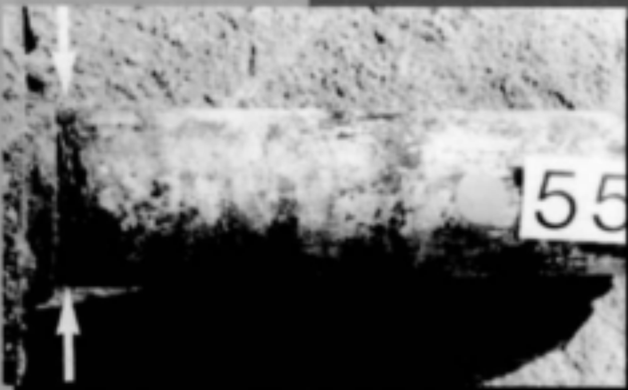
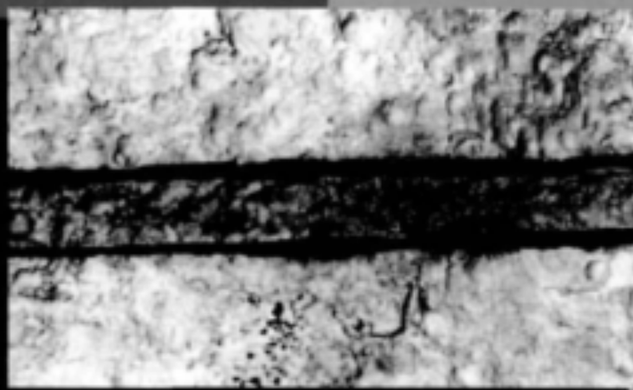
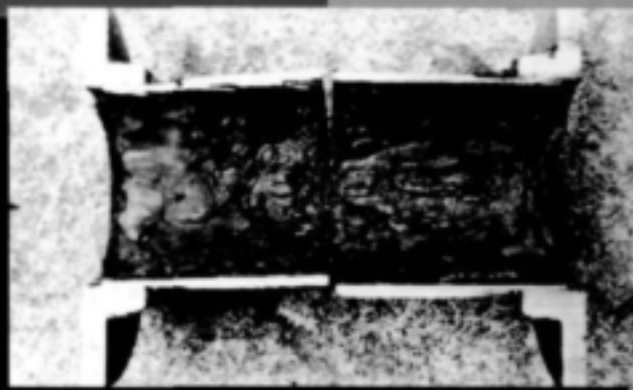
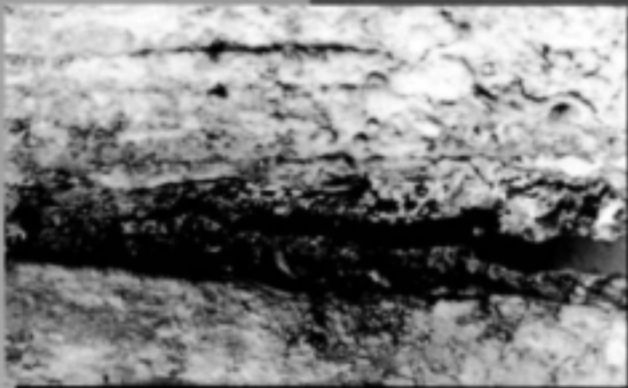
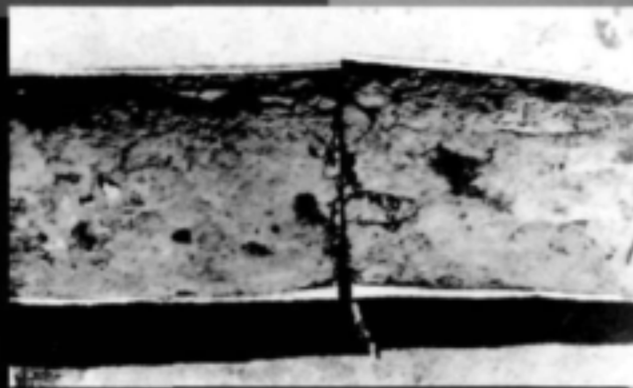
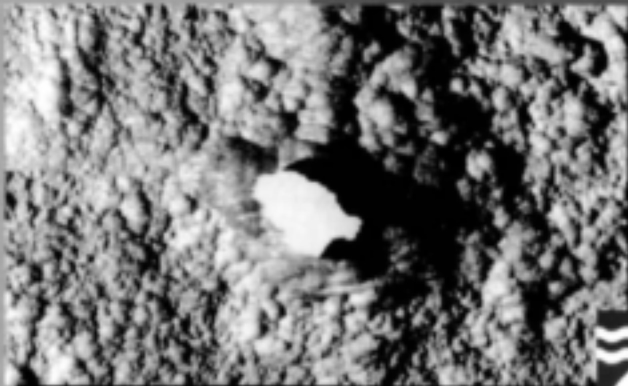
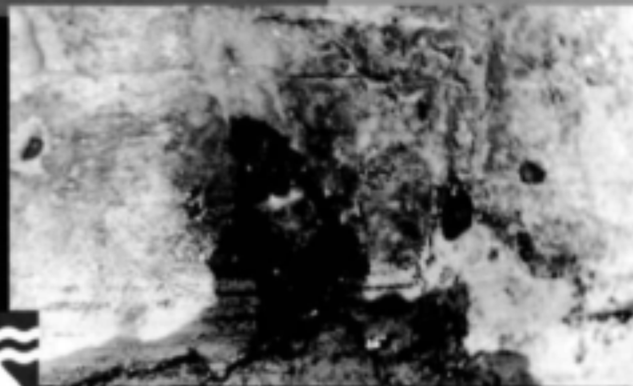
Corrosion:
Brochure for Local Authorities

JS Ramotlhola and C Ringas





TT 112/99

Corrosion: Brochure for local authorities

J.S. Ramotlhola and C. Ringas

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PRODUCTION OF CORROSION BROCHURE FOR LOCAL AUTHORITIES

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INTRODUCTION

The aim of this corrosion brochure is to provide engineers, maintenance departments, operators and plumbers with elementary reviews of corrosion damage which may occur during their water supply activities and to provide advice on remedial actions. The brochure will be limited to metallic potable water supply systems and pipelines.

Corrosion has caused extensive damage in water mains and distribution systems by thinning walls over large areas or by localised pitting. External corrosion can be accelerated by galvanic effects, stray current and microbiological activities in the soil. Internal corrosion can also have an unfavourable influence on the integrity of the system and water quality by causing leaks or by releasing corrosion products into the system.

Great increases in operational costs can result due to corrosion. This leads to pipe failures, increase in water loss due to leaks and pressure loss due to voluminous corrosion products or debris. Deterioration of drinking water quality due to corrosion products from internal corrosion can cause health hazards and can lead to the deterioration of the aesthetic appearance. By improving material quality and introducing corrosion protection techniques, in combination with the knowledge and recommendations on the use of correct materials at the correct location, a great number of these problems can be reduced or avoided.

Effective and economic corrosion prevention procedures must be followed. Non-metallic materials such as cement mortar lining, PVC and polyethylene may prove to be a viable alternative.

Corrosion failures of potable water pipes of water distributions systems can be classified as being caused externally or internally (**Figures 1 and 2**). The internally initiated corrosion failures would be bursts or leaks caused by factors such as microbiological corrosion or breakdown of internal lining. External corrosion is characterised by leaks caused by a wider range of factors such as stray currents, incorrect or insufficient cathodic protection, microbiological corrosion, absence of/or defective coatings and mechanical damage.

Steel piping suffers mostly from pitting corrosion which leads to the formation of tubercles (with reduced water flow), dissolved iron and suspended particles. Cast iron undergoes mainly a uniform-type of corrosion with the formation of tubercles, while ductile iron suffers from graphitisation and pitting. In other cases, failure of the piping systems can be caused by incorrect or poorly applied external and internal coatings.

WHAT IS CORROSION

Corrosion can be defined as the deterioration (breakdown) of a material (usually a metal) or its properties, because of the reaction with its environment. Most people are familiar with the rusting of an iron fence or a "tin" can, the degradation of steel fixtures or the rusting of an iron nail. This explains corrosion in simple terms. Most metals exist in nature as oxides or sulphides. Energy is required to convert an ore into a metal and this results in the reduction of the metal ions present in the ore. *The chemical energy of the metal may eventually be released electrochemically.* This process may be technologically useful, as in the case of a battery or by incorporation as a sacrificial anode in a cathodic protection system. Alternatively, the electrochemical process may be wasteful as in corrosion. It must be emphasised that corrosion is an electrochemical process resulting in the movement of electrons and ions. For corrosion to occur there must be an anode, a cathode, an electrolyte, and a metallic path joining the anode and the cathode.

FORMS OF CORROSION

Destruction by corrosion takes many forms, depending on the nature of the materials, the presence of inclusions, the homogeneity of its structure and the nature of the corrosive medium. Improper choice of material for a particular service or drastic change in the corrosive nature of the environment may cause a particular form of corrosion. The following are well-known forms of corrosion and their importance in relation to piping systems:

1. General corrosion

General corrosion or uniform attack occurs when there is relatively uniform metal loss. In a battery or when corrosion occurs, an electrochemical cell is set-up. The metal dissolution (the anodic or oxidation reaction) is balanced by a cathodic or reduction reaction (usually either hydrogen evolution or oxygen reduction). In a battery, the anode and the cathode are separated (the negative and positive electrodes) and are only connected when the switch is closed in the external circuit. In a corrosion cell, the anode and the cathode are on the same piece of metal. The anodes and cathodes keep changing, with the result that a uniform thickness of metal is removed after a certain time period, hence the name uniform or general corrosion.

2. Galvanic/bimetallic corrosion

A galvanic action can be created when different metals are used in pipeline construction or maintenance, and the two metals are in a common electrolyte (soil or water). In the case of distribution systems, the most common examples of galvanic corrosion are the coupling of copper household pipes to iron or steel mains and the coupling of galvanised steel pipes to cast iron pipes in water mains. Proper coating of pipelines made of different materials can reduce the effect of galvanic corrosion.

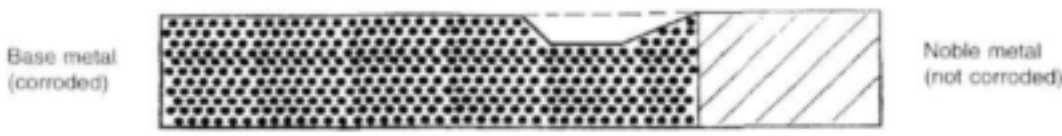


Diagram 1

3. Pitting corrosion

Pitting is a form of localised corrosion that occurs because of local cell action which produces cavities beginning at the surface. The shapes of the pits are widely varied and are usually roughly saucer-shaped, conical or hemispherical. Pitting can cause more unexpected corrosion losses than any other type of corrosion. Pitting can be prevented by cathodic protection, inhibitors and coating the surface of a metal with a layer of another alloy e.g. zinc or protective coatings.

4. Crevice corrosion

This is a severe localised attack which is often caused by the low rate of oxygen transfer into crevices. This type of corrosion occurs most frequently at overlaps of metals, crevices under bolts and rivet heads, in bolt holes, under surface deposits and even at gasket surfaces. Crevice corrosion can be minimised by filling the crevice with plastic, elastomers or other non-porous materials. Alternatively, the design may be changed to totally eliminate the crevice.

Diagram 2

5. Differential aeration

This may be caused by several factors such as differences in aeration of soil types e.g. silt vs. clay or sand; pipes extending from beneath a structure which prevents free access to oxygen into open soil, which permits free migration of oxygen. Coating of interfaces between aerated and non-aerated sections can reduce the problem.

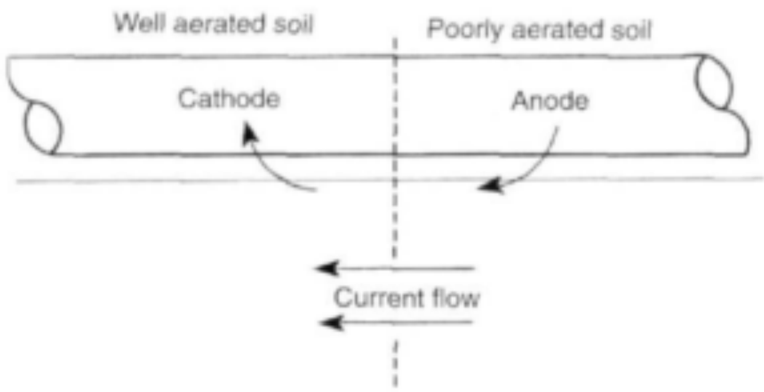


Diagram 3

6. Erosion corrosion

This type of corrosion may be encountered in pipes, valves, fittings and pumps. Impingement corrosion is often observed in tees and elbows or at other changes in flow direction. Excessively high water-flow velocities can increase corrosion action of pipe interiors by eroding protective films. Corrosion caused by erosion can be reduced by avoiding intermittent flow, protecting areas with sudden changes in velocity and reducing entrained air and turbulence. Maintenance of air valves is vital in this regard.

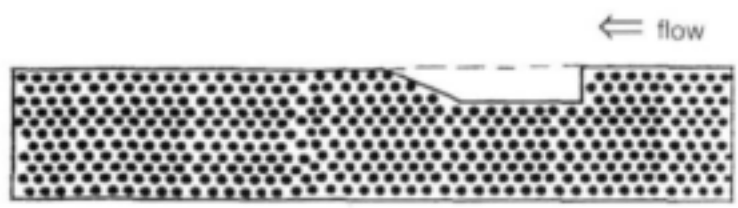


Diagram 4

7. Microbiological /microbial corrosion

Steel water pipes or mains are susceptible to microbiologically-influenced corrosion as a result of their exposure to soil and water. The necessary environment for sulphate-reducing bacteria (SRB) to proliferate, requires a supply of sulphate, an organic source of carbon and anaerobic conditions. This corrosion may develop virtually anywhere where free access to oxygen is excluded. The attack may be found under slimes, debris and tubercles. The major cause of corrosion of metallic pipes conveying potable water is microbiological corrosion **(See Figures 1 and 2)**.

Despite chlorination, slimes (biofilms) develop on unlined steel piping in potable water. The biofilm environment protects cells against the activity of chlorine and may allow for selective accumulation of bacterial species which are less susceptible to chlorine. Pitting attack of mild steel occurs beneath tubercles formed by SRB and is initiated 3 to 6 months after SRB colonisation. Microbiological corrosion results in localised corrosion, whereby pits eventually perforate the pipe wall and cause leaks. In general, the influence of the chemical parameters in potable waters on corrosion is minor compared to the role played by SRB. Corrosion rates of up to 1 mm/yr have been measured in potable water in the Gauteng area on mild steel which is caused by the activity of SRB.

This type of corrosion can be minimised by using coatings and linings, maintaining a free chlorine residual level at 0.2 mg/ and using cathodic protection where appropriate.

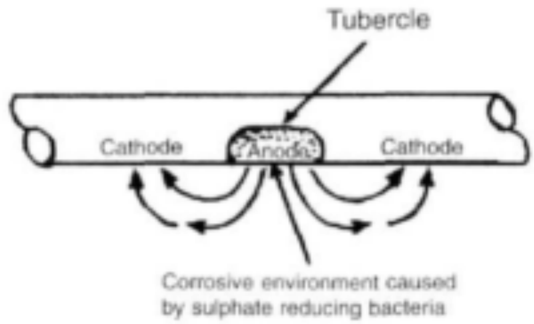


Diagram 5

8. Stray current corrosion

Stray direct current can have a severe damaging effect on buried steel pipelines. It occurs when direct current from an outside source enters the pipeline, then leaves to complete its intended circuit. The source of the direct current can be from electric railways, a direct current generator, a manufacturing plant, mines or other metallic structures protected by cathodic protection. In these cases, the ground is often used as a return path for the current. The current often strays onto the pipeline if it is in the vicinity because of its lower resistance to current flow. Corrosion occurs where the current leaves the pipeline and no corrosion occurs where the current enters the pipeline.

In South Africa, stray currents are a major cause of corrosion of buried metallic pipelines due to our extensive DC traction railway system. The effects of interference caused by other cathodically-protected pipelines can be minimised by sharing information at Regional Electrolysis Committee meetings.

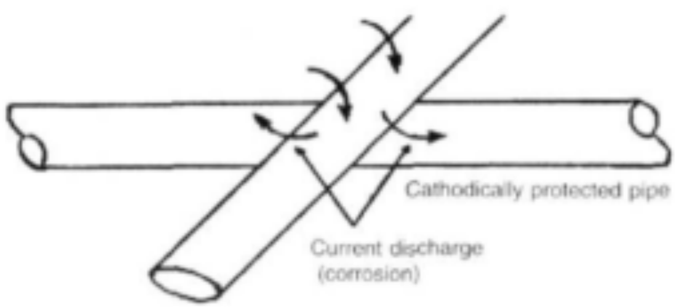


Diagram 6

9. Dezincification

Dezincification is a type of corrosion where zinc is selectively leached from alloys containing zinc such as brass, and occurs mostly after extended contact of water with dissolved oxygen.

Dezincification resistant (DZR) brass should be used in fittings even in hard water areas such as in Gauteng, because non-DZR brass shows signs of corrosion after three months in potable waters and in raw water (Vaal Dam). DZR brass should be used for both hot and cold water installations.

DIRECT CONNECTION OF NEW AND OLD PIPES

The situation arises frequently in the water supply industry when, due to corrosion damage, a section of old steel pipeline is replaced with new steel pipe. The new pipe becomes anodic with respect to the old pipe and may corrode, provided that there is an electrical connection between the pipes and the electrolyte is sufficiently conductive to support the cell.

CATHODIC PROTECTION

Cathodic protection is the application of external current to protect metallic structures by creating cathodic conditions on the surface. There are two types of cathodic protection namely, sacrificial and impressed current. Galvanic cathodic protection involves the use of sacrificial anodes which consist mainly of magnesium or zinc. The anodes have high negative potentials which provide high current output.

The cathodically-protected structure accepts current from the electrolyte and the circuit is completed through a metallic connection back to the rectifier. The structure to be protected is made cathodic by connecting the negative terminal of an external direct current and the positive terminal to an inert anode. Impressed current cathodic protection is more suitable than sacrificial anodes for protection of pipelines in high soil resistivities and long sections of lines in uncongested areas.

Cathodic protection is a technique which can reduce external corrosion of pipelines. It is not a panacea for all external corrosion problems and some corrosion can still occur even if cathodic protection is applied. However, cathodic protection is very effective when it is applied to new pipelines, and it can reduce corrosion when it is retro-fitted onto existing pipelines.

An example of the effectiveness of cathodic protection can be seen in Figure 3 which shows how the number of leaks in the Rand Water piping system has been reduced since they embarked upon a programme to cathodically protect all their pipelines.

Cathodic protection is a specialist field and expert advice should be sought for the design, installation, supervision and commissioning of cathodic protection systems.

NEW PIPELINES – WHAT TO DO?

- All linings and coatings should be correctly specified, correctly applied (according to manufacturer recommendations) and properly inspected before use. When in doubt, seek expert advice.
- All mild steel pipes must be externally coated and internally lined with organic coating.
- Improve cathodic protection on steel pipes.
- Small diameter steel pipes should be replaced with non-corrodible materials where appropriate.
- Use only brass that is dezincification-resistant.
- Select the correct material for the application.

For further information on products and services available in the corrosion field, one can consult "Buyers Guide for Southern Africa" which is published by Corrosion and Coatings. This publication is updated on an annual basis. Alternatively, one can contact the Corrosion Institute of Southern Africa (011 – 802 5145)

MYTHS

The composition of potable water affects the corrosive behaviour of metals and alloys, but since there are so many variables in describing water, it is difficult to draw up a simple expression which can be used as a corrosivity indicator. The Langelier Index is often used as a corrosivity index, where a negative value is indicative of a non-scaling, aggressive water. It has been found, however, that the maintenance of a positive index does not necessarily reduce the corrosivity of the water towards metals.

GLOSSARY

ALLOY: A substance having metallic properties and composed of two or more chemical elements, of which at least one is an elemental metal.

ANAEROBIC: An absence of oxygen.

ANODE: *The electrode where oxidation or corrosion takes place.*

CATHODIC PROTECTION: Reduction or elimination of corrosion by making the metal structure a cathode by means of impressed current or attachment to a sacrificial anode.

CORROSION: Deterioration of a substance because of its reaction with the environment.

DUCTILE IRON: Cast irons with nodular or spheroidal graphite as a result of a special treatment of the molten metal.

ELECTROLYTE: A liquid, usually an aqueous solution, in which ions conduct electrical current.

GALVANISED STEEL: Steel coated with zinc.

GALVANIC EFFECTS: Effects caused by corrosion due to two different metals in contact in an electrolyte.

GRAPHITE: Free carbon in steel or cast iron.

GRAPHITISATION: A specific form of de-alloying of cast iron in which the metallic constituents are corroded, leaving the graphite flakes.

HARD WATERS: Water that contains certain salts such as calcium or magnesium, which form insoluble deposits in boilers and form precipitates with soap.

ION: An electrically changed atom (e.g. $S0_4^{2-}$, Cl^- etc.).

LANGELIER INDEX: A calculated figure that is useful in predicting scaling behaviour of water containing calcium carbonate.

MICROBIOLOGICAL ACTIVITIES: Activities influenced by microbial species in corrosion either directly or indirectly.

STRAY CURRENT: Corrosion that is caused by stray direct currents from some external source.

SULPHATE REDUCING BACTERIA (SRB): Bacteria which thrive under anaerobic conditions and reduce sulphate ions to sulphide ions.

TUBERCLES: Knob-like mounds of corrosion products, usually caused by microbial activity.

GUIDE TO COLLATE INFORMATION FOR DATABASE DEVELOPMENT

PIPE NUMBER: ....

STAND NUMBER: ....

ADDRESS: ....

....

....

....

TOWNSHIP: ....

DATE REMOVED: ....

EXTERNAL APPEARANCE: ....

....

....

....

....

INTERNAL APPEARANCE: ....

....

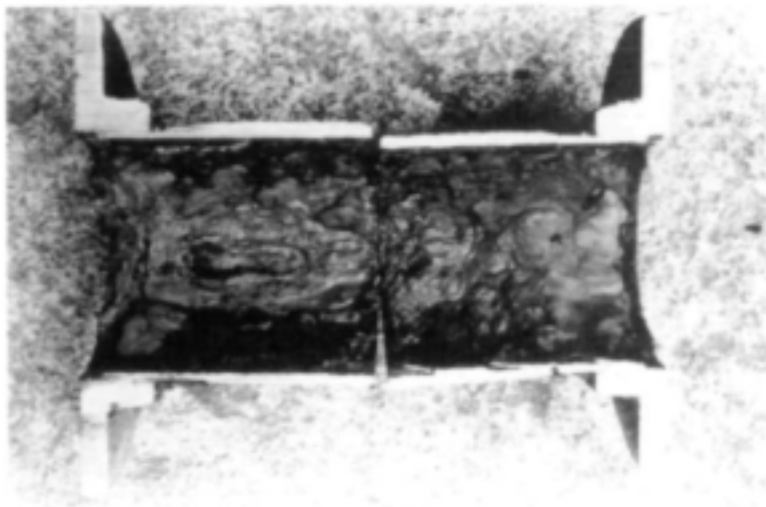
....

....

....

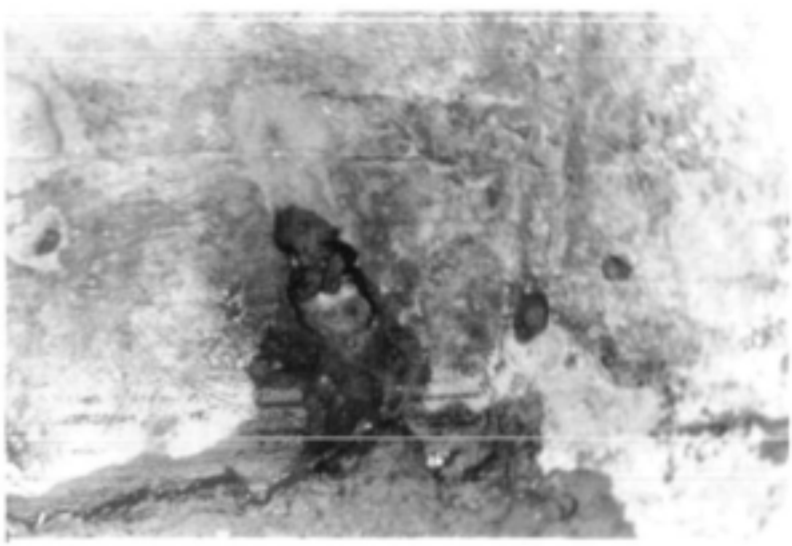
MODES OF FAILURE

Internal corrosion



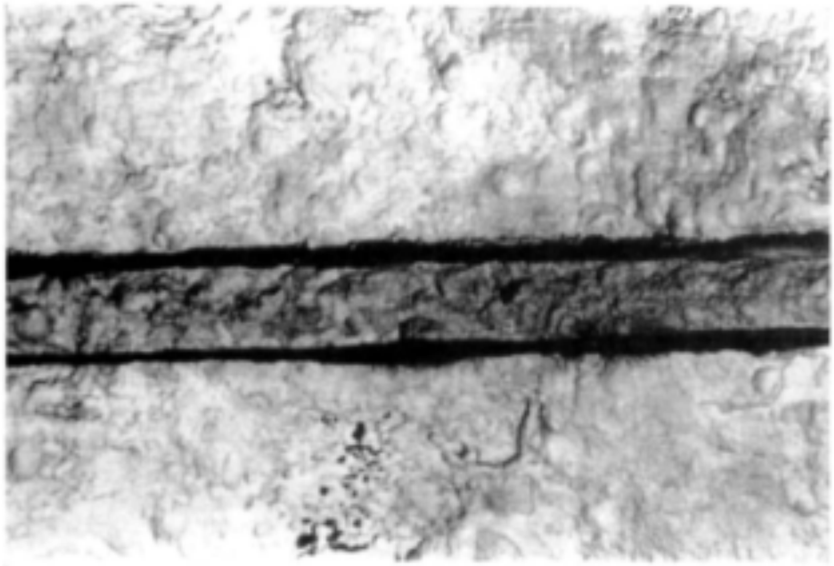
- Localised pitting
- Extensive corrosion product

Stray current corrosion



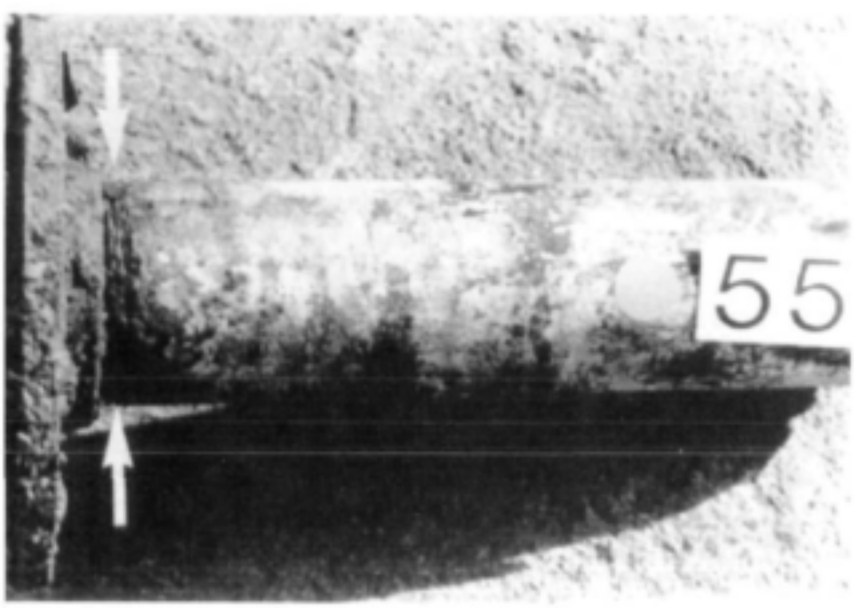
- Usually found near railway lines
- Corrosion occurs where the current leaves the pipe

Tramline attack



- Tramline corrosion (internal)
- Found on either side of the weld

Galvanic attack



- Dissimilar metals (galvanised pipe/steel flanges)
- Active metal corrodes preferentially

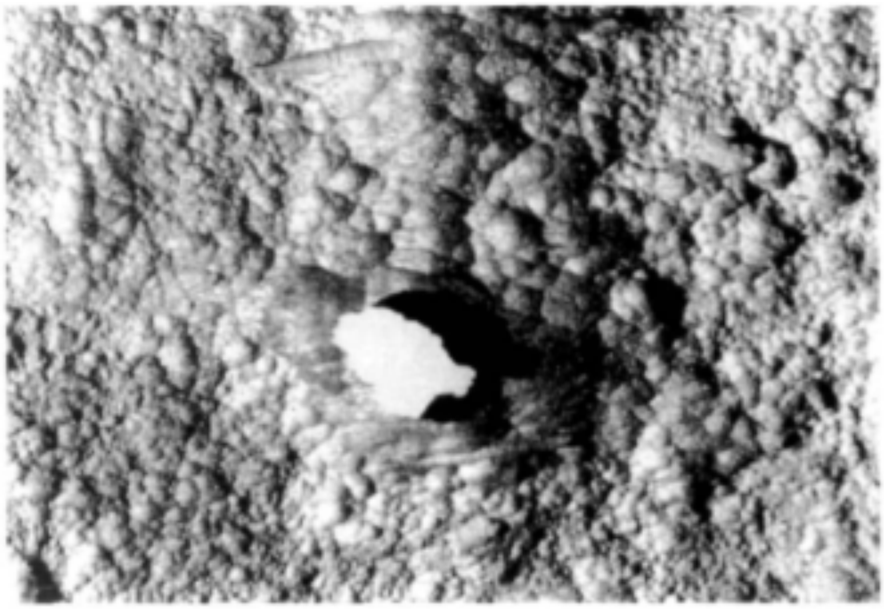
Weld corrosion

- Filler metal attack
- Similar to galvanic corrosion

Microbiological corrosion

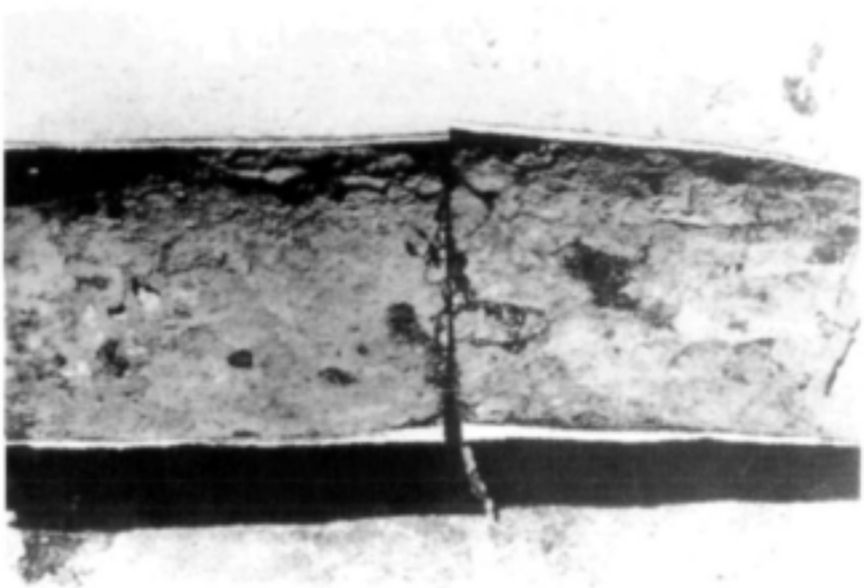
- Characteristic tubercles which appear as mounds
- Usually dark brown colour
- Once the tubercle is removed, there is a soft black layer beneath. Once this layer is removed, the metal exposed has a shiny grey appearance.

External corrosion



- Externally localised pitting
- External corrosion product
- Difficult distinguishing mode of failure (i.e. more than one mechanism)

General corrosion



- Thinned pipe wall
- Uniform metal leading to perforation

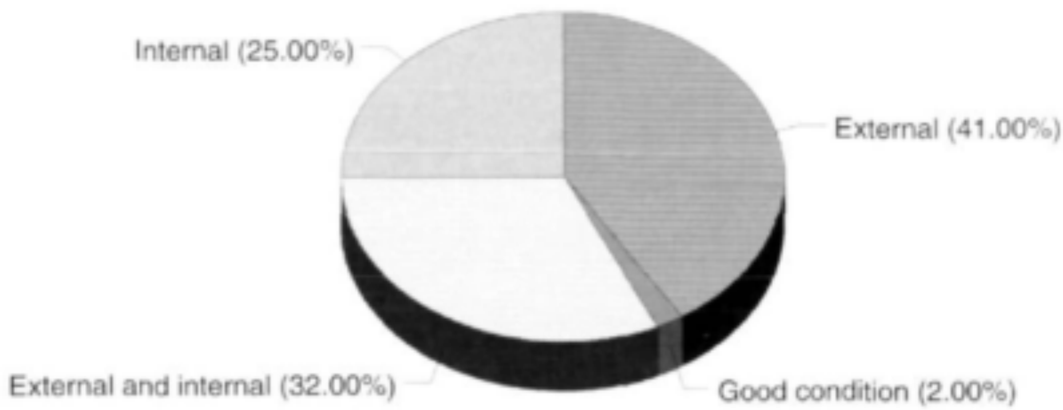


Figure 1
Pie chart showing the percentage location of corrosion.
NB: Data obtained from WRC Project No. K5/587

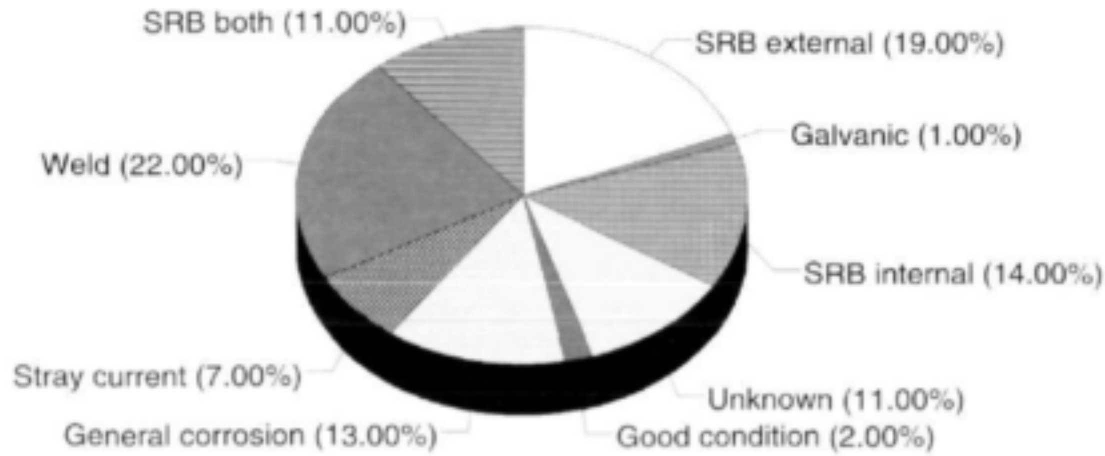


Figure 2
Pie-chart showing the percentage type of corrosion.
NB: Data obtained from WRC Project No. K5/587

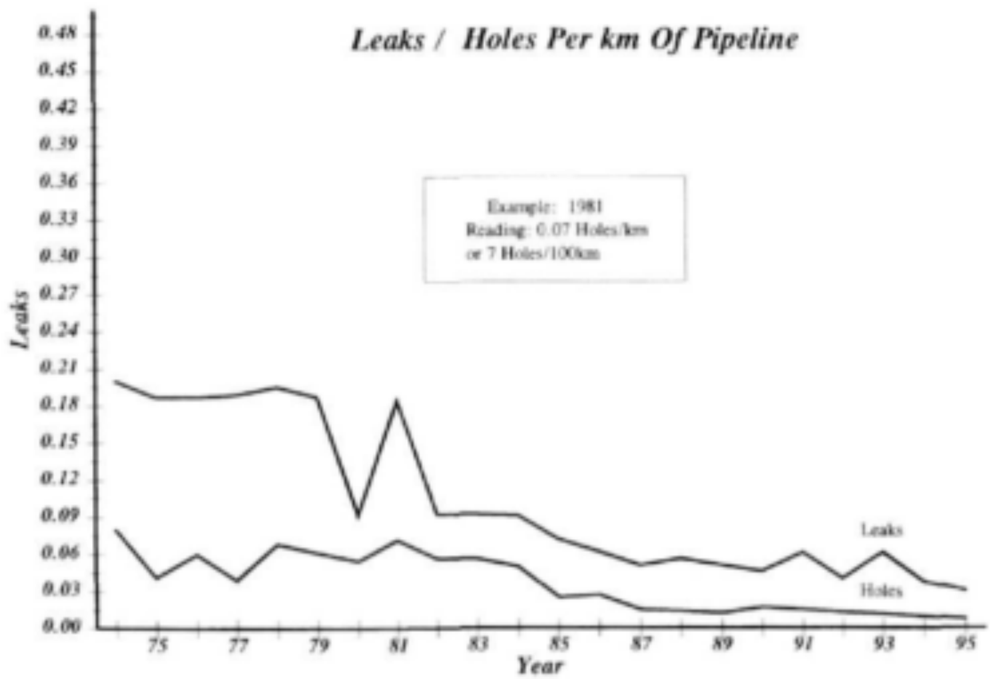


Figure 3

Graphic representation of the effect of corrosion control (cathodic protection) in reducing leaks due to external corrosion at Rand Water (Used with permission of Rand Water).