SOME PRACTICAL DESIGN ASPECTS WHEN USING DUPLEX STAINLESS STEELS IN ATMOSPHERIC TANKS AND PRESSURE VESSELS
DISCLAIMER

Whilst care has been taken to ensure that the contents of this presentation are accurate, the applications, methods and products described are for general information only and before applying any concepts the user should fully satisfy themselves of their suitability and safety

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TRIBUTE

Thanks to the late Richard Descroizilles (Dick) who provided so much theoretical and practical knowledge and support to vessel design

The industry owes him a large debt of gratitude. He is sorely missed.
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1 INTRODUCTION

• The fundamental objective when designing a containment vessel is to ensure that it is:
  • Functional
  • Safe
  • Compliant with relevant standards and code
  • Cost Effective
  • Elegant

• Many factors influence the design, but they are principally determined by:
  • Process Requirements
  • Physical Configuration
  • Interface with other plant and equipment
  • Transportability
  • Site Conditions
  • Maintenance and life cycle costs

• These influence materials of construction, size/shape and design codes

• Although the austenitic work-horses of the stainless steel family, predominantly 304 and 316, could remain the most used grades for years to come, there has been a definite migration towards duplex grades.

This is largely due to the well documented and well described relative high corrosion resistance and superior mechanical properties (strength, ductility and toughness), but major acceleration of the trend must also be attributed to skyrocketing nickel prices of the mid 2000’s considerably increasing the cost of austenitics.

• Continuing evolution of some hydrometallurgical processes imposed more corrosion-related demands on the materials of construction

• Increased awareness by end users because of the concerted marketing thrust by the duplex stainless steel producers and acceptance of newly developed duplex material properties by the Standards Authorities and Design Codes

This presentation summarises some of the corrosion and design aspects that need consideration and outlines three examples based on actual practical experience.
# Design Considerations

## Objective
- Functional
- Safe
- Cost Effective
- Elegant

## Considerations
<table>
<thead>
<tr>
<th>Process Metallurgical</th>
<th>Static</th>
<th>Dynamic</th>
<th>Manufacturability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion</td>
<td>Design</td>
<td>Strength/Durability</td>
<td>Price</td>
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<td></td>
<td></td>
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<td>Availability</td>
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<td>Workability</td>
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<td>Consumables</td>
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<td>Transport</td>
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<td></td>
<td></td>
<td></td>
<td>Erection</td>
</tr>
</tbody>
</table>

These considerations influence the material type, physical configuration and design code.

## Responsibility
- Conformance/Compliance with Standards/Regulations/Inspections

## Result
- Low maintenance - Optimum Life Cycle Costs
3 CORROSION

Duplex stainless steels exhibit relatively high corrosion resistance in comparison to standard austenitic grades. In hydrometallurgical processes, the process solution usually causes corrosion, resulting in different types of attack varying in nature and appearance. There are many types of corrosion which can influence material selection. Understanding the types of corrosion, how they work and counter-corrosion actions are important in optimising tank design life.

The following types of corrosion need to be addressed:
- Uniform Corrosion
- Pitting Corrosion
- Crevice Corrosion
- Stress Corrosion Cracking
- Corrosion Fatigue
- Intergranular Corrosion
- Galvanic Corrosion
- Fretting Corrosion
- Cavitation Corrosion

The first four are the most important.

- **UNIFORM CORROSION**
  Occurs when a large section of the passive layer is destroyed. Electro-chemical reactions cause a decrease in metal thickness per unit of time, based on solution pH, temperature, oxygen concentration and electroactive impurities. The presence of halides, such as chlorides and fluorides, increases the corrosivity of acids, especially at elevated temperatures. The attrition rate is usually expressed in mm per year. Stainless steels are considered resistant to uniform corrosion when the rate does not exceed 0.1 mm/y.

- **PITTING CORROSION**
  Results in highly localised holes that can penetrate the metal rapidly while the remainder of the surface appears intact. Usually in neutral or acidic solutions containing chlorides. It initiates more easily in stagnant rather than flowing solutions (e.g. at plant shut down).

- **CREVICE CORROSION**
  Occurs under the same conditions as pitting. However, the corrosion begins in narrow crevices rather than on a flat, unshielded surface.

- **STRESS CORROSION CRACKING**
  Is caused by the combined effect of tensile stress and a corrosive environment.
Need to study the isocorrosion charts for the material, solution and temperature

The isocorrosion diagram consists of lines, each representing an alloy and its corrosion rate at 0.1mm a year. At temperatures or concentrations above the line, the corrosion rate tends to be elevated. If the concentration is below the line, the speed of corrosion is slower.

Typically, the data used in the diagram are created through lab tests and investigation of only real-world conditions using corrosion coupon testing. Essentially, the curves on the chart reflect the situations wherein the degree of metal degradation is similar.

Using several curves in the isocorrosion diagram will show a better appreciation of the effects related to a change of condition, which may involve concentration, temperature and contaminants.

At times, it is required to superimpose data from various sources into a single chart in order to come up with a group of curves. Corrosion rates can drop or rise significantly, even with the slightest change in conditions, so anticipation of any upset conditions is important.

Isocorrosion is a good starting point to ascertain what the corrosion rates would be for the expected working life (i.e. 2 – 2.5 mm).
3 ii PITTING RESISTANCE & CRITICAL TEMPERATURES

PRE
PRE (Pitting Resistance Equivalent) or PREN (Pitting Resistance Equivalent Number) which is a measure of the relative pitting corrosion resistance of stainless steel in a chloride-containing environment. Pitting resistance of stainless steel is significantly influenced by chromium, molybdenum and nitrogen. Higher PREN numbers indicate greater corrosion resistance.

CPT
The standardised laboratory method is ASTM 150 for CPT (Critical Pitting Corrosion Temperature) enables resistance to pitting to be established without interference from crevice corrosion. It provides the critical temperatures at which pitting is initiated. The results can differ between surface roughness.

CCCT
ASTM G48 Method E is used to determine CCT (Critical Crevice Corrosion Temperature). The same criteria for surface roughness applies to CCT; use the anticipated actual material finish for the tests.

SCC
In the standardised U-bend test, samples are immersed in concentrated chloride solutions and microscopically (20x) examined for cracks at specified intervals.
3 iii CORROSION EFFECT ON FATIGUE

• Corrosion effect on fatigue is complex and has significant influence on dynamic design.

• Fatigue strength levels are sensitive to test methods and surface finish and results can be scattered due to complex nature of fatigue failure mechanisms.

• Generally researchers conclude that austenitic and duplex stainless steels have fatigue limits in air at around their 0.2% tensile proof strength. Fatigue strength values reduce as frequency increases.

• More conservative conclusion from Nickel Institute is that duplex types have fatigue limits at around 50% of tensile strength.

• Fatigue resistance dependent on stress concentration factors with notch sensitive materials more prone to fatigue failure. The higher strength and toughness of duplex types may account for the better notch sensitivity resistance.

• Corrosion pits can act as notches resulting in lower fatigue values in corrosive environments. So materials with higher corrosion resistance are better choices than those with just high fatigue strengths.

• Good pitting resistance and higher strengths of duplex make them useful choices where corrosion fatigue is a hazard.
Degradation of the material surface because of mechanical action, abrasion by slurry, or impinging liquid.

- Can either accelerate or retard corrosion rates by removal of protecting layers, or removal of corrosive deposits
- Corrosion is accelerated by high temperatures
- Agitated tank shells, bases and baffles rarely see signs of wear
- Damage generally caused by mechanical impact – loose/bent impellors or shafts
- Impellors, due to high tip speeds are generally rubber lined
- Very few instances where bases/shells are thickened or lined in the zone of impellor influence; only in highly corrosive, highly abrasive circumstances.
- Limited test data currently available ranking abrasive properties between standard austenitic and duplex grades. Some independent third party testing has been completed
- ASTM does have a range of Abrasive Wear Standards
- Duplexes in practice have higher abrasion resistance than austenitics. This is a complicated field where abrasion resistance depends on many parameters in any tribological system
### 4 Design Conditions

The designer needs to evaluate all the loads and forces exerted on the vessel

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure /Head</td>
<td>Applied gauge pressure and/or head due to density and height of liquid</td>
</tr>
<tr>
<td>Thermal</td>
<td>Forces due to expansion/contraction and effect of temperature on material properties</td>
</tr>
<tr>
<td>Flow</td>
<td>Dynamic forces exerted due to liquid streams</td>
</tr>
<tr>
<td>Wind</td>
<td>Forces depend on location, position and shape</td>
</tr>
<tr>
<td>Agitator</td>
<td>Axial, radial and torque</td>
</tr>
<tr>
<td>Nozzles</td>
<td>Loads induced by connected piping</td>
</tr>
<tr>
<td>Vibration</td>
<td>High frequency forces from associated equipment i.e. pumps</td>
</tr>
<tr>
<td>Oscillation</td>
<td>Low frequency force from eccentric inlet /outlet conditions or agitator forces</td>
</tr>
<tr>
<td>Superimposed structures</td>
<td>Overflow pipes, ladders and platforms induce dead and live loads</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Forces resulting from fluctuating pressure cycles in complete vessels or cyclic loading on nozzle necks from agitator rotation</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Mechanical forces during manufacturing process</td>
</tr>
<tr>
<td>Transportation</td>
<td>Loading/transportation/unloading may cause forces not seen in operation</td>
</tr>
<tr>
<td>Installation/Erection</td>
<td>Crane or wind forces during erection</td>
</tr>
<tr>
<td>Environment</td>
<td>External plant conditions</td>
</tr>
<tr>
<td>Seismic</td>
<td>Ground movement</td>
</tr>
</tbody>
</table>
4 Stress Considerations

The loads/forces applied by these various conditions induce a variety of stresses into the vessel material:

- TENSILE/HOOP
- BENDING
- BUCKLING
- SHEAR
- BEARING
- FATIGUE
- COMPRESSIVE

Need to consider how they affect the design of the vessel by evaluating the stress envelopes induced by the various loads.

Once the effects of corrosion are determined and the appropriate material selected, its physical properties are used in the applicable design code.
4 ii DESIGN CODES

Some of the more commonly used codes and practices:

- ASME VIII Div 1
- ASME VIII Div 2
- BS 5500
- AD-Merkblatt
- BS2564
- EN14015
- API 650
- API 620
- Company Standards
- First Principle Analysis
- Sound Engineering Practice
- Limit State Design

Fundamental objective is to ensure a safe, elegant, cost effective and functional vessel that complies with the relevant codes/regulations.
**CONTAINMENT VESSELS**

- Process vessel design is generally bespoke with a multiplicity of types, shapes and aspect ratios.

<table>
<thead>
<tr>
<th>Not Considered</th>
<th>Considered Tanks &amp; Vessels</th>
<th>Not Considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryogenic</td>
<td>Atmospheric</td>
<td>Vacuum</td>
</tr>
<tr>
<td></td>
<td>Round</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rectangular</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal</td>
<td></td>
</tr>
</tbody>
</table>

- The loads induce stresses which need to be designed in accordance with the relevant code, applicable to the shape and configuration of the vessel required by the process (e.g. API 650 for flat bottomed atmospheric tanks).
Some appropriate examples of vessels designed and manufactured in duplex over the past few years:

- **Large Leach Tanks, Atmospheric 2205**
  - 6 off Dia 11.3 x 14m

- **Horizontal Pressure Vessel 2205**
  - Dia 3.8 x 15m

- **Large Atmospheric Rectangular Vessel 2304/2101**
  - 22 x 12 x 3m
5. LARGE LEACH TANKS

2205  6 off  Dia 11.3 x 14m
5 ii HORIZONTAL PRESSURE VESSEL

2205 Dia 3.8 x 15m

Information to be presented
5 iii HORIZONTAL PRESSURE VESSEL

2205 Dia 3.8 x 15m

Information to be presented
5 iv HORIZONTAL PRESSURE VESSEL
2205 Dia 3.8 x 15m

Theoretical Cost Comparison of Horizontal Autoclave

<table>
<thead>
<tr>
<th>Material</th>
<th>2205</th>
<th>316L</th>
<th>Percentage Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass T Estimated</td>
<td>47</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Average Rand / Kg Feb '08</td>
<td>66</td>
<td>59</td>
<td>52.2</td>
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<tr>
<td>Theoretical Material Cost</td>
<td>3,102,000</td>
<td>4,720,000</td>
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</tr>
<tr>
<td>Average Rand / Kg Feb '14</td>
<td>54</td>
<td>40</td>
<td>26.1</td>
</tr>
<tr>
<td>Theoretical Material Cost</td>
<td>2,538,000</td>
<td>3,200,000</td>
<td></td>
</tr>
</tbody>
</table>

STATIC TYPE NOZZLE WITH COMPAD

DYNAMIC TYPE NOZZLE
5. LARGE RECTANGULAR VESSEL

2304 – 2101  22 x 12 x 3m
LARGE RECTANGULAR VESSEL
LARGE RECTANGULAR VESSEL
CONCLUSION

These practical examples show how the use of duplex stainless steels, with consideration of their own merits and strengths, have resulted in physical vessels that meet requisite Standards and Codes while providing cost effective, elegant solutions.

The evolution of duplex stainless steels, with increasing anti-corrosive and mechanical properties, has enabled engineers to design for more sophisticated and demanding process requirements.

In some instances, the superior mechanical properties offered by duplex stainless steels are compromised by having to comply with Standards and Codes which in some instances stipulate minimum material thickness.

This has motivated the investigation of Limit State Design in an effort to optimise configurations and thicknesses over that prescribed by elastic design.

However, serious consideration and care must be given to Limit State Design where designers must be extremely competent and experienced when applying this more complex design methodology.

This design process cannot be short cut and the load/stress envelopes must cover all anticipated operating criteria.

This presentation has attempted to provide an overview of the design process and the dynamism inherent in it.
REFERENCES

1 A review of the use of Duplex Stainless Steel in hydrometallurgical and related industries
   G. Coates, M. Pearson, G. Moe.
   8th Duplex Stainless Steel Conference, Bearne, France 2010

2 Experience with Duplex Stainless Steels in the Chemical process Industry
   Dr. J. Korkhaus
   8th Duplex Stainless Steel Conference, Bearne, France 2010

3 Use of Duplex Stainless Steels in chemical tankers: history, current use and what the future holds
   Y. Boudart and J. Peultier.
   8th Duplex Stainless Steel Conference, Bearne, France 2010

4 Duplex or Austenitic: an intelligent method for accurate material selection.
   J. P. Audouard.
   8th Duplex Stainless Steel Conference, Bearne, France 2010

5 The effect of acid concentration and temperature on corrosion and electrochemical behaviour of Duplex Stainless Steel in sulphuric acid media
   M. M. Sadauvy.
   8th Duplex Stainless Steel Conference, Bearne, France 2010

6 Duplex Stainless Steel adds structural and cost efficiency to seismic design of storage tanks
   C. Tigerstrand, J. Sjostion.
   8th Duplex Stainless Steel Conference, Bearne, France 2010

7 Utilising high strength stainless steel for storage tanks
   Dr. Anders Olsson. Avesta Polarit AB (Publ)

8 Duplex Stainless Steels for storage tanks
   Outokumpu Stainless AB. Avesta research Centre

9 Duplex Stainless Steels and technical data sheets
   Columbus Stainless

10 Sandvik Duplex Stainless Steels
    Sandvik Materials Technology

11 Duplex Stauginless Steels
    Outokumpu - Stainless Steels and high Performance Alloys

12 Handbook of Stainless Steels
    Outokumpu - Stainless Steels and high Performance Alloys

13 Corrosion Handbook
    Outokumpu - 10 edition, 2009

14 Micro abrasion - corrosion of AISI 316L Stainless Steel
    J. O. Bells, R. J. Wood, J. A, Wharton

15 Welded tanks for oil storage
    API 650

16 ASME Boiler and pressure vessel code
    Rules for construction of pressure vessels
    ASME VIII Div 1, ASME VIII Div 2

17 Process Equipment Design - Vessel Design
    L. E. Braunell, E. H. Young

18 Columbus Stainless
    David Smith

19 Nickel Institute

20 Mixtec
    John Malan

21 Duplex Stainless Steels STISPFA
    J. Grocki
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6. Group 5, Johannesburg, RSA
7. Chambishi Mine, Zambia
8. TWP, Johannesburg, RSA
9. G i Crawford, D L Charsley, N L Borrego - Styria Stainless Steel Fabrication