

Severe Nitrate Stress Corrosion Cracking in HP reactor of a Urea plant

NTT Consultancy
Giel Notten
Senior Corrosion Engineer

Summary

One main condition for atmospheric corrosion or corrosion under insulation to take place is moisture. Moisture which penetrates the insulation may originate from:

- Rain water
- Vapour resulting from "breathing" due to cyclic temperature changes, followed by dew formation
- Increased water exposure resulting from:
 - nearby cooling towers
 - water-jetting of heat exchangers
 - fire-fighting drills
 - sprinkler installations
 - leaking trace lines

Atmospheric corrosion or corrosion under insulation can have the following forms:

- Overall corrosion (crater-like attack at critical area's)
- Stress Corrosion Cracking
 - carbon steel: NO_3^- - ions
 - austenitic SS: Cl^- - ions
 - copper alloys: NH_3

This Paper discusses a severe incident of nitrate stress corrosion cracking in a HP reactor of a urea plant. Even without any nitrate fertilizer or nitric acid plant nearby the urea plant this incident could occur. This case is therefore an important learning case for any urea plant.

Introduction

During a turnaround magnetic particle inspection (MPI) was performed on welds and heat affected zones of welds at the outside of the top section of the HP reactor of a urea plant. The MPI inspection revealed presence of cracks which were located in the circumferential weld of the top hemi-head to the shell of the reactor. The cracks extended up to some 2000 mm in circumference of the reactor. The depth of the cracks reached already about half of the wall thickness of the reactor. The location of the cracks is indicated in Figure 1.

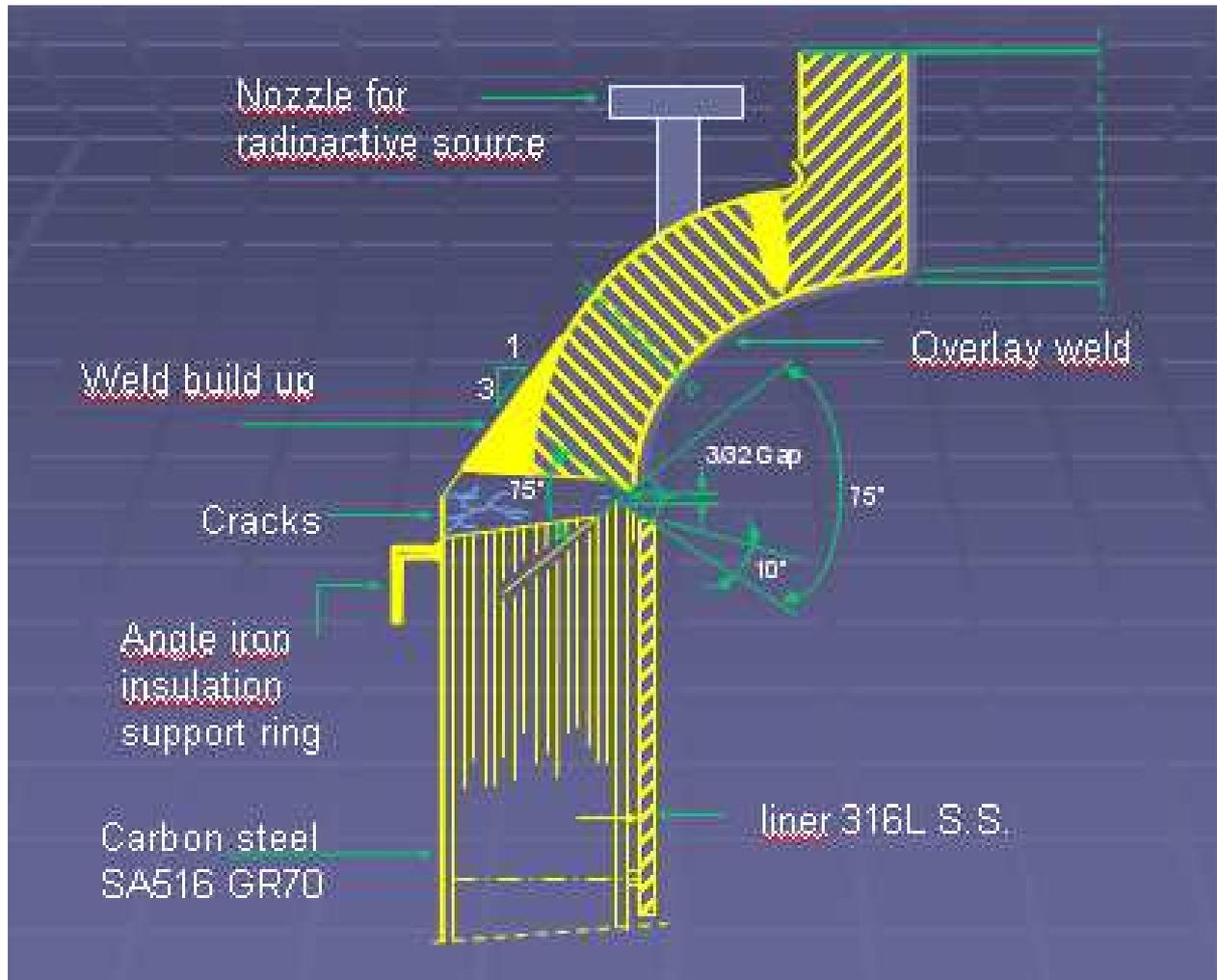


Figure 1: Location of cracks in the carbon steel shell in the top of reactor of Urea plant

It was observed that the aluminum cover sheeting of the insulation was severely damaged, especially around the manway nozzle and the nozzle for the reactive source. Rainwater could easily enter the insulation material.

The HP reactor was located near the urea prilling tower.

The operating temperature of the reactor is about 175 to 180 °C.

Cracking did occur after an on-stream time of some 20 years.

On the vessel wall a thick salt deposit layer was present, most pronounced in the area of cracking, below the location of the nozzle for the reactive source.

A sample of these deposits were analyzed on presence of nitrates. The nitrate content appeared to be 0.4% which is extremely high.

Several boat samples were taken out of the cracked area of the reactor wall.

Photo's 1 and 2 show the cracks present in boat sample 3 which was examined by Stamicarbon.

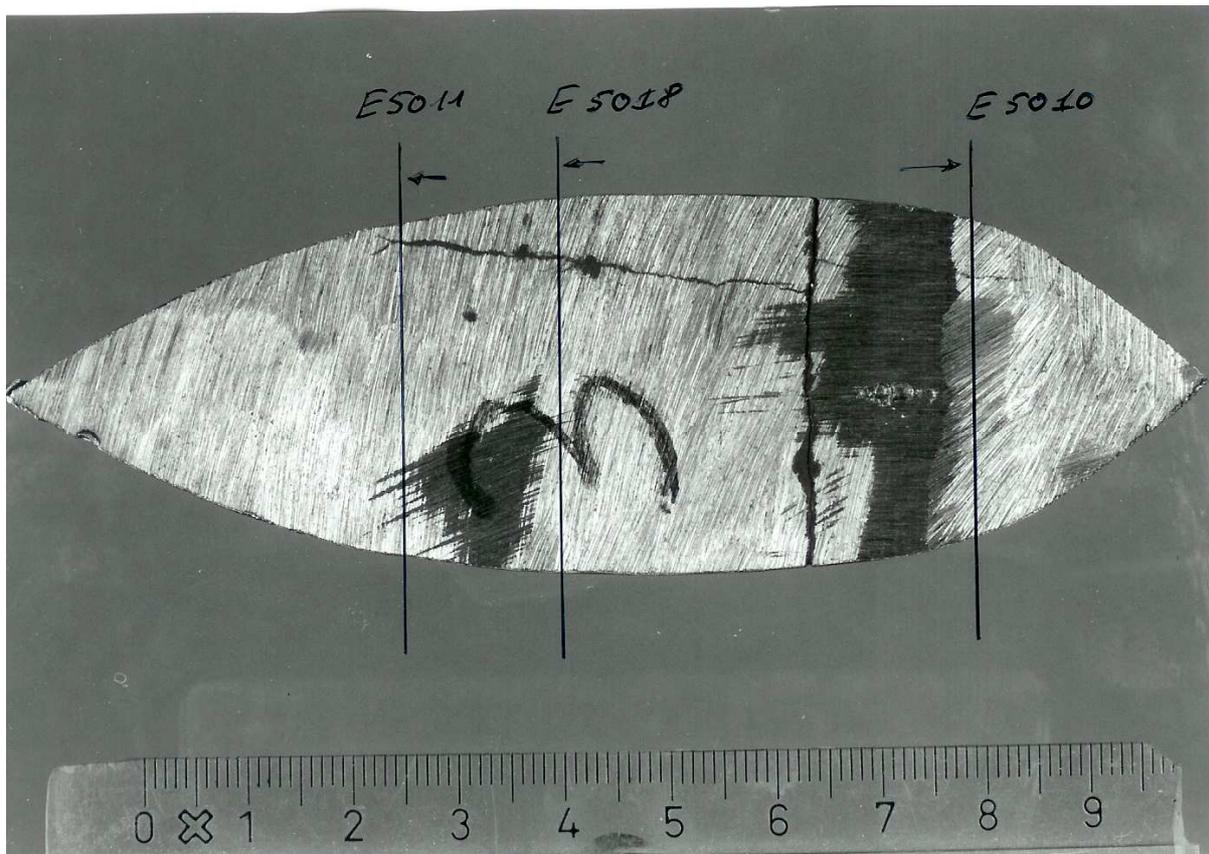


Photo 1: Cracking at outer surface of boat sample out of reactor wall of urea reactor

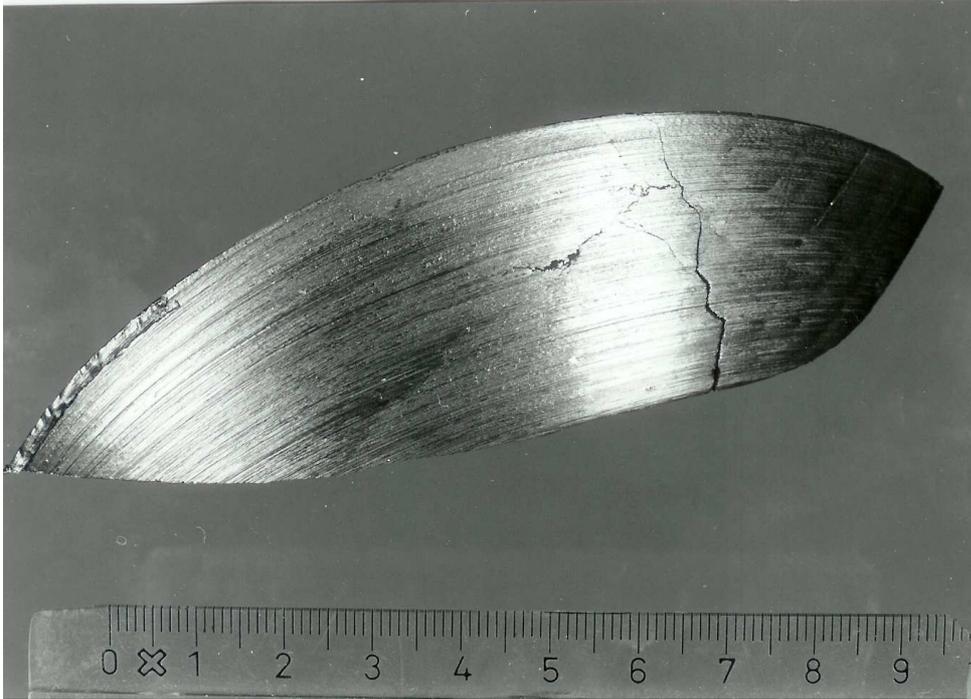


Photo 2: Cracking in depth of boat sample

Cause of cracking

Microscopic examination revealed a branched crack pattern with trans-granular and, predominant, inter-granular propagation as shown in Photo 3.

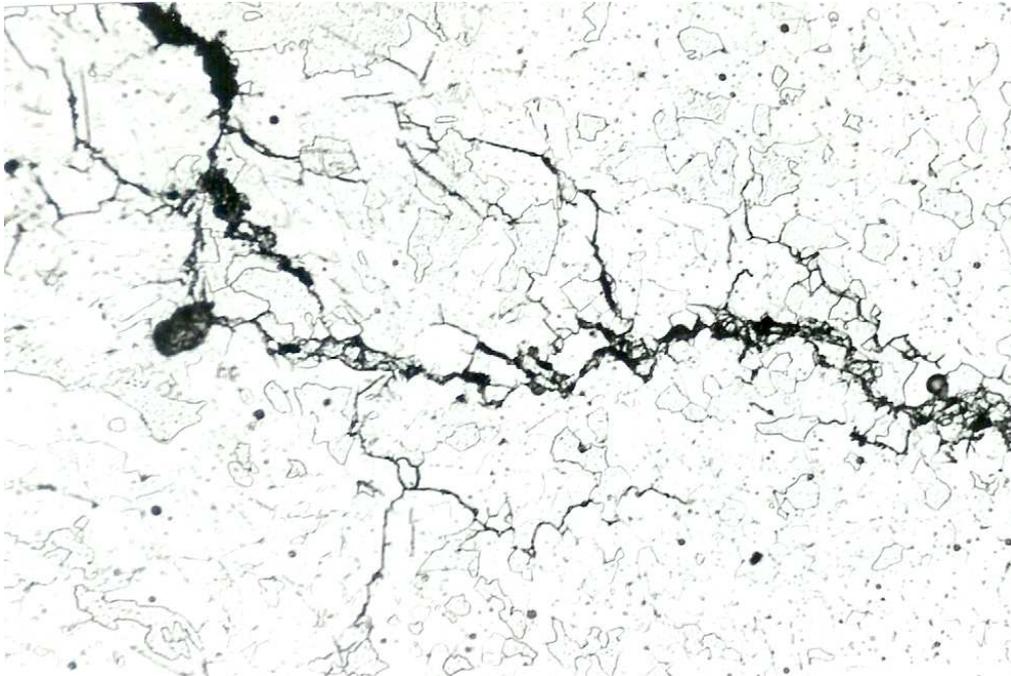


Photo 3: Predominantly inter-granular cracking weld deposit material of seam weld (etchant: nital).

Photo 4 shows a SEM picture of the inter-granular propagation of the cracks. In the boat sample examined by Stamicarbon only cracks were found in weld deposit material. The weld deposit material has a normal dendritic casting structure.

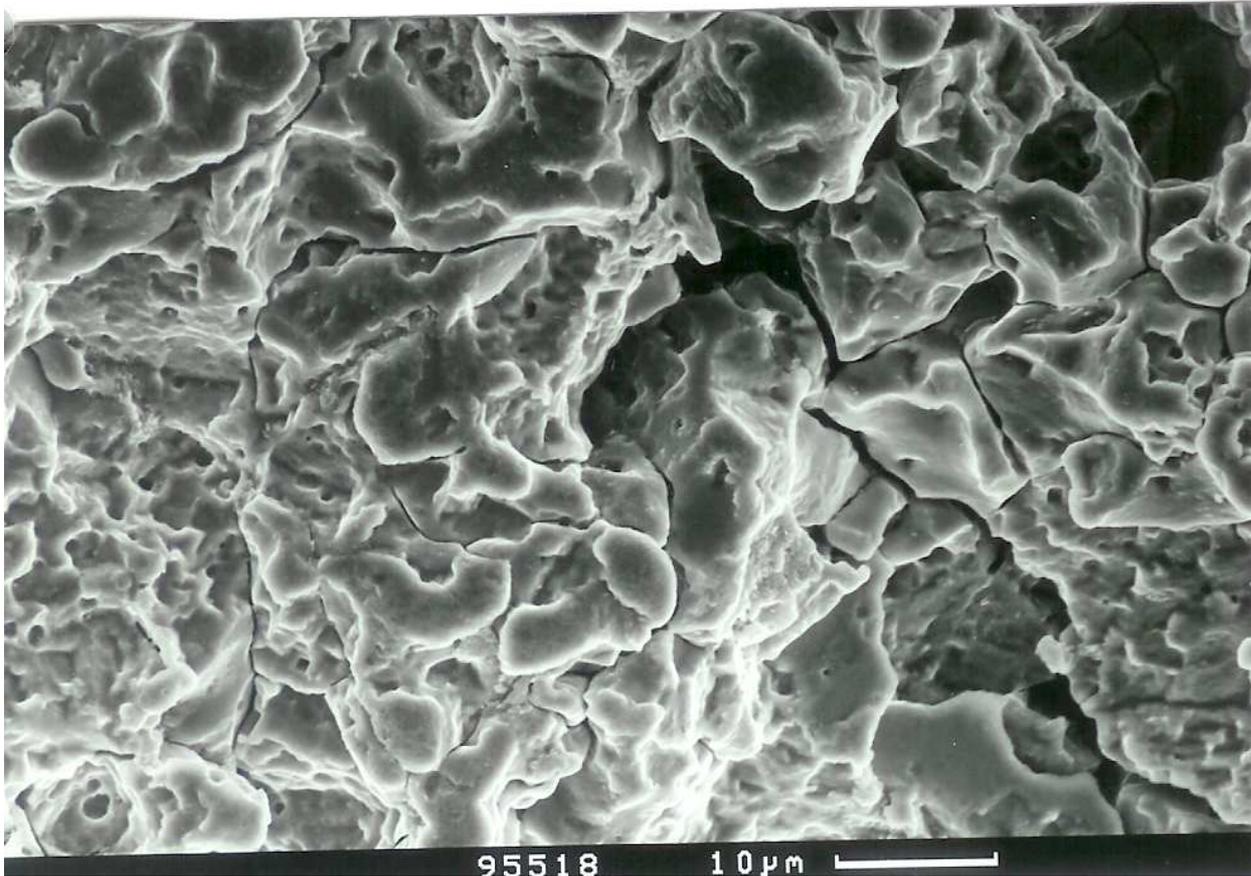


Photo 4: SEM picture of inter-granular crack propagation

Based on the presence of high amounts of nitrate as well as the results of the microscopic examination it was concluded that the cause of cracking is nitrate stress corrosion cracking.

Initially it was not clear what could be origin of the nitrate contamination. No nitrate fertilizer or nitric acid plant was located nearby concerning urea plant.

However, the nearby prilling tower causes some contamination of urea dust which can enter the insulation material together with rain water due to severe damage of the aluminum cover sheeting. By means of microbiological activity (during turnarounds) the urea decomposes resulting in the nitrate contamination.

Remarkable is the presence of the angle iron insulation support ring just below the circumferential weld where stress levels are most high. The insulation material just above this angle iron will be wet during long periods.

These aspects increase the risk of stress corrosion cracking

Conclusions

1. The cracking in the seam weld of the top hemi-head to the cylindrical part of the urea reactor is external stress corrosion cracking due to presence of nitrate originating from decomposed urea.
2. The urea dust from a nearby prilling tower could enter the insulation material together with rain water as a result of severely damaged aluminum cover sheeting.

Recommendations

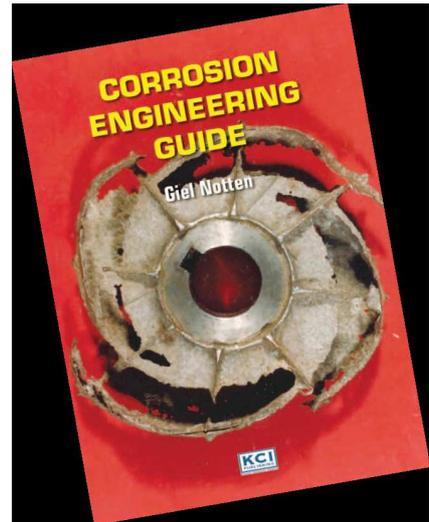
1. Take care of a proper aluminum cover sheeting to avoid ingress of water contaminated with nitrate and/or urea.
2. In case of risk of nitrate (or urea) contamination carbon steel equipment and piping operating at temperatures in between -10 and +240 °C have to be coated.
3. The angle iron insulation support ring should be fixed on the carbon steel shell in area with a lower stress level.

Giel has written the Corrosion Engineering Guide, a valuable asset for any engineer working in a urea plant.

This guide is available via:

<http://www.stainless-steel-world.com/>

Please find the Table of Content of this Corrosion Engineering Guide herebelow.



About Giel Notten

Giel is a true materials and corrosion expert who, before his retirement in 2004, spent thirtyeight years working with DSM in The Netherlands. After gaining his Engineering degree at the Higher Technical School of Heerlen, The Netherlands, he joined DSM's central laboratory.

He was to remain with the company for the rest of his career and held several positions as a materials and corrosion expert there. For the last twenty years before he retired, Giel worked in the Corrosion Department as Managing Senior Corrosion Engineer. He has further participated in numerous conferences spreading the word about his broad experiences as a corrosion and materials specialist in chemical process plants.

For Stamicarbon, a subsidiary company of DSM, and licensing DSM's know-how, he set up programmes for lifetime extension studies in urea and ammonia plants and supervised them.

He was also involved in the development of Safurex[®], the super-duplex stainless steel grade (developed by Sandvik in cooperation with Stamicarbon) for application in Stamicarbon urea plants.

Giel has always enjoyed teaching so, after only five years working in the field at DSM, he already began to develop a Corrosion Engineering course. Since then he has taught many young engineers from both inside and outside DSM about the ins and outs of corrosion control in chemical plants. He was also a board member of NACE Benelux and a member of the Contact Group Corrosion of the Dutch Chemical Process Industry and the Studiekern Corrosion of the Dutch Corrosion Society (NCC).

Since his retirement from DSM, Giel Notten has remained active as a corrosion engineering consultant. He has devoted much of his time to passing on his extensive knowledge and experience on the complicated topic of corrosion engineering to a new generation of engineers.

He has done this in the form of numerous corrosion courses and workshops.

Alongside his professional career, Giel has been very active in local societies and has been a Rabobank board member for about thirty-five years, twenty-five years of which as Chairman of the Board. Furthermore, he is an active cyclist. Together with his wife, Lianne, he has made trips up to 2500 km by bicycle to Santiago de Compostela, Spain and Rome, Italy.



Table of Contents

Corrosion Engineering Guide

1 Introduction

- 1.1 Importance of corrosion prevention and control
- 1.2 Improved equipment reliability by means of equipment condition monitoring

2 Electrochemistry

- 2.1 Introduction
- 2.2 Thermodynamics
- 2.3 Electrode kinetics
- 2.4 Application of electrochemical corrosion theory on corrosion reactions

3 Forms of Corrosion

- 3.1 Introduction
- 3.2 Electrochemical
 - 3.2.1 Uniform corrosion
 - 3.2.2 Galvanic corrosion
 - 3.2.3 Pitting
 - 3.2.4 Crevice corrosion
 - 3.2.5 Intergranular corrosion
 - 3.2.6 Selective corrosion/selective leaching
- 3.3 Electrochemical/Mechanical
 - 3.3.1 Stress corrosion cracking (SCC)
 - 3.3.2 Corrosion-fatigue
 - 3.3.3 Erosion-corrosion
- 3.4 Physical/metallurgical (mechanical)
 - 3.4.1 Hydrogen damage
 - 3.4.2 Liquid Metal Embrittlement (LME)
- 3.5 High temperature/chemical
 - 3.5.1 Oxidation and Sulphidation
 - 3.5.2 CO attack
 - 3.5.3 Metal dusting
 - 3.5.4 H₂ attack (Nelson)
 - 3.5.5 Nitriding
 - 3.5.6 Creep
 - 3.5.7 Carburisation
- 3.6 Atmospheric corrosion
 - 3.6.1 Introduction
 - 3.6.2 Forms of atmospheric corrosion
 - 3.6.3 Preventive measures
 - 3.6.4 Cases of atmospheric corrosion
- 3.7 Soil corrosion
- 3.8 Microbiologically induced corrosion (MIC)

4 Corrosion Prevention and Protection

- 4.1 Introduction
- 4.2 Design and layout
- 4.3 Materials selection
 - 4.3.1 Introduction

- 4.3.2 Carbon steel and cast iron
- 4.3.3 Stainless steels (ferritic, martensitic and austenitic)
- 4.3.4 Duplex stainless steels
- 4.3.5 Nickel and nickel alloys
- 4.3.6 Copper and copper alloys
- 4.3.7 Aluminium and aluminium alloys
- 4.3.8 Titanium, Zirconium and Tantalum
- 4.3.9 Plastics
- 4.4 Protective layers
- 4.5 Changing corrosive environment
- 4.6 Changing electrode potential (Cathodic and Anodic protection)
- 4.7 Chemical industrial cleaning

5 Corrosion Examination, Inspection and Monitoring

- 5.1 Corrosion examination
- 5.2 Quality Control of materials of construction
- 5.3 Inspection
- 5.4 On-line corrosion monitoring techniques