Modern stainless steel solutions for road and rail
Metalforum Poznan

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Wolfgang Gebel
Stainless EMEA
Outokumpu

June 4th, 2014
Contents

1. Basic information
2. Introduction
3. Formability and Corrosion resistance
4. Type of Vehicles for public transportation
5. Arguments for Stainless Steels
6. New Austenitic CrMn- steels with high mechanical strength
The stainless steel families
Lattice types and microstructures

Face-centered cubic

0.36 nm

Austenite

Body-centered cubic

0.29 nm

Ferrite

Alloying elements and heat treatment determine the crystal structure.
The stainless steel families
Lattice types and microstructures

Different lattice types lead to different material properties.
Mechanical properties, 2B finish

Yield strength $R_{p0.2}$

Tensile strength $R_m$

Elongation $A_{80}$

<table>
<thead>
<tr>
<th>Material</th>
<th>$R_{p0.2}$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_{80}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4301/304</td>
<td>280</td>
<td>580</td>
<td>50</td>
</tr>
<tr>
<td>1.4509/441</td>
<td>320</td>
<td>600</td>
<td>45</td>
</tr>
<tr>
<td>1.4462/32205</td>
<td>350</td>
<td>620</td>
<td>40</td>
</tr>
</tbody>
</table>

6/10/2014
1. Basic information
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5. Arguments for Stainless Steels
6. New Austenitic CrMn- steels with high mechanical strength
What materials are usually used for the construction of rail cars?

- reinforced plastics
- aluminium alloys
- carbon steels and low-alloy steels
- stainless steels
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6. New Austenitic CrMn- steels with high mechanical strength
Ferritic and Duplex stainless steel grades for light weight constructions

Chemical compositions (typ.values) in mass-%

<table>
<thead>
<tr>
<th>Steel grades EN 10088 ASTM A240 OTK name</th>
<th>C</th>
<th>N</th>
<th>Cr</th>
<th>Ni*</th>
<th>Mo</th>
<th>Mn</th>
<th>others</th>
<th>Rp_{0.2} [MPa] Min values according to EN 10088</th>
<th>Alloy surcharge May 2014 [€/t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4003 S40977</td>
<td>0,02</td>
<td>0,02</td>
<td>11</td>
<td>0,5</td>
<td>&lt; 0,1</td>
<td>&lt; 1,5</td>
<td>-</td>
<td>&gt; 320</td>
<td>387</td>
</tr>
<tr>
<td>1.4600 S40977 Ti</td>
<td>0,02</td>
<td>0,02</td>
<td>11</td>
<td>0,8</td>
<td>&lt; 0,1</td>
<td>&lt; 2,0</td>
<td>Ti</td>
<td>&gt; 375</td>
<td>appr. 415</td>
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<tr>
<td>1.4589 S42035</td>
<td>0,04</td>
<td>0,01</td>
<td>14</td>
<td>1,6</td>
<td>0,25</td>
<td>&lt; 1,0</td>
<td>Ti</td>
<td>&gt; 420</td>
<td>576</td>
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<tr>
<td>1.4162 S32101 LDX 2101</td>
<td>0,02</td>
<td>0,22</td>
<td>21,5</td>
<td>1,5</td>
<td>0,3</td>
<td>5,0</td>
<td>Cu</td>
<td>&gt; 530</td>
<td>677</td>
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<tr>
<td>1.4362 S32304 2205</td>
<td>0,02</td>
<td>0,10</td>
<td>23</td>
<td>4,8</td>
<td>0,3</td>
<td>&lt; 1,5</td>
<td>Cu</td>
<td>&gt; 450</td>
<td>915</td>
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</tbody>
</table>

*Reducing of Nickel results in cost savings.
Austenitic stainless steel grades for light weight constructions

Chemical compositions (typ.values) in mass-%

<table>
<thead>
<tr>
<th>Steel grades EN 10088 ASTM A240 internal</th>
<th>C</th>
<th>N</th>
<th>Cr</th>
<th>Ni*</th>
<th>Mo</th>
<th>Mn</th>
<th>others</th>
<th>Rp_{0.2} [MPa] Min values according to EN 10088</th>
<th>Alloy surcharge May 2014 [€/t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4301 304</td>
<td>0,04</td>
<td>0,04</td>
<td>18,1</td>
<td>8,0</td>
<td>&lt; 0,5</td>
<td>-</td>
<td>Cu: &lt;0,4</td>
<td>&gt; 230</td>
<td>1186</td>
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<tr>
<td>1.4318 301 LN</td>
<td>0,02</td>
<td>0,14</td>
<td>17,7</td>
<td>6,5</td>
<td>&lt; 0,5</td>
<td>&lt; 2,0</td>
<td>-</td>
<td>&gt; 350</td>
<td>1012</td>
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<tr>
<td>1.4376 / H400</td>
<td>0,04</td>
<td>0,2</td>
<td>17,4</td>
<td>4,1</td>
<td>&lt; 0,5</td>
<td>6,8</td>
<td>-</td>
<td>&gt; 400</td>
<td>1030</td>
</tr>
</tbody>
</table>

*Reducing of Nickel results in cost savings.
Stainless steel grades
Work hardening effect

Ferritic Steel Grades

Austenitic Steel Grades

UTS and YP,0.2 [MPa]

Elongation [%]

Thickness reduction [%]

Tensile strength

0,2%-Yield strength

Elongation

0 10 20 30 40 50 60 70

0 10 20 30 40 50 60 70

0 10 20 30 40 50 60 70

1400 1200 1000 800 600 400 200

1400 1200 1000 800 600 400 200

6/10/2014
Properties of stainless steel grades for railway vehicles in comparison to carbon steels and Aluminum

<table>
<thead>
<tr>
<th>Yield strength $R_{\text{P0.2}}$ [MPa]</th>
<th>Elongation $A_{80}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>300</td>
<td>10</td>
</tr>
<tr>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td>500</td>
<td>30</td>
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<td>600</td>
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<td>700</td>
<td>50</td>
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<td>800</td>
<td>60</td>
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<tr>
<td>900</td>
<td>70</td>
</tr>
<tr>
<td>1000</td>
<td>80</td>
</tr>
<tr>
<td>1100</td>
<td>90</td>
</tr>
<tr>
<td>1200</td>
<td>100</td>
</tr>
</tbody>
</table>

- **1.4301 (304)**
- **1.4318 (301LN)**
- **1.4318 TR (301LN ¼ to ½ hard)**
- **1.4362 (S32304)**
- **Nirosta®H400**
- **LDX 2101 (S32101)**
- **1.4003 (S40977)**
- **1.4018 (301LN) ¼ to ½ hard**
- **1.4589 (S42035)**
- **Al and Al-alloys**
- **Carbon Steels**

Only stainless steel features high strength combined with good formability.

New developments.
Why stainless steel does not show red rust?
Self-passivation effect

Initial state:
Fe with embedded Cr atoms

Chromium reacts with oxygen from the air, the passive layer is formed (self-passivation)

Compact passive layer of chromium oxide
Spectrum of Stainless Steels for transportation systems

Corrosion resistance (PRE-Index, Duplex PREN-Index)

Mechanical properties (Yield strength)

- Ferritic
  - 1.4301
  - 304

- Austenitic
  - 1.4318
  - 301LN
  - Nirosta®H400
  - 1.4589
  - S32304
  - H400
  - 1.4589
  - S42035
  - H500
  - 1.4600
  - S40977

- Duplex
  - 1.4318 TR
  - 301LN ¼ hard
  - 1.4318 TR
  - 301LN ½ hard
  - 1.4589
  - S40977
  - H800
  - H1000

1.4003 S40977 Ti
Corrosion attack of different steel grades after one year exposure

Atmospheric exposure (Cuxhaven, sea side)

- 1.4003 S40977
- 1.4589 S42035
- 1.4301 304

Maritime exposure (Helgoland island, swash zone)

- 1.4003 S40977
- 1.4589 S42035
- 1.4301 304
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Light Rail Vehicles

Total network
7.303 km

EU 15; 98 networks
4.918 Network kilometers

new member states;
26 networks
2.122 network kilometers

other European states;
8 networks
263 network kilometers

Reference: Metro, light rail and tram systems in Europe, Errac UITP, 2009

Reference: Stadler Rail
Implemented projects in ferritic grades, Light Rail Vehicles

Bombardier, Flexity, new Light Rail Vehicle of Krefeld city, 2010
Ferritic steel stainless grade: 1.4003 / S40977, painted

Reference: Stadtwerke Krefeld AG
Implemented projects in ferritic grades, Light Rail Vehicles

Stadler, Tango, new Light Rail Vehicle of Basel city, 2008
Ferritic steel stainless grade: 1.4589 / S42035, painted

Reference: Stadler Rail und Badische Zeitung
Implemented projects in ferritic grades, Metros

Berliner S-Bahn, Bombardier (former LEW Hennigsdorf), ongoing since 1990
Ferritic steel stainless grade: 1.4589 / S42035, painted

Reference: Wikimedia Commons, Creative Commons
Implemented projects in austenitic grades, Metros

Strong growing in Asia demands stainless steel for Metro vehicles

Metro Delhi, Bombardier, 2010
Austenitic steel stainless grade: 1.4318 / 301LN; 1.4307 / 304L brushed

Reference: Bombardier Transportation
Implemented projects in austenitic grades, Metros

Hamburger Hochbahn DT5, 2009
Austenitic stainless steel grade: 1.4318 / 301LN, side panel: 2G (grain 320 + brushed)

Roof connection  
\[ t = 2,0 \text{ mm} \]

Resistant spot welding

Side frame with windows  
\[ t = 2,0 \text{ mm} \]

Resistant spot welding

Side frame without windows  
\[ t = 1,5 \text{ mm} \]
Commuter and Regional Trains, Double-deck Coaches, ferritic grades

Double-deck Coaches of German Railways, Bombardier, ongoing
Ferritic steel grade: 1.4003 / S40977, painted

Reference: Wikimedia Commons, Creative Commons, RsVe
Commuter and Regional Trains, Multiple Units (MU), ferritic grades

Talent, Bombardier

Coradia Lint, Alstom

Commuter and Regional Trains, Electric and Diesel Multiple Units, ongoing
Ferritic steel grade: 1.4003 / S40977, painted

Reference: Wikimedia Commons, Creative Commons
1.4600 for ore/coal railway cars

Steel grade: 1.4600/1.4003 Ti
(≈S40977Ti)
Surface finish: 1D
Gauge: 3.00-8.00 mm
Customer: Sandvik (Australia)
End use: Railway cars (mining)
Demands: Corrosion resistant, weldable
Benefits: Cost-effective, weldable stainless steel

Australian ore / coal railway car
Ferritic stainless steel grade: 1.4600 / S40977 Ti
Example of a city bus made of ferritic stainless steel 1.4003 / S40977

Reference: Solaris bus and coach
Selection criteria for materials

Why is stainless steel the ideal material for railway vehicles? Certainly because of its corrosion resistance, but additionally there is a wide range of different useful properties, which cannot be offered for low cost.

<table>
<thead>
<tr>
<th></th>
<th>Stainless steels</th>
<th>Carbon steels</th>
<th>Aluminium alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Construction</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>++</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Weight, energy consumption, wear, lifecycle</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Repairing feasibility</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Experience</td>
<td>o/+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Mechanical loading cases</td>
<td>++</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Price</td>
<td>o</td>
<td>++</td>
<td>0</td>
</tr>
<tr>
<td>Lifecycle costs</td>
<td>++</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
Actual distribution of steel grades for railway vehicles in Europe

1.4589 / S42035
14% Cr + 1.6% Ni
11%

1.4318 / 301 LN
17% Cr + 7% Ni
10%

1.4301; 1.4307 / 304; 304L
18% Cr + 8% Ni
4%

Others
1%

Résumé for today:
Biggest volume for the
• cheapest steel grade with
• the lowest light weight
capability and
• lowest corrosion resistance

1.4003 / S40977
11% Chromium
74%

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Some arguments for stainless steels from the press releases of our customers

Light weight
- 10% weight reduction results in 7% energy saving for a metro system
- Weight reduction results in a lifetime increase for wheel rims.

Corrosion
- Stainless steel bodies are more expensive but they are durable and have low maintenance costs.
- A life-time of over 30 years without harmful corrosion attacks
- Car bodies made of stainless steel are very sustainable.

Manufacturing
- Good weldability.
- Also in case of an accident vehicles are easy to repair.
Some arguments for stainless steels from the press releases of our customers

**Low-floor vehicles**
- A lot of aggregates have to displaced onto the roof.
- 30% of the length consists of doors.
Both results in a very high pressure of the body, especially under oscillating loads. Therefore high strength stainless steels are the best choice for the construction.

**Recyclability**
Bodies of stainless steel vehicles are totally recyclable without any loss in quality of the steel grade. Every standard stainless steel grade is a recycled material.
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OEM´s have more than 15 years of experience with austenitic steels (H400)

Lightweight solution by:
high mechanical strength and high ductility properties.

• Advantage of the material:
  Excellent formability because of limited space.

• Lightweight potential: 20% weight saving by reduction of thickness

• Better fatigue behavior.

• Almost the same hardness in the weld seam and in the base material.
Demand of all car manufacturers: 3rd Generation AHSS (Advanced high strength steel)

Elongation after fracture $A_{80} [%]$

Yield strength $R_{P0.2} [\text{MPa}]$

1.4301 / 304
H400
1.4003 S40977

3rd generation of AHSS

Ferritic carbon Steels
3 Generation AHSS steels

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Cost effective light weight material

- High Cr and Ni content
  - High mechanical strength
  - Excellent ductility

- High Cr and low Ni content
  - Higher mechanical strength
  - Excellent ductility

- High Cr and high Ni content
  - Very high mechanical strength
  - Excellent ductility

- Low Cr content; No Nickel
  - Extreme high mechanical strength
  - Excellent ductility

Alloying design

1.4301 / 304
18-8

Rp_{0.2} temper rolling

1.4310 C1000
17-7

Rp_{0.2} phase transformation

H400
18-4

H500
14-0

H600 – H1000
14-0

H1200 PH
13-0

High Cr and Ni content
High mechanical strength
Excellent ductility

High Cr and low Ni content
Higher mechanical strength
Excellent ductility

High Cr and high Ni content
Very high mechanical strength
Excellent ductility

Low Cr content; No Nickel
Extremely high mechanical strength
Excellent ductility

Cost effective light weight material

1.4301 / 304
18-8

Rp_{0.2} temper rolling

1.4310 C1000
17-7

Rp_{0.2} phase transformation

H400
18-4

H500
14-0

H600 – H1000
14-0

H1200 PH
13-0

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Our material design strategy – H500 and its temper-rolled variants H800 / H1000

- Ni-free Cr-Mn austenitic stainless steel
- Ni substituted by Mn, C and N

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>N</th>
<th>Mo</th>
<th>PRE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>H500 (H800 / H1000)</td>
<td>0.31</td>
<td>16.0</td>
<td>14.20</td>
<td>0.45</td>
<td>0.30</td>
<td>0.03</td>
<td>19</td>
</tr>
</tbody>
</table>

*PRE = %Cr + 3.3 x %Mo + 16 x %N

<table>
<thead>
<tr>
<th></th>
<th>Rp0.2 [MPa]</th>
<th>Rm [MPa]</th>
<th>A80 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H500</td>
<td>540</td>
<td>910</td>
<td>45</td>
</tr>
<tr>
<td>H800</td>
<td>780</td>
<td>1000</td>
<td>33</td>
</tr>
<tr>
<td>H1000</td>
<td>990</td>
<td>1200</td>
<td>16</td>
</tr>
</tbody>
</table>
TIG welding

Quasistatic tensile test

<table>
<thead>
<tr>
<th></th>
<th>Nirosta® H500</th>
<th>Nirosta® H800</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIG (100%Ar)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>WIG (Ar+He)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Plasma</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Zugkraft $F_{max}$ [kN]

- Blue: Nirosta® H500 – H500
- Light Blue: Nirosta® H800 – H800
Material is now commercially available

Vari-Form: H800 Hydro formed
Crash behaviour

- dynamic three point bending test:
  - Drop height $h = 2.50\text{m}$
  - Drop mass $m = 57.90\text{kg}$
  - Speed $v_0 = 24.50\text{km/h}$

Video: TIG tailored H800 / H1000 (1.5mm) with closing plate HC340LA+ ZE
Crash behaviour

- axial crash test with rectangular tube:
  - Drop height $h = 4,00\text{m}$
  - Drop mass $m = 433\text{kg}$
  - Speed $v_0 = 30,73\text{km/h}$

TIG welded H800 (1,5mm)
Crash behavior of the B-Pillar comparison between C-steel grade with Rm = 1600 MPa; t=1.7mm and H1000; t=1.1mm

Not optimized in design for austenitic steels
Interpretation of the IIHS schematic view

C-steel grade with $R_m = 1600$ MPa; $t=1.7$mm and H1000; $t=1.1$mm – max. Intrusion

C-Steel grade
$R_m=1600$ MPa, $t=1.7$mm

H800
$t=1.1$mm

Same safety for passengers with reduced thickness
CrMn-Steels - Solution for 3rd Generation AHSS
Between 30-50% light weight potential compared to ferritic grades

Cost saving due to thickness reduction

Material is now commercially available

Elongation after fracture $A_{80} [%]$

Yield strength $R_{P0.2} [MPa]$

1.4301 / 304
H400
H500
H800
H1000

1.4003
S40977

1.4003
S40977

1.4301 / 304
H400
H500
H800
H1000

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We estimate that more than 300 kg weight reduction is possible by replacing 1.4003 with H800

Ferritic stainless steel 1.4003 / S40977 in rectangular tube construction before painting
Excellent processability in press plant, assembly plant and painting shop.

<table>
<thead>
<tr>
<th>On the road</th>
<th>ED Coating</th>
<th>Assembling line</th>
<th>Stamping plant</th>
<th>Sheet conditioning</th>
<th>Simulation</th>
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</thead>
<tbody>
<tr>
<td>Crash</td>
<td>Stone chipping</td>
<td>Spot welding</td>
<td>Formability</td>
<td>Hole expansion</td>
<td>Crash</td>
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<tr>
<td>Fatigue</td>
<td>Paint bonding</td>
<td>Spotweld adhesive</td>
<td>Press force</td>
<td>Formability</td>
<td>Formability</td>
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<tr>
<td>Corrosion</td>
<td>Adhesive Bonding</td>
<td>MIG</td>
<td>Tribology</td>
<td>Springback</td>
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<tr>
<td>Recycling</td>
<td>Contact corrosion</td>
<td>MIG solder</td>
<td>Laser</td>
<td>Trim Egde</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Clinch</td>
<td>Critical press form</td>
<td></td>
</tr>
</tbody>
</table>

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New MnCr steels from Outokumpu Nirosta

- Ready for delivery
- First small series in application and OEM enabling processes started
- High joinability for a lot of joining procedures and material partners

CrMn steels for more security, more complexibility, higher crash absorption and lightweight potential
Many thanks for Your attention

All statements as to the properties or utilization of the materials and products mentioned in this presentation are for the purpose of description only. Guarantees in respect of the existence of certain properties or utilization of the material mentioned are only valid if agreed upon in writing.