CORROSION ENGINEERING

THE WEAK SPOT?

BY

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Now in building of chaises, I tell you what,
There is always somewhere a weakest spot.

OLIVER WENDELL HOLMES, *The Deacon's Masterpiece*

Synopsis

A survey of reports on corrosion failures has shown the repeated occurrence of the same problems in various branches of engineering. The repetition of these incidents suggests that there is not only a lack of understanding of basic corrosion phenomena but also a lack of communication between corrosion technologists, designers, builders, and users of engineering structures.

Corrosion engineering like health and safety engineering cuts across all traditional engineering disciplines; this creates the communication and management problems often referred to as 'matrix management'.

This article highlights the frequency and widespread occurrence of basic corrosion problems and emphasizes the need for an effective communication system and a reappraisal of the education of engineers in corrosion technology.

Introduction

Although corrosion has been a problem since man started to use metal instead of stone, many engineers and technologists seem to be reluctant to learn from the past. In each generation, a large proportion of engineers repeat the corrosion mistakes of the past before appreciating that the design of a structure and the materials from which it is made must be matched to the environment in which it is to operate.

The first recorded report (1) of corrosion in the Royal Navy, written in 1763, concerned the effectiveness of copper sheathing in resisting the ravages of woodborers on the wooden hulls of warships. H.M.S. *Alarm,* the 32-gun frigate selected for the trials, had the bottom of her hull encased in copper. When she was beached and examined on returning from the West Indies, the surveyors reported that in some areas the iron nails securing the sheathing were 'much rotted'. Thus it was known and recorded two hundred years ago that corrosion occurs when two dissimilar metals, in contact, are immersed in sea water.

However, the mistakes made in 1763 still occur in modern engineering practice. In the sea-water-cooled evaporator of a modern ship, the copper-based end fittings were secured with steel bolts. FIGS. 1 and 2 show the end fitting and the remains of the bolts.

Similarly, when the propeller shafts of H.M.S. *Ark Royal* were removed during a major refit, it was found that residual casting porosity had developed into a crack in the copper-based liner on one of the steel shafts. Sea-water had entered the crack and a corrosion trough, corresponding to the shape of the crack, had penetrated up to an eighth of the way through the wall of the shaft (FIGS. 3 and 4).

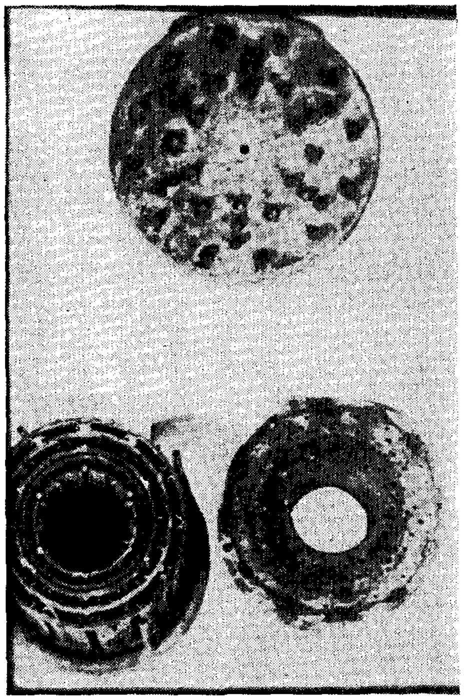

FIG. 1

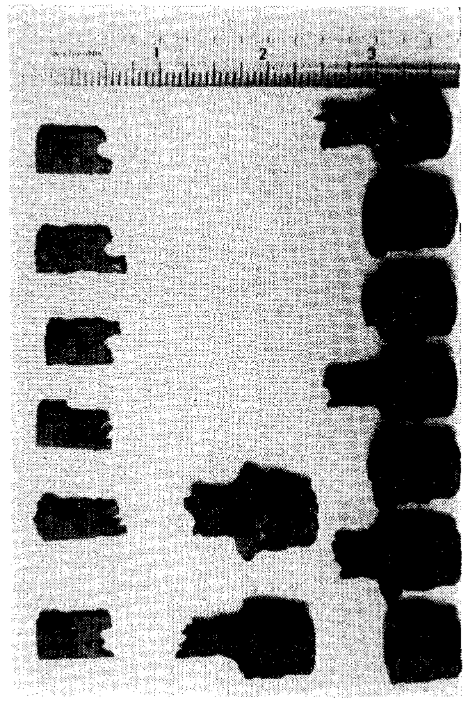

FIG. 2

FIG. 3

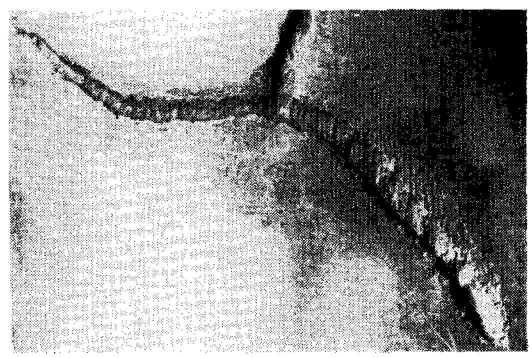

FIG. 4

These illustrations are all classic examples of the operation of a simple galvanic cell of the type shown in FIG. 5. The cell has four components:

(1) Anode, corrodes. $M \rightarrow M^{+} + e$

(2) Cathode, protected.
Basic or neutral conditions, $2H_2O + O_2 + 4e \rightarrow 4OH^{-}$
Acid condition, $2H^{+} + 2e \rightarrow H_2$

(3) Path for electrons.

(4) Electrolyte.

The aim in corrosion protection is the elimination of one or more of these components as the cell only functions when all four are present. This was realized in 1763 in the report on H.M.S. *Alarm*, although the technical reasons for it were obviously not understood. The copper plates had been covered with brown paper which, in some cases, was trapped under the heads of the nails and in the holes in the plates, effectively insulating the iron from the copper. In these areas the corrosion of the nails had been reduced. The surveyors noted this fact and recommended, in 1763, that, where iron and copper were in contact in sea-water, separators should be put between the two to control corrosion. (Their subsequent remarks seem

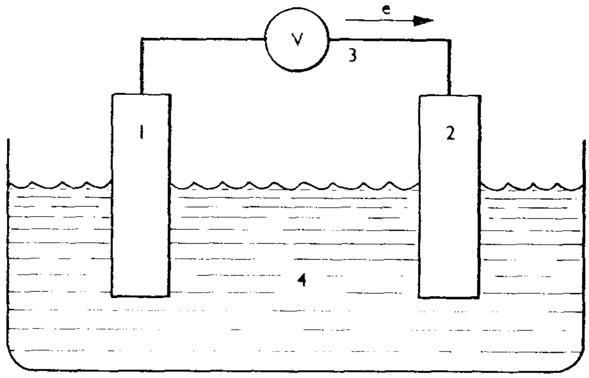

FIG. 5

strange to the modern ear as they recommended the use of flannel and lead shim.) Even now, this excellent recommendation—to insulate anodes from cathodes—has not been widely accepted as good design practice by the general engineer.

Although the examples quoted so far come from naval engineering practice, the problems of corrosion are common to all branches of engineering and all stages in the life of a structure or component. Sometimes problems are designed-in, as the evaporator unit quoted above; some are built-in due to shop floor decisions on alternative materials or production techniques; and some are caused as a result of maltreatment by the purchaser or operator.

Corrosion and the Designer

General observation shows that many design engineers are prepared to spend long hours on stress calculations and the layout and styling of a structure, but not to give the same attention to the selection of materials or elimination of design features which promote corrosion. Later they are amazed, and even offended, by the corrosion problems generated amidst the bad design features, and arrays of incompatible materials selected.

FIG. 6

An example of designed galvanic corrosion is shown by the oil valve (FIG. 6). The aluminium-alloy casing has bronze inserts to take the spindle and the securing bolts for the valve cover. Although this arrangement appears to be most unsatisfactory, no corrosion has occurred at this point as only three parts of the cell are present—the gasket and valve cover effectively preventing the electrolyte reaching the metals. At the flange, however, where brass bolts secured the two halves of the valve, the free access of sea-water completed the cell causing severe galvanic corrosion of the aluminium.

Another corrosion hazard which seems to feature in many designs is the differential aeration cell, illustrated in FIG. 7. It is most prevalent where a crevice exists between two surfaces (crevice corrosion) but it also operates in stagnant water and under debris such as piles of sand or mud.

Differential aeration occurs when an oxygen concentration gradient developes in the electrolyte; the depleted area becomes the anode, whilst that rich in oxygen becomes the cathode.

This type of corrosion is prominent on the bodywork of modern cars. The vehicle shown in FIG. 8 exhibits corrosion at crevices in the spot-welded seams, in the bottom of the doors where the outer and inner panels overlap, and behind the headlights. (The use of this illustration does not imply that the make of vehicle shown is worse or better than others in this respect; the problem is common to all makes of car.)

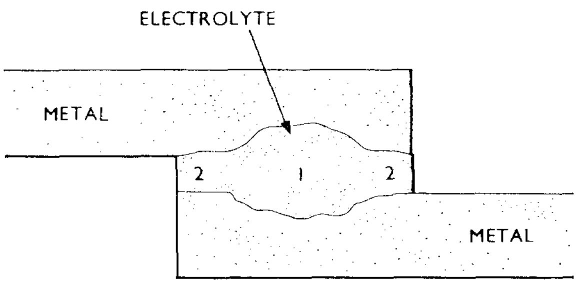

FIG. 7

FIG. 8

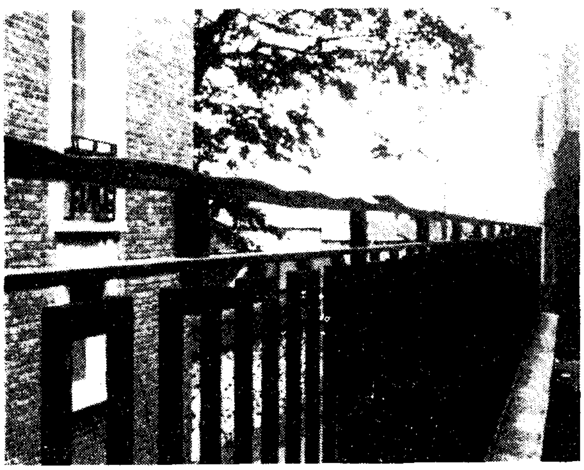

FIG. 9

A problem which is not so obvious to the owner can occur where 'sound-proofing' foam rubber is packed into the ends of box sections by car manufacturers. This absorbs water and promotes corrosion of the box section as oxygen differentials are generated. The free ends of the foam rubber in contact with air produce cathodes in the steel, and the faces pressed against the sides of the section produce anodes.

The loss of metal due to corrosion is not the only problem that occurs in the crevice cell: the corrosion products are often voluminous and in the restricted region of the crevice produce stresses of sufficient magnitude to cause plastic deformation of the surrounding structure. The amount of plastic deformation that can occur is clearly shown in FIG. 9, where the top section of a riveted railing has been deformed between the rivets by the cell that developed between the two sections of the railings.

The problem of differential aeration in structures is minimized by sealing all joints to ensure that the electrolyte cannot enter the crevice; or by providing adequate drainage to prevent the accumulation of the electrolyte and introducing an air flow to ventilate all potential danger areas. Design features which tend to promote this problem are illustrated in FIG. 10 which also shows preferred arrangements.

Many otherwise excellent designs are ruined by a lack of access to maintain the completed structure, the maintenance staff being presented with situations where repairs, repainting, or even inspection could only be carried out by 'freaks'. Such a problem is posed by the buttress of the railway bridge (FIG. 11). It is difficult to see behind the buttress and even more difficult to carry out preventive maintenance. The extensive corrosion that has occurred in the steel beam and plate is clearly seen; what has occurred behind the buttress . . . ?

Warships present particular maintenance problems as the tight utilization of space leaves very limited access. FIG. 12 shows a 1·7 metre diameter steel duct placed in a narrow covered bay close to the ship's superstructure: it is

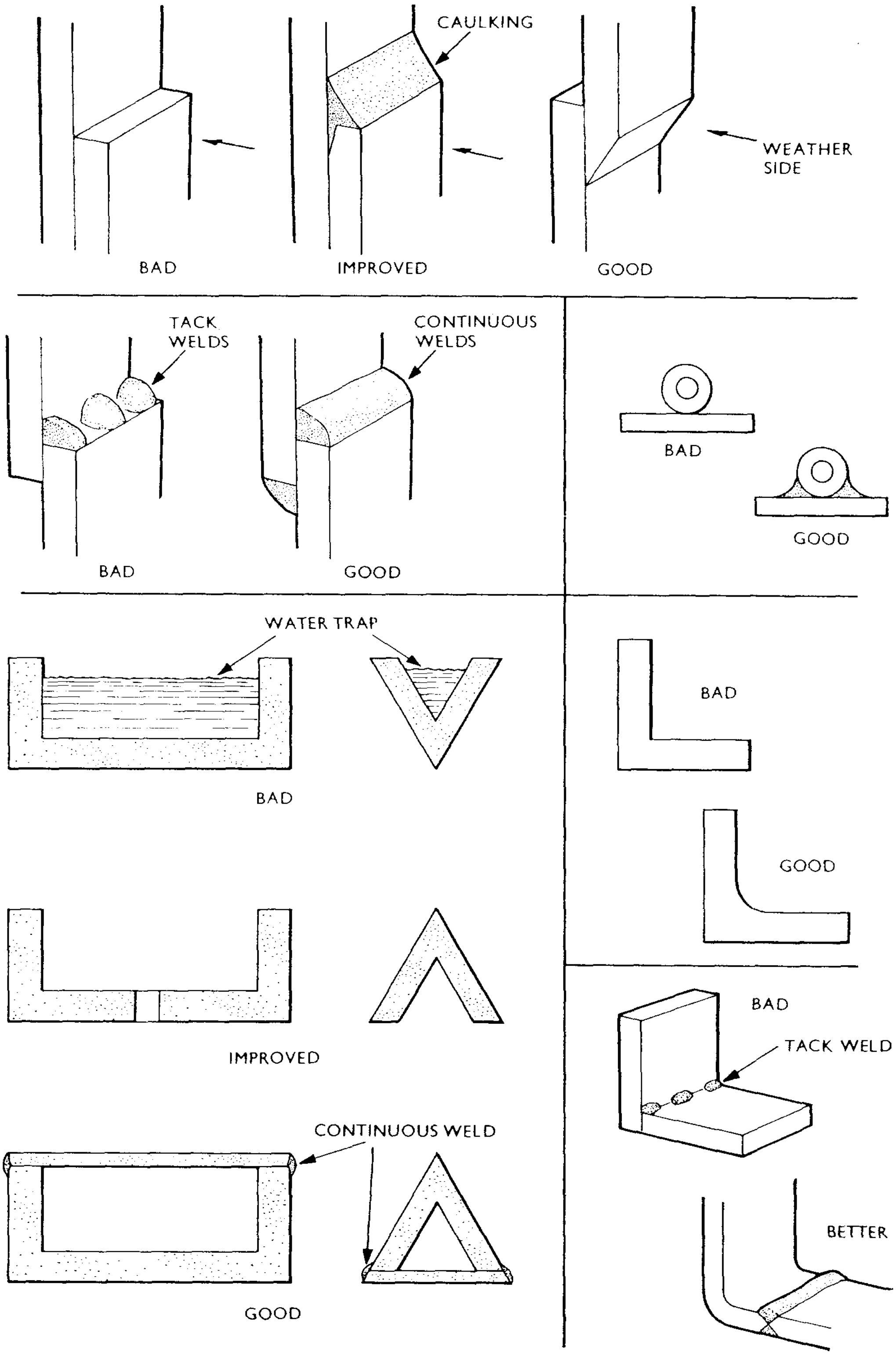

FIG. 10

impossible to reach the rear face without removing the unit. FIG. 13 shows a fire hydrant installed in a narrow gap between a hatch and the superstructure of a ship; it will be a time-consuming and onerous task to maintain or repaint the hydrant or the lower part of the hatch coaming. Corrosion

FIG. 11

FIG. 12

FIG. 14

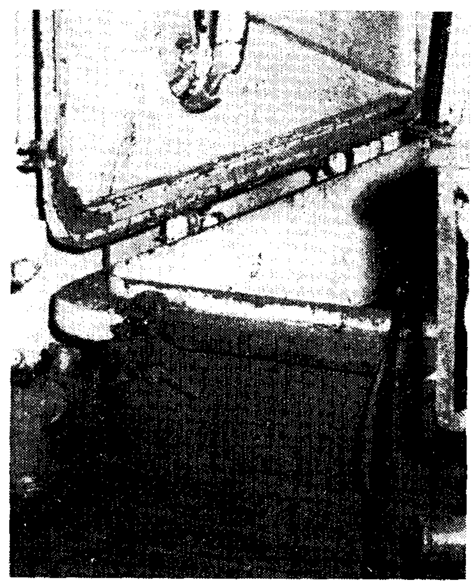

FIG. 13

recently found on the internal surface of a hull, behind an evaporator, will necessitate the cutting of the hull to gain access to the damaged area from outside the ship.

A final pitfall for designers is the lack of compatibility between the roles of different parts of a completed installation, especially where different design offices are involved. Often little thought seems to be given to the hazards presented by the functions of adjacent units which are entirely satisfactory as separate entities. The aluminium aerial-support (FIG. 14) was quite adequate for the designed task, until it was placed just behind the funnel of a ship; here, acid products from burnt fuel oil removed the paint, whilst carbon deposits from 'black smoke' coated it with an effective cathode. Corrosion soon rendered the assembly unsafe.

Corrosion and the Builder

Even when the designer has given careful thought to the selection of

FIG. 15

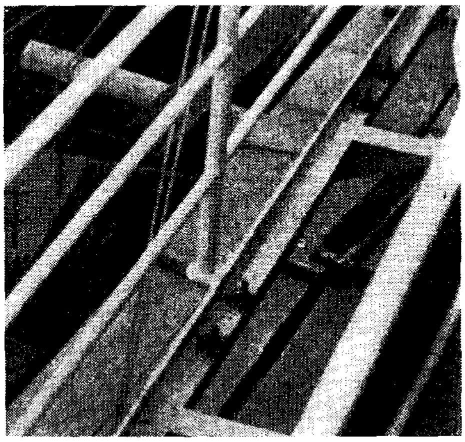

FIG. 16

materials and the elimination of undesirable features, ill-considered changes by the manufacturer may re-introduce corrosion hazards.

An elementary example of this occurred on the welded railing surrounding a coastal car park (FIG. 15). Although the designer has selected galvanized-steel tube for the construction, which would be expected to give a maintenance-free life of about fifteen years, the welding has burnt off the zinc finish leaving unprotected areas. The lack of post-weld protection has resulted in sacrificial corrosion of the zinc on the adjacent pipe, steadily removing the zinc from the whole railing.

A similar course of events has occurred on the gantry shown in FIG. 16; severe rusting ensued when post-weld protection was omitted around studs welded to the painted gantry.

A more complex situation arose during the refit of the aircraft carrier H.M.S. *Eagle*. To improve the appearance of the ratings' washroom, a formica-covered aluminium false wall was secured to the steel bulkhead, the aluminium being screwed to wooden battens with brass screws. The copper cold-water feed pipes for the sinks were concealed in the space behind the false wall. After a few months, the formica bulged in several places apparently due to ineffective adhesive. Examination revealed that severe attack and penetration of the aluminium substrate had occurred, resulting in voluminous corrosion products which had lifted the formica. The main cause of the failure was transfer of copper ions to the aluminium in the condensation formed on the cold copper pipes, aggravated by the galvanic action of the brass screws.

The first impressed-current protection trials for the Royal Navy carried out in H.M.S. *Blackwood* highlighted the ease with which installation mistakes can occur. The impressed-current anodes—old tram-lines bolted to wooden battens attached to the sides of the vessel—were incorrectly connected on one side; the ship steamed for some time using her hull to protect the tram-lines bolted to that side of the ship.

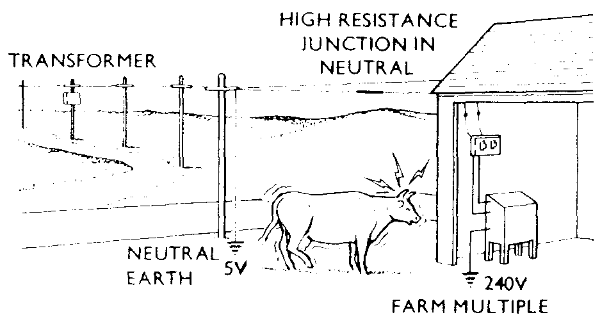

FIG. 17

This type of error often occurs in civilian life. A Devon farmer reported that his cattle were very reluctant to cross the farmyard, and after prolonged investigation it was found that the fault lay in an overhead power line feeding the farm (2). The system is sketched in FIG. 17. The power to the farm was drawn from a transformer some distance away, but the neutral line was earthed at a pole adjacent to the farmyard. The aluminium neutral power cable was joined to the farm's copper cables at a point between the buildings and the earthed pole. (The use of such bimetallic connections in the open is contrary to SWEB codes of practice.) Despite the grease packing and wrappings to protect the joint, corrosion occurred; this increased the resistance of the line until it became easier for the return to be made via the multiple earth on the farm equipment and the earth on the pole. A potential drop of some 240 volts was set up across the farmyard. Cows easily detected the small potential difference between their hooves, but farm workers, wearing rubber boots, were unaffected.

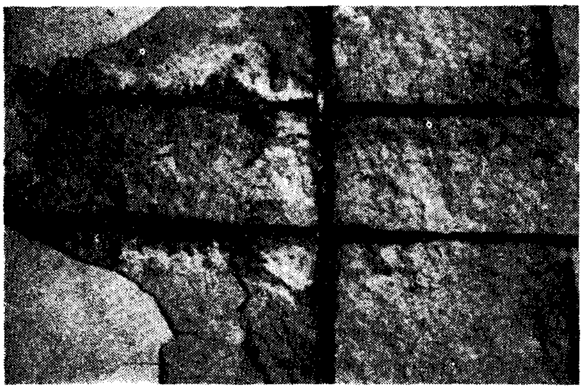

FIG. 18

FIG. 19

The construction industry, in which most of the erection occurs in the open, presents many corrosion hazards. Prominent among the problems is the spalling of concrete due to rusting of reinforcing wires. The initial highly-alkaline conditions in the concrete are to some extent self-inhibiting, but as reaction with atmospheric carbon dioxide proceeds the alkalinity falls, and corrosion ensues. The corrosion products generate tensile stresses in the concrete which lead to cracking or even spalling. FIG. 18 illustrates the spalling of reinforced concrete on a jetty in Bermuda. The problem is overcome by ensuring that there is an adequate thickness of dense concrete overlying the reinforcing wire, or by using galvanized wire (FIG. 19), or polymer impregnated concrete.

Corrosion and the User

During the operational life of a structure, corrosion hazards may be introduced by the user when embellishing, modifying, or maintaining the unit.

The search for individuality among car owners leads to many embellishments that present potential corrosion problems; additions such as extra lights and decorative trims create many unnecessary crevice cells.

Another well-known but recurring problem results from the application of underseal to the inadequately cleaned lower surfaces of used vehicles. The residual dirt and rust encourage corrosion to continue beneath the underseal, seriously affecting the ability of the vehicle to withstand accident damage.

Changes in the operational mode of a unit can introduce unsuspected hazards. A refrigerator which operated with a gaseous cooling system was converted by the owners to work with brine. In the interest of economy, the original steel pipe system with brazed joints was retained. This modification introduced an electrolyte into the unit, completing the corrosion cell and so causing the pipe system to be perforated in several places.

While embellishment and modification are often detrimental, most user corrosion problems occur as a result of inadequate maintenance procedures.

The problems of maintenance on farms, for example, are often underestimated. Areas such as milking parlours, with animal sweat, urine, and moist atmosphere, pose particular difficulties in maintaining equipment in a safe condition. After a cow had been electrocuted on a Devon farm, it was found that corrosion had occurred at the junction between the copper earth strap and the milking machine. The resistance of the joint was too high to be measured and the earth had failed to function when a fault developed in the wiring of the machine (2).

Many 'do-it-yourself' yachtsmen have erred by applying ordinary copper-based antifouling paints to aluminium hulls. Ion exchange deposits copper on the aluminium and the bimetallic cell causes rapid deterioration.

This casual approach contrasts sharply with the vigilant procedures adopted in air transport. As most aircraft materials are very susceptible to corrosion damage, safety standards are maintained only by careful inspection and thorough maintenance. Very serious damage ensues if these are neglected. The crash of a Vanguard aircraft over Belgium a few years ago was due to a toilet drain discharge leaking on to the after bulkhead causing corrosion (3).

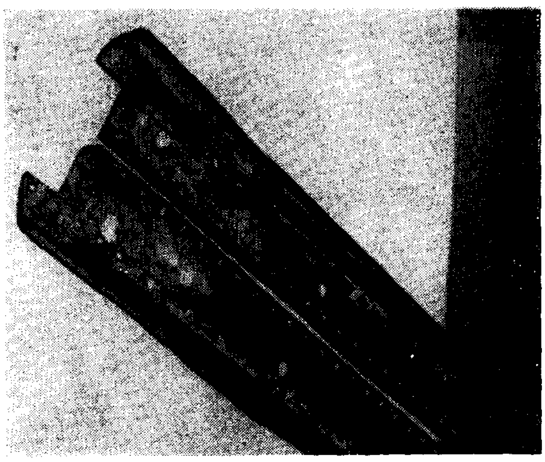

FIG. 20

FIG. 20 shows a section taken from a helicopter which received no maintenance while being transported for four days on the open deck of a ship. Severe corrosion has occurred where steel bolts pass through the magnesium-alloy sections, rendering the aircraft unflyable.

Conclusions

This article draws attention to the widespread occurrence of corrosion problems in all branches of engineering, illustrating how such problems apply to a structure from its inception to the end of its useful life. The nature of the mistakes suggests that there is a breakdown in communication between engineers and corrosion technologists in many fields, and a lack of understanding of even basic corrosion phenomena among a broad spectrum of technical personnel. The mistakes are not confined to one level of people but include design engineers, foremen, inspectors and charge hands; a lack of knowledge at any point in this chain can cause corrosion problems that negate the expertise of those at higher levels.

The nub of the problem is the communication of current experience to contemporary and to succeeding generations.

In the MOD, the link to contemporaries is made through various committees and their working parties who are continually considering the problem of corrosion. There is also a sub-section of the Ship Department which is specifically tasked with corrosion engineering of ships' materials, and establishments such as AUWE and ASWE have their own corrosion groups.

The communication with succeeding generations is made through educational establishments, such as universities and polytechnics. A survey by the authors has shown that many mechanical engineering and civil engineering courses for degree and HND/HNC students contain less than six hours of instruction in corrosion, although specific aspects may be reinforced in design lectures. Several engineering lecturers excused the limited allotment of time for the subject, but perhaps the most significant comment was, 'A degree course in engineering has to cover a very wide field, and corrosion is only one very small part of it'.

The shortness of instructional time is further aggravated by the advanced, theoretical, chemical approach of many lecturers: discussion with practising engineers has shown that this often alienates the students' interest so that corrosion technology is not so acceptable a part of training as, say, stress analysis or design, and subsequently causes even basic corrosion principles to be ignored.

While lecturers, engineers, and technical officers display such attitudes towards corrosion, the work of committees such as those established in the MOD will not be fully appreciated nor their recommendations and advice on the design, construction, or repair of structures be utilized; an attempt must be made to create, across the board, a continuous awareness of corrosion problems. The authors have found that a considerable amount of interest has been generated (and students have become very corrosion conscious) by concentrating on fundamental mechanisms, profusely illustrating each point with case histories and endeavouring at all times to show the relevance of the phenomena to the engineer's future career.

For even greater emphasis to be placed on the role of corrosion in the education of engineers and technologists, it is suggested that the tenuous links that exist between corrosion panels and research bodies, and educationalists should be strengthened. This would allow students to be made aware of relevant, current corrosion developments; lecturers to make contributions to the work of the panels; and the collection of case histories, so vital to corrosion teaching, to be further extended.

The increased flow of information, resulting from such closer links, would broaden the future engineer's awareness of corrosion phenomena, enabling him to appreciate the relevance of the work of the corrosion committees and the research and dockyard laboratories, thus helping to minimize the incidence of mistakes in the future.

Acknowledgement

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