Symposium on Harvest and Post Harvest Technology of Fish held during 24-27 November1982 at Cochin

Corrosion Behaviour of Metallic Fastenings in Contact with Wood

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The work reports the performance of fastenings made of iron, aluminium, galvanised iron, cadmised iron and aluminised iron in contact with *Adina cardifolia, Artocarpus hirsuta, Lagerstroemia lanceolata, Mangifera indica* and *Tectona grandis* as well as timbers treated with arsenic-copper-chromate preservatives. Quantitative corrosion rates of fastenings or special corrosion cylinders driven into wood-fastenings combinations exposed to fine mist of seawater and distilled water in large test chambers are given. The pH values of some common Indian boat building timbers on incubation with seawater, distilled water and the influence of acidity on corrosion of fastenings are reported. The studies have shown that aluminised iron fastenings are compatible with several boat building timbers and can be used in place of expensive copper base alloys without sacrificing efficiency.

Among the structural materials, wood continues to occupy a position of prominence in spite of research to develop newer materials. The high strength to weight ratio, high strength to cost ratio, natural durability and good working qualities favour the use of wood. For the economic use of wood, a knowledge of its properties is essential. Timber is a cellular oriented high polymeric material, the cellulose consisting 30–50% of the total wood substance. The next major constituent is lignin to the extent of 20–40% and small quantities of sugars, gums, low polymers related to cellulose, phenolic substances and tannins. The acidity of a number of species of wood grown in temperate climate has been well documented (Campbell & Packman, 1940; Gray, 1958; Sandermann & Pothikamm, 1959). Gray (1958) while studying the properties of 146 hard woods and 21 soft woods found that over 80 species of wood under moist conditons showed a pH of 4.5 or below, sufficient to accelerate the corrosion of steel nails and cadmium plated articles. Corrosion of metallic components as a result of organic vapours evolved from wood, paints, varnishes and plastics particularly in closed environment and at relative humidities have already been reported by several workers (Rance & Kole, 1958; Clarke & Conghurst, 1961; Donovan & Moynehan, 1965; Cawthrone *et. al.*, 1966). Campbell & Packman (1940) measured the acidity of air dry wood raspings and noted that 120 of them lying between a pH of 4 and 6. The corrosion of metal fastenings in wooden boats and the resultant decay in wood are (Savory & Packman, 1954) well known to boat owners. A study on the corrosion of brass screws on the wooden hulls of proud class fast patrol boat was taken up by the Hull and Structural Corrosion Sub-committee (Kingcome & Rowlands, 1958) following the failure of fastenings in these boats. Kingcome & Rowlands (1958) conducted this study and reported that brass screws have undergone severe dezicification while in contact with oak and elm and slight dezincification with mahogany. The conditions under which wood is liable to promote corrosion of metals in contact with it and the importance of moisture and salt present in wood are discussed by Farmer (1962). Wood being the principal construction material for small boats and several wharf structures, a study of the corrosion of fastenings in wood assumes considerable practical importance, but despite this, relatively little research work has been carried out. There appears that no work in this area has been carried out in India and a need was felt to obtain information concerning the corrosion behaviour of metallic fastenings in contact with common boat building timbers.

Materials and Methods

Bolts and screws of brass, mild steel, galvanised iron, aluminized iron and cadmised iron for qualitative tests and machined metallic cylinders of brass, mild-steel, aluminium, galvanised and cadmised iron for quantitative tests were used in the test. The woods used are;

Adina cardifolia (Haldu)
Adina cardifolia treated with arsenic-copper-chromate (ACC)
Artocarpus hirsuta (Aini)
*Mangifera indica (*Mangowood)
Mangifera indica treated with ACC
Tectona grandis (Teak)
*Lagerstroemia lanceolata (*Venteak)

Wooden blocks of size 30 × 10 × 5.7 cm were conditioned in an atmosphere of 100% relative humidity by spraying water or seawater as required for nearly three months prior to the commencement of experiments. Bolts and screws were driven into the wood after pre-drilling. Corrosion test cylinders measuring

12.7 mm dia. and 23 mm height were pushed into wood under pressure through pre-drilled holes (Fig. 1). That face of cylinder which is not in contact with wood but exposed to the humid air was sealed off. The wood-fastenings combinations were kept arranged in large loosely covered HDPE tanks and fine fog of water as in a salt spray test was maintained for about an hour daily. A pool of water was also kept at the bottom of tank. For tests in presence of seawater, the test blocks were periodically wetted with seawater and exposed to fog in a chamber. This arrangement helped to maintain a relative humidity of about 100% throughout the test period which ranged from few months to nearly three years. At intervals wooden blocks were retrieved from the humidity chamber and the fastenings removed after splitting the wood. Visual examination of corrosion of metal and discolouration and decay of wood were observed and in cases quantitative corrosion data are needed the metal cylinders were cleaned off the corrosion products using 10% sulphuric acid at room temperature for brass, a solution containing 2% chromic acid and 5% phosphoric acid at 80°C for aluminium, Clarke's solution for iron and saturated ammonium acetate solution at room temperature for cadmium and zinc (Champion, 1964). Some of the bolts were electrolytically cleaned in sulphuric acid at a current density of 20 A dm^{-2} to examine the nature of corroded metal.

Results and Discussion

Data concerning the acidity of *Tectona grandis, Lagerstroemia lanceolata, Artocarpus hirsuta, Adina cardifolia* and *Mangifera indica* obtained by measuring the pH value of wood dust moistened with distilled water and seawater are given in Table 1. For comparison the pH values of some common European species of wood based on Farmer (1962) are given in Table 2. The values were measured within 30 min of wetting and after 33 months of incubation at ambient temperature (28–33°C). These values are not the true pH, as there is evidence (Farmer, 1962; Packman, 1960) that the moisture condition in wood is usually a complex buffer solution containing weak acids and their salts, but they do give useful information on the relative degrees of acidity of different species of woods. It will be seen from Table 1 that the pH is characteristic for each species of wood. The lowest value was noted with untreated and chrome treated Haldu in distilled water and sea water. The same trend was observed when Haldu raspings were incubated for 33 months.

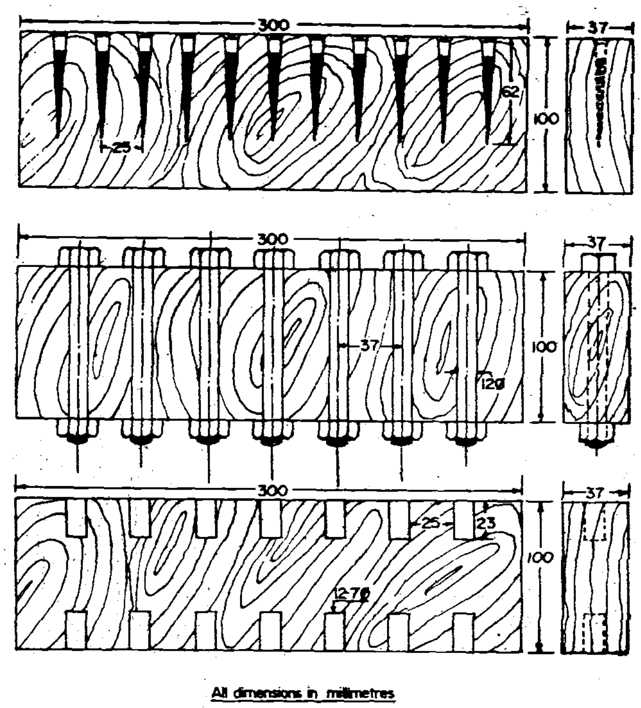

Fig. Arrangement of screws, bolts and corrosion cylinders in contract with wood for corrosion tests

Table 1. *pH values of some boat building timbers (2 samples per wood)*

Name of wood	pH value after 30 min of socking in		pH value after 33 months of socking in	
	Distilled water	Seawater	Distilled water	Seawater
Adina cardifolia	4.60–4.50	3.90–3.80	3.59–3.47	3.18–3.17
Adina cardifolia with CCA	4.80–4.70	4.50–4.40	3.61–3.57	3.46–3.27
Artocarpus hirsuta	5.30–5.40	4.80–4.60	3.86–3.73	3.51
Mangifera indica	5.30–4.50	4.6–4.4	4.02–3.89	4.24–4.08
Mangifera indica treated with CCA	5.90–5.90	5.10–5.10	4.75–4.66	4.00–4.00
Tectona grandis	5.55–5.55	5.40–5.40	4.73–4.66	4.49–4.32
Lagerstroemia lanceolata	5.15–5.20	4.60–4.40	4.04–3.98	3.39–3.22

Table 2. *pH values of some common hard woods*

Species	"Reference pH value"
Teak *(Tectona grandis)*	4.5
Elm *(Ulmus* sp.)	6.0–7.2
Balsa *(Ochroma lagopus)*	5.4–7.2
Beech *(Fagus sylvatica)*	4.5–5.9
Obecbe *(Triplochiton seleroxyton)*	4.4–5.5
Mahogany *(Khaya* sp.)	4.5–5.1
Afromosia *(Afrormosia elata)*	4.3–4.8
Sapele *(Entandrophragina cylindricum)*	4.3–4.6
Idigbo *(Terminalia iverensis)*	3.5–4.1
Chestnut *(Castanea sativa)*	3.6
Jarrah *(Eucalyptus marginata)*	3.0–3.7
Oak *(Querous* sp)	3.3–3.9

A slight reduction in acidity was noticed when Haldu and Mango wood were treated with CCA compound. A similar change of acidity was reported by Wilson (1971) who observed progressive reduction in pH values of Red-wood, Spruce, Beech and Opepe with solution strength of CCA.

Another characteristic feature that is distinct from the observed pH value is that irrespective of the species of wood, the acidity increased on storage in distilled water and seawater. Though in certain cases this increase has been ten-fold, much quantitative significance should not be attached to these values. Prediction of corrosion behaviour based on this would be done with caution, as can be seen from the corrosion values reported.

Qualitative information on the corrosion behaviour of aluminium, brass, iron, aluminized iron, cadmised iron and galvanised iron obtained by observation of fasteners in contact with wood for prolonged exposure period are given in Table 3. The wood that is exposed to sea water absorbs salt and water, which accelerate the corrosion of fastenings. Brass fastenings which are conventional materials are free from any type of deterioration. Iron fastenings suffered intensive corrosion while in contact with most species of wood, and notably the attack was more when the wood was treated with arsenic-copper-chromate wood preservative. Apart from the damaged threads and flaked layers of corrosion products, the wood in the vicinity of iron bolt became soft, fragmented and discoloured. In presence of moisture, the corrosion of iron progresses without impediment, the resultant corrosion products notably hydrated ferric oxide catalyse further reaction which act upon the cellulose and polysaccharides present in woods causing deterioration.

Table 3. *Duration of test - 860 days (salt water wetted)*

Metal	*Artocarpus hirsuta*	*Adina cardifolia*	*Mangifera indica*	*Lagerstroemia lanceolata*	*Arsenic-copper-chrome treated* *Adina cardifolia*	*Mangifera indica*	*Tectona grandis*
Brass	No visible corrosion	No visible corrosion, slight coppering	No visible corrosion, slight coppering	No visible	No visible corrosion	No visible corrosion	Bright and no signs of corrosion
Iron	Very severe corrosion and layers of corrosion products. Threadsattacked. Discolouration and softening of wood			Severe corrosion, layers of corrosion products, discolouration and softening of wood,	Very severe corrosion. Layers of corrosion products. Threads damaged. Discolouration and softening of wood		General slight rusting
Aluminised iron	Slight white corrosion product. No discolouration. No softening of wood			white deposit, no softening of wood.	No discolouration		Slight white corrosion product.
Cadmised iron	White corrosion product. Rusting in patches			Severe corrosion. Large areas of iron exposed – threads attacked. Discouloura-tion – softening of wood		Extensive corrosion. Threads attacked. Discoloura-tion – softening of wood	No rusting, white corrosion products in patches
Galvanised iron	White corrosion product. Slight signs of failure	White corrosion product. Slight signs of exposure of iron at points			Extensive corrosion. Iron exposed in patches	Severe corrosion. Iron exposed in patches	No apparent corrosion

Table 4. *Corrosion of fastenings in contact with wood ($\mu m\ yr^{-1}$)*

Period (days)	*Adina cordifolia*	*Adina cordifolia* treated with CCS	*Artocarpus hirsuta*	*Mangifera indica*	*Mangifera indica* treated with CCA	*Lagerstroemia lanceolata*
			Name of wood			
(a) Iron						
Wood wetted with water and exposed to 100% R. H.						
280	55	85	188	62	96	52
765	57	92	205	63		49
970	60	92	208	63	92	50
Wood wetted seawater and exposed to 100% R. H.						
970	332	450	1432	368	452	296
(b) *Brass*						
Wood wetted with water and exposed to 100% R.H.						
330	5.4	4.1	10	2.4	7.0	6.6
860	2.9	6.3	5	3.1	5.4	3.4
Wood wetted with seawater and exposed to 100% R. H.						
970	6.2	8.0	10	6.1	6.2	6.2
(c) *Aluminium*						
Wood wetted with fresh water and exposed to 100% R. H.						
280	20	20	17	20	20	24
765	22	21	18	23	21	26
970	22	21	18	23	21	26
Wood wetted with seawater and exposed to 100% R. H.						
970	24	22	25	24	25	29
(d) *Galvanised iron*						
Wood wetted with fresh water						
280	22	30	88	30	31	25
765	26	42	87	34	43	29
970	28	45	90	35	45	30
Wood wetted with seawater						
970	40	49	35	42	51	51
(e) *Cadmised iron*						
Wood exposed						
280	30	37	102	35	41	35
763	Base metal was exposed					
970	Base metal was exposed					
Wood exposed						
970	Base metal was exposed					

Results of qualitative data on corrosion of metals in contact with wood in fresh water and seawater are presented in Table 4. Iron had severely been attacked in all species of wood and especially with aini the rate progressively increased from 188μm yr^{-1} to 208 μm yr^{-1} implying that corrosion proceeds uninhibited. In the pH range of 4 and 9.5 rusting of iron continues rapidly as long as the basic factors, namely, oxygen and moisture are present and the porous nature of oxide film offers very little protection. The pH values as shown in Table 1 were in the approximate range of 4 and 5 which favoured the attack of iron. A severe corrosion of iron fastenings in aini has been observed rather frequently during annual maintenance of fishing boats. An increased rate of corrosion has been noted for iron in contact with arsenic-copper-chrome treated haldu and mango woods. Little information is available on the interaction of CCA treated wood with metal (Belford, 1970). Although a high degree of fixation of CCA has been reported by Narayanamurty & Purushotham (1958) and by Tewari & Purushotham (1959), the leaching of the components have enhanced the corrosion. Few of the subsequent corrosion tests carried with CCA-creosoted wood have shown a reduced corrosion rate.

Brass fastenings were found compatible with all the species of wood (treated or untreated) experimented. Brass corrosion cylinders in contact with wood for 3 years showed only a negligible rate of attack. Further, more brass fastenings are preferred to copper in view of the superior mechanical strength of the former.

In the case of galvanised iron, spot corrosion had been the disadvantage and therefore a realistic prediction of the life of zinc coated bolts for marine application in presence of wood-acid could not be made. Cadmium coating though provides cathodic protection to the underlying metal had suffered severe corrosion in contact with wood.

The rate of corrosion of aluminium in contact with wood wet with seawater and ordinary fresh water was about 17 to 25 μm yr^{-1}. It is known that acetic acid is liberated by the hydrolysis of combined acetyl groups which are present in the polysaccharide components of woods (Packman, 1960) but this exerts very little influence on the corrosion of aluminium as most aluminium alloys are inert to acetic acid (Mears, 1948). The corrosion of aluminium in humid environment is largely influenced by the specific ions and only to a much lesser extent on pH. The non-porous aluminium oxide of greater volume than the equivalent metal may confer further protective action. Contrary to the behaviour of iron, it is interesting to note that the corrosion of aluminium is not altered in presence of CCA compounds, presumably due to the beneficial effect of chromate contained in the preservative. This is in confirmity with the observation of Farmer & Porter (1963) who concluded that there is little direct effect of preservative treated wood on aluminium. It may be recalled that aluminized iron bolts in the 860 days exposure test performed satisfactorily without any signs of exposure of the base metal in treated and untreated woods. Furthermore, a self-suppressing effect on corrosion is also evident from the data in Table 4, and therefore the life of aluminizing would normally be governed by the coating thickness. With improved thermal spraying technique an aluminium coating thickness of 229 micron could be achieved. Aluminized bolts of this type can reasonably be expected to last over 10 years on boat building timbers in common use in India.

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