TALAT Training in Aluminium Application Technologies

TALAT Lectures 5104

Basic Approaches to Prevent Corrosion of Aluminium

14 pages, 9 figures

Basic Level

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Objectives:

– to describe important measures for the prevention of corrosion of unprotected, bare aluminium

Prerequisites:

– Basic knowledge of corrosion behaviour of aluminium; some knowledge of the electrochemical nature of corrosion

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5104 Basic Approaches to Prevent Corrosion of Aluminium

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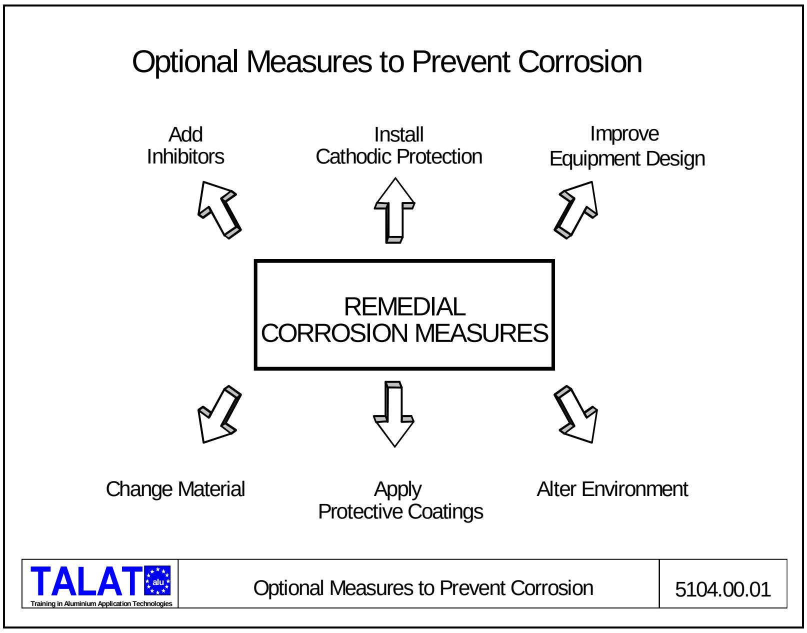
5104.00 Introduction

In general, aluminium alloys have good corrosion resistance in the following environments: atmosphere, fresh water, seawater, most soils, most foods and many chemicals. The term „good corrosion resistance“ means that in many cases aluminium alloys can be used without surface protection and will give long service lifes. Depending on the aggresiveness of the environment for a given application as well as on the function of the product and the expected service requirements and life, measure may have to be taken to prevent or limit the extent of corrosion attack. There are several options for prevention measures (see **Figure 5104.00.01**) which can be adopted.



In this lecture only those measures are treated which relate to unprotected aluminium products and components. Protective surface treatments like pretreatments, painting and anodizing are described in **Lectures 5201, 5202, 5203 and 5204**.

5104.01 Selection of Corrosion Resistant Alloys

The addition of alloying elements to aluminium affects the corrosion behaviour, and it is important to select the most adequate alloy for each environment.
The mayor alloying elements used in aluminium alloys are: copper, magnesium, manganese, silicon and zinc and the impurities in commercially pure aluminium are iron and silicon (**Figure 5104.01.01**).

Copper	reduces the corrosion resistance more than any other alloying element
Iron	reduces corrosion resistance and the content should be kept low when maximum resistance to corrosion is needed
Magnesium	has a beneficial effect on corrosion resistance
Manganese	has a slightly beneficial effect on corrosion resistance
Silicon	has a small detrimental effect on corrosion resistance
Zinc	in most environments zinc has only a small effect on corrosion resistance

TALAT — Training in Aluminium Application Technologies | Effects of Alloying Elements on Corrosion Resistance of Aluminium | 5104.01.01

Wrought Aluminium Alloys

Pure Aluminium (> 99,9 % Al)
Superpure aluminium (> 99,9 % Al) exhibits the best corrosion resistance possible with aluminium by wide margin. Performance drops sharply with the introduction of impurities, particularly copper and iron.

Al-Mn
The Al-Mn alloys have very good corrosion resistance and are used for outside applications without protection.

Al-Mg
In general, the Al-Mg alloys have the best corrosion resistance of all the aluminium alloys. Above 4% magnesium content, fabrication practice has a marked influence on their long-term behaviour in corrosive environments, even at normal temperatures. After long time exposures above 60° C the Mg-rich alloys may become susceptible to stress corrosion cracking or exfoliation.

Al-Cu
Alloys containing appreciable amounts of copper (> 0,25%) have less corrosion resistance, and should not be used in aggressive marine or industrial environments without providing protective coatings. In the past one of the most common errors was to use Al-Cu alloys in corrosive environments without adequate protective measures.

Al-Zn-Mg-Cu
Alloys containing Zn, Mg and Cu are similar in corrosion behaviour to the Al-Cu family and also require protection in corrosive environments.

Al-Zn-Mg
For this family of alloys the fabrication practices, especially thermal treatments and the composition of the alloy are critical factors in the corrosion.behaviour. Al-Zn-Mg alloys may be sensitive to stress corrosion cracking and exfoliation.

Cast Aluminium Alloys

Corrosion of aluminium castings is usually less of a problem than with sheet products since in general, the cross section is thicker and more surface corrosion can be tolerated.

Al-Mg casting alloys have a good general corrosion resistance and can be used in marine environments.

The Al-Si are generally considered to have good corrosion resistance in atmospheres and waters.

Al-Cu and Al-Si-Cu alloys require surface protection under corrosive conditions.

The behaviour of an alloy depends on the environment that it has to withstand; as an example, the following table gives an idea of the behaviour of different alloys in acids and alkalines (**Figure 5104.01.02**). The lower the rating the better the corrosion resistance.

5104.02 Improvement in Equipment Design

Since the corrosion behaviour of a metal is influenced by the physical and chemical conditions of the environment (for example temperature, contaminants, differential concentration, etc.) as well as by its chemical composition, the design can have appreciable effect on the nature and rate of corrosion.

in Acids		in Alkalines	
Alloy	Rating	Alloy	Rating
S.P.*)	6	7075-T6	7
1100-H16	24	7072	15
3003-H14	28	6053-T6	15
3003 Alclad	29	S.P.	17
7072	33	6061-T6	17
1050-H16	33	5052-H14	22
6063-T6	41	6063-T6	28
5052-H14	43	3003 Alclad	32
6053-T6	45	3003-H14	32
6061-T6	49	1100-H16	37
7075-T6	65	1050-H16	43

*) S.P. Super Purity Aluminium (> 99.99%)

TALAT Training in Aluminium Application Technologies | Behaviour of Different Alloys in Acids and Alkalines | 5104.01.02

The most common design failures encountered in service with aluminium structures involves galvanic, crevice, deposition and stress corrosion.

In the following paragraphs a general recommendation to eliminate or at least reduce the effect of these types of corrosion are given:

Prevention of Galvanic Corrosion

The following „rules“ can be suggested to minimize galvanic corrosion:

1. Select combinations of metals as close as possible in the galvanic series for the environment being considered (**Figure 5104.02.01**).

2. Use cathodic fastenings. Avoid combinations with an unfavourable (small) ratio of

anode to cathode area (**Figure 5104.02.02**).

3. Provide complete electrical insulation of the two metals joined. This may be done by using insulating gaskest, sleeves, etc. (**Figure 5104.02.03**).

4. If paint is applied, always paint the cathode. If only the anode is painted, a scratch would give an unfavourable ratio of anode to cathode area, and lead to attack at the scratch. Keep such coatings in good repair.

5. Increase the thickness of the anodic material. Alternatively, install small replaceable heavy sections of the anodic metal at the joint.

6. Where possible, place the dissimilar metal contact out of the corrosive environment.

7. Were possible, avoid threaded joints in dissimilar couples as the threads will detoriorate. Brazed or welded joints are preferred.

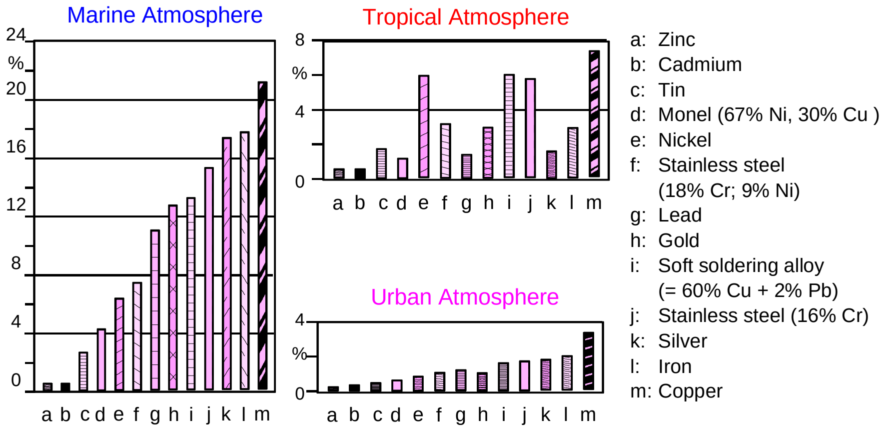
8. If possible, use corrosion inhibitors (e.g. in circulating systems).

9. In cases where the metals must remain in electrical contact through an external circuit, design the equipment to keep the metals as far apart as possible to increase the resistance of the liquid path (electrolyte).

10. If necessary and where possible, use cathodic protection with zinc or magnesium sacrificial anodes.

11. Under the most aggressive conditions, only zinc, cadmium and magnesium can be placed in contact with aluminium without causing galvanic corrosion.

Galvanic corrosion of aluminium in contact with varios metals in marine, tropical and urban atmospheres



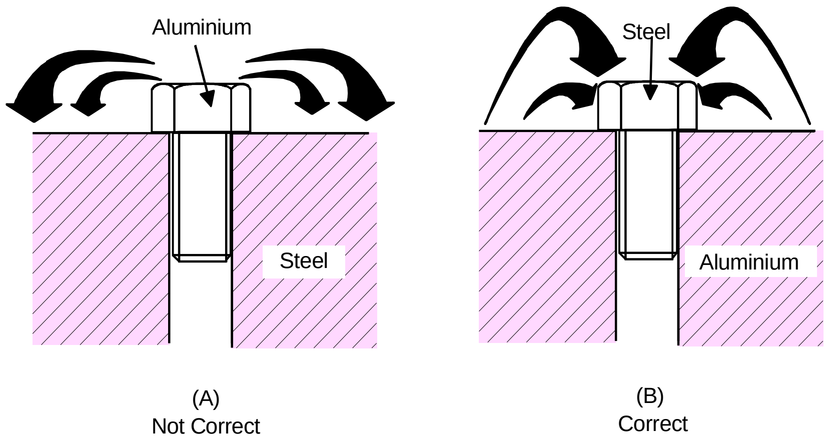
TALAT Training in Aluminium Application Technologies | Severity of Galvanic Corrosion in Various Atmosphers | 5104.02.01

Prevention of Deposition Corrosion

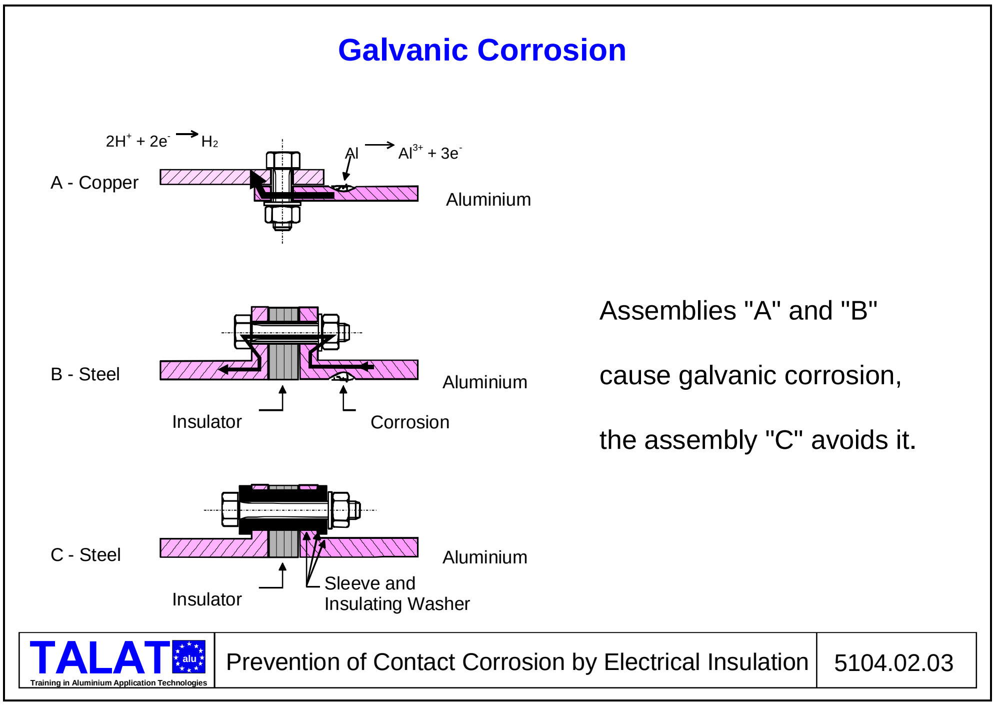
The following measures will help to reduce deposition corrosion on aluminium

1. Re-design to avoid precipitation of the more noble metal, e.g. through drainage
2. Use Alclad aluminium
3. Use inhibitors
4. Paint the source of metal
5. Clean frequently to remove the deposited noble metal

Joints with Different Metals



TALAT	Example of the Effect of Anode to Cathode Area on Corrosion of Bi-Metal Joints	5104.02.02



Prevention of Crevice Corrosion

In the design of aluminium structures exposed to a marine atmosphere for long periods of time some measures should be taken to prevent crevice corrosion.

The following measures will help to reduce crevice corrosion in aluminium structures:

1. Cover the faying surfaces before assembly with an inhibitive paint system

2. Fill the crevice with a jointing compound or resilient gasket material to prevent the ingress of moisture.

Prevention of Stress Corrosion

In the design of aluminium structures under permanent stress conditions some measures should be taken into account in order to minimize stress corrosion.

The following measures will help to reduce the incidence of stress corrosion problems in aluminium structures:

1. Ensure that an adequate cross section is used that will not be overstressed. Particular attention must be paid to residual or assembly stresses that act in the short transverse direction.
2. A good paint system which includes an inhibitive primer will offer some protection again stress corrosion. However, it should be realized that paint coatings are not completely impermeable to moisture and should not be expected to protect very

susceptible alloys.

3. Spray metallizing with some aluminium alloys will provide an appreciable measure of protection against stress corrosion, which should be further improved by painting.
4. Surface working procedures, such as shot peening or surface burnishing to achieve a compressive residual stress in the surface, when properly applied, have proven effective as a means of reducing the incidence of stress corrosion cracking.
5. Applied stresses. Sustained applied surface tensile stresses, should not exceed the following limits:
   - in the longitudinal direction 50% yield stress,
   - in the long transverse direction between 35 and 50% yield stress,
   - in the short transverse direction: as low as possible and preferably not greater than 15% of the yield stress.

Stress Corrosion Resistant Tempers

Certain of the high strength aluminium alloys systems respond to precipitation treatments (over-ageing), which result in metallurgical conditions having significantly improved stress corrosion resistance at little or no sacrifice in mechanical properties (T76, T73 tempers).

All the recommendations are general statements and a detailed study is necessary in each case.

5104.03 Alteration of the Environment

Sometimes it is possible to reduce or eliminate the aggressiveness of an environment by altering it in one way or another.

In some chemicals, for example phenol, the addition of a trace of water (e.g. 0,3%) will prevent vigorous corrosion that would occur under anhydrous conditions. In others, for example liquid sulphur dioxide, traces of water promote corrosion of aluminium.

In general, movement or turbulence, if not excessive, will sometimes prevent pitting that might otherwise occur.

The adjustment of pH to the safe range (4.5 to 8.5) will prevent or reduce corrosion.

The deaeration of water will greatly reduce its pitting tendency toward aluminium.

Raising the temperature, in general, may increase the rate of general surface corrosion, but has the beneficial tendency of reducing the rate of pitting corrosion.

Obviously, these effects are specific to individual conditions, and little more than general statements such as the above can be made on this subject.

Corrosion Inhibitors

An inhibitor is a substance which when added (usually in a small amount) to a corrosive liquid or chemical, reduces or prevents corrosion of a metal that would otherwise occur.

Inhibitors may affect the anodic corrosion reaction, in which case they are termed „anodic inhibitors“, or they may inhibit the cathodic corrosion reaction in which case they are termed „cathodic inhibitors“.

Anodic inhibitors can be dangerous if not added in sufficient amount, since while they may reduce the effective anode area, attack at the remaining sites will be more severe than in the absence of the inhibitor.

Cathodic inhibitores are safer since a partial reduction of the effective cathode area will reduce corrosion at the anode. They are, however, usually less effective than anodic inhibitors.

Chromate (in the form of sodium or potassium chromate or dichromate) is the most commonly used inhibitor with aluminium and is an anodic type inhibitor. To prevent the pitting of aluminium in aggressive water, the addition of 500 ppm. of sodium chromate or dichromate with a pH adjusted to 8.5 is effective.

Phosphate, silicate, nitrate, nitrite, benzoate, soluble oils and other chemicals have also been recommended alone or in combination to inhibit the corrosion of aluminium by aggressive waters.

Inhibition of water is usually economic only in a recirculated, closed loop system. In a mixed metal system including, for example aluminium and copper it is important to design a good inhibitor system and maintain the pH above 8.0-8.5 to prevent copper dissolution and their subsequent deposition on the aluminium. surface.

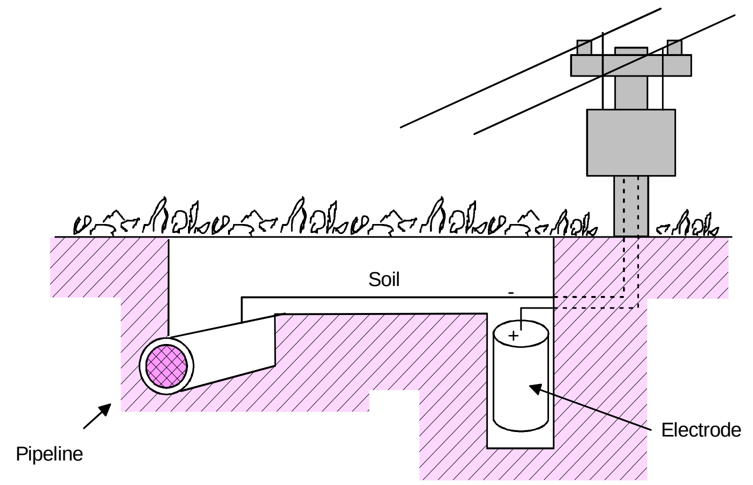
The complexity of the inhibition tends to make it difficult for a general engineer to develop a satisfactory water treatment without the help of a specialist.

Frequently, laboratory testing on location is necessary to establish the best treatment.

5104.04 Cathodic Protection

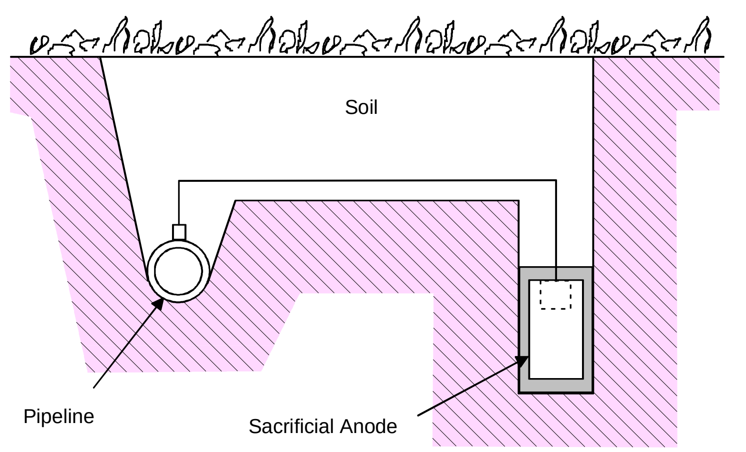
The theory of cathodic protection of a buried metal is simple. A direct electric current is caused to flow to the metal (generated by sacrificial anodes or impressed current) to be protected.

The current polarizes the local cathode areas to the potential of the local anode and creates an equi-potential surface. Thus local cell potential becomes zero and pitting does not occur.



TALAT | Prevention of Corrosion through Cathodic Protection by Impressed DC Current | 5104.04.01

The current may be produced by a rectifier with a metal or graphite electrode (**Figure 5104.04.01)** or by sacrificial galvanic anodes of magnesium or zinc (**Figure 5104.04.02)**.



TALAT | Prevention of Corrosion through Cathodic Protection by Sacrifical Anodes | 5104.04.02

To reduce the amount of current required, the metal to be protected is sometimes coated with a paint, protective tape or other wrapping material.

In the steel pipelime industry the technique of cathodic protection has been well established and its effectiveness throughly demonstrated. Experience with buried aluminium is limited to isolated experiments and a limited number of operating lines.

Sacrificial Anodes

Aluminium can be cathodically protected by coupling it to zinc or magnesium used as a sacrifical anode.

In the case of aluminium probably the mechanism of protection consists of polarizing cathodic impurities in the metal to the corrosion potential of passive aluminium counteracting the detrimental effect of such impurities.

Zinc is able to serve as a sacrificial anode to aluminium in neutral or slightly acid media in spite of the fact that aluminium is more active than zinc in the EMF series. In alkaline media aluminium looses its passivity and becomes anodic to zinc.

Magnesium has been the material normally used to protect aluminium in some cases. Corrosion has been stopped by the installation of magnesium anodes even in buried pipes with accumulation of corrosion products. In some cases over-protection may result in producing cathodic corrosion on the aluminium.

The potential generated between the magnesium anodes and aluminium normally does not exceed -1.20 volts ($Cu/CuSO_4$) and normally there is no evidence of cathodic corrosion due to alkali formation.

Impressed Current

Cathodic protection by impressed current requires a source of direct current and auxiliary electrode as shown in **Figure 5104.04.01**.

The D/C source is connected with the positive terminal to the auxiliary electrode, and the negative terminal to the structure to be protected. The current flows from the electrode through the electrolyte to the structure.

It is generally accepted that protection of aluminium is achieved when the potential of the burried aluminium surface is maintained in the range -0.85 to -1.10 volts ($Cu/CuSO_4$) and then significant cathodic corrosion does not occur until a value of -1.20 volts is exceeded.

The chemical nature of the soil can affect the safe upper potential which in some cases can be appreciably higher than -1.20volts.

The current density required depends on the environment but generally the applied current density must always exceed the current density equivalent by the estimated or measured corrosion rate (in tap water ca. 20 mA/m^2, in soil an average of 5 mA/m^2 can be estimated)

With the application of coatings on the aluminium the current density can be reduced and it will be possible to protect a pipe of 20 Km with only 90-240 mA.

Alclad Alloys

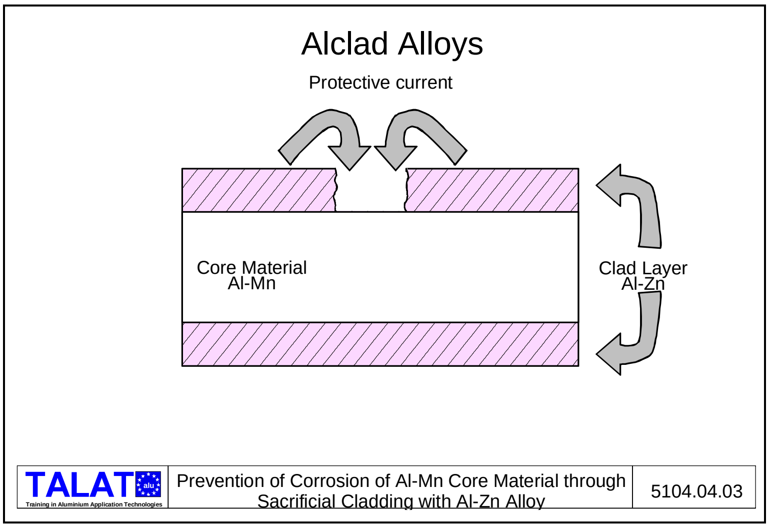
Alclad aluminium is a duplex product consisting of a thin layer of one alloy integrally bonded to a thicker core alloy. The cladding alloy is chosen as a sacrificial anode to protect the core.

The alloys normally used as cladding materials for protection purposes are of the Al-Zn family, in some cases, however, pure aluminium has been used.

The protection mechanism of the cladding products consists of galvanic protection. When a pit reaches the core material, the cladding tends to corrode preferentially, while the core remains unaffected (**Figure 5104.04.03**).

Cladding is a real possibility for extending the life of aluminium pipelines which carry a product causing pitting corrosion of the metal.

Conventionally, the cladding on each side of sheet has been 5% of the total thickness of the sheet.



Practical Case

How to minimize the pitting of aluminium by an aggressive water?

Here are four possible preventive measures that should be considered:

1. Use Alclad alloys

Use 3003 or 65S clad with 72S. This will not prevent pitting but it delays perforation by an appreciable margin.

2. Increase wall thickness

Experience with large water storage tanks suggests that, provided the wall thickness is 6-7 mm perforation will no occur for a very long period of time (probably 50-100 years) even though pitting does occur. This is because the rate of penetration diminishes rapidly with time.

3. Use inhibitors

The use of inhibitors which will completely prevent pitting is usually economically feasible only in closed circulating systems

4. Apply cathodic protection

An impressed current cathodic protection system will prevent pitting, or arrest pitting in progress, and may be applied to tanks or vessels. It is not possible to cathodically protect the inside of small diameter pipelines.

5104.05 Literature/References

ASM (Ed.): "Metals Handbook", Vol. 13 "Corrosion"

Hollingsworth, E.H., Hunsicker, H.Y. and Schweitzer, P.A.: Corrosion and Corrosion Protection Handbook, Pt. Aluminium Alloys, pp.153-186, Marcel Dekker Inc., New York and Basel, 1989

5104.06 List of Figures