Material Selection for Stainless Steel Goes One Step Beyond...

May 5, 2011
MetalForming Magazine Webinar Presented by Outokumpu Stainless

www.outokumpu.com/na
Welcome/Introductions

Moderator: Brad Kuvin, Editor MetalForming Magazine

Panelists:

- Dave Houck, Outokumpu Distributor Sales Manager and Segment Leader
- Poul-Erik Arnvig, Outokumpu Vice President, Market Development
- Mikael Johannesson, Outokumpu Product Manager Strip

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Outline for Today

• Overview of Outokumpu Stainless
• Material Selection
  • Austenitic and duplex alloys
  • Ferritics
  • Corrosion resistance
  • Structural efficiency
  • High temperature
• Welding of stainless
• Questions & Answers
Disclaimer

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Overview of Outokumpu Stainless
Outokumpu: A Global Leader in Stainless

- Outokumpu’s main markets
  - Europe 75%
  - Asia 12%
  - North and South America 11%

- Market leader in duplex grades with a global market share of 50%
Outokumpu and the Invention of Stainless

Outokumpu – Finland
1910 Copper ore was found in Outokumpu and the journey to an international multi-metals company started
1977 Stainless steel production started in Tornio

Avesta – Sweden
1924 Stainless steel production started in Avesta
1930 Duplex production started

Sheffield – The UK
1913 Stainless steel invented in Sheffield

Outokumpu – Finland
1990-2000 Exit from some other metals and mining started
1998 Major expansion of steel production

Avesta Sheffield
1992 Avesta and the stainless business of British Steel are combined to form Avesta Sheffield

2001 Avesta Sheffield and Outokumpu’s stainless business merged to form AvestaPolarit
2002 Outokumpu acquired all shares of AvestaPolarit
2005 The vision of becoming undisputed number one in stainless introduced
2000-2006 Exit from other metals, mining and technology
2007 Outokumpu – an international stainless steel company
2010 Ferrochrome capacity expansion started
A Broad Range of Products and Grades

- Coil, sheet and plate
- Quarto plate
- Thin strip
- Tubular products
- Long products
Serving a Wide Range of Industries

Architectural, Building & Construction
- Structural
- Heating, Cooling, and Ventilation
- General AB&C

Process and Resources
- Pulp & Paper
- Food & Drink
- Desalination
- General Industrial
- Mining
- Pumps, Perforators & Textile Applications

Catering and Appliances
- Commercial Catering
- Household Goods

Chemical, Petrochemical & Energy
- Oil & Gas
- Chemical & Pharmaceutical
- Energy

Transport
- Automotive
- Heavy Transport

Distributors Processors
North American Locations

- **Chicago, IL**
  - Coil Products - Import Sales Company (GS&M)

- **Brockville, ON**
  - BU-OSTP (Fitting)

- **New Castle, IN**
  - BU-SP Quarto Plate

- **Richburg, SC**
  - BU – Long Products Billet, Bar & Wire Rod

- **Wildwood, FL**
  - BU-OSTP (Pipe) Continuous & Batch
Material Selection
Stainless Steel is Everywhere!
Grades of Stainless and Microstructures

Austenitic grades
304/304L, 316/316L
18 % Cr, 8 % Ni

Ferritic grades
409, 430
12-18 % Cr, 0-0.5 % Ni

Duplex grades (ferritic-austenitic)
LDX 2101®, 2205 Code Plus Two®, LDX 2404™, 2507
21-25 Cr, 1.5-7% Ni

“LDX 2101”, “2205 Code plus 2” and “LDX” are registered trademarks of Outokumpu Inc., LDX 2404 is trademark of Outokumpu Inc.
Austenitics

- Typical austenitic characteristics:
  - Corrosion resistance
    - Wide range of alloys and resistance levels available
    - Type 304 is “at the low end” but “OK”
  - Many surface finishes available
    - Hygienic and aesthetic demands
  - Very good formability
  - Good weldability
  - Non-Magnetic
  - Tough at cryogenic (very low) temperatures
  - Can be formed to very high strength (cold hardening)
Type 316 Characteristics

• 16 % Cr, 10% Ni, 2% Mo
• Austenitic grade with properties more or less equal to 304, except corrosion resistance
• Next step when corrosion resistance of 304 is insufficient
• Not recommended in oxidizing acids such as HNO₃ or CrO₃
• Applications
  • Paper machines
  • Food industry
  • Plate heat exchangers
  • Architecture
Properties of Ferritic Grades

- Immune to stress corrosion cracking (SCC)
- Sensitive to intergranular corrosion
- Limited weldability, due to grain growth and second phase precipitation
- Thermal expansion as C-steel
- Reasonable thermal conductivity
- Good formability (limited stretch formability)
- Brittle at low temperatures
- Magnetic
- General maximum thickness, 0.16” (4mm)
Duplex Stainless Steel

- Corrosion resistance – Good to excellent
- Excellent resistance to stress corrosion cracking
- Mechanical strength – ~2 x austenitics (YS)
- High hardness
- Good wear resistance
- Good weldability and machinability
- Good formability
- Less brittle than ferritics at low temperature
- Magnetic
- Lower thermal expansion than austenitics, similar to carbon steel
High Alloyed Austenitics

• Very good resistance to uniform corrosion
• Very good to excellent resistance to pitting and crevice corrosion
• Very good resistance to various types of stress corrosion cracking
# Which Steel Grade Should I Choose?

## Outokumpu Stainless Steel Grades

<table>
<thead>
<tr>
<th>EN</th>
<th>ASTM/AISI</th>
<th>Outokumpu steel name</th>
<th>Typical chemical composition, %</th>
<th>National steel designations superseded by EN</th>
<th>Outokumpu products</th>
<th>Welding consumables</th>
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<tbody>
<tr>
<td>1.4003</td>
<td>304</td>
<td>304L</td>
<td>0.08 –</td>
<td>18.5 or 19.0</td>
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<td>-</td>
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<tr>
<td>1.4028</td>
<td>201</td>
<td>201</td>
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<td>420</td>
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## Heat Resistant Steels

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<tr>
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<tr>
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<td>0.08 –</td>
<td>18.5 or 19.0</td>
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## Austenitic Steels

<table>
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<td>-</td>
<td>-</td>
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</table>
Corrosion Resistance

Water
The most common corrosive liquid – but hard to predict the corrosivity
• Different “types” of water
• Corrosion mainly associated with: chlorides, oxidants, pH, biological activity, and temperature
What is Chloride?

A very common ion found in water and in many salts

- Tap water < 250 ppm
- Salty taste > 250 ppm
- Brackish water ~ 3000 ppm
- Seawater 20000 – 30000 ppm
Localized Corrosion

Localized corrosion is the common name of pitting and crevice corrosion.

• Increased risk by:
  • Chlorides
  • Elevated temperatures
  • Low pH
  • Oxidants (chlorine, hydrogen peroxide…)
  • Micro organisms
  • Design
  • Crevices
  • Stagnant solutions
  • Weld oxidation
  • Coarse surface finish
Pitting Corrosion

Pitting corrosion resistance can roughly be estimated by a calculation of the PRE (Pitting Resistance Equivalent) formula:

\[ \text{PRE} = \%\text{Cr} + 3.3 \times \%\text{Mo} + 16 \times \%\text{N} \]

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>PRE</th>
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<tr>
<td>304</td>
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<td>316</td>
<td>24</td>
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<tr>
<td>317</td>
<td>33</td>
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<tr>
<td>904L</td>
<td>34</td>
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<tr>
<td>254 SMO®</td>
<td>43</td>
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<tr>
<td>654 SMO®</td>
<td>56</td>
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<tr>
<td>LDX 2101®</td>
<td>26</td>
</tr>
<tr>
<td>2304</td>
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<td>LDX 2404™</td>
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<tr>
<td>2205</td>
<td>35</td>
</tr>
<tr>
<td>2507</td>
<td>43</td>
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</table>

* Alternative formulas exist
Beer Production

Application

- Microfilter in beer production
- The microfilter removes suspended yeast from the liquid, stopping the fermentation process and stabilizing the product

Material

- Hot rolled plates and plasma-cut rounds in 1.4307 (304L), 3.2" in thickness
- Hot and cold rolled sheets of various austenitic grades, 0.16” – 0.4” thick
- Hot rolled bars of 1.4404 (316L) and 1.4571 (316Ti)

Remarks

- The main stainless product in this type of microfilter is a round plate used to make the filter plate for the microfilter. The rounds used for the microfilter are plasma-cut at a service center from Outokumpu hot rolled plates.
# Atmospheric Corrosion Categories

<table>
<thead>
<tr>
<th>ISO</th>
<th>Typical environment</th>
<th>Material</th>
</tr>
</thead>
</table>
| C1  | Indoor, heated facilities
Outdoor, deserts, and the arctic                                                      | 430, 304, LDX 2101        |
| C2  | Indoor, not heated
Outdoor, little pollution, and dry areas                                               | 430, 304, LDX 2101        |
| C3  | Indoor, humid facilities
Coast line, low salt depositions
City and industry atmosphere, normal pollution                                           | 304, 316, LDX 2101, LDX 2404 |
| C4  | Indoor, chemical production facilities
Polluted city and industry atmosphere
Coast line, normal salt deposition                                                       | 316, 904L, LDX 2404, 2205+2, 2507, 254 SMO |
| C5  | Industry atmosphere, high pollution, and humidity
Coast and offshore area, high salt deposition                                              | 2507, 254 SMO              |
Atmospheric Corrosion – Surface Finish

Type 316 railings beside a beach.
Specifying the surface roughness is almost as important as selecting the right stainless steel grade.

Ra 83 µ inch

Ra 29 µ inch
**Stove/ Professional Pan**

**Application**
- Cooking surface
- Max temperature: 392°F

**Material**
- Outokumpu 2304 (EN 1.4263, S32304)
- Thickness: 1”

**Remarks**
- 2304 solid substituted 316L clad solution, utilizing the higher heat transfer coefficient of 2304 and ensuring a flatter and simpler surface (polished) to produce with a corrosion resistance on par or better than 316L.
Stress Corrosion Cracking, SCC

Chloride-induced stress corrosion cracking

- 304L
- 316L
- 430
- LDX 2101®
- LDX 2404™
- 2205 Code Plus Two®
- 2507
- 904L
- 254 SMO®
- 4565
- 654 SMO®

Ferritic SS

Duplex SS

Superaustenitic SS
Corrosion Resistance – Uniform Corrosion

- The corrosion process proceeds uniformly over the entire exposed surface or over a large area.
- Most cases of uniform corrosion or general corrosion occur in strong acids or in hot alkaline solutions.

![Graph showing the relationship between pH and weight loss per square meter per hour.](image)

- **Weight loss, g/m²•h**
  - **Corrosion**
  - **Passive**
  - **Corrosion**

![Image of corroded material.](image)
Corrosion Resistance – Uniform Corrosion

Iso-corrosion diagram
0.1 mm/y (0.004 inch/year)
in sulphuric acid
Wine and Juice Storage Tanks

Application
• Application: 53 tanks for wine, 12 tanks for unfermented grape juice
• Size: Diameter 43’, height 53’

Material
• LDX 2101 (EN 1.4162, S32101), 2304 (EN 1.4362, S32304), 4301 (EN 1.4301, 304)
• Product type: CPP & QP
• Dimensions: 0.16” – ½”, 79” wide

Remarks
• LDX 2101 and 2304 were used to build the roof and the uppermost part of all new tanks due to weight savings and corrosion resistance.
Strong influence of material

Material

$\frac{R_{p0.2}}{\rho}$
Design Codes

$\frac{E}{\rho}$
Stability

Shape

Strong influence of shape

Heavy gauges

Thin gauges

Pressure Vessel

Storage tank

Weight Savings Potential: ~30-50%

Bridge

High Speed Train

Weight Savings Potential: ~10-30%

Material selection of SS – Webinar

35 May 5, 2011
Corn Silos

Application

• Application: Corn silos
• Size: Diameter 21.3’, height 44.3’ + 17.1’ cup

Material

• LDX 2101® (EN 1.4162, S32101)
• Thickness range: 0.12” – 0.24”

Remarks

• LDX 2101 substituted 304L. The weight savings was 12 ton/tank. Extra benefits were better corrosion resistance, better abrasion resistance, less welding costs, less transport costs.
Formability

- Chemical composition
- Mechanical properties
- Microstructure and phase transformations
- Work hardening
- Surface conditions
- Lubrication/tool material
- Temperature
- Forming speed
Chemical Composition (Austenitics)

- **Ni** – Less strain hardening – for deep drawing and spinning
- **- Ni** – More strain hardening – for stretch forming and hydro forming

- **Cr** – Less strain hardening, general formability decreases dramatically when ferrite is formed

- **Low N** – More strain hardening – for stretch forming and hydro forming
- **Optimum N** – Between 0.025 - 0.060% for drawing

- **Boron and Ti** – Bad for anisotropy, increased earing when drawing.

- **Sulphur** – As low as possible.

- (Other elements influenced as well)
Tank and Heat Shield

**Application**
- Application: DEF tank and heat shield on truck

**Material**
- LDX 2101 (EN 1.4162, S32101) – DEF tank
- Thickness: 1/16”
- 304 – Heat shield

**Remarks**
- LDX 2101 has strength to minimize added weight and corrosion resistance which keeps the DEF uncontaminated while being easy to clean on the outside without any loss in properties over time. Replaces plastic alternative.
- Heat shield in 304 with excellent formability and good ”high temperature” resistance. Replaces ferritic BA alternative due to better formability.
High Temperatures

- Muffle tubes
- Muffle
- Radiant tubes
- Inner covers for bell furnaces
- Heat treatment tray
High Temperature Considerations

- High temperature = above approx. 900°F, typically below this temperature ordinary austenitics can be used
- High temperature effects
  - Oxidation: Begins at around 1300°F
  - High temp. corrosion from molten salts
  - Creep – very slow mechanical breakdown under prolonged loading below proof strength
  - Erosion at high temp
  - Mechanical strength (also relevant to consider at low temp)
  - Fatigue (also relevant to consider at low temp)
  - Microstructural stability to maintain low temp properties
### Recommended Maximum Service Temperature in DRY AIR!

<table>
<thead>
<tr>
<th>Austenitics</th>
<th>Outokumpu</th>
<th>EN</th>
<th>ASTM</th>
<th>Max. Service Temp. °F (°C)</th>
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<td>1.4948</td>
<td>304H</td>
<td></td>
<td>1470 (800)</td>
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<td>4878</td>
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<td>321H</td>
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<td>1470 (800)</td>
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<td>153 MA™</td>
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<td>S30415</td>
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<td>1830 (1000)</td>
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<td>309S</td>
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<td>1830 (1000)</td>
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<td>S30815</td>
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<td>4841</td>
<td>1.4841</td>
<td>314</td>
<td></td>
<td>2060 (1125)</td>
</tr>
</tbody>
</table>
Rare Earth Metal Additions

• The thin and adherent oxide is beneficial
  • when temperatures are cycled, e.g. in batch processes
  • in erosive environments, e.g. in gas streams containing particles

• The high creep strength is beneficial because
  • lower risk of deformation
  • thinner gauges can be used for a defined load
  • higher loads and/or longer life time for a defined thickness
**Outokumpu MA Grades for High Temperature**

Creep Strength

- **MA Grades**
  - **153 MA™**
  - **253 MA®**

- **“Standard” HT Grades**
  - **309S**
  - **310S**

Creep deformation test:
The 310S and 321 rings collapsed due to own weight
1832°F, 35h, 0.04” gauge

**“HT Corrosion Resistance”**
Flex Tubes

Application
- Application: Flex tubes

Material
- Outer shell: 304L (or 321/316Ti/309)
- Inner shell: 309 (or 321/309)
- Mesh: 304L

Remarks
- Ease of formability again leads to choice of 304 while temperature scan go high, but no significant wet corrosive factors. Stronger and more wet corrosion resistant grades may be used. At the top of temperatures, a more heat resistant grade, type 309, is chosen.
Automotive EGR System

Application
- Application: EGR system

Material
- Flanges: Austenitic 304L or ferritic 430
- Cooler: 316L or 904L
- Inlet tube: 153 MA
- Thickness: 0.008 – 0.010”

Remarks
- Mix of different grades to optimize cost and performance. Specialized heat resistant grades for hottest end. 304 for ease if formability. Ferritic when possible to optimize cost.
Welding of Stainless Steels

- Austenitics have generally very good weldability.
- Duplexes also have good weldability, but are generally less “forgiving.”
- Ferritics may be welded, but good weld-properties are hard to achieve.
- Heat resistant grades (austenitics) have good weldability.
Tips for Welding Stainless, Part 1

• Most stainless steels are weldable, but parameters and methods differ depending on type of stainless steel and thickness
  • Use and choose the right filler
    ✓ Appropriately alloyed
    ✓ Control heat input and interpass temp (especially duplex)
  • Consider what joint type to use:
    ✓ I, V, X etc.
    ✓ Nose, smaller for special grades
    ✓ Increase the joint angle and use root gap for special grades
  • Clean before welding
    ✓ Remove grease, dirt, paint, other metals (Zn, Cu, Al), etc.
    ✓ Use non-chlorinated solvents such as acetone and ethanol or similar
Tips for Welding Stainless, Part 2

• Use appropriate shielding- and backing-gas when using “Arc-welding” methods
  ✓ Avoid oxidation colors to minimize post weld cleaning
  ✓ Use nitrogen-containing gas for duplex alloys to improve weld-metal properties

• Use an appropriate post-weld treatment:
  ✓ Pickling (ASTM A380), grinding, polishing
  ✓ Heat treatment

• Qualify the welding procedure and always ensure proper ventilation
Machining

Machining index V5 milling

Cutting speed m/min

Low alloyed

Highly alloyed

A qualified truth

Material selection of SS – Webinar

May 5, 2011
Cost Efficiency

Cost Efficiency = Maximum Performance of the Investment

- Minimize Total Material Cost
- Minimize Total Fabrication Cost
- Minimize Total Life Cycle Cost
Critical Factors to Reach Cost Efficiency

**Structural Efficiency**
- Utilize Material Strength – Weight Savings
- Allowable Design Strength – Codes & Guidelines
- Shape Optimization – Stiffness/Stability Critical Design Criteria

**Durability**
- Corrosion & Mechanical (Wear, Fatigue, Dent) Resistance
- Service Life Time
- Life Cycle Thinking – Environmental Impact, Life Cycle Cost (LCC)

**Manufacturability**
- Material Cost/Unit of Weight – Alloying Cost Fluctuation (Ni etc.)
- Ease of Fabrication (Time and Cost/Unit)
- Product Availability & Quality
Useful Sites About Duplex Stainless Steel

Tank and tube dimensioning,
Corrosion Handbook, Welding Handbook,
ACOM, References
www.outokumpu.com
Products >>
Tools >>

Life Cycle Cost and more
www.euro-inox.org
LCC analysis>>

More on Stainless
www.ssina.com
&
www.worldstainless.com
• Quarterly newsletter on fabrication published by Outokumpu technical and commercial team.
• To become a subscriber log onto www.outokumpu.com, visit North American section, and click on “Subscribe Now”
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www.outokumpu.com/na