating that insulates wood as well as prevents air and flame from coming into contact with the wood itself. Some retardants may also provide a gas that inhibits the combustion of the gases given off by the wood as it is heated. Retardants may as well change the thermal reactions that occur during combustion. Depending on the particular situation, and on the particular fire retardant employed, any or all of these mechanisms may occur.
There are two general types of fire-retardant treatments: surface coating with fire resistant paint and pressure impregnation with waterborne salts.

7.1 Surface coatings

While surface coatings are generally less effective than pressure impregnation, they provide the only means of providing some protection to existing structures. The effectiveness of these paints depends on their chemical composition and on the thickness of the applied coating. A number of different formulations are available. In water-based paints, ammonium phosphate or sodium borate are commonly used to provide some fire resistance. In oil-based paints, chlorinated paraffins and alkyds plus antimony trioxide are most common. Most of these fire-retarding paints are intended for interior use, though there are a few that may be used on exterior surfaces.

7.2 Pressure impregnation

Like surface coatings, most pressure impregnation treatments are also intended for interior use, though again there are a few formulations for outdoor exposure. Because of the depth of penetration and the amount of chemicals that may be forced into the wood, this technique provides a greater degree of protection than do surface coatings. To be effective, the amount of fire-retardant salt which penetrates into the wood should be in the range of 40–80 kg/m³. It should be noted, however, that these fire-retardant treatments generally have some effect on the mechanical properties of wood. Strength may be decreased by up to 20%; in the United States, the allowable design stresses for treated wood are reduced by 10% compared with those for untreated wood. There may be some difficulties in machining treated wood because of the abrasive effects of the salt crystals that are used in most fire retardants on the cutting tools. As well, gluing of treated wood becomes more difficult.

The salts that are typically used are combinations of ammonium sulphate, zinc chloride, monoammonium phosphate, diammonium phosphate, boric acid and sodium tetraborate. The salts are best impregnated into air-dry or kiln-dry wood, and a depth of impregnation of at least 1.3 cm should be achieved. It should be noted that since most of the salts used for this purpose are water-soluble, care must be taken to ensure that they are not leached back out of the wood by exposure to excess moisture.

8 Economic considerations

It is difficult to over-estimate the cost to individuals, and to society at large, of permitting wood to rot or otherwise degrade prematurely. Globally, the annual losses due to decay of wood from the biological processes discussed earlier has been estimated to be US$ 10 billion. For instance, in the United States alone, homeowners spend at least US$ 500 million per year simply on replacing rotted and termite damaged wood, exclusive of labour costs. Similarly, in the Canadian province of
British Columbia alone, the cost of repairs to the ‘leaky condominiums’ built in the late 1980s and early 1990s was estimated to be up to US$ 500 million. The cost of ‘doing it right’ in terms of both the treatment of the wood itself and the architectural design (rain screens, protective envelopes, proper attention to ventilation, etc.) might have added 7%–10% to the original selling price of each unit, but would have saved vastly more in terms of both reconstruction costs and personal suffering.

**Literature for further reading**


