

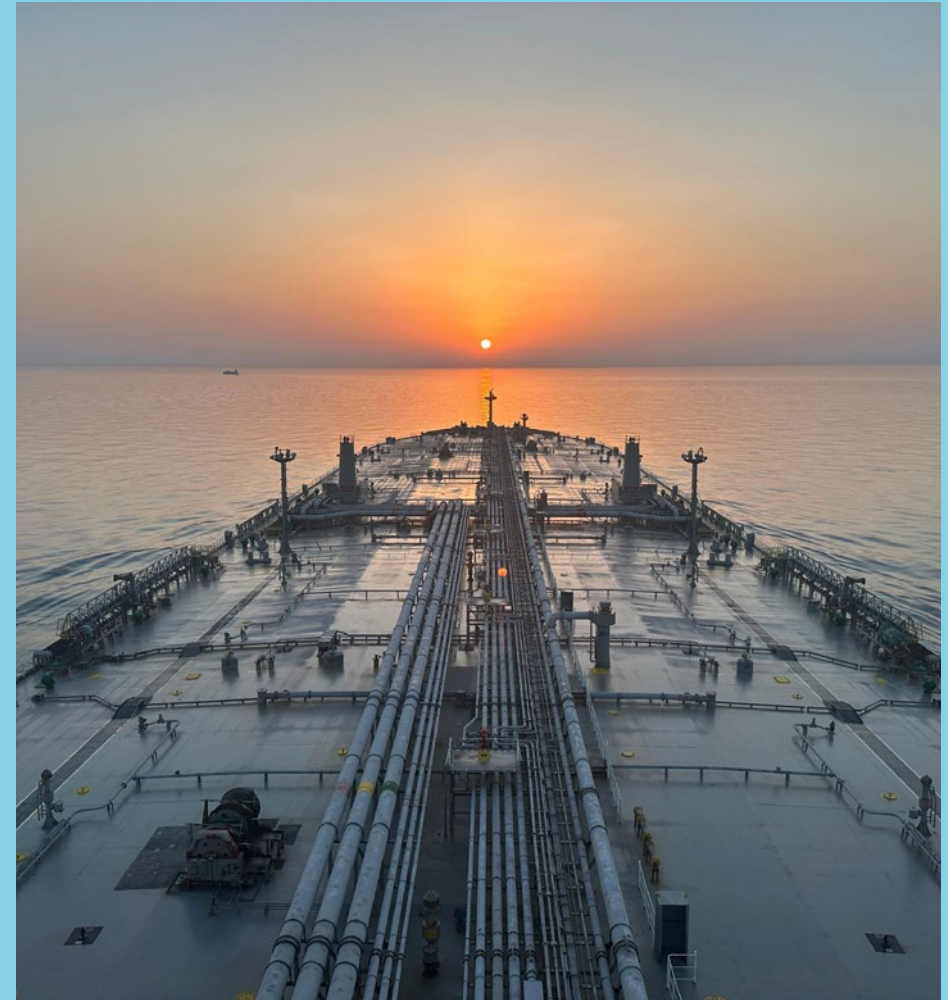
# Risk Focus: Chemical Tanker Stainless Steel Cargo Tanks

A Guide for Stainless Steel Chemical Tanker Operations

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## A guide for stainless steel chemical tanker operations

This article brings together the key content and technical guidance presented by Sedgwick Marine Technical Services, providing a structured reference for professionals involved in stainless steel chemical tanker operations. Designed for marine inspectors, cargo surveyors and engineering personnel, it offers practical insights into the inspection, maintenance and operational considerations essential to maintaining safety, compliance and performance in the chemical tanker sector.

### Introduction to stainless steel

Steel is essentially an iron-based alloy consisting of iron and a low level of carbon. For example, mild steel, also commonly known as low carbon steel contains up to 0.25% (weight) carbon for strengthening, with other elements such as for about 0.4 to 0.7% manganese, 0.1 to 0.5% silicon, and some residuals of sulfur, phosphorus, and other elements for other metallurgical purposes.

When steel is added with more than 10% chromium, such steel is defined as stainless steel, which is a class or series of steel with enhanced corrosion resistance. It is to be remembered that stainless steel does not resist all corrosive substances.

Corrosion resistance of stainless steel is achieved from the formation of a very thin chromium oxide ( $\text{Cr}_2\text{O}_3$ ) passive layer, typically only several nanometres thick, on the surface. This is because chromium is a reactive element thus it oxidises readily to passivate and exhibit excellent resistance to many environments. Although often described as “stainless”, the protection is not perfect and can deteriorate when the passive layer is damaged or exposed to aggressive environments.



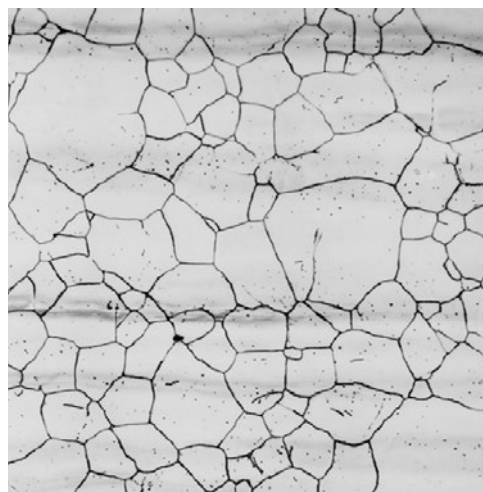
## Stainless steel grades

Common grades of stainless steel are classed as ferritic, austenitic and duplex stainless steels. These classes are differentiated on the basis of its microstructure, whether they are wholly ferrite, wholly austenite or an almost 50-50 mixture of ferrite and austenite.

Ferritic stainless steel exhibit magnetism whilst austenitic stainless is non-magnetic, and duplex stainless steel is magnetic because of its ferrite content.

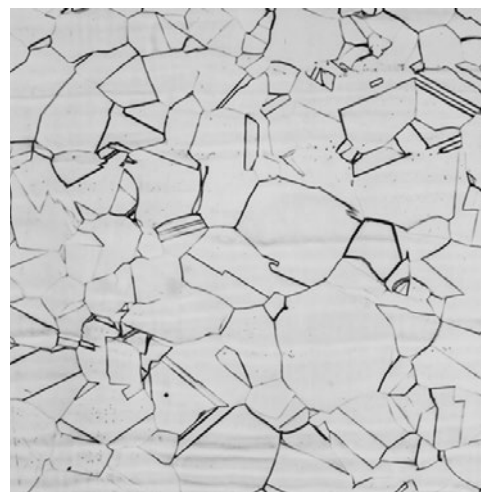
Austenitic grades such as 316L and 316LN provide excellent corrosion resistance and weldability.

Duplex 2205 contains approximately equal ferrite and austenite phases, providing higher strength and improved resistance to localised corrosion.



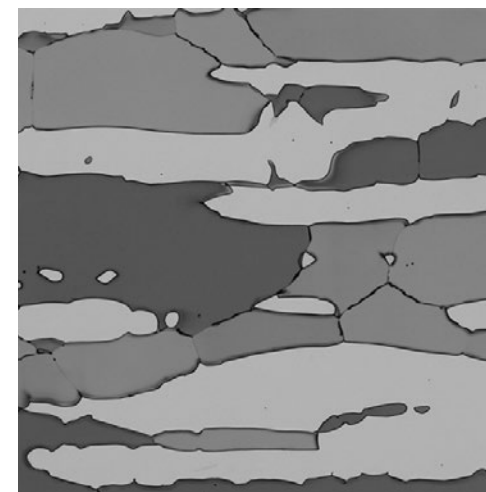
*Ferritic structure*

25  $\mu\text{m}$



*Austenitic structure*

25  $\mu\text{m}$



*Duplex structure*

50  $\mu\text{m}$

These images are microstructures that were revealed on metallographic specimens after polishing to a mirror-finish surface, chemically/electrochemically etched, and examined under an optical microscope.

## Introduction to corrosion

Corrosion can be defined as the degradation of material when exposed in an environment. The environment can be out in the open or in an enclosure, with or without oxygen. There are eight forms of corrosion. The basis for this classification is based on the appearance of the corroded metal. Each form can be identified by mere visual observation, which is most cases, are visible by the naked eye but sometimes magnification is helpful or required.

The eight forms of corrosion are as follows (in no particular order of importance):

1. Uniform or general attack
2. Galvanic or two-metal corrosion
3. Crevice corrosion
4. Pitting corrosion
5. Intergranular corrosion
6. Selective leaching
7. Erosion corrosion
8. Stress corrosion

Although stainless steels tend not to suffer from uniform corrosion, they are more susceptible to damage by localised corrosion, such as pitting and crevice corrosion.

Manufacturing processes such as melt quality, heat treatment and the amount of cold working can have an impact on its corrosion performance. During the heat treatment process, the temperature, hold time, and quench rate control the kinetics of the phase transformation. Studies have shown that a uniform distribution of the stable austenite phase with complete solution of carbides, achieved in a well-controlled quench-anneal (solution-annealing with a fast quench) process exhibits the greatest pitting resistance. Solution-annealing procedures for all austenitic alloys are similar and consist of heating to a temperature of about 1095°C (2000°F), holding for a time sufficient to accomplish complete solution of carbides, and quenching at a rate fast enough to prevent re-precipitation of the carbides. [Ref: ASM Handbook Volume 4: Heat Treating]. Severe cold-working increases the pitting attack of austenitic stainless steels thus preferential edge pitting can be observed on most wrought stainless products. Therefore, deficiencies in the chemical composition and manufacturing process can be revealed from the examination of the steel's microstructure and in-service corrosion behaviour.

Poor welding also increases the pitting attack of austenitic stainless steels by disrupting the protective chromium oxide passive layer, altering the microstructure and introducing surface defects.

It is important to be aware that stainless steels have their limitations too. When there is presence of combined contributing factors, stainless steels can experience stress corrosion cracking, chloride-stress corrosion cracking, corrosion fatigue cracking, hydrogen induced cracking (delayed brittle fracture caused by impregnation of hydrogen during processing that led to brittle failure during subsequent loading) and intergranular corrosion.

In other words, stainless steels are not immune to every environment. For example, stainless steels perform poorly in reducing environments such as 50% (volume) sulphuric and hydrochloric acids at elevated temperatures and experience a breakdown of the protective passive layer over the entire metal surface.



Example of pitting corrosion.

## Pitting Resistance Equivalent Number (PREN)

PREN is useful to compare resistance to pitting corrosion between the different grades of stainless steels based on their chemical compositions but **cannot be used to predict whether a particular grade will be suitable for a given application, where pitting corrosion may pose a hazard.**

$$\text{PREN} = \% \text{Cr} + (3.3 \times \% \text{Mo}) + (16 \times \% \text{N})$$

Chromium, molybdenum and nitrogen increase pitting resistance. Tungsten is also included in the molybdenum-rating factor to acknowledge its effect on pitting resistance in the tungsten bearing super-duplex types, for example 1.4501. A modified formula is then used:

$$\text{PREN} = \% \text{Cr} + 3.3(\% \text{Mo} + 0.5 \times \% \text{W}) + (16 \times \% \text{N})$$

Typical duplex grades possess higher PREN values than 316L/316LN and are therefore more resistant to fluoride- or chloride-induced attack.

A list of the PREN values for the various grades of stainless steels is provided opposite for reference.

| Grade               | Type                      | Cr        | Mo      | N         | PREN              |
|---------------------|---------------------------|-----------|---------|-----------|-------------------|
| <b>Ferritics</b>    |                           |           |         |           |                   |
| 1.4003              | K03                       | 10.5-12.5 | NS      | 0.030 max | 10.5-12.5         |
| 1.4016              | 430                       | 16.0-18.0 | NS      | NS        | 16.0-18.0         |
| 1.4113              | 434                       | 16.0-18.0 | 0.9-1.4 | NS        | 19.0-22.6         |
| 1.4509              | 441                       | 17.5-18.5 | NS      | NS        | 17.5-18.5         |
| 1.4521              | 444                       | 17.0-20.0 | 1.8-2.5 | 0.030 max | 23.0-28.7         |
| <b>Austenitics</b>  |                           |           |         |           |                   |
| 1.4301              | 304                       | 17.5-19.5 | NS      | 0.11 max  | 17.5-20.8         |
| 1.4311              | 304LN                     | 17.5-19.5 | NS      | 0.12-0.22 | 19.4-23.0         |
| 1.4401/4            | 316/316L                  | 16.5-18.5 | 2.0-2.5 | 0.11 max  | 23.1-28.5         |
| 1.4435              | 316L (2.5% min Mo)        | 17.0-19.0 | 2.5-3.0 | 0.11 max  | 25.3-30.7         |
| 1.4406              | 316LN                     | 16.5-18.5 | 2.0-2.5 | 0.12-0.22 | 25.0-30.3         |
| 1.4539              | 904L                      | 19.0-21.0 | 4.0-5.0 | 0.15 max  | 32.2-39.9         |
| 1.4563              | Sanicro 28                | 24.0-26.0 | 3.0-4.0 | 0.11 max  | 35.9-43.0         |
| 1.4547              | 254SMO                    | 19.5-20.5 | 6.0-7.0 | 0.18-0.25 | 42.2-47.6         |
| 1.4529              | 1925hMo                   | 19.0-21.0 | 6.0-7.0 | 0.15-0.25 | 41.2-48.1         |
| 1.4565              | 4565S                     | 24.0-26.0 | 4.0-5.0 | 0.30-0.60 | 42.0-52.1         |
| <b>Duplex</b>       |                           |           |         |           |                   |
| 1.4062 <sup>1</sup> | 2202                      | 22.0      | 0.4     | 0.20      | 26.5              |
| 1.4162              | 2101LDX                   | 21.0-22.0 | 0.1-0.8 | 0.20-0.25 | 24.5-28.6         |
| 1.4362              | SAF 2304                  | 22.0-24.0 | 0.1-0.6 | 0.05-0.20 | 23.1-29.2         |
| 1.4462              | SAF 2205                  | 21.0-23.0 | 2.5-3.5 | 0.10-0.22 | 30.8-38.1         |
| 1.4410 <sup>2</sup> | SAF 2507 <sup>2</sup>     | 24.0-26.0 | 3.0-4.0 | 0.24-0.35 | > 40 <sup>2</sup> |
| 1.4501 <sup>2</sup> | Zeron 100 <sup>2</sup>    | 24.0-26.0 | 3.0-4.0 | 0.20-0.30 | > 40 <sup>2</sup> |
| 1.4507 <sup>2</sup> | Ferrinox 255 <sup>2</sup> | 24.0-26.0 | 3.0-4.0 | 0.20-0.30 | > 40 <sup>2</sup> |

The nearest AISI grade is shown, where appropriate, otherwise a typical trade name used by some of manufacturers is shown.

Image source: British Stainless Steel Association

## Materials of construction of marine cargo tank

316L, 316LN and Duplex 2205 are common cargo tank materials. The 'L' denotes leaner alloy with lower carbon, 0.03% maximum. Lowering the carbon content reduces the susceptibility to intergranular corrosion and improves the weldability of austenitic stainless steels. Higher chromium, molybdenum and nitrogen contents generally improve pitting resistance, although molybdenum may become a concern in very high nitric acid concentrations.

## Why stainless steel is used

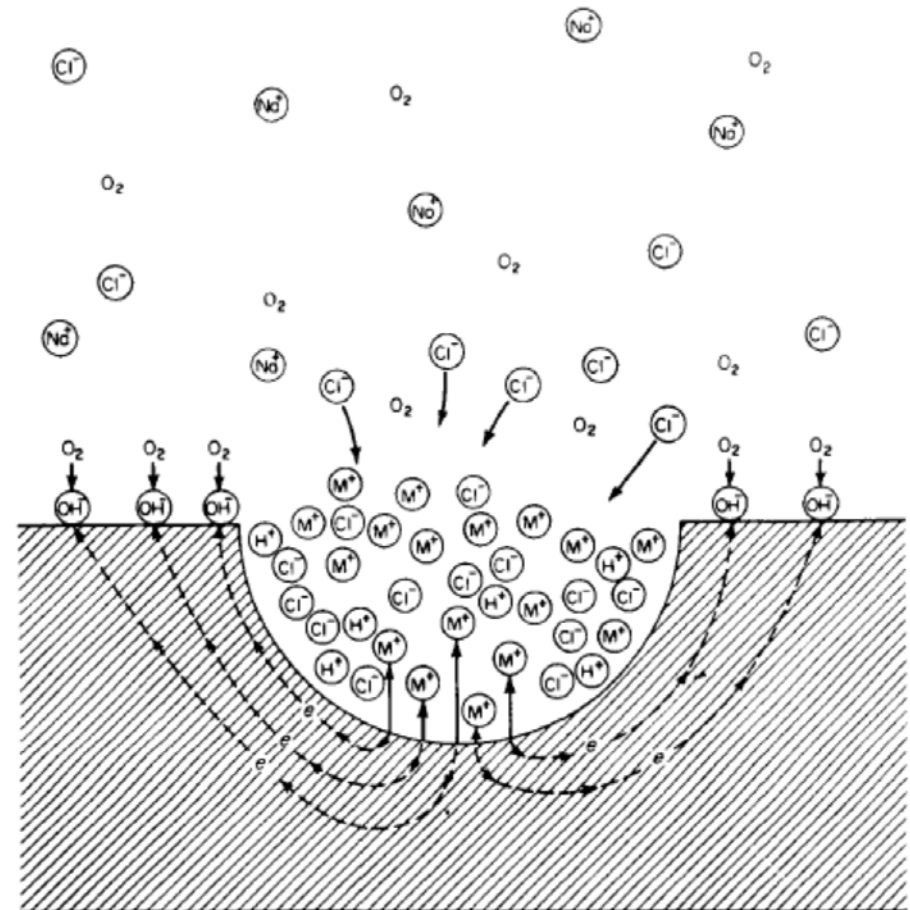
Stainless steel is selected because of its broad chemical resistance, favourable mechanical properties, durability, cleanability and ability to carry aggressive chemical cargoes.

## Aggressive cargoes

Cargoes requiring particular attention include phosphoric acid, hydrochloric acid and nitric acid. Austenitic stainless steels are generally suitable for nitric acid service; however, very high concentrations may favour materials with higher chromium and lower molybdenum content. Also, chloride and fluoride contaminants can significantly increase corrosion risks.

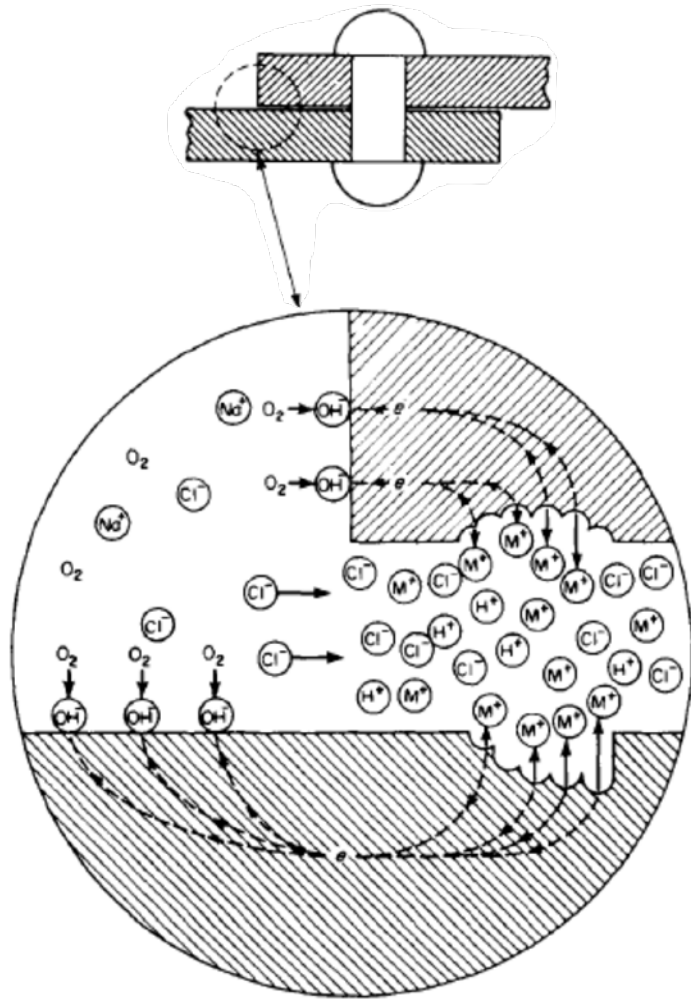
## Corrosion mechanisms

Loss of passivity can occur through de-passivation (breakdown of passive layer), can occur through chemical attack, contamination, surface damage or unfavourable pH conditions. Localised metal loss commonly develops as pitting corrosion and crevice corrosion. These mechanisms may appear as isolated pits, pit clusters or attack hidden beneath deposits and attachments. Pits that form and reach a pit depth where the solution in the pit bottom becomes concentrated, lower in pH (more acidic) stimulating the migration of ions and the rapid dissolution of the metal, can self-sustain their growth. This is called an autocatalytic process.



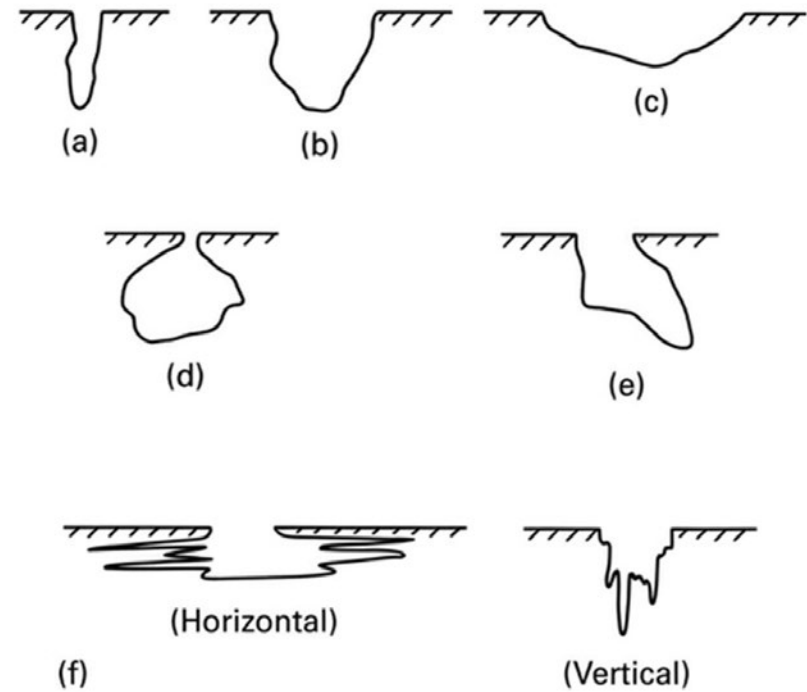
*Pitting corrosion*

*Image source: Fontana, M.G., Corrosion Engineering, 1987.*



Crevice corrosion

Image source: Fontana, M.G., Corrosion Engineering, 1987.



Variations in the cross-sectional shape of pits. (a) Narrow and deep. (b) Elliptical. (c) Wide and shallow. (d) Subsurface. (e) Undercutting. (f) Shapes determined by microstructural orientation.

Image source: ASM Handbook Volume 13A with reference to ASTM G46 - Standard Guide for Examination and Evaluation of Pitting Corrosion.

## FAQs

### Is it sufficient to conduct a general visual inspection of the bulkheads after cargo discharge?

#### Inspection scope

Tank inspections should examine the four bulkheads, tank top, heating coils, U-bolts, cargo pumps, drop lines, floating level gauges, welding seams and ladders. Visual assessment should be supplemented with roughness and passivation measurements.

#### Inspection hotspots

Key locations include liquid lines, general wall surfaces, corners, welds, heating coil undersides and obscured surfaces of sounding pipes. These locations frequently retain residues or experience flow-related attack.

#### Indicators of degradation

Features to look for include increased roughness, black reflective powder, brown streaking, isolated pits, pit clusters, hidden pits, peeling, flaking and magnetic response following repairs or grinding of austenitic or duplex stainless steel-clad tanks.

### How do we know if the surface condition is acceptable or not?

#### Acceptance criteria

Surface roughness should not exceed 3.5 µm. Passivity should be at least 60 on a scale from 0 (active) to 100 (fully passive). Higher roughness increases risk of residue entrapment and difficulty in re-passivation.

#### Inspection tools

Surface roughness meters and stainless steel passivity meters are used to quantify surface condition. Passivity meters evaluate the electrochemical behaviour of the surface and estimate the effectiveness of the passive layer.

#### Corrective actions

When roughness or passivity limits are not met, pickling and passivation treatments should be considered. Restoration aims to remove contamination, dissolve damaged surface layers and promote redevelopment of the chromium-rich passive layer.

#### Surface treatment methods

Pickling removes weld oxides and a thin layer of stainless steel using acid-based treatments, which may include hydrofluoric acid in the formulation. Passivation improves passive layer formation without significant metal removal and may use nitric acid, citric acid formulations or electropolishing.

Hydrofluoric acid requires stringent safety controls and licensing where applicable. It is a schedule 7 poison and in concentrations greater than 1% requires a specific licence for use.

#### Applicable standards

Relevant standards include ASTM A380 for cleaning, descaling and passivation and ASTM A967 for chemical passivation.

#### Repair and follow-up

Damaged areas are repaired through grinding and surface restoration. Subsequent evaluation is to focus on appearance, roughness and passivity to confirm recovery of corrosion resistance.

### Sometimes the tank surface showed discolouration after cargo discharge, but the surface appears to be smooth? What can the crew do?

#### Other surface observation – discolouration

Stainless steel surfaces in chemical tankers may exhibit discolouration following discharge of chemical cargoes. Discolouration may not necessarily indicate physical damage.

Discolouration on the tank surfaces can be attributed to various factors, such as chemical reactions between cargo residues, oxidation because of temperature effects or chemical reactions or electrolytic processes. When stainless steels are heated, oxidised scale forms on the surface. A halo effect may be present when the passive layer is not uniform, and the thickness variation creates an optical light-reflection effect.

It is still advisable to conduct a close-up examination of the discoloured surface conditions.

#### Key lessons

Temperature control, pre- and post-carriage roughness measurements taken at the same location consistently, systematic passivity assessments, and repeatable inspection practices provide stronger evidence when evaluating cargo-induced damage.

## Conclusion

Stainless steel remains an important material for chemical tanker cargo tanks because of its durability, cleanability and resistance to a broad range of aggressive cargoes. However, it is not immune to corrosion. Its performance depends on the selection of an appropriate grade, the integrity of its passive surface layer, the cargo chemistry, operating environment, and the quality of ongoing inspection and maintenance.

Effective condition assessment therefore requires more than a general visual inspection alone. Particular attention should be given to known hotspots, including welds, corners, heating coils, liquid lines and obscured surfaces, supported by consistent surface roughness and passivity measurements. Changes such as pitting, increased roughness, discolouration, deposits or surface contamination should be examined carefully to determine whether they indicate cargo residue, deterioration of the passive layer or more significant corrosion damage.

Where surfaces do not meet the required condition, appropriate cleaning, pickling, passivation or repair may be necessary, followed by further assessment to confirm that corrosion resistance has been restored. Most importantly, temperature control, repeatable inspection practices and measurements taken at consistent locations before and after cargo carriage provide a stronger evidence base for distinguishing pre-existing conditions from cargo-related damage.

A systematic and well-documented approach helps marine inspectors, cargo surveyors and engineering personnel to identify emerging concerns earlier, support technically robust conclusions and protect the long-term condition of stainless steel cargo tanks.

## References:

- ASM Handbook Volume 1 - Properties and Selection Irons Steel and High Performance Alloys
- ASM Handbook Volume 4 - Heat Treating
- ASM Handbook Volume 9 - Metallography and Microstructures
- ASM Handbook Volume 13A - Corrosion - Fundamentals, Testing, and Protection
- British Stainless Steel Association
- Fontana, M. G., Corrosion Engineering, 1987



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