

Chapter 1-1THE NATURE OF CORROSION

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Introduction

1 Metallic elements are usually compounded with other elements when they are mined and compared with the metal these compounds are relatively stable. Corrosion is the tendency of metals to revert to the thermodynamically more stable oxidized state, which occurs when they react with dry air to form metal oxides or with acids and alkalis to form metal salts. Some metals such as gold and platinum strongly resist corrosion.

2 Reactions between metals and their environments may occur either dry (frequently referred to as oxidation) or in an aqueous environment (electrochemical corrosion).

OXIDATION

General

3 In a strict chemical sense oxidation occurs whenever a metal is converted to its ions, but the term is normally used to describe the direct combination of a metal with the oxygen of the atmosphere. Although water vapour in the air plays a part in the oxidation of some metals, the phenomenon is essentially a 'dry' one. With the exception of gold and platinum, all metals in contact with air form a very thin invisible oxide film.

Effect of oxide film thickness

4 The oxide film that forms on metals generally tends to protect them from further corrosive attack. If this were not so, metals would steadily corrode away altogether. Oxygen reacts instantly with bare metal to produce a film and as the film forms it adheres to the metal surface and may provide a barrier between the oxygen and the metal surface. Further oxidation depends on the characteristics of the oxide film.

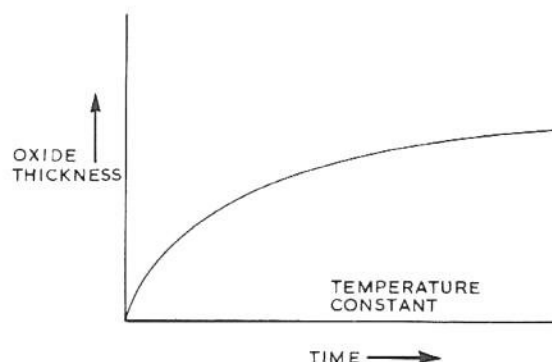


Fig 1 Oxide thickness against time at a constant temperature

5 The oxidation rate normally falls sharply as the film thickness increases. A general curve for the rate of oxidation of a metal in atmosphere where the temperature is kept constant is shown diagrammatically in fig 1. It can be seen that the oxide film growth rate decreases with time and in practical terms this means that generally the film eventually protects the underlying metal against further corrosion. This does not always happen, since all or any of the following events may occur:

5.1 Oxides may react chemically or combine with water to produce a film that is not impervious to the passage of further oxygen through it.

5.2 The oxides on the surface of the metal may volatilize as, for example, molybdenum dioxide (MoO_2) volatilizes above 750°C (1382°F).

5.3 The oxide skin may crack or flake and expose the metal surface to further oxidation.

Effect of temperature

6 The effect of an increase in temperature is usually to increase the rate of oxidation of a metal and this effect is shown graphically in fig 2. It shows how the oxide thickness of a metal in the atmosphere varies with respect to time when the temperature varies. The growths in this instance are smooth but in practice there may be discontinuities in them caused by the effects given in para 5.

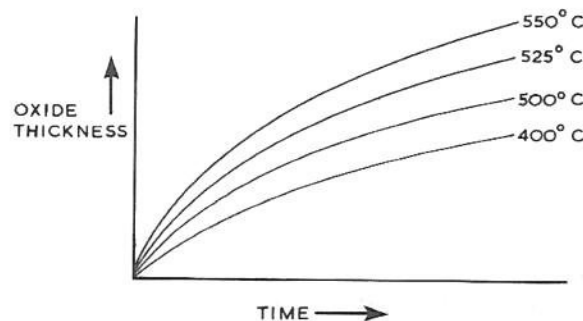


Fig 2 Oxide thickness against time when the temperature varies

Effect of alloying

7 Alloying a metal with another metal sometimes improves the oxidation resistance of the original metal. Fig 3 illustrates the effect of additions of aluminium on the oxidation resistance of iron. It can be seen that the greater the percentage of aluminium added to the iron the slower is the rate of growth of the oxide film thickness.

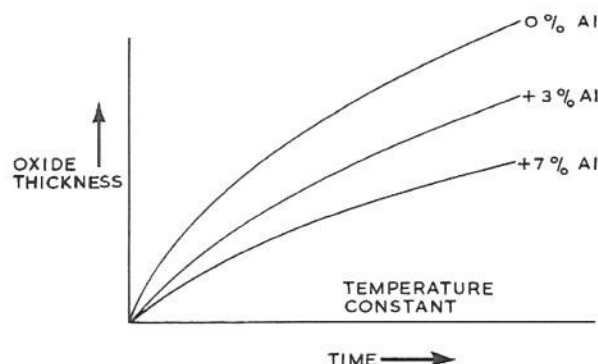


Fig 3 Oxide thickness against time with varying additions of aluminium to iron

8 The reason for the improved oxidation resistance of iron-aluminium alloys is that the oxide film formed on them is relatively rich in aluminium oxide

and is more protective than iron oxide. Two further examples of the use of aluminium in this way are:

8.1 If copper-aluminium alloys are heated for a short time at 800°C (1472°F) in dried air, selective oxidation occurs which gives a very protective pure alumina film on the surface.

8.2 A similar process can be applied to sterling silver (92.5% silver, 7.5% copper) in which 1% of the copper is replaced by aluminium to produce an alumina coated alloy which has no tendency to tarnish.

9 A further example of alloying is the addition of chromium to nickel. The corrosion and oxidation resistance of stainless steels is due to the formation of protective films rich in chromium oxide. In the same way chromium gives oxidation resistance to nickel-base alloys such as furnace wires (80% Ni, 20% Cr) and gas-turbine alloys.

ELECTROCHEMICAL (GALVANIC) CORROSION

The corrosion cell

10 The mechanism of electrochemical corrosion, both on single metal surfaces and at bi-metallic contacts, is similar to that of a primary cell which produces low voltage direct current. When zinc and copper plates are partially immersed in dilute sulphuric acid and are electrically connected through an ammeter and voltmeter (see fig 4) the potential difference between the plates causes a current to flow. The zinc forms the anode of the cell and is oxidized to its positively charged ions which dissolve in the sulphuric acid electrolyte. At the surface of the copper plate, the cathode of the cell, a balancing reaction occurs when the electrons, formed in the anode reaction and conducted through the external circuit of the cell, meet with positively charged hydrogen ions to give hydrogen gas. The thermodynamic driving force of this cell is the difference in galvanic potential of the two metals. The metal of lower potential in such a cell forms the anode and is oxidized or corroded.

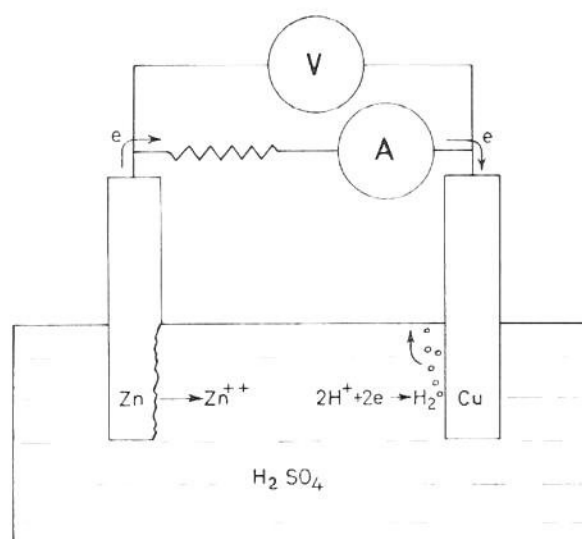


Fig 4 Simple primary cell

11 Similar electrochemical corrosion processes with balancing anodic and cathodic reactions occur in neutral (non-acidic) electrolytes such as water or water containing traces of dissolved inorganic matter. Again, the anodic reaction will involve oxidation (corrosion) of the metal with the lower galvanic potential, but the cathodic reaction will usually be the reduction of oxygen dissolved in the electrolyte.

12 The electrode processes which occur in many electrochemical cells, can be expressed chemically as follows:

12.1 Anode reaction $M \rightarrow M^{++} + 2e^-$ where M is a divalent metal.

12.2 Cathode reaction in acidic electrolyte $2H^+ + 2e^- \rightarrow H_2$.

12.3 Cathode reaction in neutral electrolyte $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$.

Factors affecting the rate of corrosion

13 Corrosion in its initial attack and subsequent progress is usually a complex phenomenon in which several factors are involved. These are summarized in the paragraphs that follow.

Conductivity of solution

14 The higher the electrical resistance of the solution, the lower the corrosion current. This suggests an explanation of the negligible corrosion that occurs in pure water with its high electrical resistance and the comparatively severe corrosion that occurs in sea water, which by comparison with pure water, conducts electricity quite well. Adding various chemicals to the electrolyte in the example shown in fig 5 changes the reaction and resistance of the cell. A few of these changes are discussed in para 15 and 16.

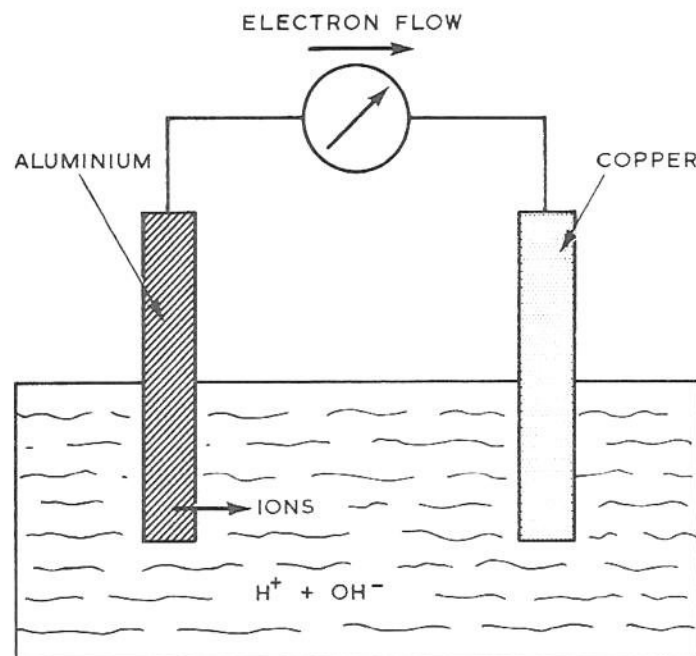


Fig 5 Copper, aluminium and water electrolytic cell

15 Addition of sodium chloride (salt). If salt is added to the electrolyte the following events occur:

15.1 The chloride ions (Cl^-) break down the oxide films present on the metal surfaces.

15.2 The resistance of the circuit is decreased and the current increases.

16 Addition of an acid (such as hydrochloric acid). If an acid is added to the electrolyte the following events occur:

16.1 The oxide film is dissolved.

16.2 The resistance of the circuit is decreased.

16.3 The anode reaction remains $\text{Al} \rightarrow \text{Al}^{+++} + 3\text{e}^-$.

16.4 The cathode reaction becomes $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$.

Potential difference between metals

17 The galvanic potentials of metals and alloys can be measured and typical values found in solutions containing chloride ion (sea water or neutral 3.5% sodium chloride solution) are indicated in fig 6. From these values of galvanic potential it is possible to predict which of two metals will form the anode in a corrosion cell in chloride ion solutions. However, different corrosion potentials are obtained in different electrolytes and it is not possible to use the galvanic series in fig 6 to predict the position or severity of corrosion attack in a bimetallic corrosion cell. More reliable indications can be obtained from Chapter 2-1, Table 1 (Degree of corrosion at bimetallic contacts).

Polarization

18 When current passes in a cell the potentials of the cathode and anode tend to approach one another. This change in potential (usually measured in volts) is due to polarization. Polarization to a large extent determines the rate at which corrosion proceeds.

19 Polarization can occur in several ways, for example, by changes in the concentration of the electrolyte adjacent to the anode and cathode or by the collection of hydrogen at the cathode. If it occurs mainly at the anode, corrosion is said to be anodically controlled. Similarly it is cathodically controlled when polarization occurs mainly at the cathode. Where some polarization occurs at both anode and cathode, corrosion is said to be under mixed control.

20 The beneficial effect of polarization in reducing rates of corrosion is often countered by the action of depolarizers. Oxygen at the cathode is a depolarizer since it facilitates the discharge of hydrogen ions, but anodic as well as cathodic depolarizers exist.

21 Some metal couples polarize strongly so that only a small amount of corrosion current flows, but others polarize very little and the initial corrosion current is maintained. The open-circuit potential in sea water of aluminium/stainless steel is similar to that for aluminium/copper. The aluminium/stainless steel couple polarizes appreciably but the aluminium/copper couple does not, with the result that the corrosion of the aluminium by the copper is more severe than the corrosion of the aluminium by the stainless steel.

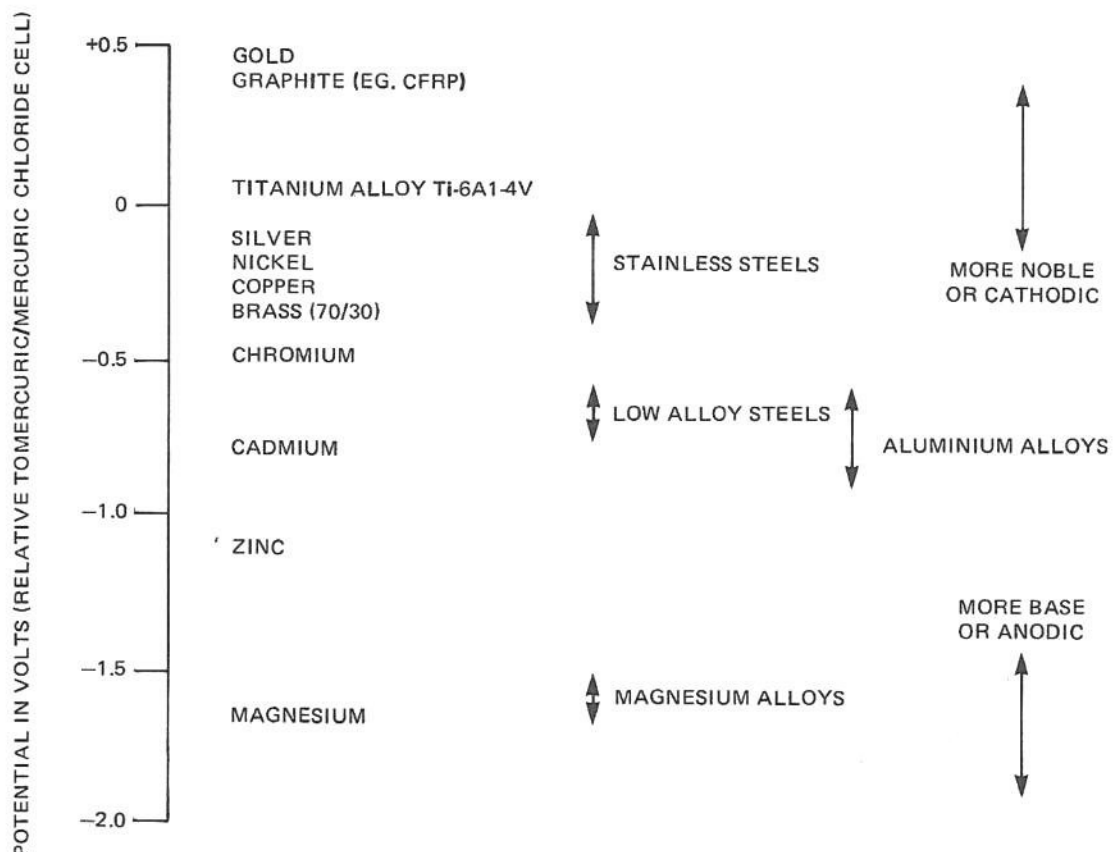


Fig 6 Galvanic potentials in chloride ion solutions

Electrical resistance of the metal path

22 The higher the electrical resistance of the metal path between two metals becomes, the weaker is the corrosion current that flows. In some instances when corrosion products form in faying surfaces, the corrosion product may increase the electrical resistance between two dissimilar metals and tend to inhibit corrosion between them. In other instances when two dissimilar metals are insulated from each other corrosion products containing occluded metal may bridge the insulation between the metals and allow electrochemical reaction to take place and promote corrosion. Sometimes corrosion products may hold the corrosive constituents of the environment and these may promote further corrosion.

Ratio of cathode to anode area

23 The ratio of the cathode area to anode area affects the current density and thus the severity of the corrosion process. The lower the ratio the lower the rate of corrosion. Conversely where there is a large cathode and a small anode the rate and intensity of corrosion tends to be severe.

24 Figure 7 illustrates the effect of the cathode area to anode area ratio. It may be observed that the following effects occur:

24.1 In fig 7a the steel plate is the cathode and has a large surface area which is 'fed' by the small surface area of the aluminium rivet and the result is that severe corrosion occurs.

24.2 In fig 7b a large anode is 'feeding' a small cathode and so relatively little corrosion occurs; but some corrosion does occur and the situations arising in fig 7a and 7b should be avoided if possible.

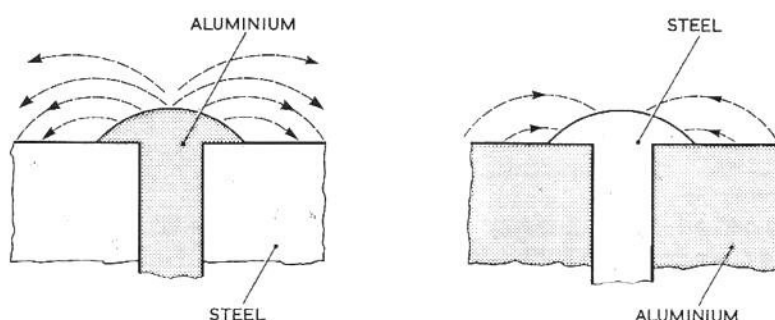


Fig 7 The effect of the cathode/anode area ratio on corrosion

Single metal corrosion cells

Electrochemical corrosion between alloy or metal constituents

25 Structural metal and alloy surfaces immersed in an electrolyte invariably show areas of differing galvanic potential which give rise to local corrosion cells. Examples include differences in potential between metal grains and grain boundaries, between precipitates within grains and the bulk of the grains, and between inclusions in metals and the bulk of the metal. As in a two-metal corrosion cell the more anodic material corrodes.

26 The presence of small quantities of impurities in metals may markedly increase rates of corrosion. For example, the corrosion of almost pure aluminium in dilute hydrochloric acid and of almost pure magnesium in a 3% salt solution, is greatly accelerated by iron inclusions of a fraction of one per cent by weight of the metals. The resistance of corrosion of some alloys can be greatly improved by eliminating impurities and inclusions.

Oxygen concentration corrosion cell

27 Corrosion cells can be set up by local differences in composition of an electrolyte. A common instance of this occurs where one part of an electrolyte is exposed to the atmosphere and therefore contains the maximum of dissolved oxygen, whilst another part is deficient in dissolved oxygen, perhaps because it is in a crevice or under a pile of debris.

28 Parts of a metal that are in contact with liquid having a high concentration of oxygen will become cathodic and be protected from corrosion and the areas where the oxygen concentration is low will become anodic and will be corroded. This is known as the 'differential aeration' principle and is of importance in explaining many corrosion phenomena.

Electrochemical corrosion where the temperature is not uniform

29 Corrosion can occur in a single metal immersed in an electrolyte if there are differences in electrode potential due to variations in temperature from point to point. Under conditions where the solution temperature varies, appreciable corrosive attack may occur. This fact is of importance in the corrosion of boilers and heat exchangers.

TYPES OF CORROSION

General

30 Brief descriptions of the more common forms of corrosion are given (para 31 to 49). It is emphasized that the processes of corrosion are complex and the various types seldom occur separately. One type of corrosion frequently leads to another and two or more types can exist simultaneously in one area. All forms of corrosion result from a failure of the applied protective treatment.

Surface corrosion

31 Surface corrosion is a fairly uniform corrosion attack which slowly reduces the cross section of the metal. It is the least damaging form of corrosion. A mild attack may result only in general etching of an area while a heavier attack may produce deposits which depend on the type of metal that is attacked. Pure aluminium, stainless steel and copper have more resistance to surface corrosion than have aluminium alloys, magnesium and non-stainless steel. Generally surface corrosion is not very damaging (except where a long period of time elapses) but it gives a warning of possibly worse corrosion to follow. Fig 8 illustrates two examples of surface corrosion.

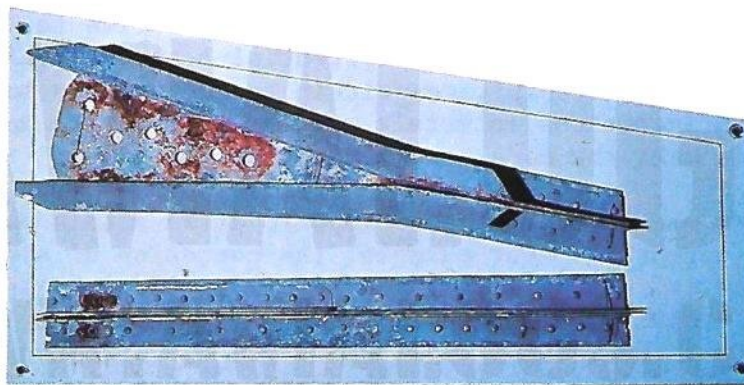


Fig 8 Surface corrosion on aluminium alloy structural components

Crevice corrosion

32 Crevices are liable to preferential attack, usually by a differential aeration form of corrosion intensified by the high ratio of cathode to anode area involved (see para 23 and 27). The attack is more intense where crevices are so situated that they collect dust and moisture. Fig 9 shows diagrammatically how crevice corrosion may occur and fig 10 and 11 show practical examples of crevice corrosion combined with dissimilar metal corrosion (see para 33).

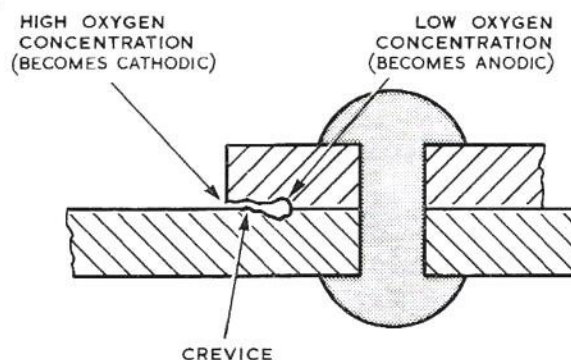


Fig 9 Diagrammatic example of crevice corrosion



Fig 10 Crevice corrosion between skin and stringer in a Sea King lower fuselage rear bay

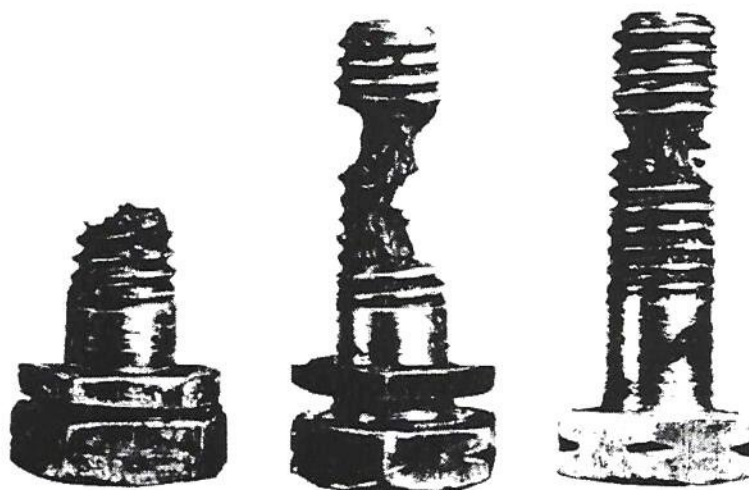


Fig 11 Severe dissimilar metal corrosion of stainless steel bolts

Note...

The bolts illustrated in fig 11, were screwed into electro-tinned brass nuts and immersed in an aqueous solution of calcium hypochlorite (bleaching powder). This test was carried out after reports of corroded bolts in aircraft fresh water tanks cleansed with bleaching powder.

Dissimilar metal corrosion

33 One of the more common forms of corrosion is that which occurs between two dissimilar metals in contact with each other and where there is moisture present (see para 11). It is caused by the difference in galvanic potential of the two metals. This type of corrosion is sometimes referred to as galvanic corrosion and examples of it are given in fig 12 and 13.

34 Severe dissimilar metal corrosion is likely where steel bolts, nuts or studs are in contact with magnesium-rich alloys, for example, on aircraft wheels.

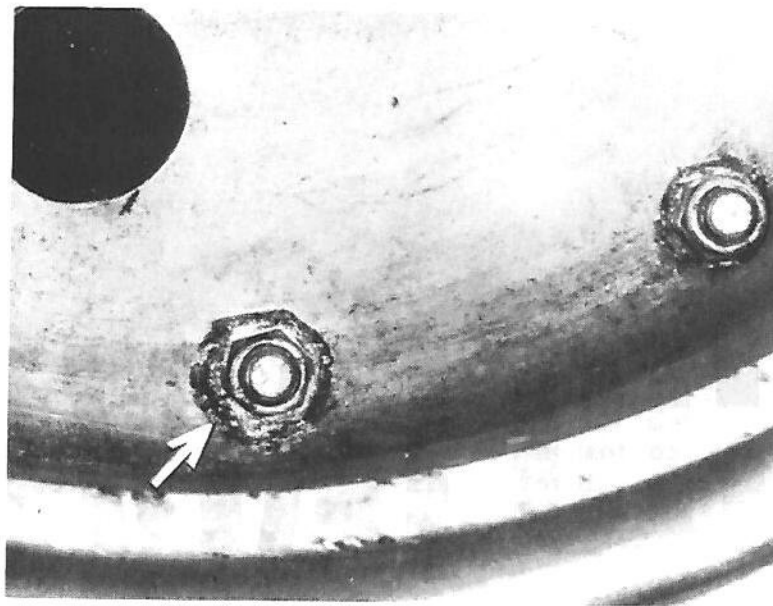


Fig 12 Dissimilar metal corrosion on an aircraft wheel where stud bolts are in contact with the magnesium alloy wheel

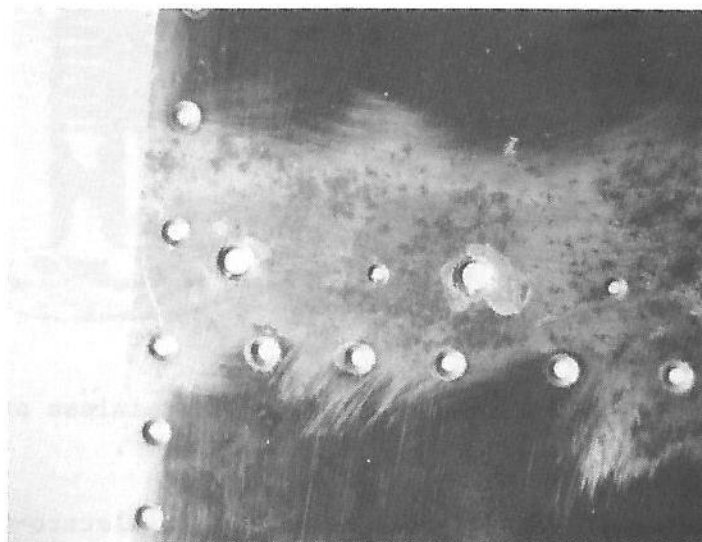


Fig 13 Dissimilar metal corrosion damage at a fastener hole, where a steel bolt is fastened through a skin of magnesium alloy

Pitting corrosion

35 Pitting can occur on aircraft materials when the protective film, whether natural or applied, breaks down locally. Pitting corrosion may lead to intergranular corrosion (refer to para 39).

36 Pitting often stems from the screening effect of silt, scale or corrosion deposits that reduce the oxygen concentration at local points on a metal surface and thus establish differential concentration cells. Local rough spots, inclusions, contaminations and lack of homogeneity in the alloy or metal are also possible causes of pitting corrosion. In size and depth, the pits are widely variable and a large number of pits can give a surface a blotchy appearance. Chromium plated steels, stainless steel, aluminium and magnesium alloys are particularly susceptible to pitting corrosion.

37 Examples of pitting corrosion can be seen in fig 14 and 15. Fig 16 shows a microsection which illustrates pitting corrosion in association with intergranular cracking (see para 39).



Fig 14 Pitting corrosion on a Gnome engine compressor stator blade

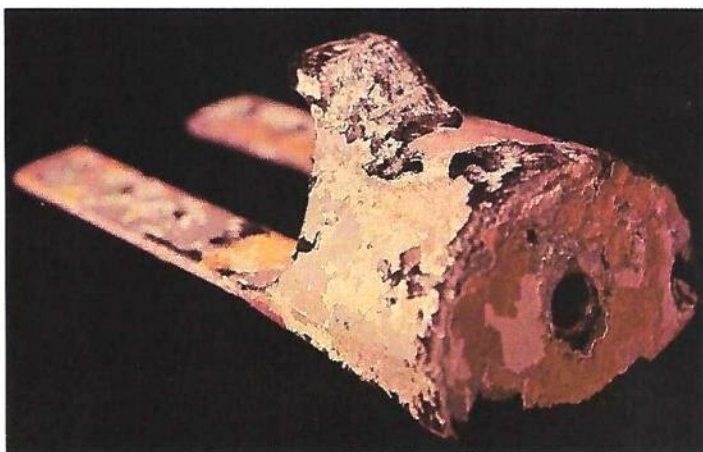


Fig 15 Advanced pitting corrosion of magnesium alloy stringer end cap



Fig 16 Microsection illustrating pitting corrosion and associated intergranular cracking in the surface of aluminium alloy (magnified 500 times)

Filiform corrosion

38 Filiform corrosion occurs beneath thin protective coatings on aluminium and steel alloys. On aircraft structures the attack often starts at fasteners and extends as thread-like lines of corrosion under the paint and it may not be readily visible until it has become quite severe. The damage is usually very shallow and not structurally dangerous. Fig 17 shows filiform corrosion around fasteners in aluminium alloy.

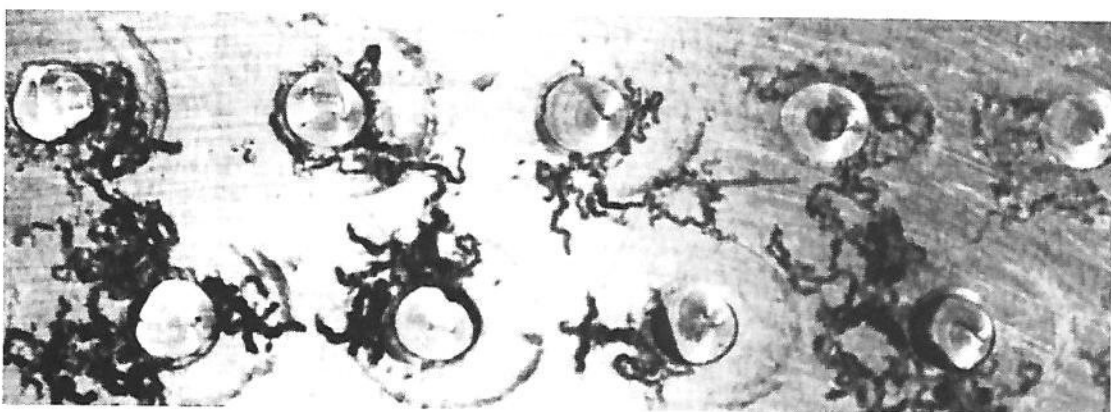


Fig 17 Filiform corrosion around fasteners in L72, 20 swg aluminium alloy

Intergranular corrosion

39 Intergranular or intercrystalline corrosion results from micro-galvanic cells at the grain boundaries in the alloy. Corrosion proceeds from the metal surface in narrow pathways along grain boundaries, often penetrating quite deeply and having a serious mechanical weakening effect. The amount of metal

corroded is small, relative to the volume of metal affected. Indication of the damage may not be visible to the naked eye.

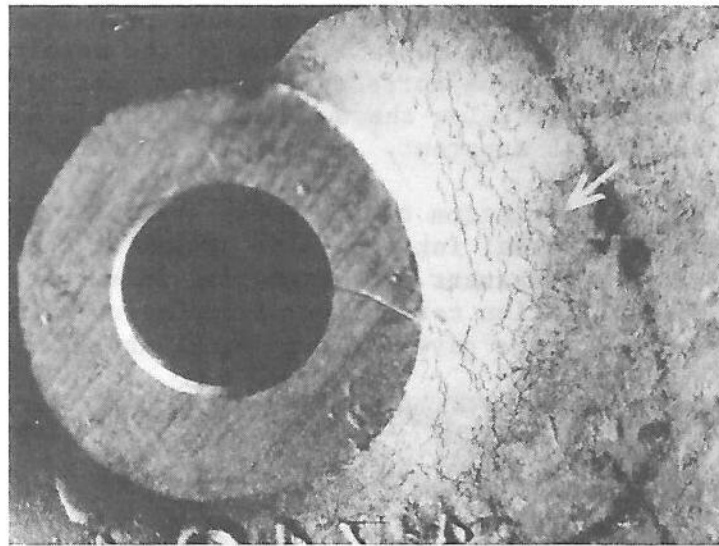


Fig 18 Intergranular corrosion on a forged, aluminium alloy hydraulic valve, has caused a fine network of cracking

40 Intergranular corrosion is illustrated in fig 18 where an example of corrosion on a forged aluminium alloy hydraulic valve is shown. Fig 19 is a microsection showing severe intergranular corrosion of an aluminium alloy.

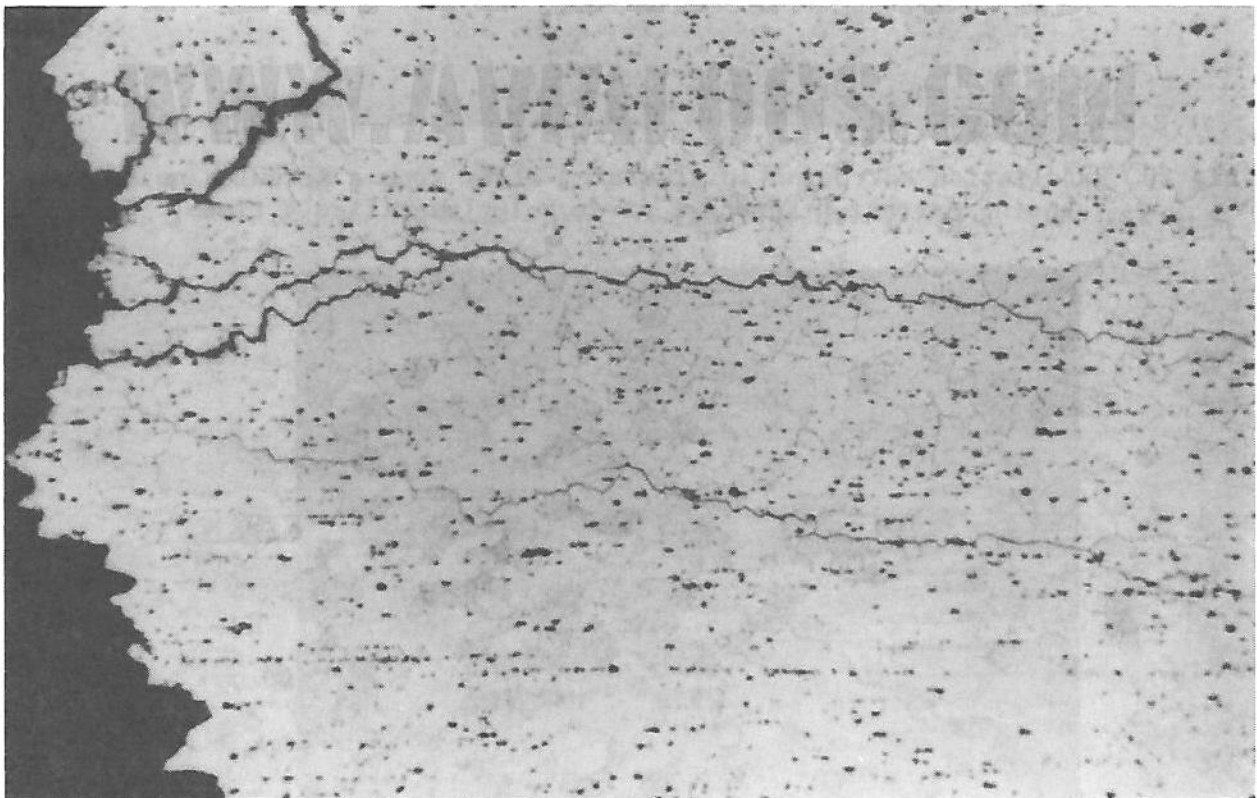


Fig 19 Microsection showing intergranular corrosion of an aluminium alloy (magnified 150 times)

Exfoliation corrosion

41 Exfoliation or layer corrosion of certain wrought aluminium alloys, is a form of intergranular corrosion in which the attack occurs in layers parallel to the surface. The wedging action of the corrosion product, which occupies a larger volume than the alloy, will cause lifting of the metal surface. This appears at an early stage when the corrosion is on or just below the surface. When the corrosion occurs well below the surface, extensive damage can occur before surface deformation is apparent.

42 The elongation and reorientation of the metal grain during extrusion or rolling, is conducive to eventual intergranular attack in the direction of grain flow. Improper heat treatment or overheating in service may also be a contributory cause of exfoliation corrosion. Examples of exfoliation corrosion in aluminium alloy are given in fig 20, 21 and 22.

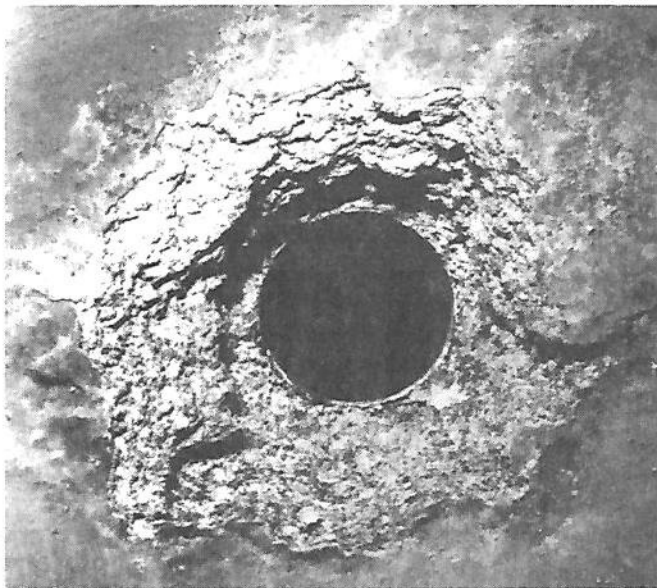


Fig 20 Exfoliation corrosion in aluminium alloy from a Hercules mainplane, showing corrosion around a rivet hole (magnified 4 times)

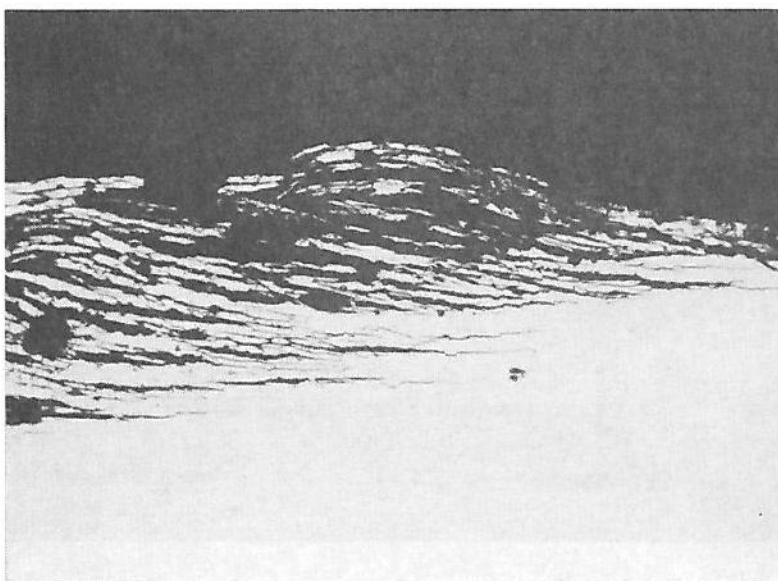


Fig 21 Section through the exfoliation corrosion damage around a fastener in a Hercules mainplane skin material (magnified 100 times)



Fig 22 Exfoliation corrosion damage at the edge of an access hole in aluminium alloy skin

Dezincification corrosion

43 Dezincification and graphitization (para 45) are types of corrosion that do not generally affect aircraft but are described for general interest.

44 Dezincification corrosion involves the removal by corrosion, of a metallurgical phase or constituent from a copper base alloy, leaving the other phases or constituents in a somewhat non-coherent condition. This type of corrosion is now rare in cold working brasses due to the inhibiting effect of an arsenic addition. It is encountered when two-phase brasses are used in sea water, where the removal of zinc leaves affected zones that have characteristic contrasting red copper spots and patches. Attack of this type can also occur with other alloys which may suffer selective removal of nickel or aluminium; in the latter, the attack may not be obvious to the eye and can only be reliably judged by fracturing the component. The effect can be local or general, confined to surface layers or present in depth and can weaken mechanically, or virtually destroy the part affected. A microsection showing the dezincification of brass is shown in fig 23.

Graphitization (graphite softening)

45 Graphitization corrosion, which is similar in many respects to dezincification described in para 43, affects cast iron buried in waterlogged clay soils or immersed in certain liquids. The parts may retain their shape but become very weak and brittle. The ferritic constituents corrode leaving a weak mass of graphite and corrosion product.

Fretting corrosion

46 Examples of fretting corrosion are given in fig 24 and 25. Fretting corrosion is the result of rubbing contact between two heavily loaded surfaces, one or both of which are metallic. The rubbing movement, which may

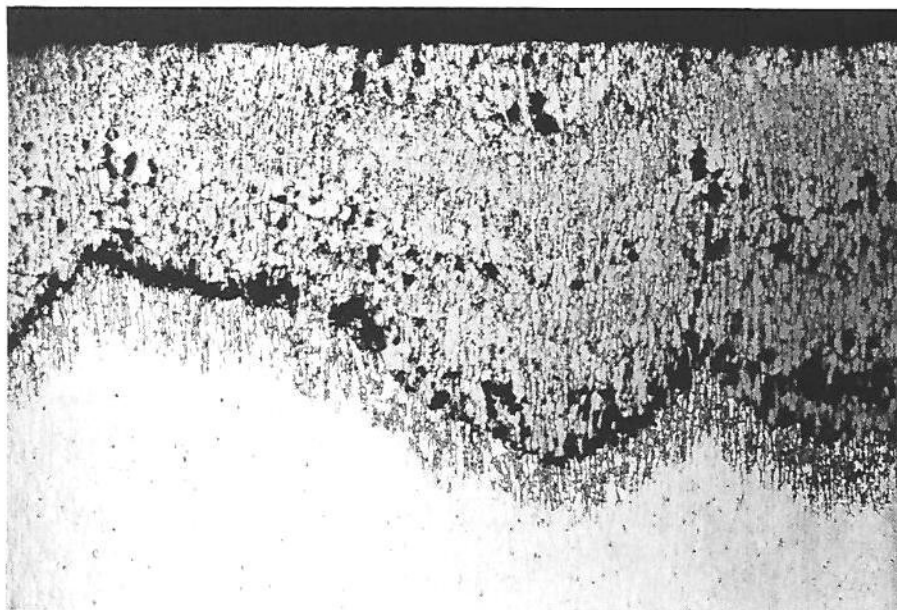


Fig 23 Dezincification of brass

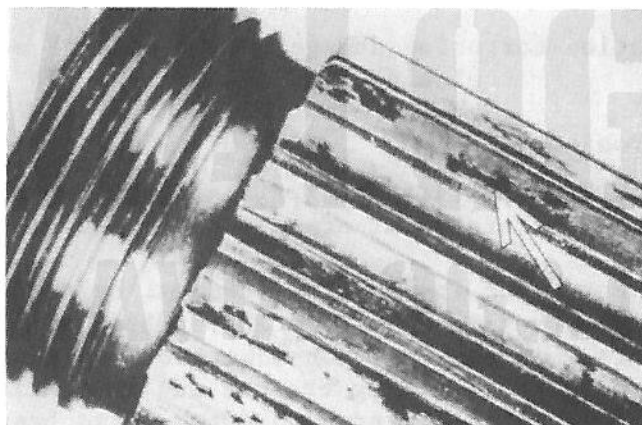


Fig 24 Fretting corrosion on a spline as indicated by surface roughness on the serrations

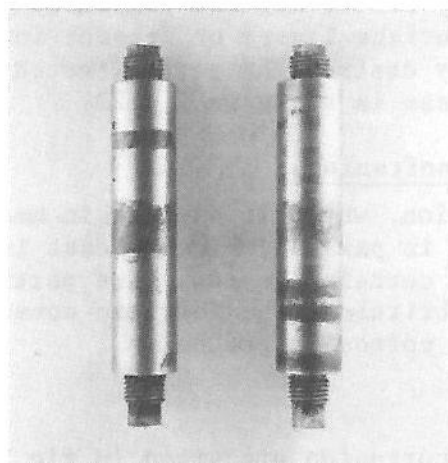


Fig 25 Fretting corrosion damage to flying control hinge pins

be minute (in some instances elastic movement only), destroys any natural protective film and also removes particles of metal from the surface. The particles removed form an abrasive, which aggravates the effect of the rubbing action and the surface is continually removed to expose fresh metal to the corrosive attack. This form of attack can eventually cause cracking and fatigue failure, and sometimes affects splined drives, gear wheels, tailplane screw jacks and their collars.

47 Moisture tends to reduce fretting, probably by acting as a lubricant, while an increase in temperature can often be beneficial for reasons that are not at present known. If a surface is phosphated, or lubricated with oil or soft metal deposits, fretting corrosion is reduced.

48 When fretting corrosion occurs, the material may appear coloured or fine particles of metal may be seen. The corrosion product, if present, is black or dark brown in colour.

49 Fig 26 shows the general effect of various measures on the fretting fatigue life of two steel members bolted together. As may be seen, lubricants and shot peening tend to increase the life of metals in loaded contact. Further details of fretting fatigue experiments may be obtained from specialized books.

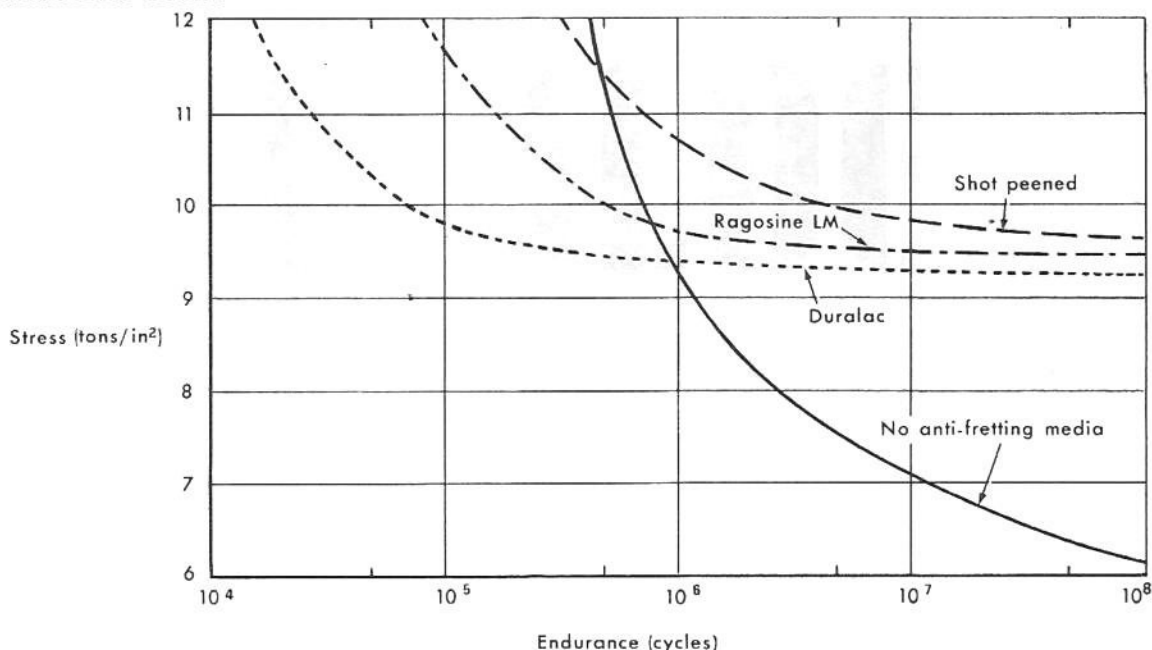


Fig 26 Results of fretting fatigue experiments

STRESS CORROSION CRACKING

General

50 Stress corrosion cracking is a cracking process caused by the conjoint action of a sustained tensile stress and a corrosive environment. Only certain combinations of alloys and environments result in stress corrosion cracking, but this type of failure may occur at stresses well below the yield strengths of the alloys. Many of the high strength structural alloys used in aircraft are prone to stress corrosion cracking in a wide range of environments and are particularly susceptible in marine environments. Examples of stress corrosion cracking are given in fig 27 to 30.

Stresses causing stress corrosion cracking

51 In aircraft alloys, the principal stresses causing stress corrosion

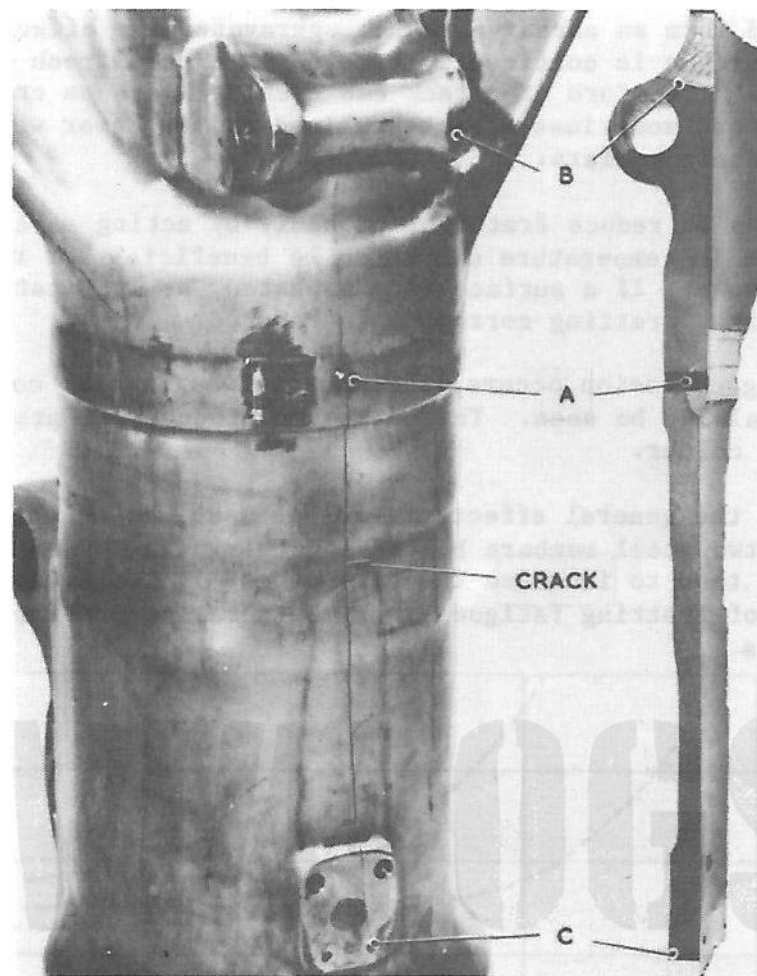


Fig 27 Stress corrosion cracking of an aluminium alloy forging

Note...

The forging illustrated in fig 27 housed a cadmium plated, phosphor bronze bush, which was located by a cadmium plated screw (A). Fretting between the bush and forging, removed the plating from the bush and the end of the screw, allowing dissimilar metal corrosion to develop between the bush, screw and forging. Corrosion pitting of the forging, initiated an area of stress corrosion cracking at A, which resulted in a rupture of the forging between B and C.

cracking, are not the applied service loads but the stresses developed within the metal during manufacture and during assembly, for example internal stresses arising from quenching after heat treatment, from force fits, from badly mating parts or from welding. Only in components such as undercarriage jacks, are the service stresses alone likely to be great enough to cause stress corrosion. Service stresses are significant when they act in the same direction as internal or assembly stresses.

52 The detailed mechanisms of stress corrosion cracking are not understood and may be different for different alloys. Susceptibility to stress corrosion cracking for many alloys depends markedly on heat treatment.

53 If a smooth stress corrosion test specimen is exposed to a controlled corrosive environment and subjected to a constant applied tensile load, then the total time to failure will be made up of three periods:

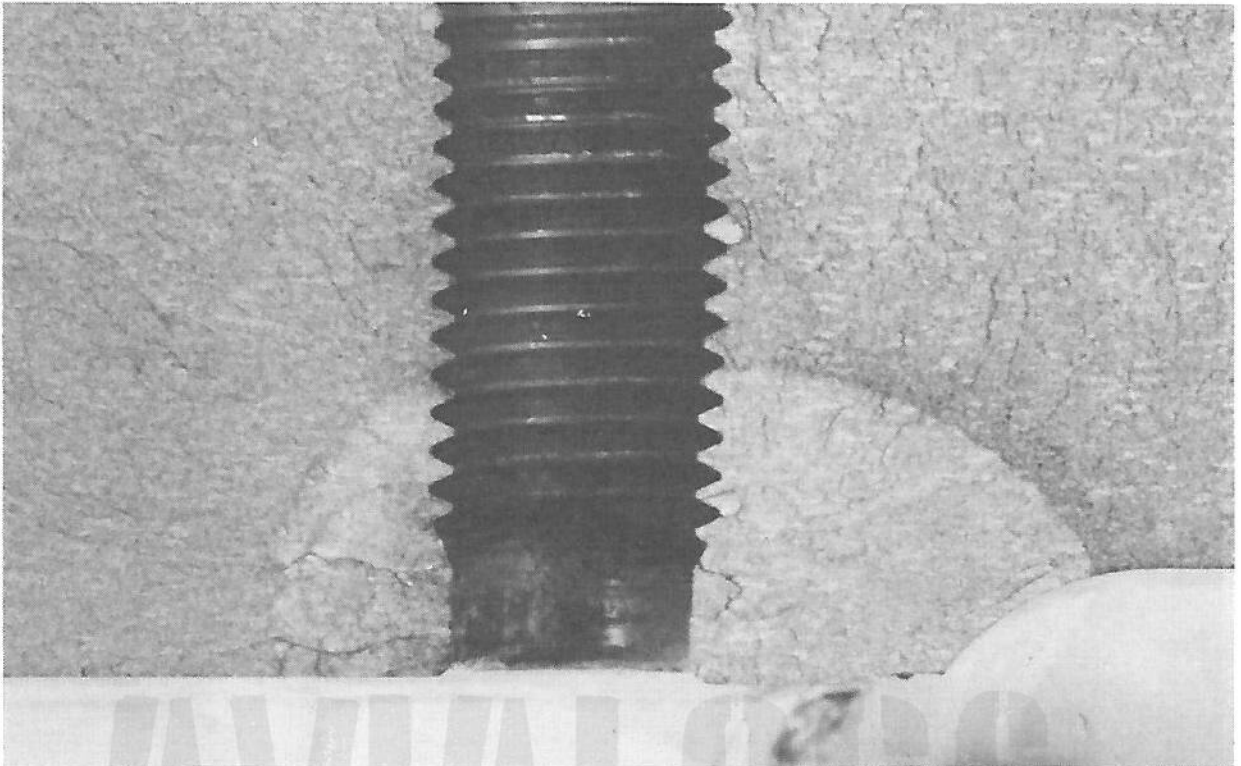


Fig 28 Details of stress corrosion cracking at A in Fig 27

Note...

Stress corrosion cracks are often very fine and the parts affected may show little sign of external corrosion.

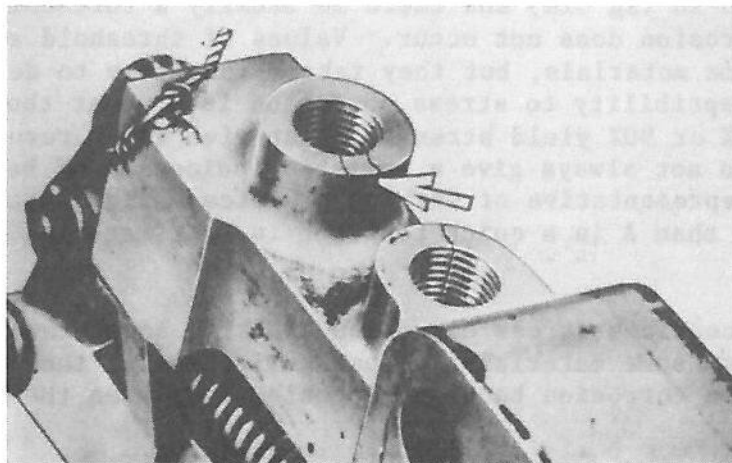


Fig 29 Stress corrosion cracking on the bosses of a forged aluminium alloy component

53.1 An incubation period during which a stress corrosion crack initiates (usually as a result of film breakdown or corrosion pitting).

53.2 A period of slow growth.

53.3 An extremely short period of rapid unstable crack growth (independent of environment and caused by mechanical overload).

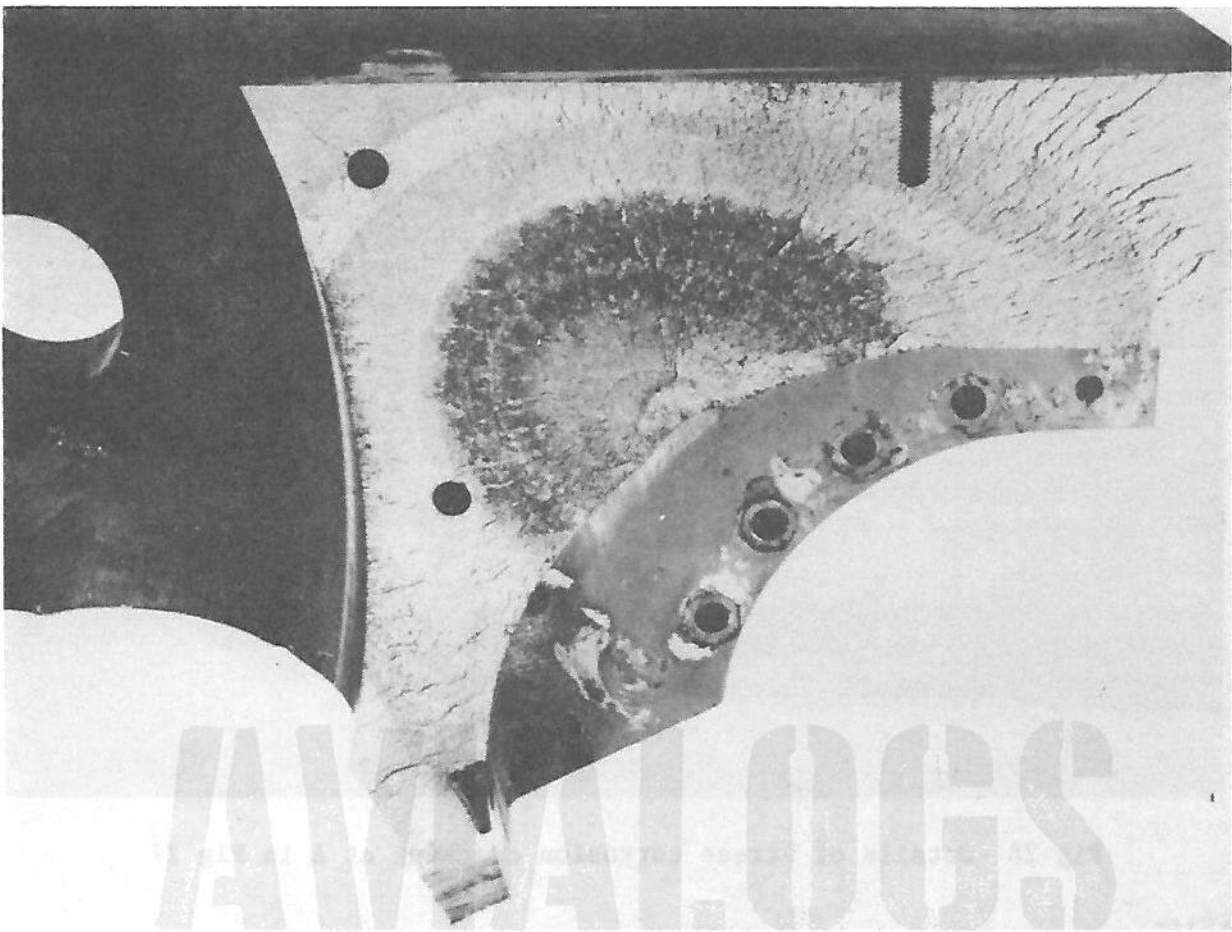


Fig 30 Stress corrosion cracking in Canberra centre section forging

54 The life to fracture of a susceptible material increases as the stress is reduced (as shown in fig 31a) and there is usually a threshold stress below which stress corrosion does not occur. Values of threshold stresses are available for some materials, but they take a long time to determine and much testing for susceptibility to stress corrosion is done at those high stresses (for example, 75% or 90% yield strength) that give quick results. Tests at high stresses, do not always give a reliable indication of behaviour at lower stresses, more representative of working practice; fig 31b shows how material B appears better than A in a quick test but in fact material A is safer at lower stresses.

55 With some exceptions stress corrosion cracking accelerates with rise of temperature. With some materials in some environments, the effect is so marked that stress corrosion becomes a problem only when the system is hot.

Corrosion fatigue

56 When a metal is subjected to alternating stresses, it will fail at stresses considerably below the static tensile stress. This is known as fatigue failure. For steels, there is a critical alternating stress, the fatigue limit, below which failure will never occur; this limit is somewhat less than half the tensile strength (dotted line in fig 32). Aluminium alloys do not show a fatigue limit (the dotted line in fig 32 never quite becomes horizontal) but the alternating stress which can be withstood for 10^7 to 10^8 cycles can, for most practical purposes, be taken as a fatigue limit.

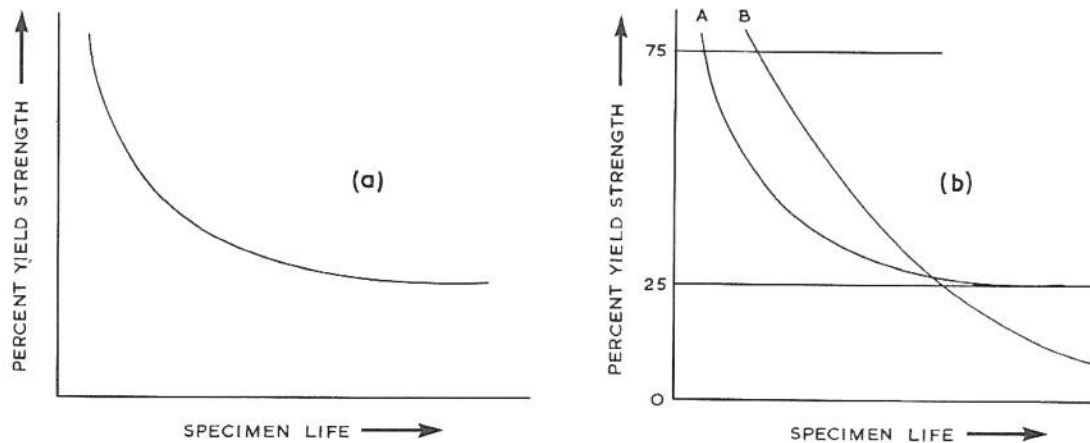
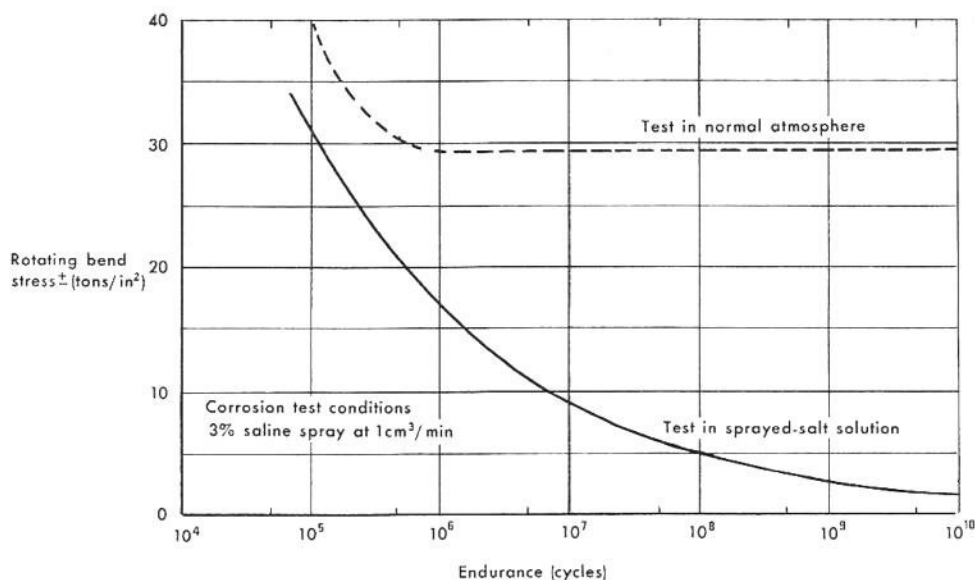


Fig 31 Typical stress corrosion curves

57 When fatigue occurs in a corroding environment, fatigue properties are reduced (fig 32) and the fatigue limit of ferrous metals can disappear in a severely corrosive environment. An example of corrosion fatigue is given in fig 33.

Mechanism of corrosion fatigue

58 The mechanism of corrosion fatigue is similar to that for stress corrosion, with the exception that the applied loads are cyclic instead of static. Crack propagation is aided by the corrosion that occurs at the root of the crack during the tensile part of the loading cycle.

Fig 32 The corrosion fatigue strength of 60 ton/in² steel (S96)

Hydrogen embrittlement of steels

59 Many of the standard surface protection treatments, including cleaning and electroplating treatments, are liable to introduce hydrogen into steel. Baking treatments, usually at 190 to 230°C (374 to 446°F) are therefore required after surface protection processes in order to avoid consequent

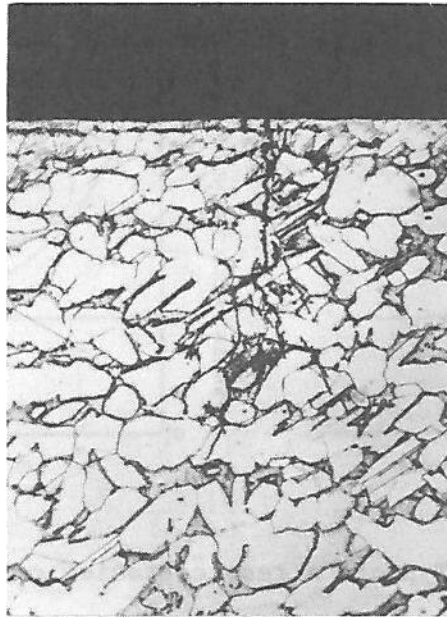


Fig 33 Corrosion fatigue crack in naval brass, etched (magnified 200 times)

hydrogen embrittlement; since the susceptibility of steels to hydrogen embrittlement increases as their tensile strength increases, longer baking times are required for the higher strength steels.

60 The loss of ductility due to hydrogen embrittlement may be revealed by slow strain-rate mechanical tests, not by fast strain-rate tests such as impact tests. Though slow strain-rate tensile tests have indicated no loss of ductility, high strength steel components subjected to sustained tensile loads well below the yield strength of the steel, can fail suddenly after a period of several weeks as a result of hydrogen embrittlement. It is probable that hydrogen embrittlement is the mechanism leading to stress corrosion cracking of very strong steels.

Microbiological corrosion

61 Corrosion caused directly or indirectly by micro-organisms have often been termed microbiological corrosion and can be brought about in the following ways:

- 61.1 The production, by the micro-organisms, of corrosive substances such as hydrogen sulphide, ammonia and organic and inorganic acids.
- 61.2 By the micro-organisms acting as depolarizers or catalysts in corrosion reactions.
- 61.3 By the micro-organisms causing local depletion of oxygen.
- 61.4 By water being held in contact with a metal surface by matted fungi and micro-organisms.

62 The most common microbiological corrosion in aircraft is that caused by the fungal contamination of fuel tanks (see fig 34). Certain fungi can grow at the interface between fuel and water in the fuel tank and feed on the fuel itself. In well developed cases, a dense mat of fungus forms on the floor of the tank, retaining water and preventing free flow to the drain cock. In integral fuel tanks this can then cause serious corrosion of the aircraft structure and penetration of the bottom wing skin has been known to occur from contamination of integral wing tanks. Further information on microbiological

corrosion is given in Chapter 1-2 and 2-3.

63 Another form of microbiological corrosion is the corrosion of the underfloor structure by toilet and galley spillage, there is evidence that such spillage can be more corrosive than its chemical composition (for example, acidity and chloride content) can account for and the extra attack may be due to fermentation by yeasts and bacteria.

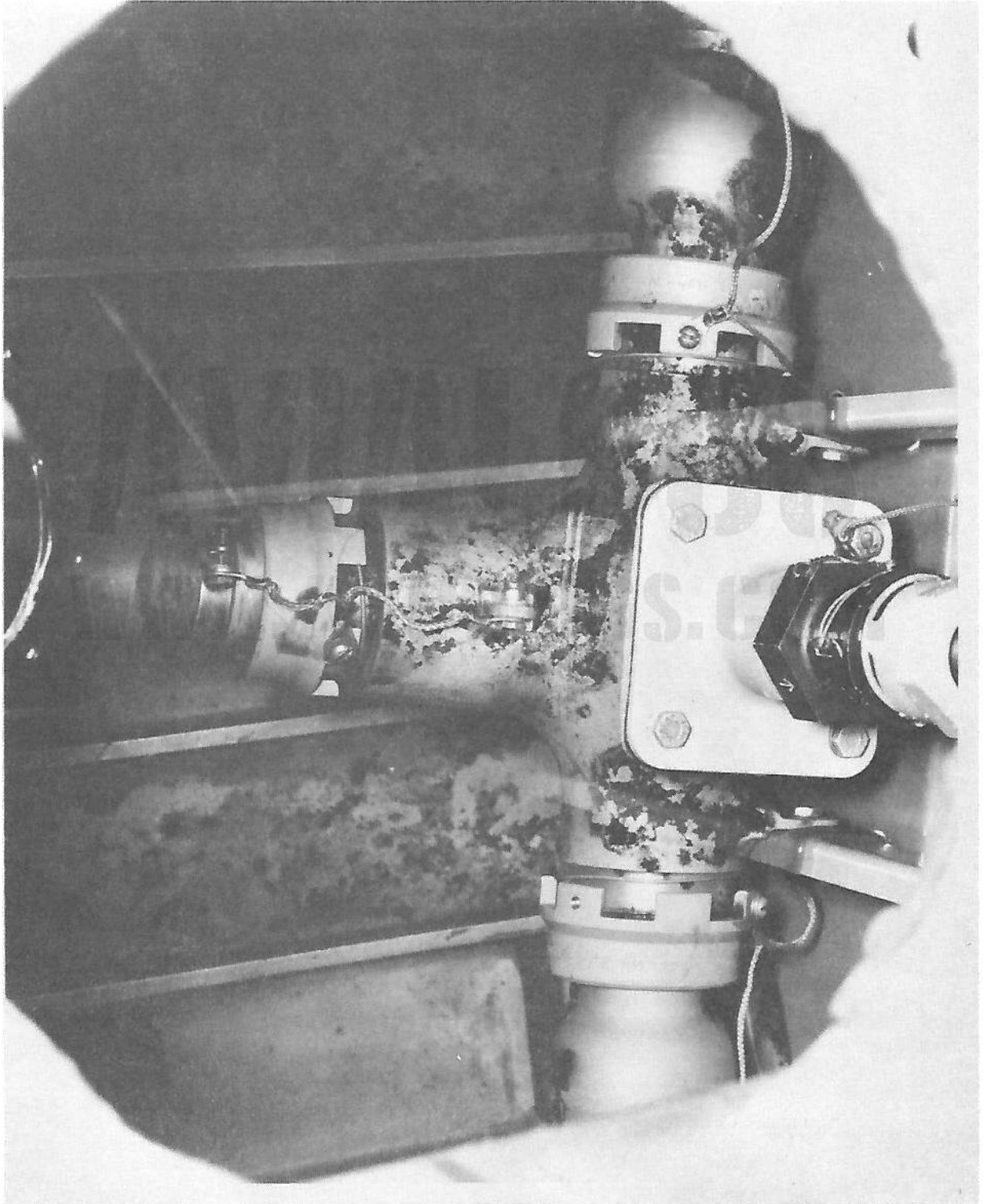


Fig 34 Microbiological corrosion in a fuel tank (British Aerospace)

corrosion is given in Chapter 1-2 and 2-3.

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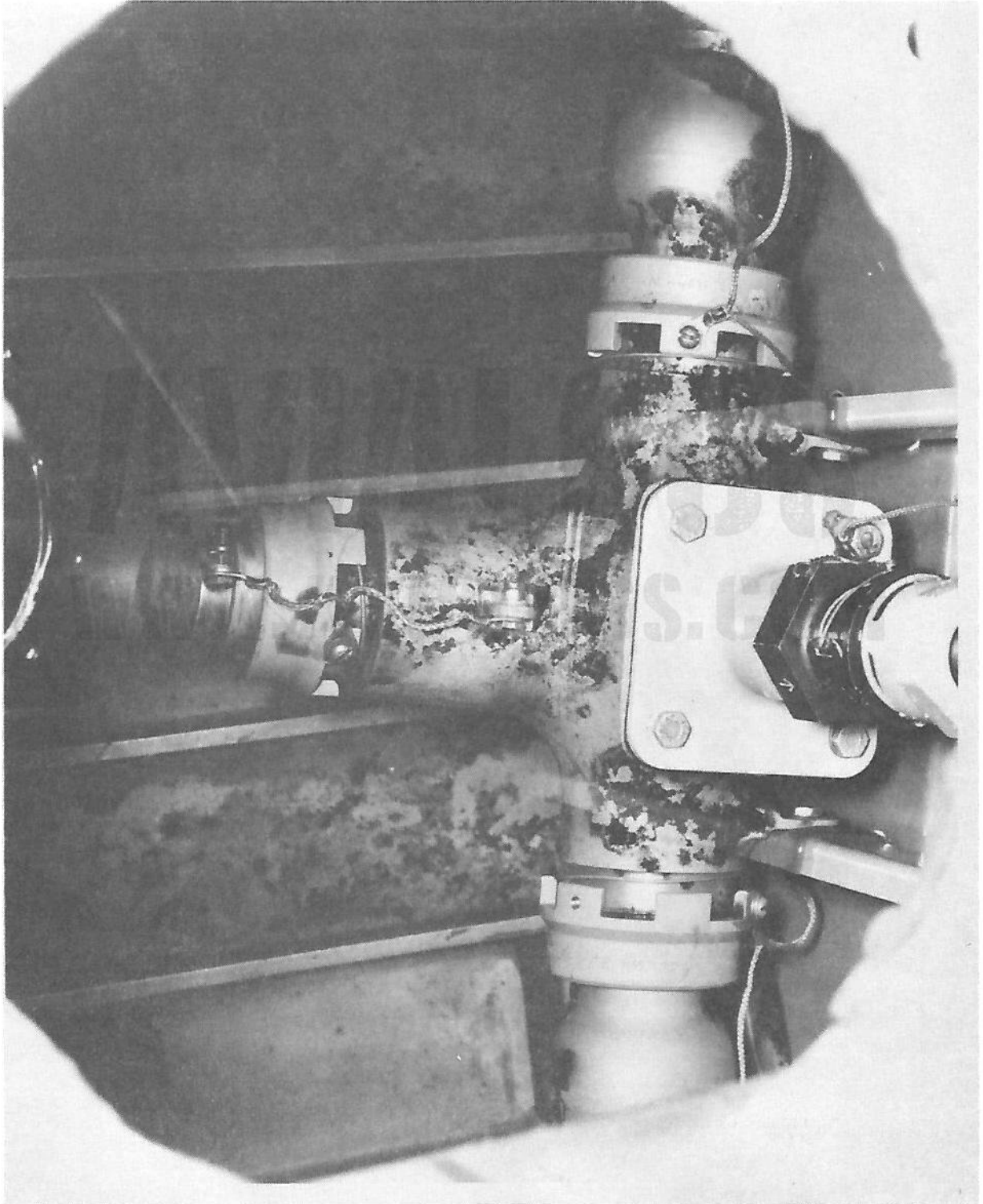


Fig 34 Microbiological corrosion in a fuel tank (British Aerospace)