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Stainless Steel - Meeting the needs of the Water Industry

Dr Peter Cutler, Nickel Institute

Presented at:

Symposium for Polska Unia Dystrybutorów Stali (Polish Steel Distributors’ Association), Warsaw
8 January 2008
What are the needs of the water industry?

Equipment which:
– maintains the purity of the water
– is durable and low maintenance
– is cost effective
– has proven performance

Today we will illustrate how stainless steel can meet these needs.

Stainless steels in the water industry

- Benefits of using stainless steels in water applications
- The importance of good practice
- Examples from around the world
What is stainless steel?

- Steel containing more than 10.5% chromium
- Chromium reacts with oxygen in the air or dissolved in water to form the protective passive layer
- The passive layer is self-healing (in most situations) if damaged
- Nickel improves characteristics, including formability
- Molybdenum improves resistance to local corrosion

Maintaining water purity

- Materials should not release substances into the water
Maintaining water purity

• EU Drinking Water Directive (based on former WHO guidelines), weekly averages:
  – Cr < 50 μg/l
  – Ni < 20 μg/l [WHO now revised to 70 μg/l]

• EU pre-normative research pipe rig tests showed Cr and Ni leaching values < 5% of EU maxima

• UK Drinking Water Inspectorate study, 24 hour stagnation tests in 54.5 mm pipe:
  – Cr < 1 μg/l
  – Ni < 2 μg/l
  – “… the use of products made from the specified grades of stainless steel [1.4307, 1.4404, 1.4462 and similar] in contact with water for public supply would be unobjectionable on health grounds.”

• Experience confirms low leaching levels
Scottish Hospital

Nickel pickup in water (ppb)

Water analyses taken over a 1250 day (3.5 year) period after installation of stainless steel plumbing

Nickel was in all cases < 20 ppb (EU Drinking Water Directive maximum)

<table>
<thead>
<tr>
<th>Day</th>
<th>Cold Water 304 1.4307</th>
<th>Cold Water 316 1.4404</th>
<th>Hot Water Mixed 304 and 316</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.7</td>
<td>0.6</td>
<td>3.8</td>
</tr>
<tr>
<td>1</td>
<td>1.1</td>
<td>1.9</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
<td>1.9</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
<td>1.3</td>
<td>5.5</td>
</tr>
<tr>
<td>4</td>
<td>1.7</td>
<td>1.6</td>
<td>5.7</td>
</tr>
<tr>
<td>11</td>
<td>1.5</td>
<td>6.1</td>
<td>9.3</td>
</tr>
<tr>
<td>18</td>
<td>&lt;0.5</td>
<td>1.1</td>
<td>11.1</td>
</tr>
<tr>
<td>25</td>
<td>1.0</td>
<td>0.7</td>
<td>15.4</td>
</tr>
<tr>
<td>32</td>
<td>1.1</td>
<td>2.1</td>
<td>14.0</td>
</tr>
<tr>
<td>180</td>
<td>1.0</td>
<td>&lt;0.5</td>
<td>2.8</td>
</tr>
<tr>
<td>1250</td>
<td>0.6</td>
<td>&lt;0.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Mo and Cr < 2 ppb throughout

Approvals to use stainless steels

- Local approvals in EU Member States will be replaced by European Acceptance Scheme
- USA:
  - specified grades approved for public water supply without restriction under ANSI/NSF 61
  - approved under International Building Code
  - approved under International Residential Code
- Local schemes in Australia/New Zealand, China, Malaysia
Maintaining water purity

Metals entering drinking water from treatment or distribution

↓

Waste water treatment

Discharged in water

In sewage sludge

May restrict use of sludge as agricultural fertiliser

Not a problem for stainless steel

Characteristics of Stainless Steel in Use
Characteristics of stainless steels in use

• Excellent corrosion resistance:
  – no general corrosion so no need for corrosion allowance
  – no need for protective coating
  – no need to control water chemistry (except biocide)
  – no need for corrosion protection system
  – water purity is maintained
  – equipment is durable with low Life Cycle Cost
• Tolerance of high flow rates
• Good strength and ductility
• Lightweight design is possible
• Ease of fabrication
• Readily available in many forms
• Fully recyclable and contributes to sustainability

How to benefit from stainless steel

• Follow good practice
• Remember, like most other metals, stainless steel can corrode if not used properly!
Good practice in selection and use

- Best performance when:
  - correct grade for application
  - correct design
  - correct fabrication (off-site if possible)
  - correct installation and commissioning
  - correct operation within design envelope
  - correct maintenance
- Information on good practice is available from stainless steel suppliers and development associations

Grade selection guidelines

**Chloride content of the water is most important parameter**

Practical experience and tests show crevice corrosion is unlikely if:

<table>
<thead>
<tr>
<th>Chloride level</th>
<th>Suitable grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;200 ppm</td>
<td>304 (1.4307), 316 (1.4404)</td>
</tr>
<tr>
<td>200 - 1000 ppm</td>
<td>316, duplex 2205 (1.4462)</td>
</tr>
<tr>
<td>1000 - 3600 ppm</td>
<td>duplex 2205, 6% Mo superaustenitic, superduplex</td>
</tr>
<tr>
<td>&gt;3600 ppm and seawater</td>
<td>6% Mo superaustenitic, superduplex</td>
</tr>
</tbody>
</table>

Other grades with equivalent corrosion resistance may be suitable.

For hot water or to be more conservative, use limits of 50 ppm for 304 and 250 ppm for 316
Maximum Chlorine Cl₂ Levels in Water to Avoid Crevice Corrosion

Types 304 and 316 can resist chlorine levels normally present in domestic water systems

- Type 304 (1.4307) < 2 ppm
- Type 316 (1.4404) < 5 ppm

Shock dosing, such as 25 - 50 ppm free chlorine for 24 - 48 hours, is common practice and has not been found to cause problems. But flush the system thoroughly afterwards.

Stainless Steel Fasteners

- 304 or 316 stainless
- Avoid 303 (1.4305) stainless (‘free machining’)
- Grades:
  - Softened
  - Cold- worked
  - High-strength

ISO 3506 Standard:
- 1: Bolts
- 2: Nuts
Design and Fabrication

- Minimise opportunity for crevice corrosion:
  - good detailing to avoid sediment in joints
  - welded connections when possible

Tank Centre Drains

Invites corrosion
Good
Best
Crevice corrosion can occur when the wrong grade of stainless steel is selected for the conditions. Type 316 used in a coupling for seawater. It was successfully replaced with a 6% Mo stainless steel.
Minimising the effects of crevices

• Design to avoid crevices
• Prefer loose open crevices
• Avoid stagnant conditions in raw waters
  – Provide good flow and turbulence
• Keep crevices dry
  – Seal weld
  – Seal with mastic
• Use good fabrication practice
• Use more corrosion resistant grade of stainless steel

Design and fabrication

• Good welding practice:
  – full penetration welds without defects
  – avoid or remove heat tint
**Heat Tint**

10 ppm Oxygen → 25000 ppm

AWS D18.2

Heat tint up to Number 3 is probably acceptable in most water situations

---

**Pickling**

Before

After
Pickling

- Chemical treatment to remove metallic contamination and heat tint
- Standard Practice ASTM A 380

Pickling

Spray Pickling
Design and fabrication

• Good housekeeping during material storage and fabrication
  – iron contamination causes cosmetic rusting
    • clients do not like it
    • prevent or remove it

Corrosion of embedded iron in a stainless steel pipe bend
Caused by sparks from grinding nearby carbon steel
Design and Fabrication

- Avoid galvanic corrosion of other metals by use of stainless steel or copper-based fittings or insulate from iron and steel.

Galvanic corrosion between a carbon steel support ring and the large Type 304 hot water storage tank to which is was welded. The tank was lagged with fibreglass and water leaked into the lagging.
Guidelines to avoid galvanic corrosion

• Use materials of similar electrode potential (e.g., stainless steel and copper alloys)
• Insulate between the two different metals so current cannot flow
• Where this is not possible, make the key component (e.g., fasteners) from a more noble material (e.g., stainless steel)
• Ensure the less noble material (e.g., galvanised steel) is present in a much larger surface area than the more noble material (e.g., stainless steel)

Pitting
Possible causes in waters

• Surface inclusions (such as MnS) exposed
• Surface contamination (such as embedded iron particles)
• Chloride (Cl\(^-\)) levels too high
• Over-chlorination (Cl\(_2\)) in treated waters
Guidelines for avoiding microbiologically influenced corrosion (MIC)

- Some instances of MIC have occurred when hydrostatic pressure tests have been carried out with untreated water which has then been left in the equipment
- Always remove heat tint
- Use drinking water for hydrostatic testing

Well water left in tank for 3 months

Handling oxidants

Stainless steels resist oxidants used in water treatment, such as:
  - Chlorine
  - Ozone
  - Chlorine dioxide
  - Potassium permanganate
Chlorine practices

Care required:

- Injection areas - do not inject against stainless steel
- Excessive dosing - avoid
- Where chlorine vapours can collect - vent or wash down or choose a higher grade of stainless steel

Good practice in selection and use

- Best performance when:
  - correct grade for application
  - correct design
  - correct fabrication – off-site if possible
  - correct installation and commissioning
  - correct operation within design envelope
  - correct maintenance
- Information on good practice is available from stainless steel suppliers and development associations
Guidelines for good practice

• American Water Works Association standards on stainless steel in pipes, couplings, tapping sleeves, flanges and fittings
• Applications for Stainless Steel in the Water Industry, IGN 4-25-02, WRc
• UK – Operating Guidelines and Code of Practice, British Stainless Steel Association: an integral part of approval of stainless steel products by UK Drinking Water Inspectorate
• Germany – DIN 50930
  – Part 4 – evaluation of the corrosion likelihood of stainless steels
  – Part 6 – influence of the composition of drinking water
• France - ASTEE
• Similar guidelines elsewhere would increase correct use of stainless steels

Applications
Screens

Drinking water treatment

Slide gates
Drinking water treatment

316Ti pipework in Germany

Lightweight

Welded and flanged construction

Drinking water treatment

316 for ozone generator, Italy

316L ozone/chlorine mixer, USA
Drinking water treatment

316L granular activated carbon tanks, Italy

Reservoir lining

Stainless steel wallpaper lining of reservoir, Remscheid, Germany
Japanese study showing buildup of chlorides over time in a tank vapour space

Chloride Cl⁻ concentration, ppm

0 1 2 3 4 5 6 7 8
pH

10 100 1000 10000

17 months
15 months
6 months
3 months

Liquid in tank

On tank wall above liquid

Municipal water storage tank – Matsuyama, Japan

Roof + top 7.5m of side wall: 2205

Floor + 2.2m side wall: 304

4m intermediate side wall: 316

Staircase, Piping and ancillaries: 304
Distribution

Karlskoga, Sweden

150 mm pipe replacing cast iron and plastic

- Leak-free after 10 years
- Lightweight means lower cost installation

Cost comparison of distribution piping

<table>
<thead>
<tr>
<th>Nominal Pipe Diameter Inches</th>
<th>Ductile Iron Class 51</th>
<th>304 Sch. 10</th>
<th>316 Sch. 10</th>
<th>2304 Sch. 10</th>
<th>2205 Sch. 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1</td>
<td>1.03</td>
<td>1.11</td>
<td>1.22</td>
<td>1.45</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1.06</td>
<td>1.15</td>
<td>1.27</td>
<td>1.57</td>
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<tr>
<td>10</td>
<td>1</td>
<td>1.09</td>
<td>1.20</td>
<td>1.34</td>
<td>1.63</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0.82</td>
<td>0.91</td>
<td>1.02</td>
<td>1.26</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>0.69</td>
<td>0.75</td>
<td>0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>0.69</td>
<td>0.76</td>
<td>0.97</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* 2003 costs, relative to ductile iron
Distribution pipe

Vancouver, Canada

Grade selection in soil

• No stray currents
• No anaerobic bacteria
• pH > 4.5

<table>
<thead>
<tr>
<th>Résistivité (Ω.cm)</th>
<th>Concentration en ions chlorure (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td>&gt; 5000</td>
<td></td>
</tr>
<tr>
<td>2000 – 5000</td>
<td>1.4401 / 1.4362</td>
</tr>
<tr>
<td>1000 – 2000</td>
<td>1.4462</td>
</tr>
<tr>
<td>&lt; 1000</td>
<td></td>
</tr>
</tbody>
</table>

Arcelor Mittal
Pumping station pipework, New York

One of 3 pumping stations using cast stainless steel laterals and wrought butterfly valves

Valves must operate when needed!

1.07 m stainless steel valve
Reducing Leakage, Trenchless Techniques and Plumbing

Couplings and clamps

Stainless steel is widely used for couplings, tapping sleeves, spacers and restraining and repair clamps
Tunnel lining

Stainless steel waterproof membrane in tunnel lining, Rovereto, Italy

Reservoir lining

Stainless steel wallpaper lining of reservoir, Remscheid, Germany
Service pipe replacement, Tokyo

- 10 year programme
- **Leak-free – avoided need for a new reservoir**
- Earthquake resistant
- Ease of installation and 30% cheaper

Reducing Leakage

- Repair – stainless steel clamps
- Replace – strength of duplex may be advantage
- Reline – trenchless technology to avoid disruption

Padua, Italy

Trenchless technology minimises disruption

Push lengths up to 1 km

Costs for one example 40% of traditional full excavation

Nominated for European Sustainable Development Award in 2000
Trenchless technology

Pipe lengths are welded together in a small chamber then pushed inside the existing old main

Directional drilling to install water pipe through Mesa Verde National Park, USA
World Heritage Site

11 km of trenches unacceptable
Plumbing

- Growth continues in Germany – now ~15%
- Wide variety of fittings systems available
- Perception as an expensive option may be ignoring considerable time-saving during installation and more favourable costs for larger sizes.

Coiled stainless steel tubing for jointless hot or cold water supply in Japan

Mainly used in high-rise residential unit projects
Type 316 is used because it work hardens less than Type 304, making it easier to bend

Standard sizes:

<table>
<thead>
<tr>
<th>OD mm</th>
<th>Wall mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.52</td>
<td>0.7</td>
</tr>
<tr>
<td>12.7</td>
<td>0.8</td>
</tr>
<tr>
<td>15.88</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Plumbing

Pressfit system for joining stainless steel pipes

Using bronze pressfittings

Munich stadium
Stainless steel pipe and fittings, China

Japanese compression fitting which shows if the joint has been tightened

The red ring disappears when the fitting is tight

Designed to avoid problems experienced with pressfittings that were not crimped and which leaked in wall cavities
Water tank, Bangkok

Refurbishment of New York Plaza Hotel

Lightweight, grade 316
Stainless steel pressure piping for high rise buildings

The Aurora residential tower
Brisbane, Australia
69 levels
Completed May 2006
$250 million development

The Aurora residential tower – 69 levels

108 mm OD x 2 mm wall
Type 316 stainless steel
Pressfittings

Working pressure: up to 2600 kPa or 26 Bar
System can be pressure tested up to 4000 kPa or 40 Bar
Plumbing

Domestic hot water tank: usually 2304 duplex or 316L

Plumbing

Stainless steel tap, Italy
Durability, Life Cycle Cost and Recyclability

After 25 years!
Lightweight installation

Thin wall + high ductility → cheaper joining methods

Lightweight:

→ cheaper transport

→ more shop fabrication

→ cheaper support systems

→ cheaper installation

350 mm drinking water main in a sports stadium, Detroit, USA
Comparison of Initial Costs

Example taken from:
The Steel Construction Institute, UK    IGN 4-25-02, January 1999
Applications for Stainless Steel in the Water Industry

<table>
<thead>
<tr>
<th></th>
<th>DN150 6&quot;NB</th>
<th>DN300 12&quot;NB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Cost</td>
<td>Weight</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>208</td>
<td>346</td>
</tr>
<tr>
<td>Ductile iron</td>
<td>144</td>
<td>428</td>
</tr>
<tr>
<td>Saving over carbon steel</td>
<td>52%</td>
<td>71%</td>
</tr>
<tr>
<td>Saving over ductile iron</td>
<td>31%</td>
<td>77%</td>
</tr>
</tbody>
</table>

Cost Benefits of Using Stainless Steel

Costs over the life of the structure

- Smooth internal surfaces mean less energy for pumping
- Reduced inspection frequency and costs
- Reduced maintenance costs – no recoating
- Replacement is largely eliminated
- Reduced downtime
- Reduced leakage
- Long service life
- 100% recyclable at end of life
Life Cycle Cost =
(whole of life cost)

Initial Installed Costs
- Materials
- Fabrication
- Installation

+ Costs over the life of the structure
- Maintenance
- Replacement
- Disruption

Comparisons of Life Cycle Costs
Examples taken from:
The Steel Construction Institute, UK    IGN 4-25-02, January 1999
Applications for Stainless Steel in the Water Industry

Manhole equipment
Pipeline equipment
Ductwork in sewage inlet
Elevated tank equipment
Life Cycle Cost Example

- First stainless steel raw water pipe in India
- 300 mm x 3 mm replaced 13 mm cast iron
- Lightweight meant easy installation in hilly country
- >50 year life expected (2 replacements of cast iron in that time)
- **Smooth bore meant sustained low pumping costs**
- **LCC analysis: 60% saving over 50 years**

Life Cycle Cost Example

Lightweight bridges are used to carry potable water and pedestrians across river spans up to 632 m in Japan

85% Type 304
10% Type 316
Some 2205 near the coast

**No repainting**

**40% cheaper over 30 years**

First one built: 1983
Max pipe diameter: 0.8 m
Max weight of stainless steel: 45 tons
There are now ~3000 such bridges in Japan (10,000 tons of stainless steel)
Aerial sewer pipe carrying sewage from a housing estate in Auckland, New Zealand

60 m long, 300 mm dia x 3 mm wall spiral welded 316L pipe with flanges in 304L. It was lowered into place by helicopter.

Waste water treatment - LCC

Huddersfield, UK

Waste water treatment

- 98% reduction in maintenance costs
- 25% extra plant capacity
Stainless steel is fully recyclable

• Stainless steel melted today contains about 60% recycled material

• The growth in the use of stainless steel prevents that percentage from being higher

Further information, guidelines etc

• I D Inox – www.idinox.com
• Nickel Institute – www.stainlesswater.org

A shining example after 25 years!