# Guides to practice in Corrosion Control

# CORROSION OF METALS BY WOOD

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# CORROSION OF METALS BY WOOD

## 1 INTRODUCTION

Wood is a corrosive substance by nature, and can be made more corrosive by treatment given to it. Unlike most other corrosive substances, one of the corrosive chemicals in it, acetic acid, is volatile, and in an ill-ventilated space, wood can cause corrosion of metal nearby but not actually in contact. Where there is contact in atmospheric conditions, corrosion can occur by the usual micro-electrolytic mechanisms, and in immersed conditions, large-sized electrolytic cells can form. Corrosion problems caused by wood can therefore arise in three areas:

(a) inside wooden containers, by vapour corrosion without contact;
(b) at contacts in land-based structures, through attack by wood acids and wood treatment chemicals;
(c) at contacts in immerse structures, where macro-galvanic mechanisms predominate.

## 2 SOURCE OF CORRODENT

### 2.1 NATURAL CORRODENTS

The principle constituent of wood is cellulose, which is a polysaccharide, i.e. a polymer made of sugar molecules joined in long chains. Each sugar unit contains mildly basic hydroxyl radicals, a proportion of which is combined with acetic acid radicals (acetylated) in the form of ester (organic salt) groupings. These groupings can combine with water (hydrolyse) to give free hydroxyl radicals and acetic acid.

The chemical equation is:

$$\underset{\text{acetylated group}}{X - 0.CO.CH_3} \quad + \quad \underset{\text{water}}{H_2O} \leftrightarrows \underset{\text{free radical}}{X - OH} \quad + \quad \underset{\text{acetic acid}}{CH_3COOH}$$

where X is the sugar unit in the chain.

This is an equilibrium reaction, which causes the moisture in wood to be always acid, but because the acetic acid is volatile and can escape, the reaction move slowly to the right hand side all the time. The acetyl radical constitutes about 1 to 6% by weight of dry wood, more in hardwoods than in softwoods, and this figure determines the total quantity of acetic acid than can be formed. The rate of emission of acetic acid depends on the species, and a wood of lower acetyl content can liberate acetic acid faster under given conditions than another wood of higher content. In a given wood, the rate of formation of acetic acid depends on the temperature and the moisture content of the wood, and the rate of its escape to the atmosphere depends on the geometry of the piece of wood in question. Besides acetic acid, small quantities of formic, propionic and butyric acids are present in wood, but their effects can be neglected in comparison with those of acetic acid.

Wood contains from 0.2 to 4% of mineral ash, which consists largely of calcium, potassium and magnesium as carbonate, phosphate, silicate, and chloride; aluminium, iron and sodium are also present. Sulphate contributes 1 to 10% of the ash by weight, and chloride 0.1 to 5%, and these two radicals augment the corrosive action of the acetic acid.

## 2.2 EFFECT OF FUNGI

In experiments on the development of acidity in wood during storage, and its liberation to the atmosphere, it has been found that wood preservatives which inhibit the growth of fungi and other biological actions do not affect the formation of acetic acid, showing that the mechanism is purely chemical and not biological. On the other hand, free acid does not appear when the wood is infected by certain fungi. These fungi are of the thermophilic type which are able to grow well at relatively high temperatures, but are still active at warm atmospheric temperatures. The mechanism by which the fungi prevent the accumulation of acid is not certain, but it appears likely that they act by neutralising or decomposing the acid as fast as it is produced and not by preventing its formation. The idea of using fungi to inhibit the development of corrosive acid may appear attractive, but these fungi will only grow when the wood is damp and therefore open to attack by wood-rotting fungi.

In extreme cases of fungal attack within enclosed spaces, volatile products from the fungi themselves, mainly carbon dioxide but probably with traces of other volatile acids, can attack metals within the enclosure.

## 2.3 EFFECT OF KILN DRYING

Kiln drying accelerates the production of free acetic acid in wood, but most of the acid does not have time to escape. Kiln dried wood is more acid and more immediately corrosive than air dried wood, though it contains less combined acid that can be set free in later years.

## 2.4 ADVENTITIOUS CORRODENTS

The natural chloride content of wood is low (0.1 to 5% of the ash, which is 0.2 to 4% of the dry weight of the wood), but cases have occurred of severe corrosion of metals in contact with woods that were not particularly acid, but which were found to contain appreciable quantities of salt, up to 0.8% by weight. Wood can absorb salt; the likely sources of adventitious salt are twofold:

(a) salt spray and mist near the coast;
(b) the floating of logs in seawater.

The following are examples of corrosion in wood found to contain substantial quantities of chloride:

(i) corrosion of plain steel nails in tile battens in a church in a south coast town resulting in tiles falling from the roof; ascribed to sea spray ;
(ii) corrosion of steel cables wound on soft wood drums;
(iii) bimetallic corrosion of nickel plated steel covers to coffin handles made of nyatch, a timber from south-east Asia;

(iv) corrosion of coppered iron tacks fixing canvas to the ramin frames of hospital beds. The bimetallic corrosion produced enough alkali to degrade and weaken the canvas.

In examples (ii) to (iv) the source of chloride was probably the floating of logs in seawater. Timber is often floated downstream to the coast, and may float in seawater for some time before it is picked up for further transhipment.

## 2.5 TREATMENTS FOR WOOD THAT INTRODUCE CORROSIVE SUBSTANCES

### 2.5.1 Salt seasoning

In Section 2.4 above, the accidental contamination of wood by salt was mentioned. Even larger quantities of salt, up to 4% by weight, can be introduced by a slat seasoning process used in some parts of the world for drying certain hardwoods, including maple. In this process the green timber is close piled with layers of salt between the boards. Salt absorbed by the wood lowers the vapour pressure of water in it, so that when the boards are subsequently dried, the rate of evaporation at the surface, and the extent of surface checking, is reduced.

Salt seasoning was thought to be the cause of corrosion of the screws, brackets and other metallic components in contact with maple in certain pianos, especially some stored in humid conditions, for example, in tropical climates . The maple was found to contain up to 4% salt. Other metals parts in the same pianos in contact with other woods not containing salt did not corrode.

### 2.5.2 Flame retardants

The salts most commonly used in the UK are mono- and di-ammonium phosphate, ammonium sulphate, boric acid and borax. Most proprietary materials are mixtures of such substances. Formulations may include copper-chrome-arsenic fungicide to give a dual purpose material, and corrosion inhibitors may be added. The concentration of flame retardant in the surface of the wood can be quite high. Of these salts, ammonium sulphate is considerably corrosive. The ammonium phosphates are less corrosive, but not negligibly so. Boric acid is not appreciably corrosive, and borax is a mild inhibitor. All the salts increase the moisture content of the wood in contact with air of given relative humidity. The ammonium compounds can reduce the mechanical properties of the wood, especially if the wood is kiln dried after impregnation. Corrosive flame retardants can contribute markedly to the corrosion of metal in contact with wood, but not, except in the unusual circumstances described in Section 5 below, to vapour corrosion.

### 2.5.3 Preservatives

Treatments to prevent attack by fungi and wood-boring insects fall into four main types:

(a) *Creosote or tar oil* This substances have little corrosive action, except towards lead; in so far as they waterproof the wood, the effect may be protective.

(b) *Copper-chrome-arsenic (CCA)* This is widely used. The chromium salt constituent may have a small protective effect, and the arsenate radical a small corrosive one, but other salts formed during the process, notably sodium sulphate, remain soluble and are corrosive. In addition, the copper itself is potentially corrosive, for copper-based preservatives can leach soluble copper compounds to the extent of parts, or tenths of parts per million, and this copper can then plate out as metal on to iron, zinc and aluminium, forming galvanic cells that accelerate the corrosion of the substrate metal. The leaching is much greater from freshly treated wood, and it is recommended that preserved wood be allowed to age for seven days before fasteners are inserted in it, thereby giving time for the preservative to become fixed in the wood.

(c) *Naphthenates* Copper naphthenate has the same potential hazard by formation of soluble copper as copper-chrome-arsenic. Zinc naphthenate does not.

(d) *Boron compounds* These have a negligible corrosive effect on fasteners but prolonged exposure to damp causes the formation of alkali which might degrade the wood.

(e) *Organic solvent types* Examples are pentachlorphenol and lauryl pentachlorphenate, sometimes containing water repellents. They have a negligible effect on corrosion unless alkali produced by other corrosive action decomposes them to form soluble chloride. Any water repulsion they confer will be beneficial.

## 3. RELATIVE ACIDITIES OF WOODS

Table I lists the acidities of a number of woods (the pH values of a standard quantity of 5 parts of distilled water in contact with 1 part of wood raspings or sawdust).

**Table I Acidities of woods**

| Wood | Typical pH values | Vapour corrosion hazard |
|---|---|---|
| Oak | 3.35, 3.45, 3.85, 3.9 | High |
| Sweet chestnut | 3.4, 3.45, 3.65 | High |
| Steamed European beech | 3.85, 4.2 | Fairly high |
| Birch | 4.85, 5.05, 5.35 | Fairly high |
| Douglas fir | 3.45, 3.55, 4.15, 4.2 | Fairly high |
| Gaboon | 4.2, 4.55, 5.05, 5.2 | Fairly high |
| Teak | 4.65, 5.45 | Fairly high |
| Western red cedar | 3.45 | Fairly high |
| Parana pine | 5.2 to 8.8 | Moderate |
| Spruce | 4.0, 4.45 | Moderate |
| Elm | 6.45, 7.15 | Moderate |
| African mahogany | 5.1, 5.4, 5.55, 6.65 | Moderate |
| Walnut | 4.4, 4.55, 4,85, 5.2 | Moderate |
| Iroko | 5.4, 6.2, 7.25 | Moderate |
| Ramin | 5.25, 5.35 | Moderate |
| Obeche | 4.75, 6.75 | Moderate |

These pH values are probably reasonably representative of the acidities of the wood stored at temperate temperatures and humidities. Under extreme storage conditions, much greater acidity can develop, as shown in Table II.

**Table II Acidity of birch stored under damp conditions at 48 °C**

| Storage time (days) | pH of moist wood |
|---|---|
| 0 | 4.60 |
| 7 | 4.40 |
| 14 | 4.12 |
| 19 | 4.11 |
| 36 | 3.85 |
| 55 | 3.80 |
| 103 | 3.48 |
| 126 | 3.32 |

It is probable that other woods will develop much greater acidity in this way if stored under extreme conditions.

Values of pH give a measure of the content of free acetic acid in the wood at the time of measurement. An idea of the total reservoir of potential acid, i.e. the content of combined acetyl groups, and the rate at which the acetyl groups can hydrolyse to form free acetic acid, is given for five woods in Table III:

**Table III Acetyl content of wood before and after damp storage for two years at 48 °C**

| Wood | Acetyl content, %wt of wood | | Acetyl hydrolysed %wt of wood | Acetyl hydrolysed % of that present |
|---|---|---|---|---|
| | Before storage | After storage | | |
| Oak | 2.59 | 0.13 | 2.46 | 95 |
| Beech | 3.21 | 1.40 | 1.81 | 56 |
| Birch | 3.64 | 1.67 | 1.97 | 54 |
| Douglas fir | 1.10 | 0.38 | 0.72 | 65 |
| Obeche (18 months) | 1.41 | 0.96 | 0.45 | 32 |

The figures in Table III illustrate:

(a) there is a wide range of initial acid contents in different species of wood;
(b) that woods vary in the ease with which the acetyl is hydrolysed to free acetic acid;
(c) that a wood with a lower acetyl content (oak) can give more free acid in a given time than woods with higher content (beech and birch);
(d) that even after two years' damp storage at 48 °C, five of the six woods still retained an appreciable amount of acetyl yet to be hydrolysed – only the oak is harmless, so far as potential production of further acetic acid is concerned.

The experiments above were done under extreme conditions of storage. The writer estimates that the equivalents to two years at 48 °C are four years at tropical temperatures and 20 years at temperate temperatures; if the wood were moistened only intermittently, the periods would be much longer. The general conclusion is that all woods produce acetic acid as they age, and that acid continues to be formed for many decades after the wood is felled, even from those woods in which initial production is relatively rapid.

The acid in the wood, as revealed by the pH value, can cause corrosion by contact, and that evaporating from the wood can cause vapour corrosion within enclosed spaces. The third column in Table I classifies the woods broadly for the vapour corrosion hazard they give. It will be seen that there is a rough, but only a rough, correlation between the pH values quoted and the vapour corrosion hazard. We have seen, however, (Table II), that pH values can change markedly during storage, so not much reliance can be placed on theme. As a rough rule, woods with acidities of pH less than 4.0 are likely to be highly corrosive, and those of pH more than 5.0 relatively safe. A better rule is to rely on the practical results given in column 3 of Table I; oak and sweet chestnut, long known for their corrosive properties, should be avoided, and choice made where possible from woods classified as only moderately corrosive. As with attack by other corrosive substances, the influence of moisture on the rate of attack, by contact or by vapour, is paramount, and will be considered in Section 4.2 below.

## 4 VAPOUR CORROSION INSIDE WOODEN CONTAINERS

### 4.1 METALS SUSCEPTIBLE

The corrosive agent is acetic acid emitted by the wood, and the metals most susceptible are those readily attacked by it. The following list shows the degree of susceptibility to attack:

*Group 1 – Severe attack*
  - Cadmium,
  - Carbon steels
  - Low alloy steels
  - Lead and lead alloys
  - Zinc and zinc alloys
  - Magnesium and its alloys

*Group 2 – Moderate attack*
  - Copper and its alloys (but see section 5 below)

*Group 3 – Very slight attack*
  - Aluminium and its low strength alloys; slightly greater for Al-Cu and Al-Zn alloys
  - Nickel

*Group 4 – Insignificant attack*
  - Austenitic stainless steel
  - Chromium
  - Gold
  - Molybdenum
  - Silver
  - Tin
  - Titanium and its alloys

### 4.2 EFFECT OF HUMIDITY

Table IV gives typical results of the corrosion in an enclosed vessel of four metals by 1% acetic acid dissolved in various solutions chosen to maintain the relative humidity within the vessel at the levels stated. The vessels were kept at 30 °C.

**Table IV Corrosion of metals by an acetic acid atmosphere at various humidities**

| Metal | Corrosion, g/dm$^2$, in 40 days | | | |
|---|---|---|---|---|
| | 72% RH | 85% RH | 96% RH | 100% RH |
| Cadmium | 0.12 | 1.4 | 1.6 | Very large |
| Zinc | 0.12 | 0.75 | 1.05 | Large |
| Steel | Trace | 0.9 | Very large | Very large |
| Copper | Trace | Trace | 0.65 | 1.0 |

These figures show the paramount influence of relative humidity on vapour corrosion by acetic acid. Even steel, which is particularly heavily attacked at high humidities, is attacked only very slowly at 72% RH (and below). It is interesting that this threshold figure is the same as for the corrosion of steel by the sulphur dioxide in an industrial atmosphere. Copper, on the other hand, has a threshold above 85% RH, and a not too high rate of corrosion at 96% and 100% RH, hence its classification as a Group 2 metal in section 4.1. Some other evidence puts the threshold for magnesium alloy at 63% RH.

Although no figures are available, it is a reasonable assumption that water promotes the formation of acetic acid in wood (the forward reaction in the equation in Section 1). It then follows that high humidity has a twofold effect, in that it both promotes the formation of acid and the subsequent corrosion by that acid.

## 4.3 EFFECT OF CONCENTRATION OF VAPOUR

Table V shows the threshold concentration of acetic acid solutions whose vapours cause corrosion in a close space of the five metals listed at 100% RH and 30 °C. The rates of corrosion below the thresholds are low but not nil.

**Table V**

| Metal | Threshold concentration, %vlv, of acetic acid solution in water | |
|---|---|---|
| | For appreciable corrosion | For rapid corrosion |
| Cadmium | 0.01 | 0.05 |
| Zinc | 0.001 | 0.01 |
| Steel | 0.001 | 0.01 |
| Copper | 0.1 | 1.0 |
| Brass | 0.1 | 1.0 |

*Note 1* The concentration of acetic acid in the vapour phase, mg/1 (ppm) = 0.13 x the acid content of the solution, %vlv.
*Note 2* “Appreciable” corrosion means 0.005 g/dm$^2$/day, “rapid” means 0.05 g/dm$^2$/day.

At humidities lower than saturation, the arbitrary thresholds would be higher.

Unfortunately, no determinations have been made of the actual concentrations of acetic acid vapour inside wooden boxes, but it is clear that corrosion is caused by only very small quantities.

## 4.4 CYCLING OF ACETIC ACID VAPOUR

Although some metals exposed to high concentrations of acetic acid vapour give a corrosion product of the metal acetate, the normal corrosion product is basic and may contain little acetate. This implies that the initial acetate corrosion product hydrolyses to release acetic acid again, so that a small initial quantity of acid causes a disproportionate amount of corrosion. The same cycling effect is well known in the corrosion of steel by sulphur dioxide.

## 4.5 CONDITIONS INSIDE WOODEN BOXES

If a sealed *metal* box is warmed, the relative humidity of the air inside decreases, the absolute humidity (g water vapour per $m^3$) remaining the same. If a sealed *wooden* box is warmed, however, so much moisture is released from the wood that the relative humidity actually increases, the absolute humidity increasing sharply. This effect is illustrated indirectly by Table VI, which shows the approximate moisture content of wood required to give rise at different temperatures to a relative humidity of 80%, a level at which acid vapour corrosion proceeds rapidly.

**Table VI**

| Temperature, °C | Moisture content of wood to give 80% RH |
|---|---|
| 15 | 20 |
| 25 | 18 |
| 40 | 16 |
| 70 | 12-14 |

The moisture content of well dried wood is of the order of 16 to 18%. The figures show that even with well dried wood, a corroding humidity can be reached easily in a temperate climate, and all the time in a tropical one. If the wood becomes wetted, corrosive conditions can develop at any temperature, and be very severe at higher temperatures.

## 4.6 AVOIDANCE OF VAPOUR CORROSION INSIDE WOODEN BOXES

### 4.6.1 General note on avoidance of vapour corrosion

Vast numbers of metal objects are transported in wooden boxes without loss by corrosion. The metals are protected, the wood is of the less corrosive sort, is dry to begin with and does not become wet for any length of time, and the packs are opened promptly. It is when one or more of these conditions does not apply that vapour corrosion can become a hazard.

### 4.6.2 Choice of wood

Use Table I to avoid the more corrosive woods and to choose from the less corrosive ones. For woods not in the table, use past experience or, as a last resort, go by the pH value and choose a wood with pH greater than 5.0. (Any laboratory can determine the pH value quickly and easily.)

### 4.6.3 Condition of wood

Avoid fresh wood. Avoid kiln dried wood. Avoid damp wood. Keep wood in a dry atmosphere for as long as possible before use.

### 4.6.4 Ventilation

Acid vapours will not corrode if they blow away, but a small amount of ventilation is useless, especially if venting is blocked when boxes are piled. Only open slats are likely to give enough ventilation.

### 4.6.5 Coating the wood

The emission of acetic acid vapour from wood is retarded, but not stopped, by paint or lacquer applied to the wood. *It must not be forgotten, however, that oleoresinous and some other paints and phenolic varnishes themselves emit corrosion vapours* (formic and acetic acids). Choice of coating must be made from those known not to emit corrosive vapours, viz: nitrocellulose (a fire risk), shellac (probably a poor barrier) or preferably acrylics and two-pack epoxides and polyurethanes.

Lime washing, which might be expected to absorb acetic acid vapours, has been found ineffective.

### 4.6.6 Impervious linings

Boxes can be lined with aluminium or zinc foil. If the lining is complete and remains intact, no vapours can pass it. Glues must not spill inside, as many glues emit corrosive vapours.

### 4.6.7 Inner packs

The safest way of protecting valuable goods is first to pack them in a vapour-proof wrapping, heat-sealed or zipped, and preferably desiccated inside, with a transparent window behind which is lodged a cobalt chloride humidity indicator. Polyethylene of thicker gauges is a fairly good barrier, but the best is the sandwich containing a centre layer of aluminium foil. With a first class barrier, even wood shavings could be used as an outer cushioning material, though if the barrier becomes torn, dire trouble would ensue.

### 4.6.8 Protective coatings on steel

Corrosion by acetic acid vapour resembles that by sulphur dioxide in an industrial atmosphere, though in the most severe cases it is more rapid than anything caused by an atmosphere that is still breathable. It follows that protective treatments effective against industrial atmospheric corrosion show an equal order of effectiveness against vapour corrosion. For smaller items, the following protective treatments, additional to those that might be thought adequate for service use, should be considered:

(i) Full colour chromate passivation of zinc and cadmium gives some useful protection.
(ii) A tin flash (2.5 µm) over cadmium plate gives useful protection provided the tin is not porous.
(iii) Etch primer gives very fair protection to zinc and cadmium plate. A full paint scheme, applied over etch primer or over chromate passivation, gives excellent protection.
(iv) Tin plating, itself highly resistant to vapour corrosion, gives excellent protection, until it breaks down, when corrosion is accelerated. A minimum thickness of 25 µm) is recommended. Tin can be lacquered or painted for extra protection.
(v) Tin, cadmium and tin zinc alloy plating have no consistent advantage over cadmium and zinc.
(vi) Nickel plus chromium coatings should give the same order of protection

### 4.6.9 Protective coatings on other metals

Zinc should be treated as for zinc plate in Section 4.6.8 above. Magnesium alloy, being highly susceptible, should never be crated in other than the fully protected condition. Aluminium and its alloys with their normal protective treatments, and stainless steel, will be safe. Copper and its alloys will need protection by lacquering or painting; plating with tin, silver or gold will give good protection.

### 4.6.10 Temporary protectives

These will give the same order of protection as against atmospheric corrosion, see the relevant guide on this website Guide in the present series.

### 4.6.11 General note on protection

The relative corrosivities of rural, industrial and marine atmospheres are fairly well known, and good choices of protectives can be made. Conditions inside a wooden box are less predictable and can be worse than any natural atmosphere; a box made of freshly felled oak stored out of doors in the tropics would corrode even a highly resistant metal in time. The statements about protective efficiency given above apply only when precautions have been taken to avoid severe accumulations of corrosive vapour.

### 4.6.12 Precautions during storage

Boxes should be stored under ventilated top covers. If storage in the open is unavoidable, white plastic drapes can be used for protection against rain and sunshine, with the proviso that enclosing a box already damp is worse than useless. The drape should be white, to prevent the box becoming too warm in the sun, for the relative humidity inside a wooden box *rises* with a rise in temperature. (Section 4.5.)

## 5 AN UNUSUAL CASE OF THE VAPOUR CORROSION OF A COPPER ROOF

Rapid severe corrosion from the inside has occurred on the copper roof of a belfry in Denmark. The roof was supported above a concrete floor by wooden trusses treated with a fire retardant consisting of ammonium sulphate, di-ammonium phosphate, boric acid and sodium borate. Condensation occurred within the roof-space, and the water leached ammonium salts from the wood and then dripped on to the floor. The alkali in the concrete reacted with the ammonium salts to form ammonia vapour which attacked the copper. The initial cuprammino corrosion product decomposed to a basic sulphate/carbonate releasing ammonia which further attacked the copper. A thickness of 0.8 mm was penetrated in three years.

It is possible for ammonium salts to emit ammonia. Of all metals, copper is particularly susceptible to attack by ammonia. It is unwise to have ammonium salts near copper, and disastrous if alkali is present too.

## 6 CORROSION IN CONTACT WITH WOOD, INLAND STRUCTURES

### 6.1 WOODS

The pH values of woods (Table I) are of direct relevance to corrosion by contact, but the information they give is only relative. The values are those of the aqueous extracts, not of the actual moisture within the wood. Values vary within a species, from heartwood to sapwood (heartwood being usually somewhat more acid) and with storage (Section 3). For deeply embedded fasteners, the permeability of wood towards water, oxygen and carbon dioxide also plays a part. Iron fasteners in impermeable woods, such as the white oaks, can last a long time even in immersed conditions, probably because of lack of oxygen and of carbon dioxide to decompose the initial acetate corrosion product (Section 4.4). Some authors have suggested that the tannins in wood act as corrosion inhibitors, but it may be that their effect, in any, is as oxygen scavengers. Notwithstanding the reservations above, experience has shown that the four most acid woods in Table I are oak, sweet chestnut, Western red cedar and Douglas fir, and are indeed those most liable to corrode metals embedded in them, or in contact with them under damp conditions.

### 6.2 METALS

The order of susceptibility to corrosion by contact is broadly the same as that to vapour attack, as given in Section 4.1. That the susceptibility of zinc is as high as steel does not mean that it is not worth while using zinc coated steel; the steel will not rust until the zinc has corroded away, which under less than severe exposure conditions, can take a long time.

### 6.3 MOISTURE CONTENT

The moisture content of dry wood is some 16 to 18% by weight and at this figure the corrosive effect is mild. Under damp conditions, however, moisture is absorbed and the wood becomes corrosive. The passage of moisture across the grain is a slow process, and occasional wetting will affect only the surface layer. Conversely, saturated wood takes a long time to dry out. Diffusion along the grain can be a hundred times more rapid, and exposure of end-grain to the weather should be avoided.

## 6.4 WOOD TREATMENTS

The additional corrosion hazard from sea salt (Section 2.4), salt seasoning (2.5.1), some flame retardants (2.5.2) and some preservatives (2.5.3) have already been discussed. A simple test paper can be prepared for detecting the presence of chloride in wood.

## 6.5 AVOIDANCE OF CORROSION

### 6.5.1 Effect of conditions of use

The conditions of use determine the likely moisture content of the wood and hence its corrosivity, and therefore in turn the precautions that must be taken to avoid corrosion. Recommendations are therefore given below in terms of use.

### 6.5.2 Heated indoor conditions

The risk of corrosion is always present, and galvanising (or other forms of zinc coating) of steel fastenings is the minimum precaution. The liability to damp depends very much on the design of the structure, the location of heat insulation, and ventilation. If conditions are not known to be favourable, fasteners of aluminium, stainless steel, copper alloy, monel, or plastic coating steel should be used; these materials are preferable for all tile and batten nails in roofs especially near the coast. In timber treated with flame retardants, stainless steel, monel or plastic coated steel is recommended; aluminium is marginal in this case, and copper suspect (Section 5).

Timber treated with CCA preservative should be allowed to age for at least a week before fasteners are inserted (Section 2.5.3b); if conditions are not known to be favourable, zinc coatings and aluminium are suspect, and stainless steel, copper alloy, monel and plastic coated steel preferred; it might have been better to have chosen an organic solvent preservative in the first place. Steel brackets, and steel members in composite structures should be zinc coated steel)

### 6.5.4 Structures in the open

Semi-permanent structures such as fences, sheds and greenhouses are normally treated with preservative, not painted. Zinc coated (galvanised or sheradised) steel fasteners are adequate for the less corrosive woods. For the more corrosive woods – such as cedar – stainless steel, copper alloy or monel should be used.

Permanent structures are normally painted or oiled. It is essential to maintain paint, as blistering paint forms a poultice that may hold water and cause local damp spots, rot and corrosion (ladders are never painted, because of the danger of this effect at the critical point where the rung enters the side). Zinc coated steel fasteners are less than adequate and corrosion resisting metals should be considered the norm.

The corrosive flame retardants (Section 2.5.2) and salt treated wood (2.5.1) should not be used in outside situations. Aluminium should not be used in contact with wood treated with copper preservative. Copper preserved wood should be aged for seven days before fasteners are inserted.

Essential features of design to prevent wood becoming wet and rotting, viz: good ventilation, good drainage, avoidance of pockets, and avoidance of exposed end grain, also help to prevent corrosion.

### 6.5.5 Degradation of wood by corroding metal

Wood corrodes metals, and corroding steel also degrades wood, as anyone who has tried to mend an old fence will know. Alkali produced at local cathodic areas and iron salts at local anodic areas both cause degradation of wood and loss of strength. Iron stains on wood around steel fasteners are produced by interaction between iron salts and tannins and related substances in the wood; they indicate that corrosion and degradation are starting. Iron stains are not always associated with present corrosion, however, as they can be caused by traces of iron salts left behind from wood working and smoothing operations.

# 7 CORROSION IN CONTACT WITH WOOD, IMMERSED STRUCTURES

## 7.1 ELECTROCHEMICAL MECHANISMS

By definition the wood is always wet, and the acid in it, aided by salt if immersion is in seawater, acts as a bulk electrolyte in which various electrochemical cells can be formed, which can be more vigorous than the micro-cells set up in atmospheric corrosion; in particular, the wood can be degraded by alkali formed at a cathode as well as by iron salts formed at a rusting iron anode.

i) *Oxygen concentration cells.* The shaft of a fastener inserted into wood becomes starved of oxygen and anodic, and the exposed head becomes cathodic. The cathodic alkali gives negligible protection to the head as it is soon washed away, but may cause alkaline degradation of the wood at the area of emergence.

ii) *Other concentration cells.* A cell may be set up when a single piece of metal passes through two different woods, caused by differences between the contents of acid, salt and oxygen in the two woods. A case has been reported of severe corrosion and degradation of parts of a fishing vessel made of beech planking fastened by galvanised nails to oak frames (see front cover). The metal in the beech planks became severely corroded, and corrosion product softened the oak frames at contact with the beech. As other parts of the ship, made of oak planks on oak frames, were in good condition after 20 years, the failure in the composite part of the structure was attributed to a complicated concentration cell effect.

iii) *Bimetallic corrosion cells.* Wet wood, especially salty wood, is an electrolyte, and bimetallic cells are readily set up between two different metals in contact with one another and embedded in wood. A common case is where copper-base fasteners are used to attach wooden planking to a steel framework, where the corrosion of the steel is accelerated and the alkali formed on the cathodic copper degrades the wood and loosens the fastener.

Stray currents from electrical apparatus can accelerate corrosion by forming an imposed galvanic cell. Corrosion takes place where the positive current enters the metal (where the electrons leave); reversal of normal galvanic polarity can sometimes occur, leading to unexpected effects.) This effect can also occur on the positive side of an unconnected piece of metal embedded in wood carrying a stray current, for the current will pass through the metal in preference to the surrounding wood.

## 7.2 AVOIDANCE OF CORROSION

Corrosion resisting fasteners, i.e. stainless steel, monel or copper alloy should be used unless galvanised steel is known from experience to be satisfactory. Bolt holes and bolt heads should be heavily caulked with bitumen, chlorinated rubber, epoxy pain or other resistant coating. Massive metal parts, e.g. iron brackets and floors, should be insulated from timber frames by such coatings or by sleeves or sheets or plastic or bituminised felt. Bimetallic contacts should be rigorously avoided; if two metals must be used, they should be insulated by plastic sleeves. Mixtures of wood species, joined with metal fasteners, should be viewed with caution. Stray currents from electrical apparatus must be avoided. Cables should be well insulated, and a single earthing point is advisable.

# 8 CHECK LISTS

## 8.1 WOODEN BOXES

| *1A Risk of corrosion* | | | | |
|---|---|---|---|---|
| Conditions | | Risk of Corrosion | | |
| | | Low | Medium | High |
| Length of storage | less than 1 month | X | | |
| | 1-5 months | | X | |
| | 6 months and longer | | | X |
| Conditions of storage | indoor temperate | X | | |
| | outdoor temperate | | X | |
| | indoor tropical | | X | |
| | outdoor tropical | | | X |
| Metals (Section 4.1) | Group 1 | | | X |
| | Groups 2 and 3 | | X | |
| | Group 4 | X | | |
| Corrosivity of wood (Table 1) | high or fairly high | | | X |
| | moderate, seasoned | X | | |
| | moderate, kiln dried | | X | |

Balance the high, medium and low entries; if the risk is low to medium, protective measures are advised, if it is medium or higher, protective measures are essential.

| *1B Effectiveness of protective measures* | | | |
|---|---|---|---|
| Protective measure | Effectiveness | | |
| | Low | Medium | High |
| Temporary protection on metal, thin | -X | | |
| Temporary protection of metal, thick | | X | |
| Full paint scheme on metal | | | X |
| Permeable wrap | X | | |
| Dessicated pack | | | X |
| Lining of box (or paint, Section 4.6.4) | | X | |
| Ventilation, good | | X | |
| Ventilation, poor | X | | |

Balance the effectiveness against the risk; if the risk is in excess, consider more effective protective measures.

## 8.2 STRUCTURES

Before erecting a timber structure with metal parts, estimate the risk of corrosion from the table below.

*2A Risk of corrosion*

| Conditions | | Risk of Corrosion | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Life of structure | semi-permanent | | X | |
| | permanent | | | X |
| Exposure | indoor, heated | X | | |
| | covered, unheated | | X | |
| | open | | | X |
| Corrosivity of wood (Table 1) | high or fairly high | | | X |
| | moderate | | X | |
| Situation | within 1 km of coast | | | X |
| | 1-5km from coast | | X | |
| | inland | X | | |
| Wood treatments | salt seasoning | | | XX |
| | fire retardant | | | X |
| | inorganic preservative, fresh | | X | |
| | inorganic preservative, aged | X | | |
| | organic preservative | X | | |

Balance high, medium and low entries, and select an appropriate metal from Table 2B below.

*2B Corrosion behaviour of metals in wood*

| Metal | | Corrosion behaviour | | |
|---|---|---|---|---|
| | | Poor | Medium | Good |
| Steel | uncoated | X | | |
| | zinc coated | | X | |
| | zinc coated plus paint | | | X |
| | plastic coated | | | X |
| Aluminium | | | X | |
| Copper alloy | | | X | |
| Stainless steel | | | | X |
| Monel | | | | X |
| Insulation, plastic or bituminised | | | | X |