JUBCOR 2024

CONFERENCE & EXHIBITION

INNOVATIVE SOLUTIONS FOR CORROSION CHALLENGES

Challenges and Lessons Learned in Corrosion Management for Urea Solution Storage Tank Bottom Plate

Presented By

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Abstract

Urea solution, a corrosive medium stored at temperatures around 90°C, poses significant challenges for tank materials. In this paper, we explore the case of an austenitic stainless steel tank that suffered corrosion and cracking in bottom plate due to impurities in the sand beneath it and chloride contamination. The original tank bottom plates experienced chloride stress corrosion cracking from the soil side, necessitating replacement.

The upgraded solution involved installing Duplex Stainless Steel (DSS) bottom plates, known for their superior resistance to chloride pitting attack. However, after 10 years in service, the new DSS bottom plate corroded and leaked. Upon inspection and removal of parts of the tank foundation, it revealed not only corrosion attack on the Duplex stainless but also severe corrosion of the old austenitic stainless steel bottom plate left over.

This paper discusses several critical aspects:

- Soil Purity Recommendations: We emphasize the importance of assessing soil purity during tank installation. Contaminants in the soil can accelerate corrosion processes, impacting the tank's longevity.
- Best Practices for Tank Bottom Plate Replacement: Proper procedures during tank bottom plate replacement are crucial. Ensuring thorough soil removal and addressing potential contamination are essential steps.
- Crevice Corrosion in Duplex Stainless Steel: We highlight the significance of crevice corrosion in Duplex SS, especially in chloride-contaminated environments. Understanding this mechanism is vital for preventing future failures.
- Temporary Repairs and Inspection Methods: When leaks occur, temporary repair actions are necessary to maintain tank integrity. We discuss effective inspection methods and strategies for continued operation until a planned turnaround allows for complete bottom plate replacement.

Introduction – Production of Urea

- Urea is produced by reacting ammonia with carbon dioxide under a pressure of 150–220 bar, in a reactor at temperatures in the range of 170–200 °C.
- The reaction consists of two steps; first, the formation of ammonium carbamate (NH_2COONH_4) followed by its decomposition into urea CO $(NH_2)_2$

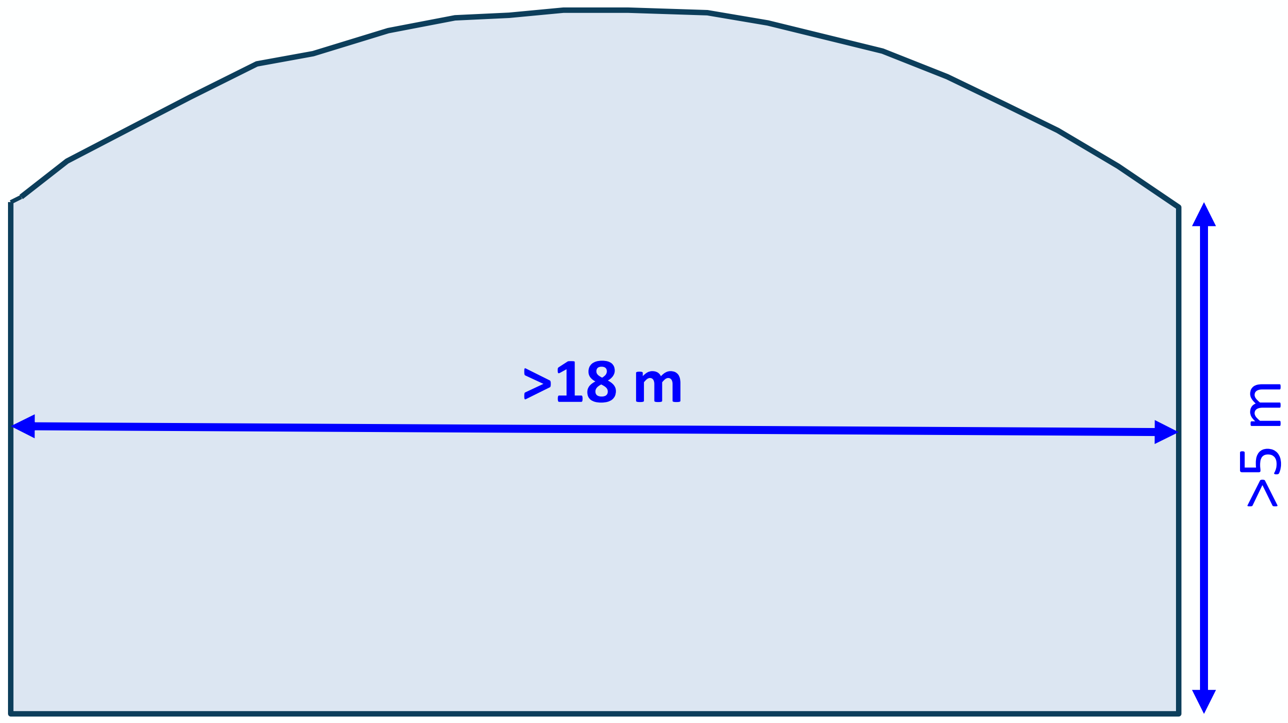
$$NH3 + CO2 \rightleftharpoons \text{Carbamate} \rightleftharpoons \text{Urea} + H2O$$

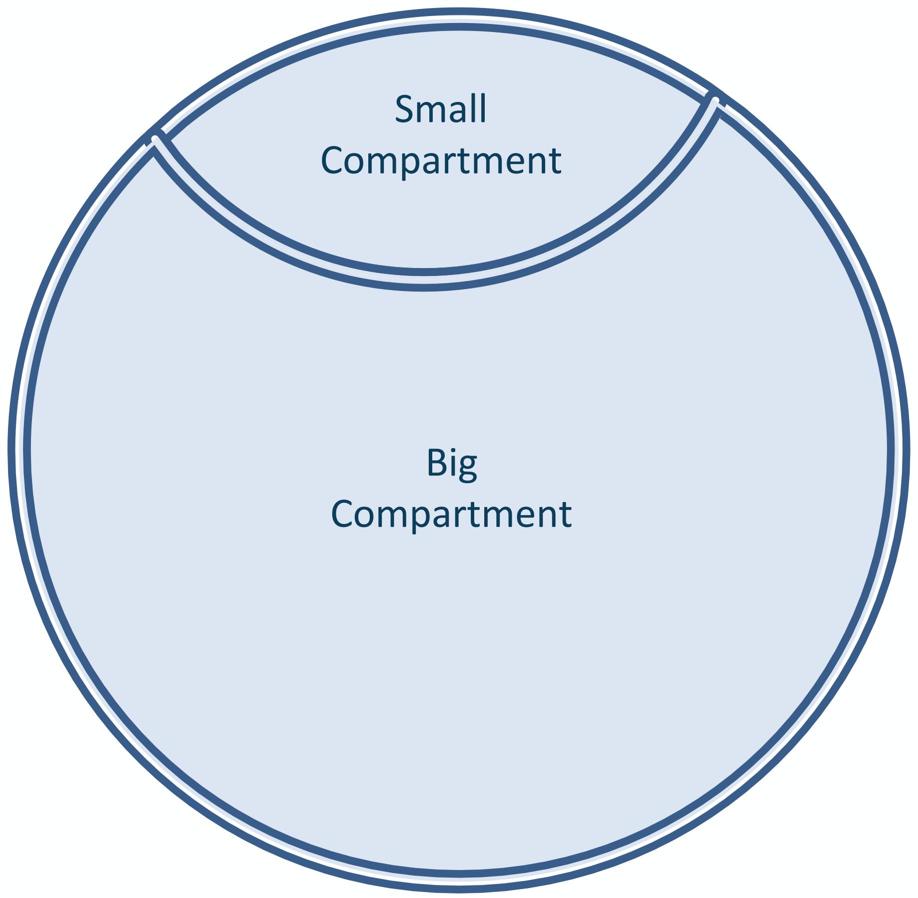
- Ammonium carbamate, which is present both in the reactor and the decomposition stages, is highly corrosive and active corrosion rate of 316L can be as high as 50 mm/year. Corrosivity of carbamate increases with temperature and is also affected by the ammonia/carbon dioxide ratio. Very few materials have adequate resistance to corrosion in such environment.
- Specific Austenitic stainless steel urea grades (SS 316L UG; 25Cr-22Ni-2Mo / 310LMo) and super duplex stainless steel (patented alloys) with restricted manufacturing quality control were developed in recent years. In addition to the use of Titanium and Zirconium in some if the urea striper tubes.
- On other hand, Urea solution is mildly corrosive and requires handling in relative high temperature in austenitic stainless material (SS 304L / 316L)

Example of carbamate corrosion

Urea Solution Tank

Tank Data	
Shell material	SS 304L
Bottom plate material	Duplex stainless steel UNS 31803, Thk. 7mm Original bottom plate was SS 304 and replaced after repeated cracks
Tank diameter/ height (m)	> 18 m / >5 m
Temperature (Design /operating)	> 150°C / >90°C
Service fluid	Urea solution
Construction code	API 650
Insulation	Yes
Construction year	2004





- Vertical insulated tank fabricated from austenitic stainless SS 304 L used for storage of Urea solution at temperature 93 °C
- The tank constructed from two different compartments (internal divider wall)

Tank Corrosion History

01 **Tank placed in service.**
- Bottom plate material SS 304

03 **2012 bottom plate replacement**
- New Bottom plate Duplex SS installed
- Old SS 304 plate maintained under the new bottom plate after cutting 500 mm from the annular plate
- Sand not replaced

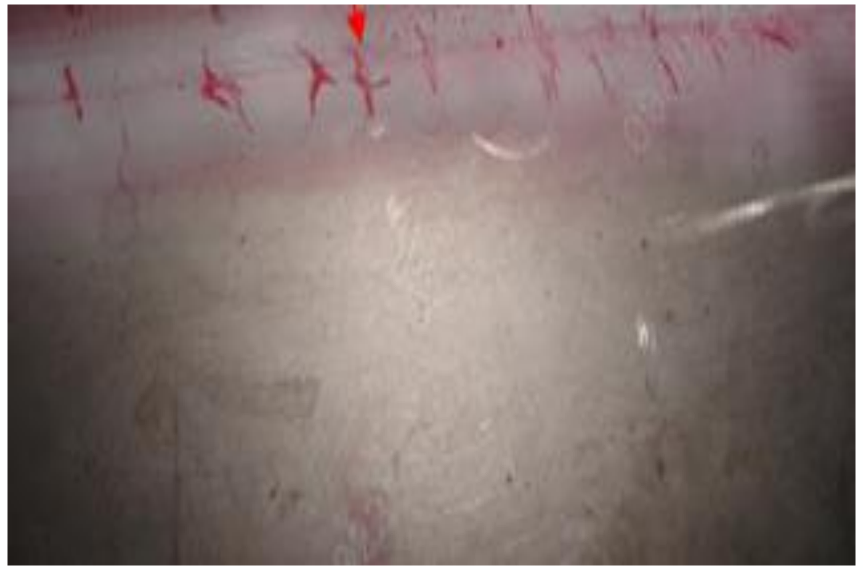
04 **Bottom plate leak**
- Leak observed from underneath bottom plate
- Heavy corrosion observed in the bottom side of DSS and old SS 304 plate

02 **2008 Inspection**
- Multiple Cracks observed in bottom plate caused by Chloride SCC
- Sand sample contained ~700 ppm chloride

- Tank bottom plate was initially SS 304 then attacked by Chloride stress corrosion cracking from soil side after one year in service.
- Sand sample showed chloride content > 700 ppm.
- Bottom plate replaced by DSS, working satisfactory fro 11 years, then leak again

Bottom Plate Replacement History and Highlights

- Stress corrosion cracks (SCC) were seen in all the lap joint welds between annular plate and sketch plate. Many of these cracks were extending to the parent metal on either side. Also weld defect such as pin hole, porosity observed in the welds.
- The tank was inspected by vacuum box and confirmed leaking. The repair was done using patch plate covering the defected welds. The location of the patches provided is shown in the sketch below.
- Sample was collected from the crack location the Lab results confirmed that the cracks were caused by chloride stress corrosion cracking.
- Sand sample collected and showed chloride content of > 600 ppm.
- It was recommended back then to replace the bottom plates with upgraded material (i.e. duplex stainless steel UNS 31803) the replacement was executed in 2012.

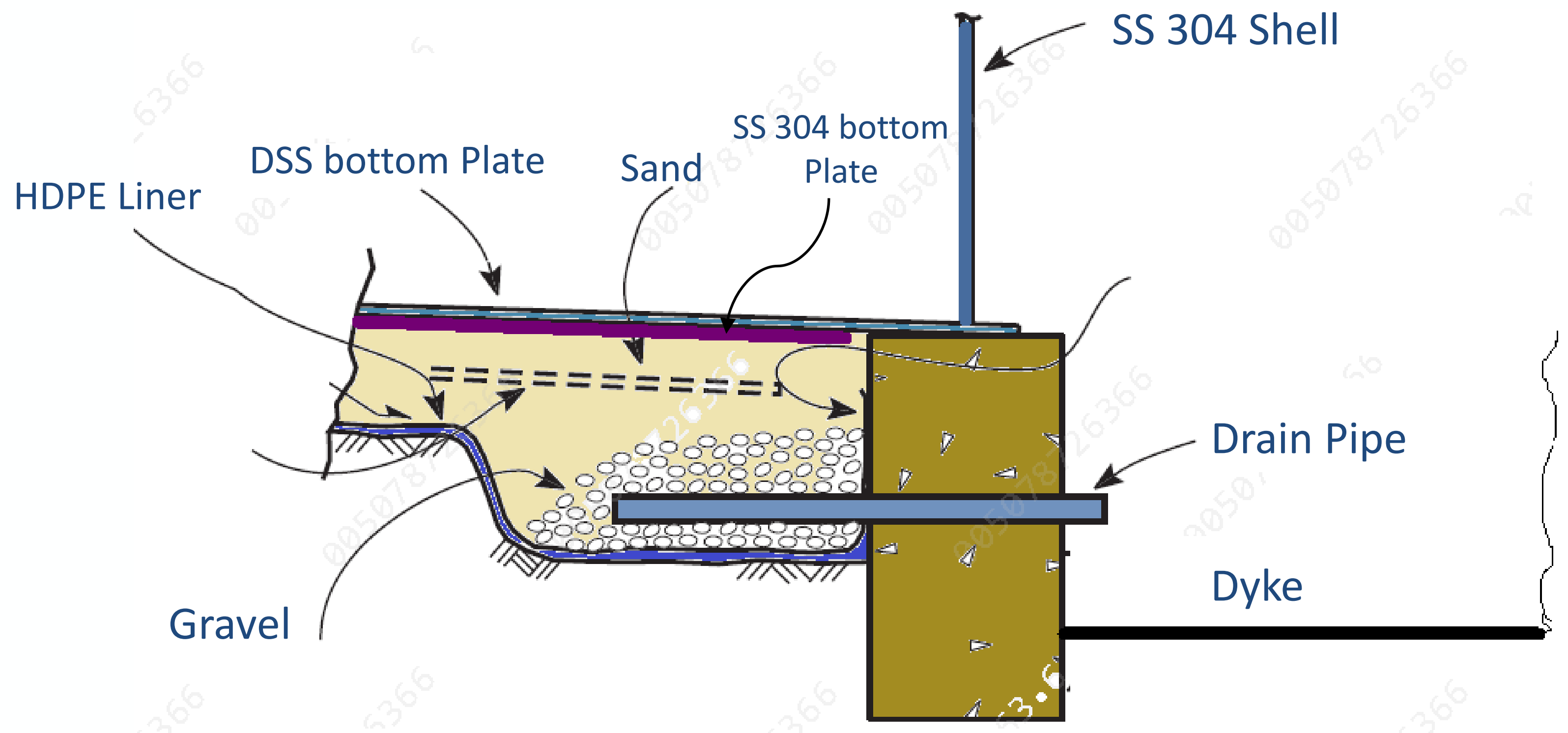


Bottom Plate Replacement From SS 304 to DSS

Bottom plate was replaced in 2012 with upgraded material (duplex stainless steel UNS 31803)

Duplex Stainless Steel Bottom Plate Leak

- Urea solution and ammonia smell was noticed from the bottom of the tanks from south side. Location of the leak is shown in the drawing below.
- After removing the wrapping around the foundation below the bottom plate. Broken pieces of the foundation covered with white deposit observed.
- The white deposit was found inside the dyke.
- The solution was coming from under the bottom plate
- The tank equipped with Release Prevention Barrier (RPB) including HDPE liner and drain nozzles from foundation which helped in containing the leak in the tank dyke without environmental impact

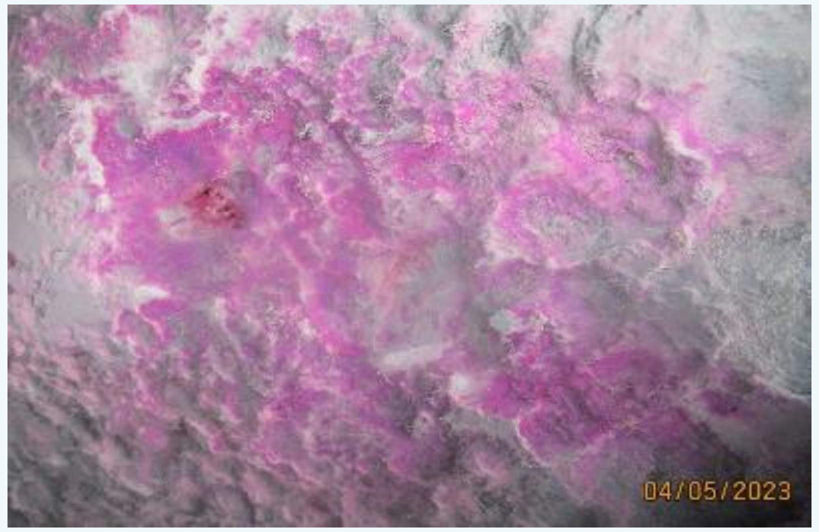


Inspection and Findings

Partial removal of the concrete ring, controlled manual excavating under the tank bottom plate.

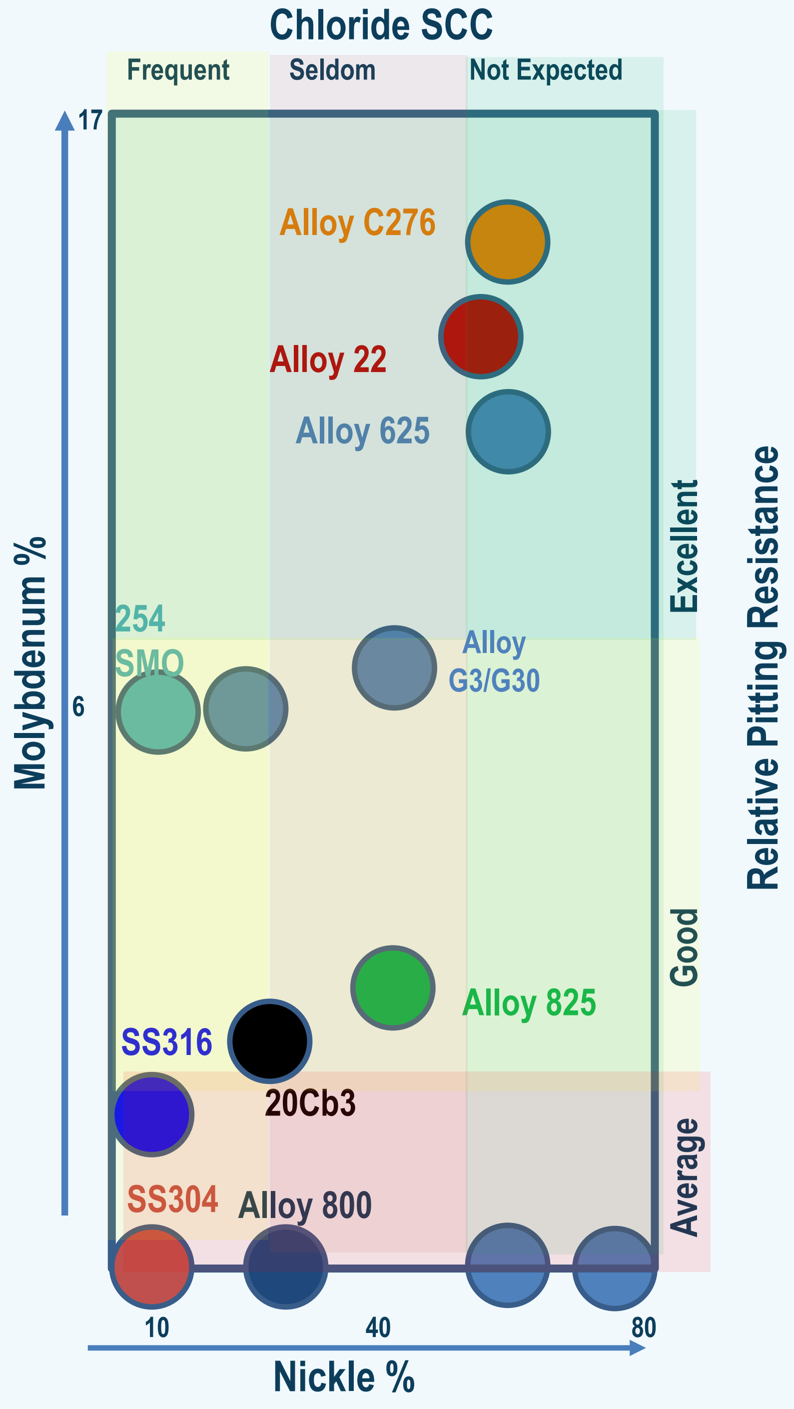
Old bottom SS plate corroded and leak observed between the two plates

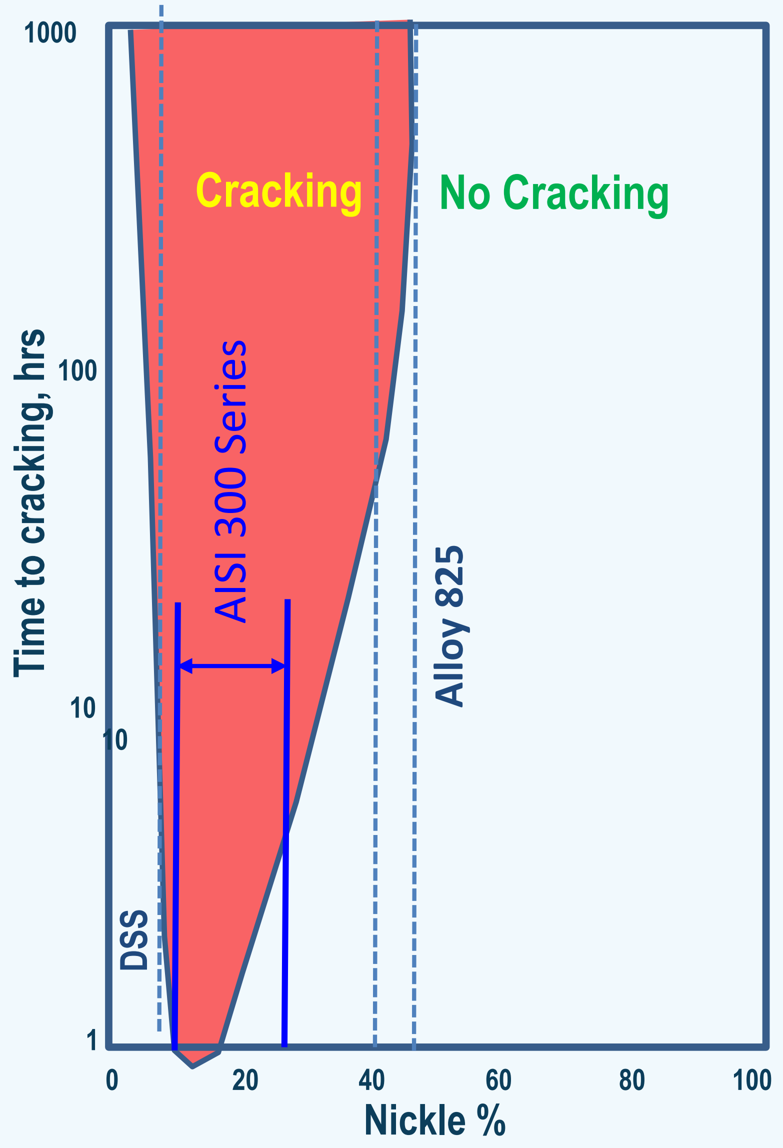
Cleaning showed high corrosion to old SS 304 plate; And pitting attack in the DSS plate



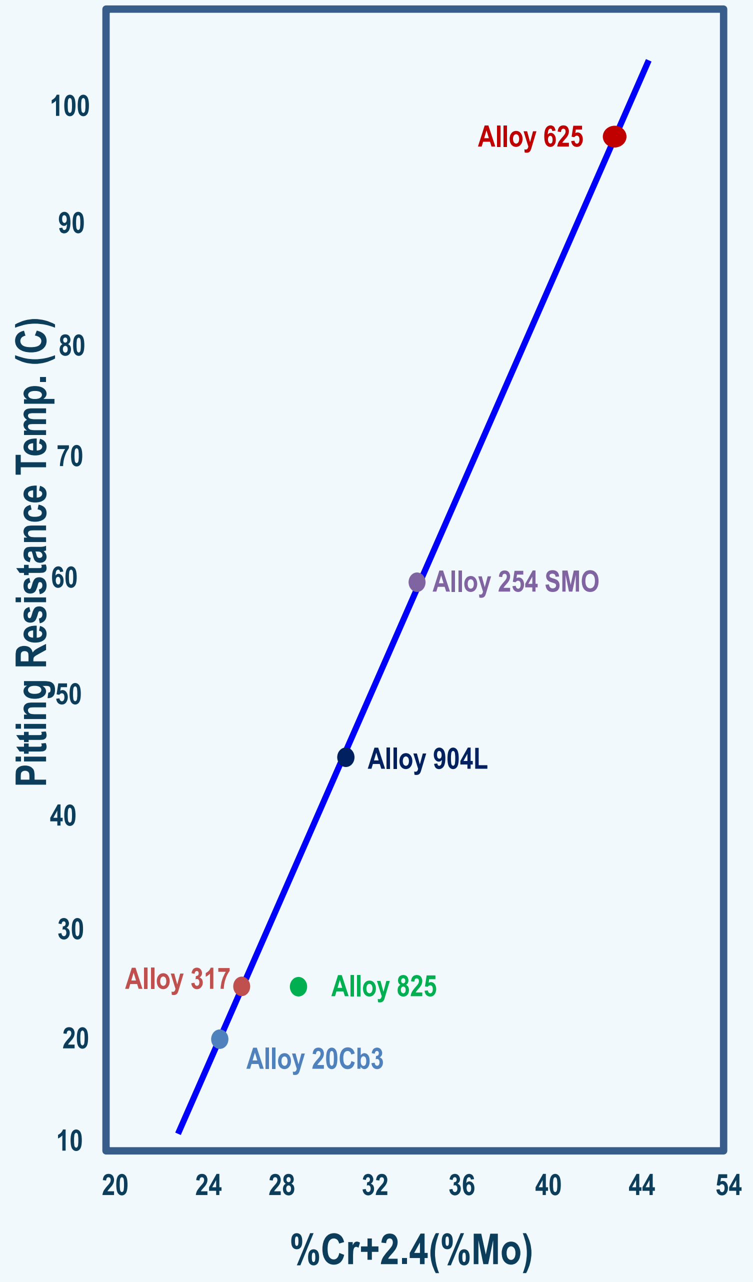
Leak from deep pits

Pitting and Chloride SCC Background

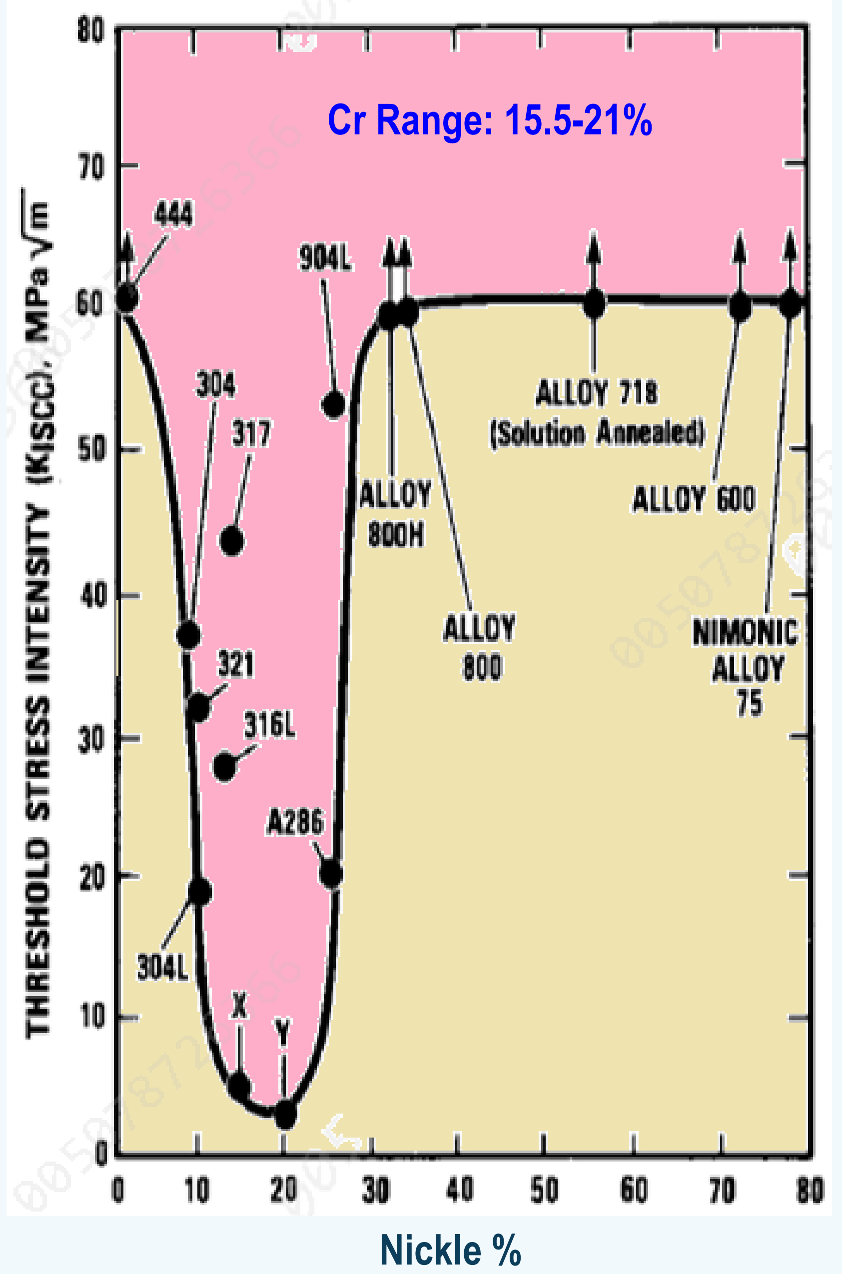




Copson Curve - Effect of Ni content on SCC susceptibility of SS wires containing 18-20% Cr in Mg Cl solution boiling at 154 C



Critical temperature for pitting in 4% NaCl + 1%Fe2 (SO4)3 + 0.01 M HCL versus composition for Fe-Ni-Cr-Mo alloys



Effect of Ni content on the SC threshold stress intensity of various alloys in an aerated aqueous 22% NaCl solution at 105 °C

Reference:

- Material Selection handbook, ASM
- Stress Corrosion Cracking, ASM
- High performance alloys for resistance to Aqueous Corrosion, Special Metals

- High Ni contents (about 43%) would be required for resistance to chloride SCC. (Copson curve)
- Cr and Mo has a very good relationship to enhance critical pitting temperature in a salt solution.

Pitting and Chloride SCC Background

Resistance to pitting and crevice corrosion can be, to some extent, measured using comparison factors.

All are used to rank the relative resistance of alloys to the forms of localized corrosion.

- Critical pitting temperatures **(CPT)**
- critical crevice temperatures **(CCT)**
- Pitting Resistance Equivalency Numbers **(PREN)**

The CPT for an alloy is determined by conducting a test in accordance with ASTM Standard Test Method G-48, Method C. CPT may be estimated by:

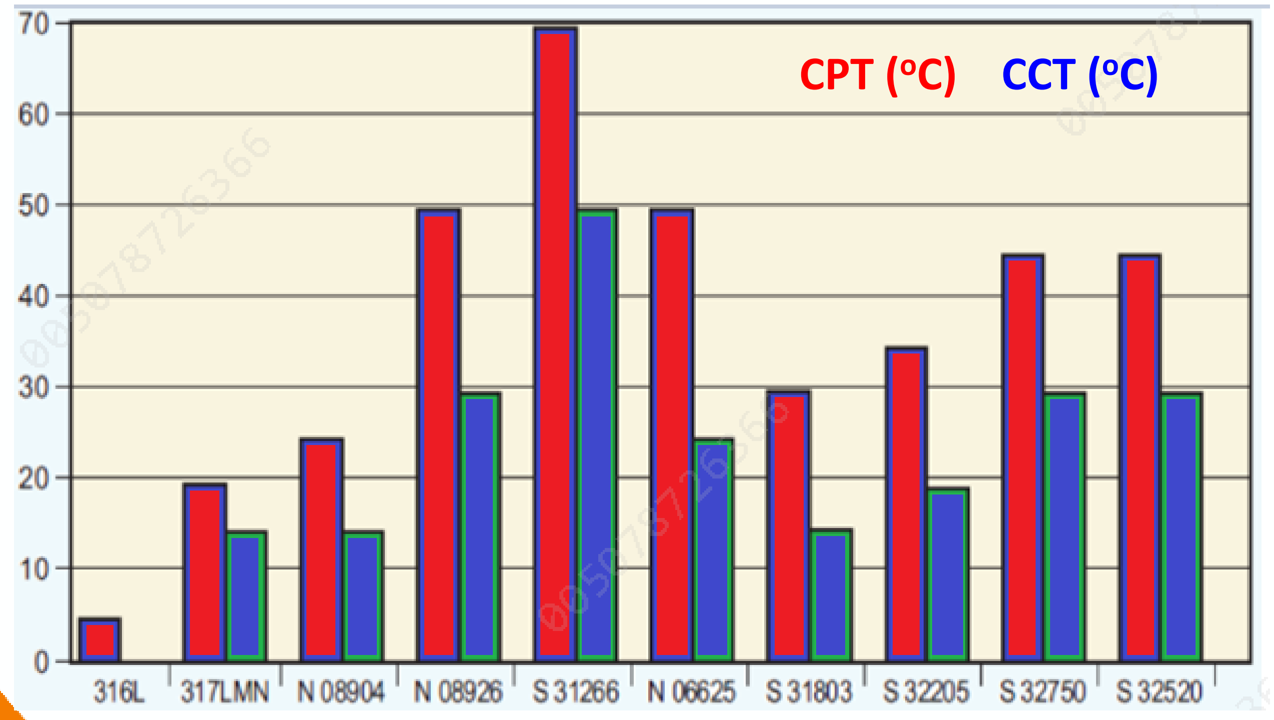
CPT (deg. C) = 1.5 (%Cr) + 7.6 (%Mo) + 4.9 (%Nb) +8.6 (%W) -36.2

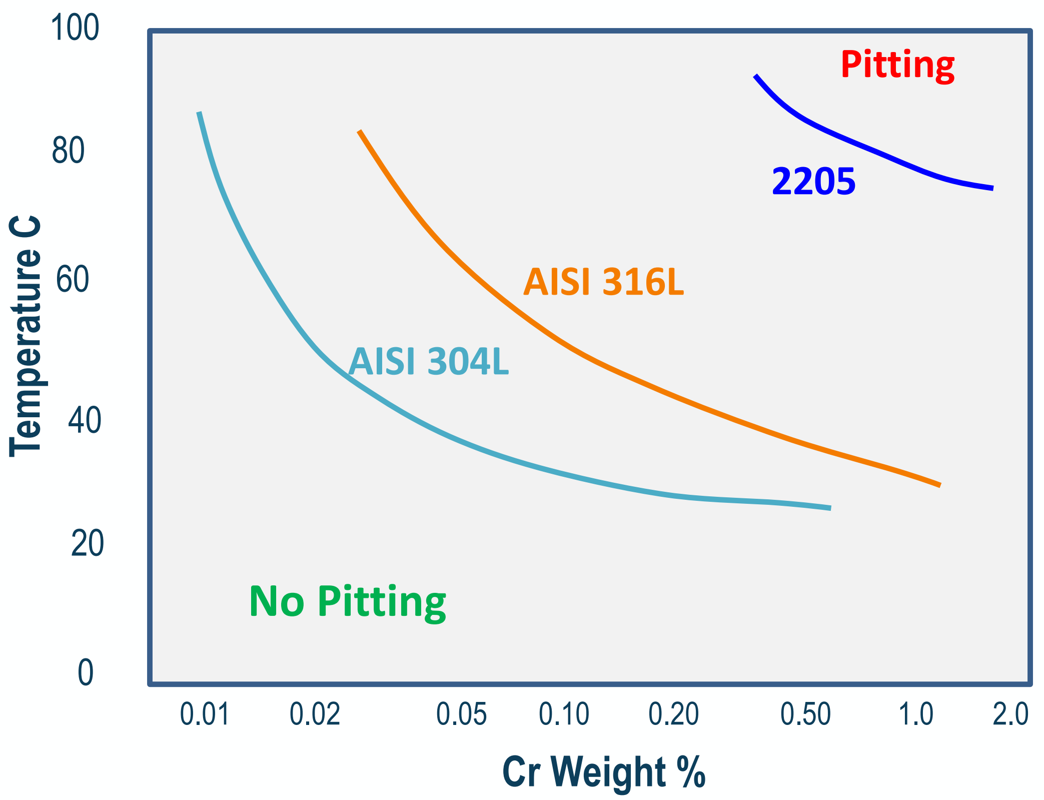
The CCT for an alloy is determined by conducting a test in accordance with ASTM Standard Test Method G-48, Method D. CCT may be estimated by:

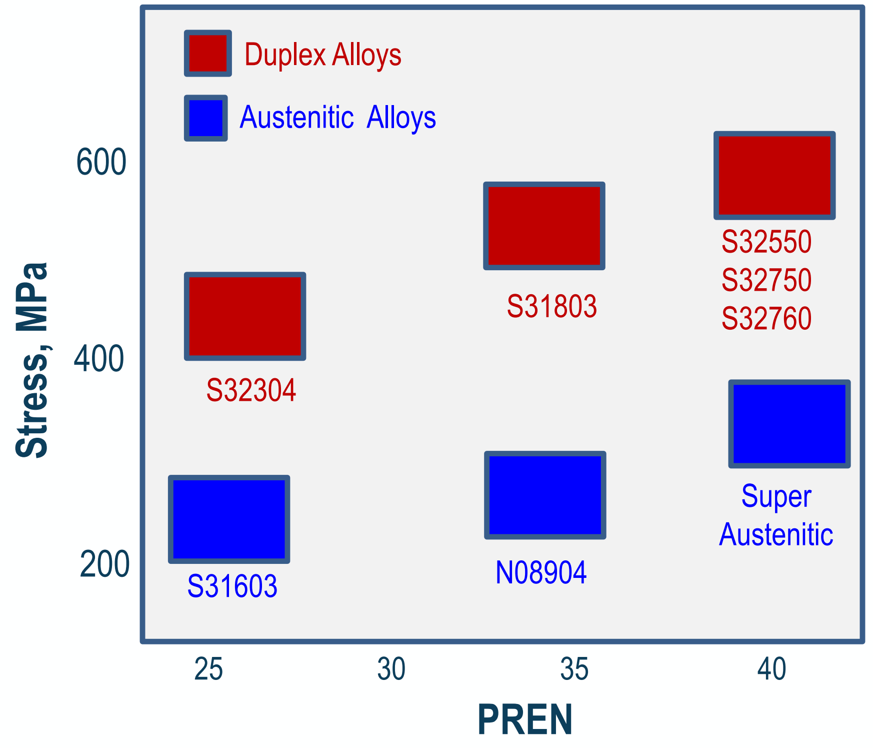
CCT (deg. C) = 3.2 (%Cr) + 7.6 (%Mo) + 10.5 (%N) +81

Pitting resistance equivalency number (PREN) – The corrosion resistance of pit-resistant stainless steels is largely determined by their composition. The PREN typically used to compare stainless steels is determined by a calculation based on their contents of chromium, molybdenum and Nitrogen:

PREN= %Cr + 3.3 (% Mo + 0.5 × % W) + 16 (%N)

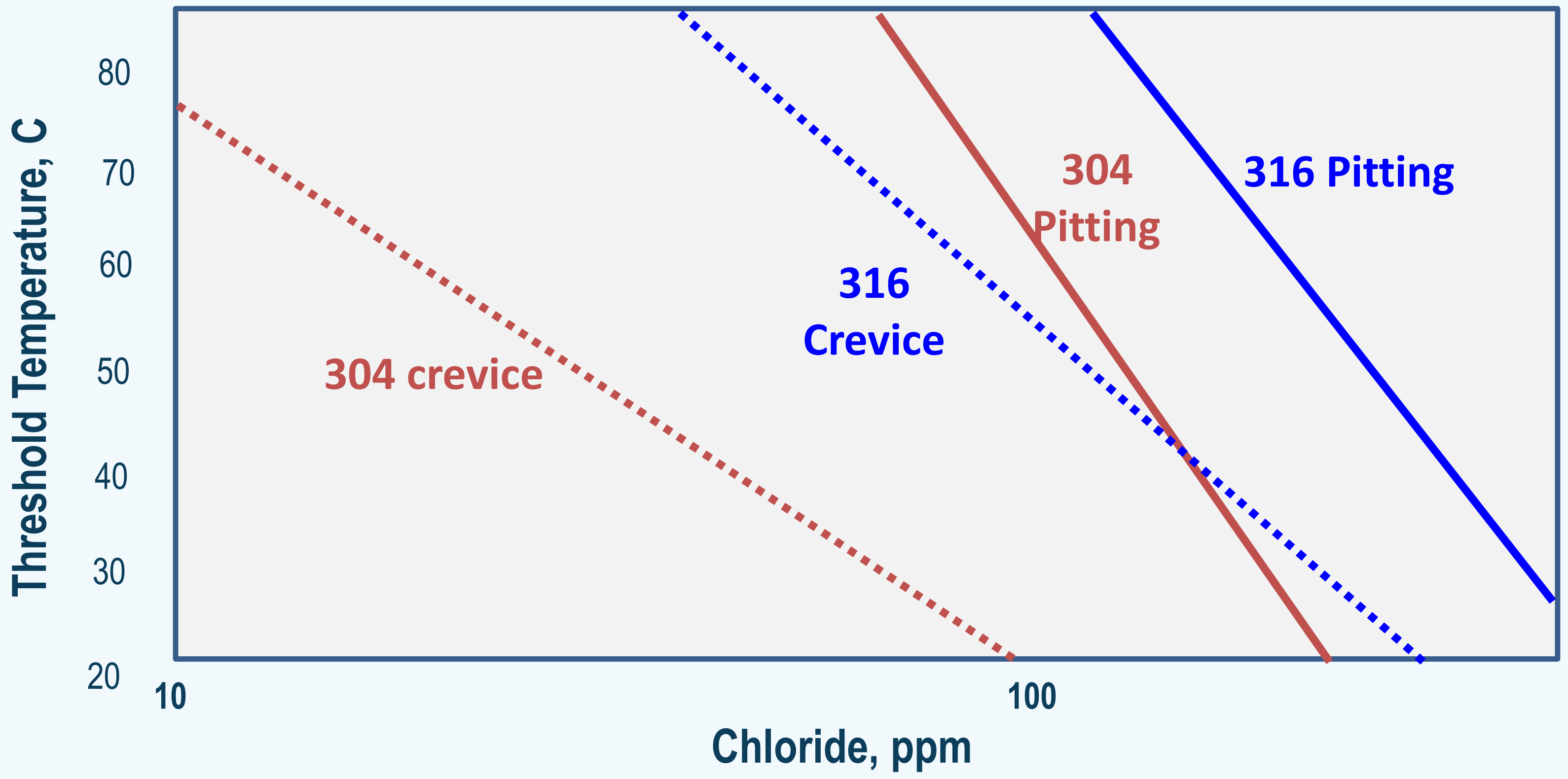




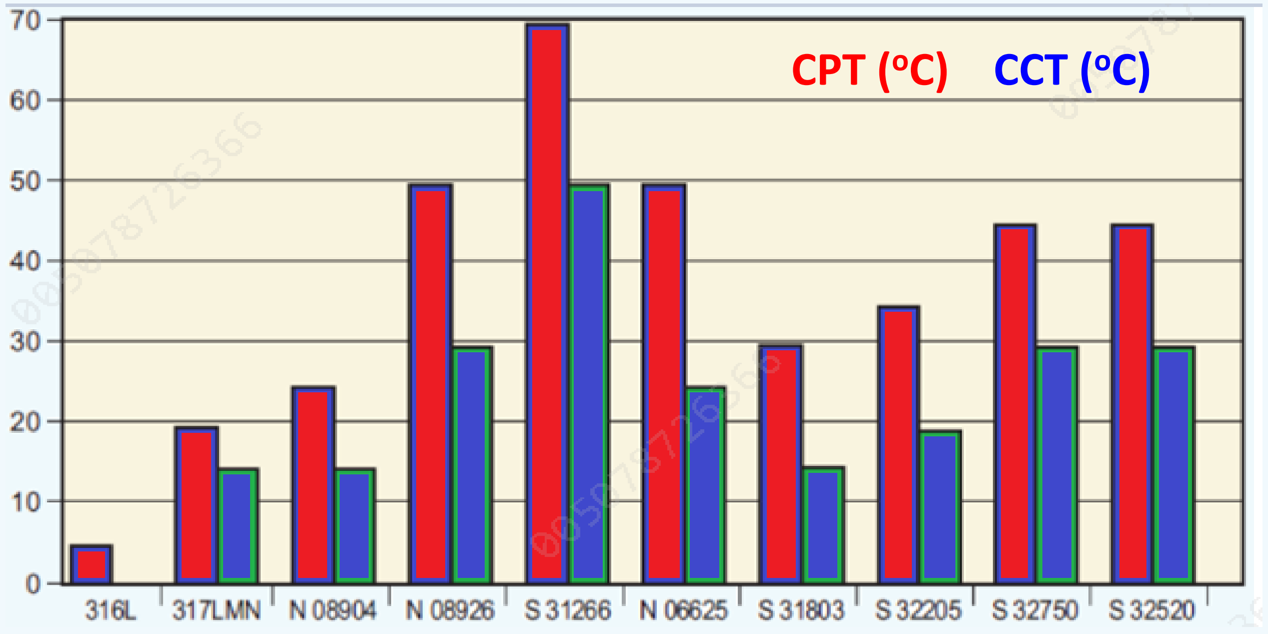


Comparison of the Proof Stress and Pitting Resistance of Duplex and Austenitic SS

Impact of Crevice on Austenitic and DSS Corrosion Resistance



Risk of pitting and crevice corrosion of standard grades of stainless steel in oxygen saturated waters with varying chloride levels

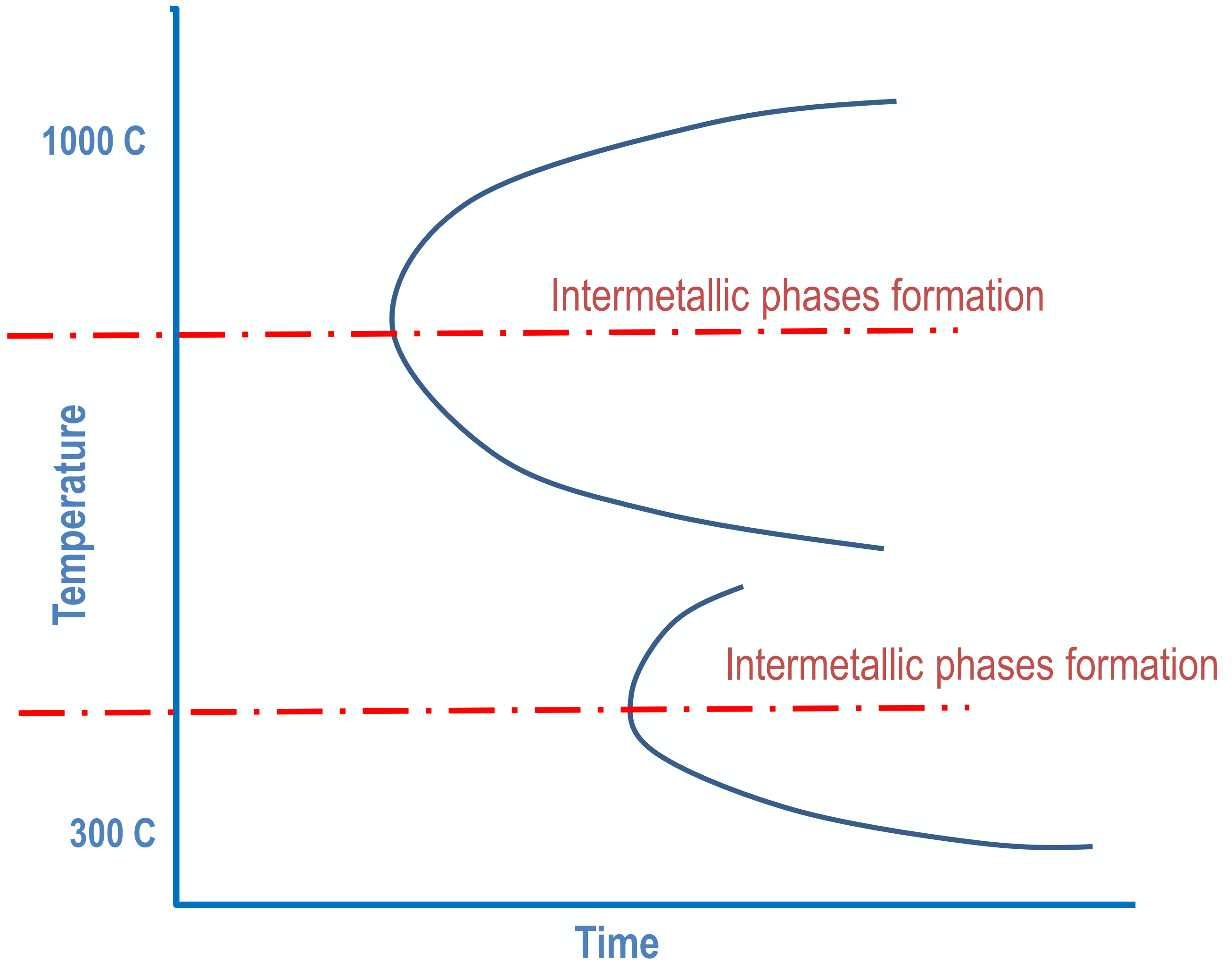


Reference: - API 938 C, Use of DSS in oil refinery Industry
- ASM Handbook, Volume 13 B

- Stainless steels are more likely to be attacked at crevices resulting from equipment design or attachment of barnacles.
- Pitting resistance and corrosion resistance are significantly dropped in corrosion resistance
- In chloride environments, the possibility of crevice corrosion must be considered when crevices are present because of equipment design or the formation of adherent deposits.

Duplex Stainless Steel Embrittlement

ASME Code Maximum Allowable Temperate for Different Grades of DSS		
Grade	**ASME Sec. VIII div.1 °C (°F)**	**ASME B31.3 °C (°F)**
S32304	**316 (600)**	**316 (600)**
S32550	**260 (500)**	**Not listed**
S31803	**316 (600)**	**316 (600)**
S32750	**316 (600)**	**316 (600)**



Maximum operating temperatures are limited by the susceptibility of the Ferritic phase to 475 °C (885 °F) embrittlement.

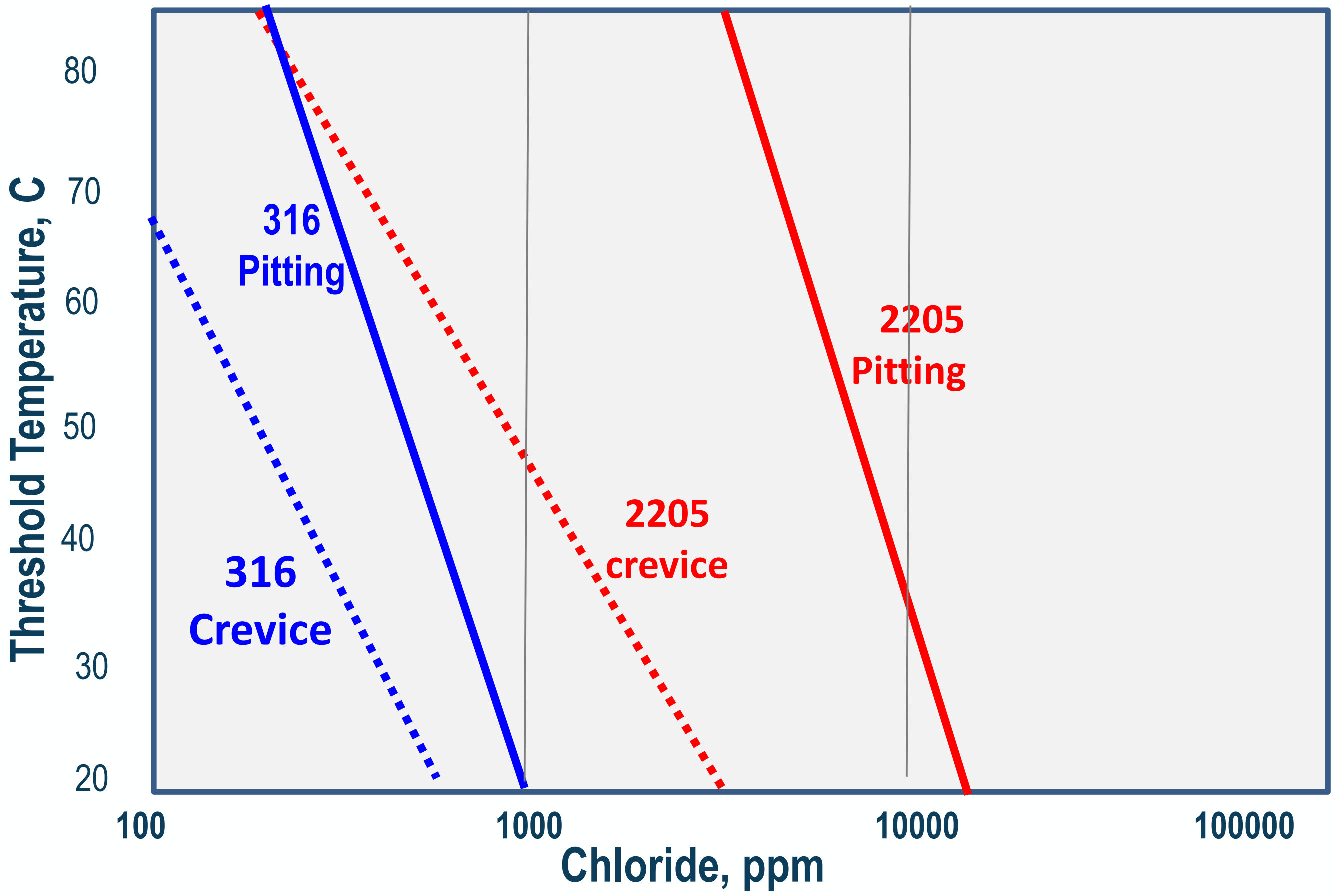
Most Codes applicable to refinery equipment and piping limit the various DSS grades to between 260 °C to 340 °C (500 °F to 650 °F)

The formation of harmful intermetallic phases results from excessively high heat inputs excessive cumulative time at high temperatures. They are extremely detrimental to impact toughness and corrosion resistance.

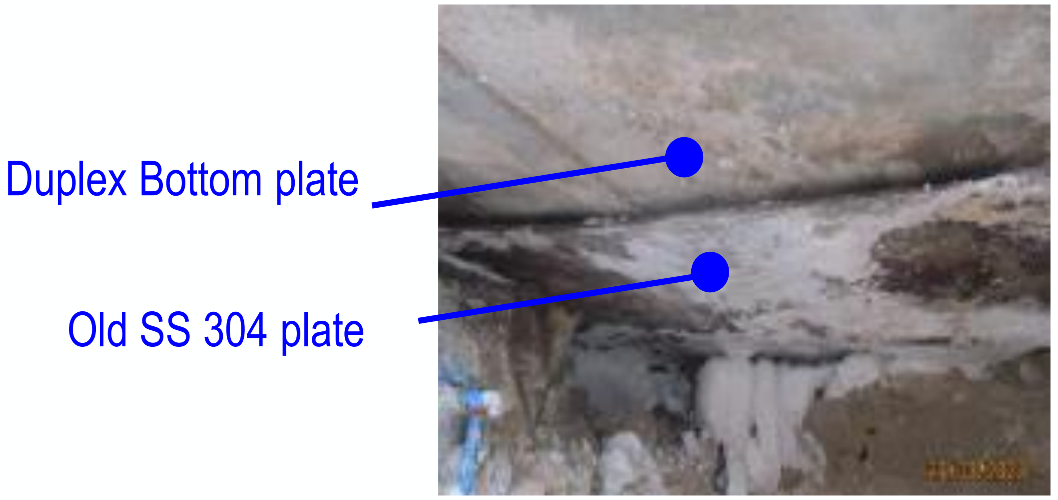
Reference: API 938 C, Use of DSS in oil refinery Industry

Analysis

- The bottom plate is attacked by corrosion from the bottom side
- The area of the annular plate where the old SS 304 plate was removed in 2012 has no signs of corrosion
- Removed part of the old SS 304 during the patch plate repair showed sever corrosion attack allowing the sand and underneath moisture to divert into the gap between DSS and SS 304 plate
- Sand was not replaced and analysis done in 2008 showed Cl content of 700 ppm
- DSS can be subjected to chloride attack in case of Crevice and under high concentration of chloride and high temperature conditions. the parameters are allocated on the enclosed curve
- While there is no crevice, even at the high temperature (90 C) and high chloride content, pitting attack for DSS is not foreseen. Please see the solid line for 2205 in the enclosed graph. In addition to the findings where the annular plates (away from the crevice area) is not corroded.
- Reducing the chloride content to level lower than 100 ppm should protect DSS from being vulnerable to pitting corrosion even in crevice conditions (taking in consideration that actual chloride content can be much higher than measured values outside the crevice).



Risk of pitting (solid line) and crevice corrosion (dashed line) of higher alloyed stainless steels in oxygen saturated waters with varying chloride levels. Dotted line is a plate heat exchanger.

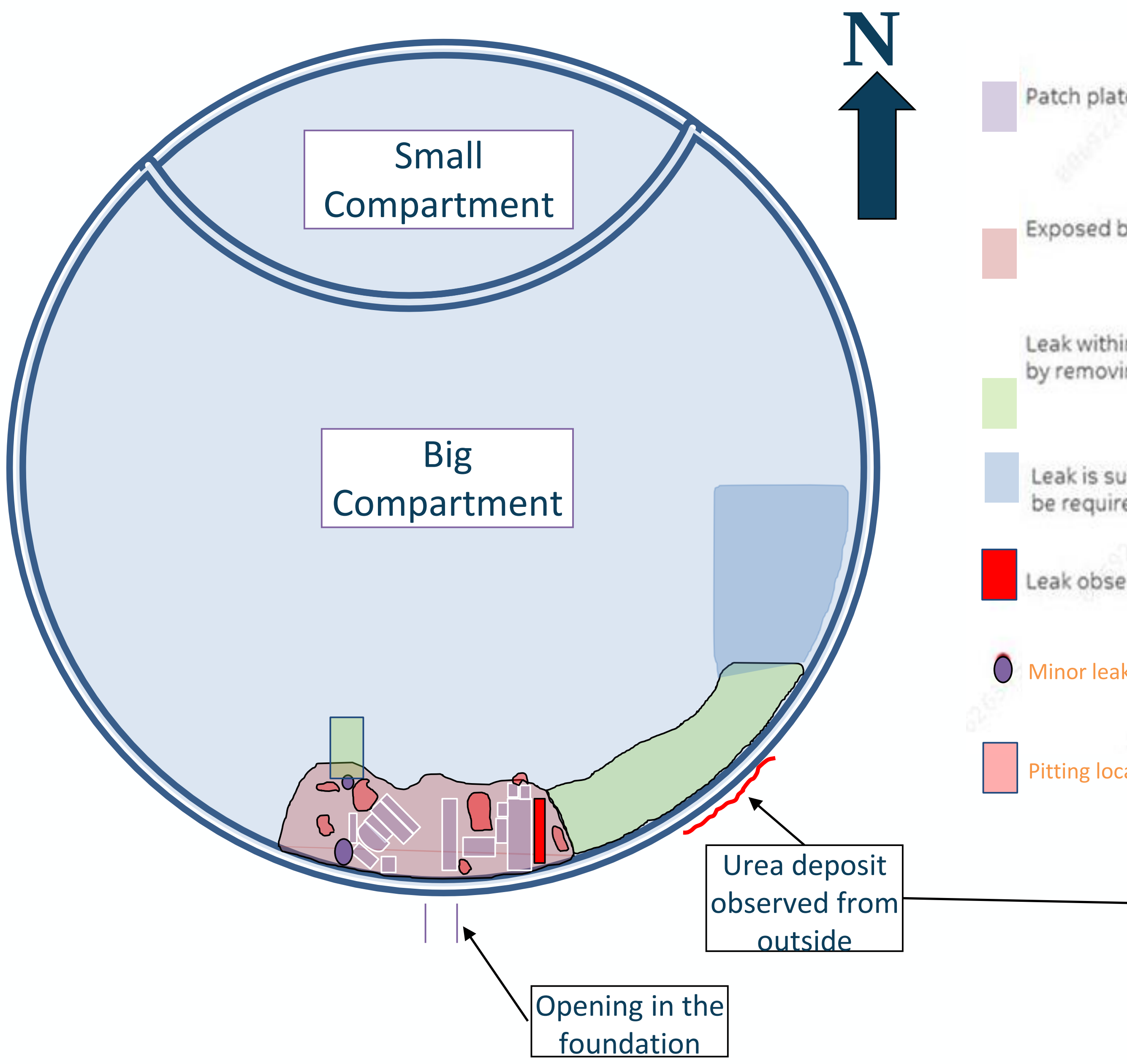


After Excavation, no corrosion away from crevice area

Temporary Repair of DSS Bottom Plate

Try to draw by schematic drawings

- Risk assessment and JSA
- Reduce tank level to the minimum
- Excavation at the leak location at level higher than the liner level to ensure marinating protection of soil and environment impact
- Sand sample taken for analysis showed high Cl content
- Old bottom plate (SS 304) cut and removed (severely corroded)
- Cleaning and DPT for the DSS plate
- Measurement and mapping of the pitting area
- Welding of patch plates to the bottom plates
- DPT for the patch plates' welds
- Backfilling by clean sand
- Building back the foundation ring
- Maintain the tank level to the lower level as practical by operation
- Maintain monitoring possible leaks for the bottom plate through the drain nozzles



Replacement of DSS Bottom Plate

- Replace full bottom plate using duplex stainless steel plate with same specifications, dimensions and thickness of the existing bottom plate
- Detailed method of statement for the installation and ITP plan shall be developed and approved by SAN
- Remove old duplex and SS 304 bottom plates totally and scarp it
- Remove the existing sand and new clean sand with indicted specifications below shall be used
- Sand shall be lap tested to ensure quality prior backfilling
- Install Release Prevention Barrier (RPB) including HDPE liner as per configuration recommended in API 650

Property	Recommended Value
Resistivity (ohm-cm)	**10,000 – 30,000**
Chlorides (ppm)	**< 10**

API Std. 653 / 650 / 651 / 575: Captured Guidelines

- Suitable noncorrosive material cushion such as sand, gravel, or concrete shall be used between the old bottom and the new bottom.
- Voids in the foundation below the old bottom shall be filled with sand, crushed limestone, grout, or concrete.
- Installation of a new tank bottom, after removal of the existing tank bottom, shall meet all requirements of API 650.

API Std. 653

Tanks with CP installed under bottom plate

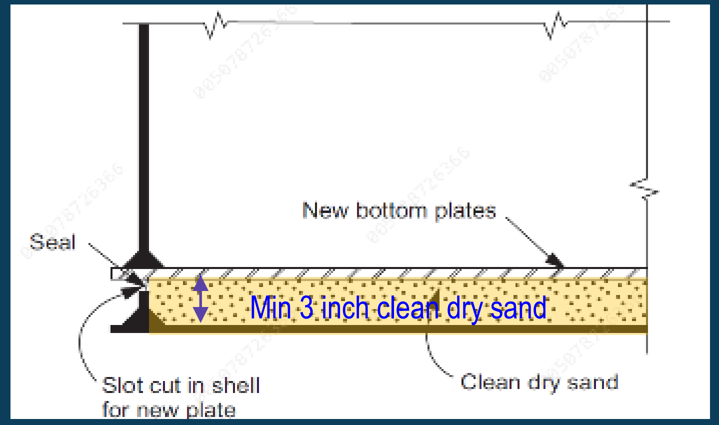
- Consideration shall be given to removal of the entire bottom and unused dead shell to prevent shielding of CP current to the new bottom.
- Removal of the old bottom is also important in preventing galvanic corrosion (refer to API 651).
- Consideration shall be given to installing under-bottom leak detection at this time (such as an RPB) to contain and channel any bottom leak to a location where it can readily be observed from outside of the tank

API Std. 653

- Chlorides will affect the resistivity of soil, and act as a depolarizing agent which will increase the current requirement for CP of steel.
- Pitting corrosion on steel can begin at chloride levels of 10 ppm
- here is currently no industry consensus on an acceptable range for chloride levels, therefore the tank owner/operator should specify the acceptable chloride level.

API RP 651

When new tank bottom plate installed through slots, perimeter layer of clean sand fill, metal grating, or a concrete pad should be installed under and at least 3 in. (76 mm) beyond the projection of the new bottom so that the shell is supported on the foundation through the new bottom



API RP 575

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THANK YOU

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