

# Understanding Corrosion Chapter 4; Tea Staining

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12 March 2026

# Agenda

Introduction

What is Tea Staining?

What Causes Tea Staining?

Stainless Steel Grade Selection

Surface Roughness

Product Drainage

Forming & Welding

Summary



# Introduction

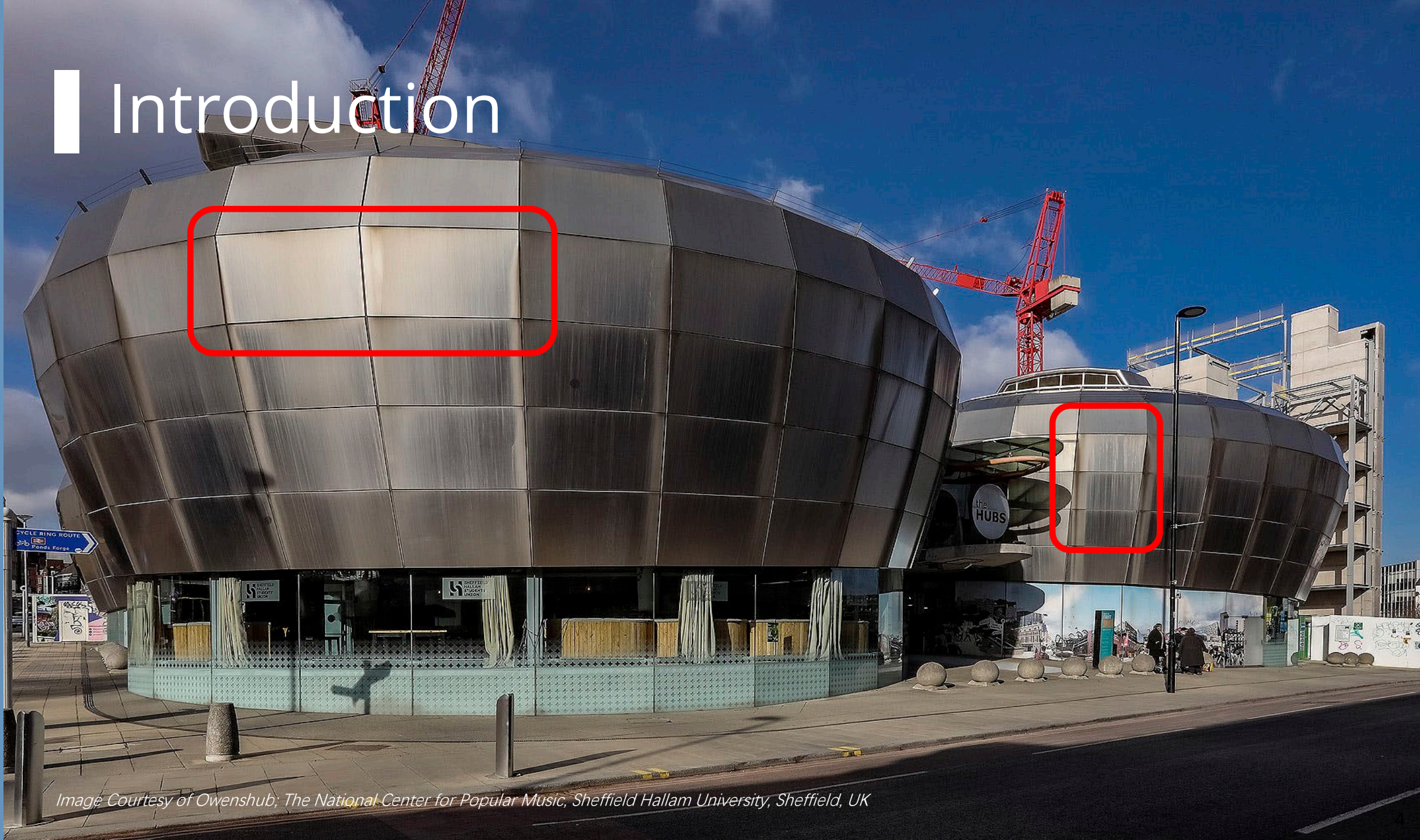


Picture courtesy of tandg-promech.co.uk

When selected and used correctly, Stainless Steels;

- Offer an **enduring reputation** for their timeless **visual appeal** and
- Deliver **material resilience** and **structural integrity**
- Removal of tea staining is often straightforward and is covered in the Appendices

# Introduction



# What is Tea Staining?

**A discoloration of the surface of Stainless Steel products**

- Corrosion, but not serious
- Purely cosmetic, unless it is not removed
- Generally, does not affect the structural integrity or the lifetime of the material
- Often associated with experiences observed near coastlines
- Unsightly and often impacts negatively on societal attractiveness
- Negatively impacts on the credibility of Stainless Steels

*Data Sources; ASSDA 2025, worldstainless 2026*

# What is Tea Staining?

**A relatively common unsightly surface occurrence**

- Gives the impression of a corroding material
- Often found
  - in coastal locations
  - where high-Chloride water is used for 'washing down' surfaces
- Tends to follow the 'grain' of any material surface finish

*Data Sources; ASSDA 2025, worldstainless 2026*



*Image courtesy of aestainlessdirect.com.au*

# What Causes Tea Staining?

# What Causes Tea Staining?



Chloride corrosion of Stainless Steels

Chlorine and harsh chemicals used on Stainless Steel surfaces

Inappropriate Stainless Steel grade selection for the operating environment

Stagnant water (pooling) .... resulting from poor drainage / design

Rough Stainless Steel surfaces (generally  $>0.4$  microns Ra)

Lack of processing and materials selection knowledge

Contamination from contact with Carbon Steels and associated products

# What Causes Tea Staining?



*Image courtesy of Anzor*

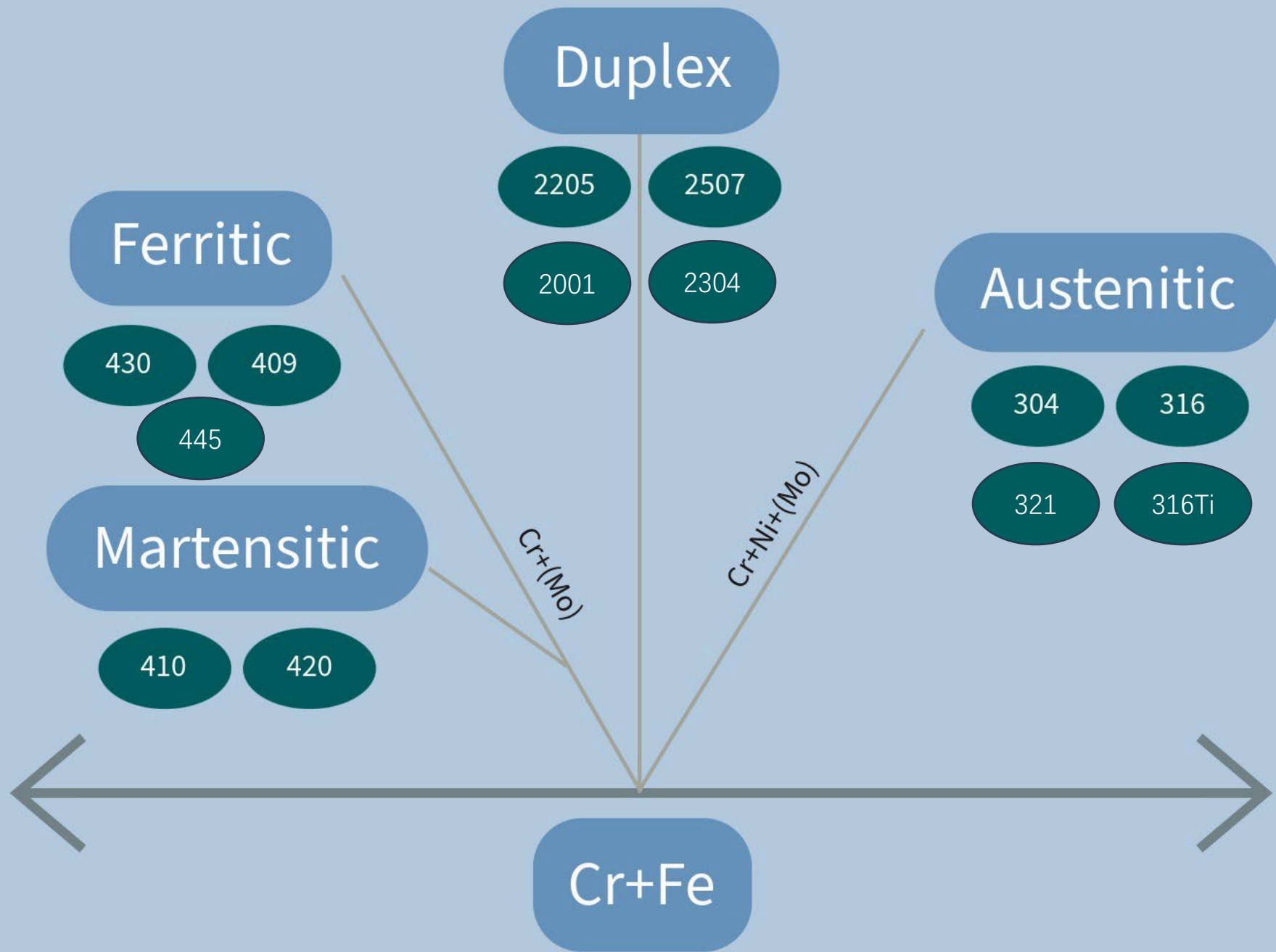


*Image courtesy of Jo Claes*



*Image courtesy of Tim Collins*

# Grade Selection



# Grade Selection



Selecting the correct grade for the operating environment is important



Initial guidance exists through key specifications

# Grade Selection; Chloride Exposure



Chlorides in an operating environment can lead to pitting corrosion



Coastal environments are a clear case in point



Chlorides clearly exist in sea water, but also in the local atmosphere



In windy locations, Chlorides can travel 20+km inland



Tea staining on non-immersed products is an early pitting corrosion indication

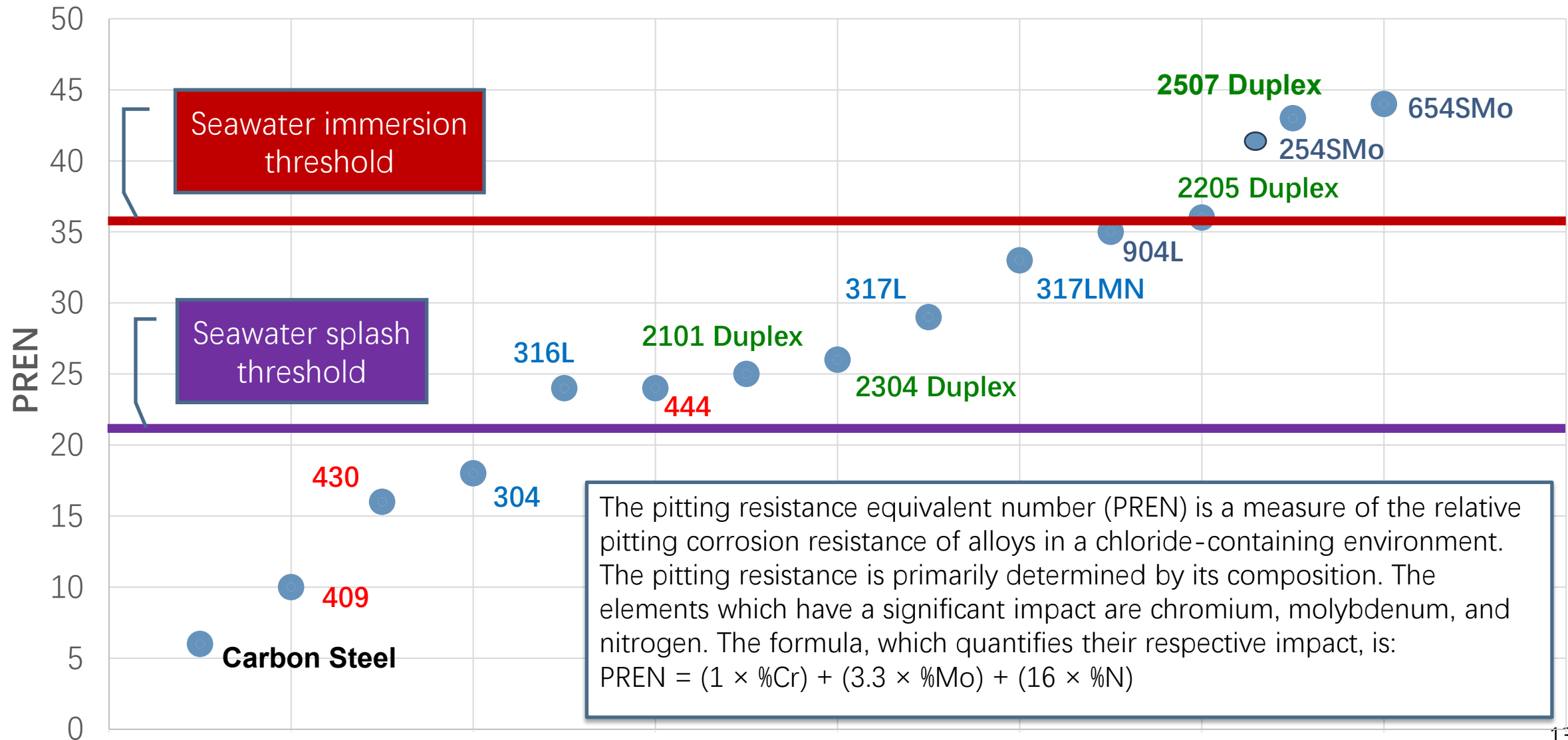
Resulting from Chlorides in the atmosphere and carried by winds



Mo-bearing Stainless Steels will provide appropriate corrosion resistance

However careful Stainless Steel grade selection is critical

# Pitting Corrosion & PREN



# High PREN Grades

The Stainless cladding here is made from grade 254SMO

19.5%Cr, 17.5%Ni, 6.0%Mo, 0.5%Cu, 0.2%N

Whilst what is shown is not exactly tea staining and the product is sound ....

.... it shows how the impact of Chlorides affects the surface appearance of even highly alloyed Stainless Steel grades

**Key Message;** Never underestimate the impact of Chlorides



Image courtesy of Nippon Yakin Kogyo  
2026

# Is Considering Chloride Exposure Sufficient?



Exposure to Chlorides including atmospheric and wind-borne Chlorides

Exposure to Sulphur Dioxide including wind-borne  $\text{SO}_2$



The ability to employ cleaning regimes or benefit from natural cleaning (eg; rain washing)



# Selecting Appropriate Stainless Steels for Structural Applications

Good tools exist for selecting appropriate Stainless Steel grades for use within structural applications

eg;

EN 1993-1-4 2015-10 / Eurocode 3  
Covers both structural products and non-structural products

The essence is about selecting the correct grade type

ie; The process offers up a selection of grades that will perform well within the defined operating environment

# Selecting Appropriate Stainless Steels for Structural Applications

- Operating environment is assessed by a Corrosion Resistance Factor (CRF)
- 3 components exist ...  $CRF = F1 + F2 + F3$ 
  - ✓ F1 rates the risk of exposure to Chlorides arising from salt water / deicing salts and airborne Chlorides
  - ✓ F2 rates the risk of exposure to Sulphur dioxide
  - ✓ F3 rates the cleaning regime or exposure to washing by rain
- A table indicates for a given CRF the corresponding material Corrosion Resistance Class (CRC); Stainless steel grades are placed in CRCs numbered I to V

# CRF F1; Risk from Exposure to Cl<sup>-</sup> ions

| Score | Environment                       | Examples                                                                                                                | M (dist from sea)               | S (dist from de-icing) |
|-------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------|------------------------|
| 1     | Internally controlled environment | Cl <sup>-</sup> ion free environment                                                                                    | NA                              | NA                     |
| 0     | Low risk of exposure              | External environment a significant distance away from Cl <sup>-</sup> ion sources                                       | >10km                           | >0.1km                 |
| -3    | Medium risk of exposure           | External environment a reasonable distance away from Cl <sup>-</sup> ion sources                                        | 1km-10km                        | 0.01km-0.1km           |
| -7    | High risk of exposure             | External environment a short distance away from Cl <sup>-</sup> ion sources <i>(including windborne Cl<sup>-</sup>)</i> | 0.25km-1km<br><i>(&lt;25km)</i> | <0.01km                |
| -10   | Very high risk of exposure        | eg; Tunnels where de-icing salts are used or are carried in the tunnels                                                 | NA                              |                        |
| -10   | Very high risk of exposure        | North Sea DE coast, all Baltic coastal areas, Irish sea coast                                                           | <0.25km                         |                        |
| -15   | Extremely high risk of exposure   | Eastern Atlantic coast of EU and all coastal areas of BE, DK, FR, NL, NO, IRE, SE & UK                                  | <0.25km                         |                        |

# CRF F2; Risk from Exposure to SO<sub>2</sub>

| Score | Exposure Description    | Examples                                                  | Average Deposition                 |
|-------|-------------------------|-----------------------------------------------------------|------------------------------------|
| 0     | Low risk of exposure    | European coastal environments                             | <10 micrograms / m <sup>3</sup>    |
| -5    | Medium risk of exposure | Inland non-industrial locations                           | 10-90 micrograms / m <sup>3</sup>  |
| -10   | High risk of exposure   | Heavily concentrated industrial locations<br>Road tunnels | 90-250 micrograms / m <sup>3</sup> |

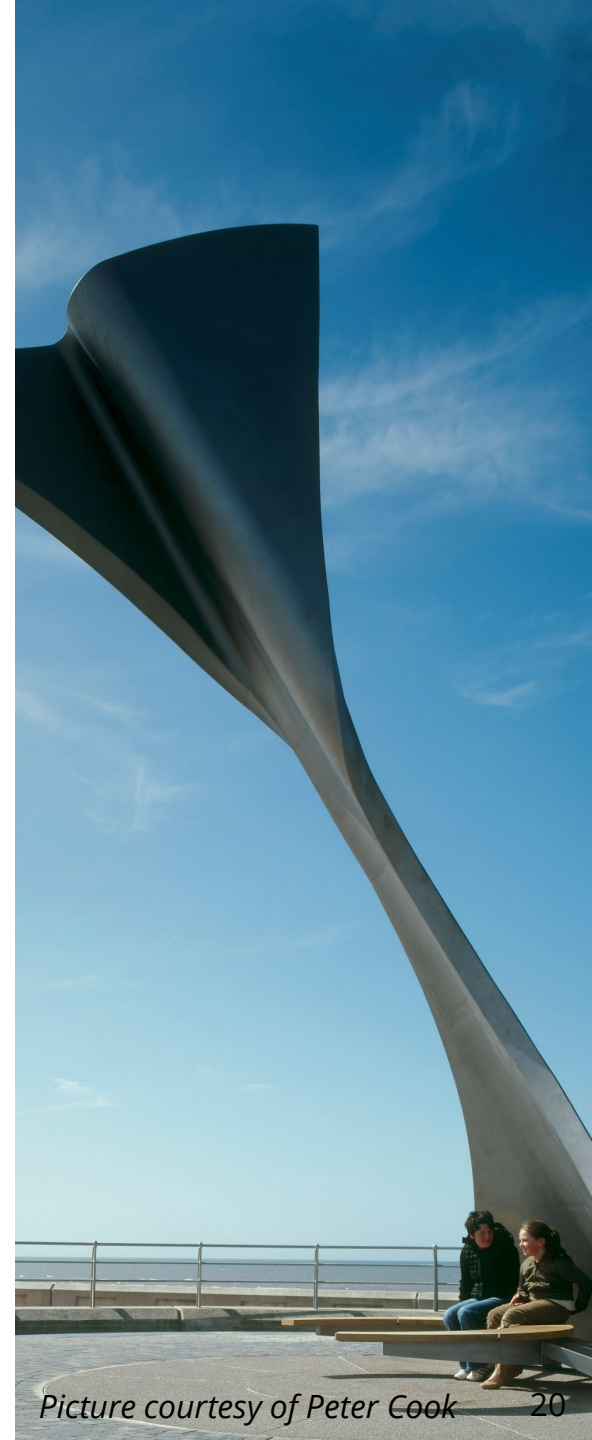
# CRF F3; Impact of a Cleaning Regime or Exposure to Natural Rain Washing

| Score | Cleaning / Washing Regime                                   |
|-------|-------------------------------------------------------------|
| 0     | Fully exposed to regular natural washing by rain            |
| -2    | Specified regular cleaning regime in place                  |
| -7    | No washing by rain and no specified regular cleaning regime |

In order to consider F3 appropriately natural washing of the whole installation must be considered

The image shows a coastal stainless wind-break structure with integral seating

Consideration of natural or planned washing on both sides of the structure is vital



# CRC & Suitable Grades

| CRF        | CRC | Ferritic Grades          | Austenitic Grades                                            | Duplex Grades                     |
|------------|-----|--------------------------|--------------------------------------------------------------|-----------------------------------|
| 1          | I   | 1.4003 / 1.4016 / 1.4512 |                                                              |                                   |
| 0 to -7    | II  |                          | 1.4301 / 1.4307 / 1.4311 / 1.4306 / 1.4541 / 1.4318 / 1.4567 | 1.4482                            |
| -8 to -15  | III | 445J2                    | 1.4401 / 1.4404 / 1.4435 / 1.4571 / 1.4429 / 1.4432 / 1.4578 | 1.4062 / 1.4162 / 1.4362 / 1.4662 |
| -16 to -20 | IV  |                          | 1.4439 / 1.4539                                              | 1.4462                            |
| < -20      | V   |                          | 1.4565 / 1.4529 / 1.4547                                     | 1.4410 / 1.4501 / 1.4507          |

# Let's Consider an Airport Roof



# CRF F1; Risk from Exposure to Cl<sup>-</sup> ions

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| Score | Cleaning / Washing Regime                                   |
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CRF = -7 + 0 + (-7) = -14  
which aligns with a  
CRC of III

# CRC & Suitable Grades

| CRF        | CRC | Ferritic Grades          | Austenitic Grades                                            | Duplex Grades                     |
|------------|-----|--------------------------|--------------------------------------------------------------|-----------------------------------|
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Data Source; EN 1993-1-4 2015-10 / Eurocode 3, Annex A

# Having Selected the Correct Grade ... ... What's Missing?



1. The defined specification for product surface roughness

All specified Stainless Steel products specified must be considered



2. Has drainage been correctly considered?

When the final product has been designed and created



3. Processes that can cause local weakening of inherent corrosion resistance

ie; Welding and forming processes

# Surface Roughness



# Surface Roughness

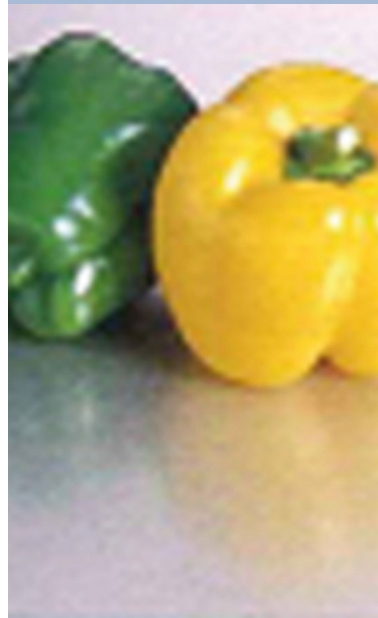
**2D;** A dull, cold rolled finish produced by cold rolling to the specified thickness



**BA;** A finish produced by performing bright annealing in an inert atmosphere after cold rolling



**No.6;** A soft satin finish having lower reflectivity than brushed finish



**2B;** A bright cold rolled finish produced in the same way as a 2D finish with the annealed and descaled coils receiving a final cold rolled pass on polished rolls



**No.3;** A semi-polished surface, typically used for kitchenware such as utensils and countertops



*Pictures courtesy of POSCO*

# Surface Roughness

- Surface roughness of Stainless Steels
  - ✓ Often not considered thoroughly enough
  - ✓ Generally considered as 'smooth materials' (based on common daily usage of stainless steels at home)
- Many different surface finishes are available
- The roughness of the surface in use has a significant impact on tea staining
- How roughness is specified is therefore important

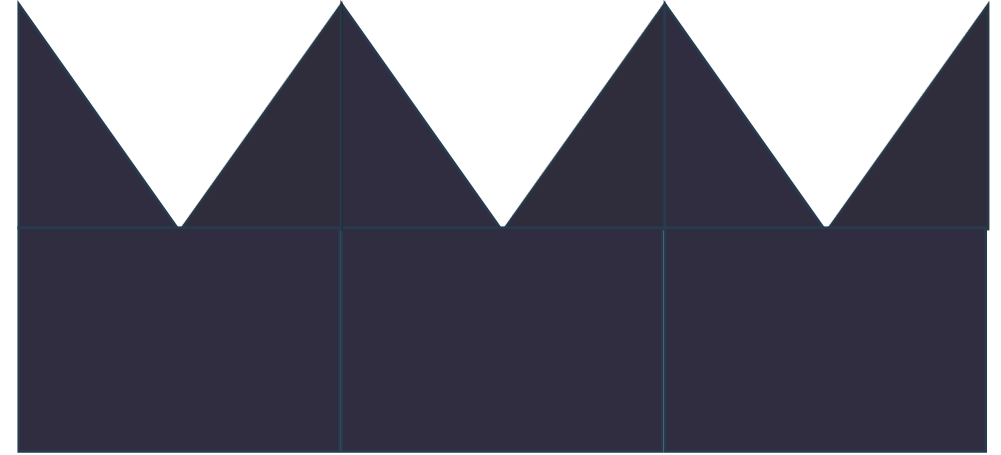


# Product Surface Roughness

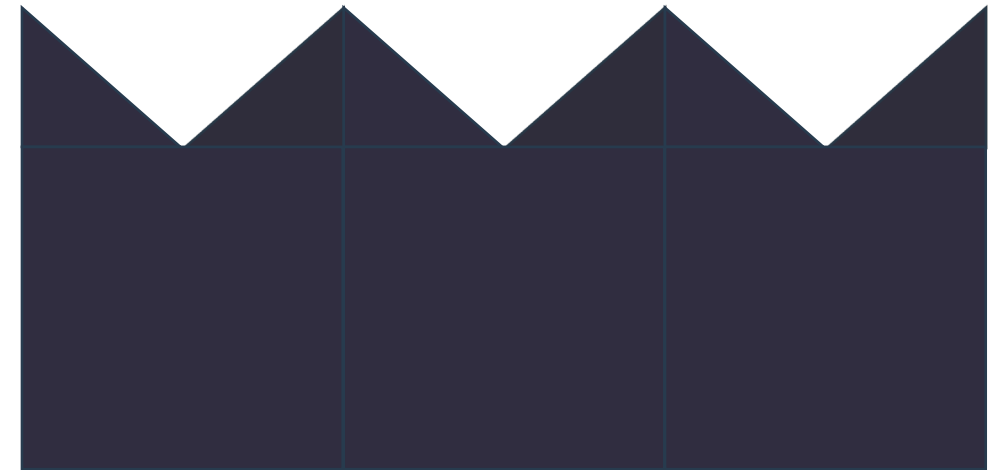
Consider two different material surface roughness conditions

What happens over time when the two surfaces are in a coastal or Chloride-containing location?

Rough Surface

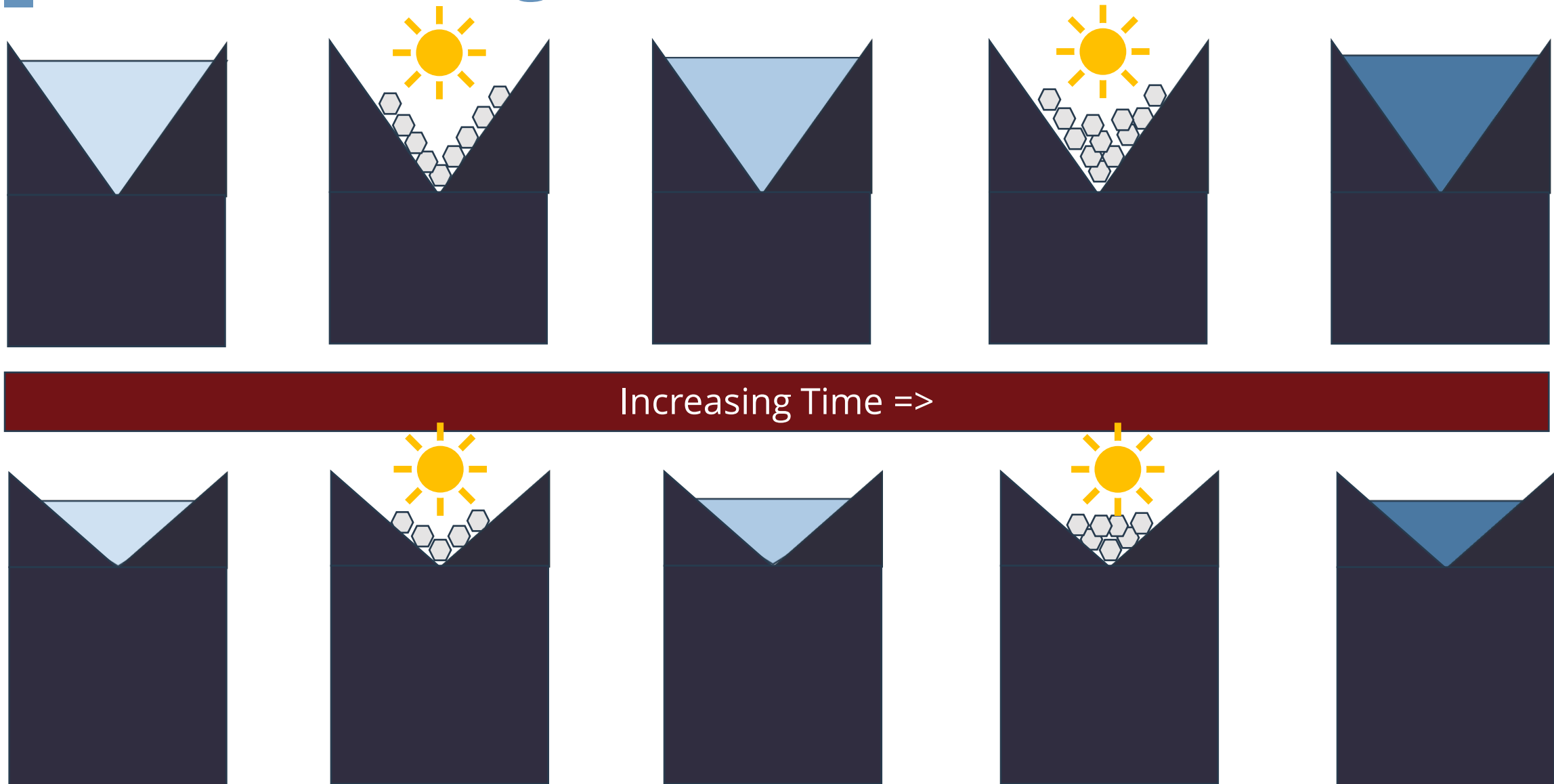


Less Rough Surface



The material surface roughness profiles above are simplified and exaggerated

# Surface Roughness & Chlorides



# Surface Roughness

- 'Wetting - evaporation cycles' increase the Cl<sup>-</sup> concentrations in the grooves of rough surfaces
  - Wet high-Chloride concentrations will initiate tea staining corrosion
- Smoother finishes are better in terms of their resistance to tea staining
  - There is always a roughness – cost trade-off
  - A maximum roughness 0.4 microns R<sub>a</sub> gives very satisfactory outcomes
  - At reasonable cost
- Regular washing with clean fresh water and/or rain offers a beneficial effect

Key Message; Trying to lower up-front material costs is a folly ...  
additional cleaning / maintenance costs will arrive quickly !!

# Surface Roughness

## Solution

- Specify and insist on a smooth and clean surface finish
- A finish alone is inadequate if you don't indicate the required roughness
  - eg; No.4 brushed finish use abrasives in the 180 – 400 grit range
  - If you don't specify 0.4 microns Ra maximum expect disappointment



*Image courtesy of; ArtSteelMatters, May 2025*

# Drainage



# Drainage

- Items and structures made using stainless steels must not retain water
- Drainage channels must be well-designed and well-constructed
- Horizontal surfaces must be able to resist potential damage such that water cannot then 'pool' on these surfaces
- The pooling of water will create the right conditions to allow a 'wetting-evaporation' cycle to operate

These situations create increasing Cl- concentration due to regular 'wetting - evaporation cycles'

# Drainage

- One potential weakness associated with drainage channels is the likelihood of **blockages**
- Blockages will result in '**pooled**' water and can be caused by
  - ✓ Known annual events like **leaf fall** in the Autumn months
  - ✓ **Littering** that is not routinely removed
  - ✓ **Dumped debris** from nearby building or maintenance activities
- Designers must take these likely events into account and/or ensure preventive solutions exist

# Fabrication & Welding Processes



*Images courtesy of Sheetstainlesssteel.com & weldguru.com*

# ■ Fabrication

# Fabrication

## Issues to Always Avoid

Carbon Steel contamination of Stainless during forming

Stainless contact with Carbon Steel grinding dust or swarf (ie; extremely small pieces of metal produced when a material is machine shaped or cut)

Stainless material placement on Carbon Steel beams or products

Handling Stainless Steel surfaces with Carbon Steel equipment eg; Uncoated lifting equipment, contaminated gloves

## Things to Always Ensure

Using protective temporary coatings during forming operations

- ✓ Polyethylene (PE) coatings with pressure-sensitive adhesives
- ✓ These coatings can also be used during material storage and transport activities

Fabrication workplaces for Stainless Steels should be uncontaminated

Handling equipment should be made from Stainless or correctly coated

Different gloves should be used when working with Stainless Steels

# Fabrication

Good



Clean fabrication shop. No Carbon Steel

Not Good



Clean fabrication shop. Carbon Steel supports !

# Welding



# Welding

## Advantages

Weld metal properties equal to that of annealed base material alloy

Strongest jointing system

Can be undertaken onsite or in a fabrication shop

Joins thin and thick material of any shape

Joins similar and dissimilar metals (usually carbon steel with proper choice of filler material)

Resists fatigue cycles and other cyclical loads well

Same corrosion and heat resistance as the annealed base material alloy

## Limitations

Not possible with all stainless steel grades

Requires qualified operators and procedures

May cause heat-induced material shape distortions

Post-weld finishing operations are required for a good-looking finish, eg; sand blasting

Loss of mechanical properties in case of cold-worked material

# Welding; Weld Spatter

- ✓ Sourced from molten weld metal droplets
- ✓ Occurs during the welding process - mainly with GMAW
- ✓ Damages passive layers
- ✓ Leads to tea-staining appearance
- ✓ **Need to remove the weld spatter, repolish the surface & re-passivate**



*Data source; The Welding Institute, UK & worldstainless 2025*

**GMAW = Gas metal arc welding**

# Welding; Weld Decay

- ✓ Occurs when weld heat affected zones are exposed to temperatures 510° – 790°C
- ✓ Leads to Chromium Carbide precipitation at material grain boundaries
- ✓ Compromises passive film corrosion protection
- ✓ Can look like tea staining but is really intergranular corrosion



# Welding; Weld Decay

## How to avoid;

- ✓ Use low-Carbon Stainless Steel grades like 304L and 316L
  - Carbon contents less than 0.03% in the material chemical analysis
- ✓ Choose stabilized Stainless Steel grades like 316Ti and 347
  - Ti and Nb additions combined preferentially with Carbon to protect the passive film
- ✓ Undertake solution annealing of welded parts followed by rapid quenching
- ✓ Control welding heat input and increase HAZ cooling rates



# Summary 1/3

Tea staining is often misunderstood and is seen as early corrosion

Choosing the wrong Stainless Steel grade for an operating environment will, as a minimum promote tea staining

Equally, not considering the needed material surface roughness will also create an environment where tea staining develops

Poor designs that do not permit liquid drainage will create future problems

Fabricating Stainless Steels in dirty & contaminated shops is a disaster

Not avoiding the outlined welding pitfalls will lead to future disappointment

# Summary 2/3

- Tea staining can easily discredit Stainless Steels as it is unsightly
- Thoughtful Stainless Steel selection will ensure trouble-free service for many decades

The 5 'golden considerations' that should always be followed are:

Select the Correct Grade for  
the Environment

Define the Correct Surface  
Roughness Needed

Design for Drainage

Use Clean & Uncontaminated  
Fabrication Shops

Avoid Known Welding Pitfalls

# Summary 3/3



Trying to save cash by overlooking the golden considerations will just cost more during the usage phase of a product or installation



Saving 10%-15% of the 'up-front' cost through sub-optimal thinking is likely to cost >50% more during the usage phase of an asset

Thank you for your attention

Any questions?

# ■ Appendices



# Removing Existing Tea Staining

On smooth Stainless Steel surfaces it is easy to remove tea staining

A Stainless Steel scourer gently used with warm soapy water will remove tea staining

Rinsing the surface afterwards with clean water is also important

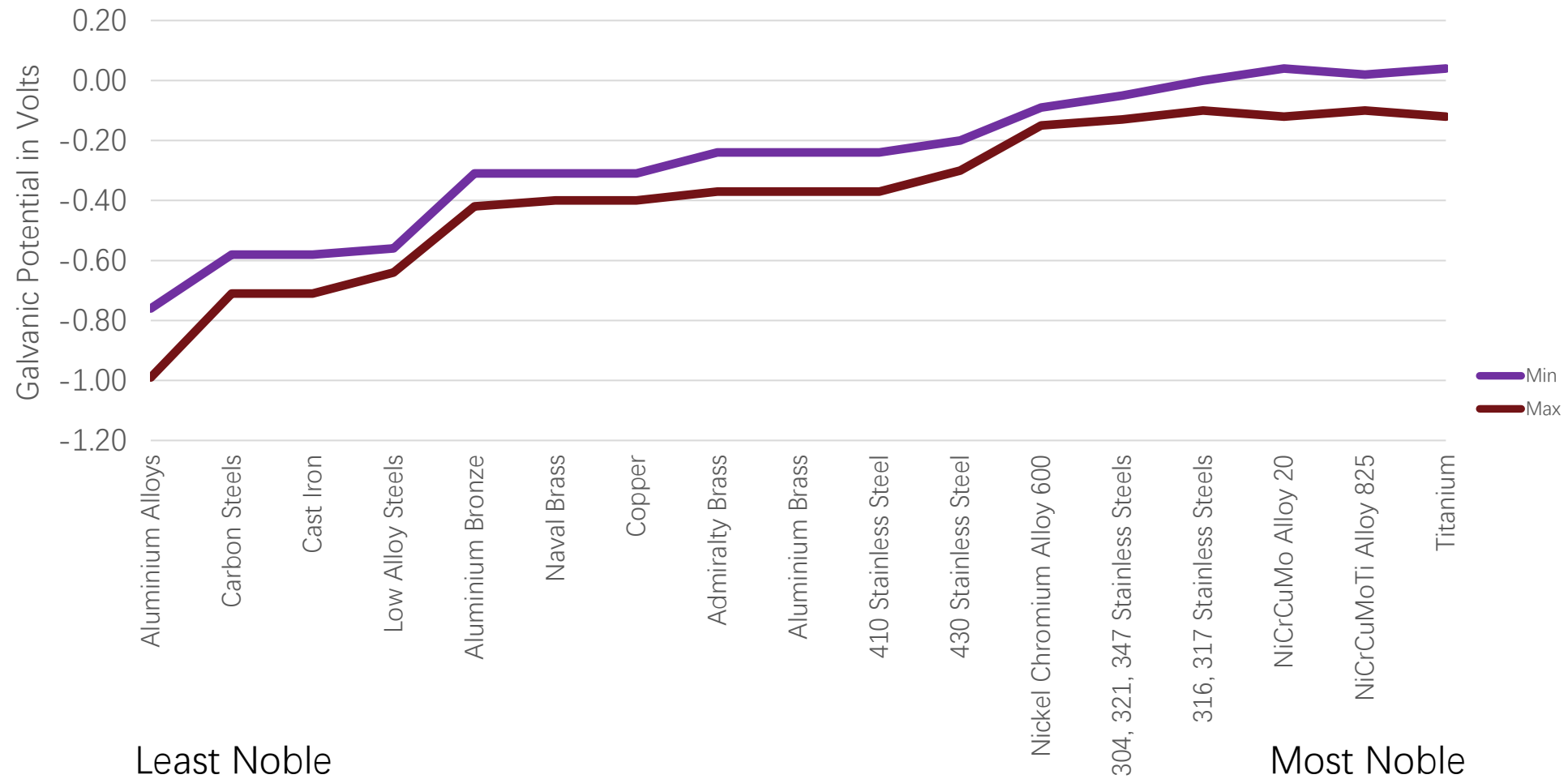
On rough Stainless Steel surfaces, the deeper surface grooves may present challenges to removing tea staining

Gentle scrubbing using Stainless Steel brushes with warm soapy water is likely to remove the tea staining

The rough surface however is likely to support the rapid return of tea staining

Correct grade selection is important but defining surface finish is vital too

# Simple Galvanic Series for Common Metals & Alloys



Least noble metals in contact with most noble metals is likely to promote galvanic corrosion which can be mistaken for tea staining

# Coastal Tea Staining

Primary causes;

Rough surface of the tubes

Weld spatter around the welds

Note; No tea staining on the drawn wire

*Image; Dashdoor.com*



# Rough Surface Tea Staining

Primary cause;

Rough surface on the main chamber  
outer

*Image diometonline.co.uk*



# Further reading



Surface treatment: <https://worldstainless.org/about-stainless/process-and-production/surface-treatment/>



Standards: <https://worldstainless.org/about-stainless/properties/stainless-steel-standards/>



Other corrosion webinars: <https://worldstainless.org/about-stainless/education/worldstainless-webinars/understanding-corrosion/>



Life Cycle Costing: <https://worldstainless.org/sustainability/economic/life-cycle-costing/>

# world**stainless**

worldstainless.org

