INTRODUCTION TO STAINLESS STEEL

M. O. Lewus
Technical Advisor,
BSSA

TWI Technology Centre,
Riverside Park, Middlesbrough
18/06/15
SUMMARY

- The BSSA
  - What we do!
- What makes stainless steel stainless: ‘the passive layer’
- 5 Types of Stainless Steel
  - Metallurgy
    - Structure
    - Mechanical and physical properties
    - Applications
- Structure, composition and property factors affecting weldability
# BSSA: WHAT WE DO

## HELP & ADVICE
- The Stainless Steel Advisory Service (SSAS)
- Website: [www.bssa.org.uk](http://www.bssa.org.uk) (>1.5 million hpy)
- To date, over 42,000 technical enquires answered

## TRAINING & EDUCATION
- Starter and Advanced Stainless Steel Courses
- Fabrication Seminars
- Bespoke in-company Courses
- Open seminars (e.g. CE Marking), eNewsletters, Information campaigns

## EVENTS
- Forums
- Conferences
- Networking social functions

## MARKET DEVELOPMENT
- CPDs for architects
2 Current Courses:
1. Intro. to Stainless Steel
2. Mechanical Testing Techniques
BSSA: CPDs

• RIBA Approved CPDs

1. Stainless Steel for Architects

2. Specifying Stainless Steel for Architectural Applications

3. Designing Building Exteriors in Stainless Steel

4. Stainless Steel in Swimming Pools
Snap-shot of 2015

>75% concerned with standard grades – technical enquiries from: manufacturers (25%), Stockholders (21%), Fabricators (13%), End users (8%)

Technical Issues:
- Material selection
- Specification/grade
- Supply of materials
- Corrosion
- Surface treatment
DEFINITION OF STAINLESS STEEL & THE PASSIVE LAYER
What is a stainless steel?

An increasing wt.% of chromium dramatically reduces atmospheric corrosion until its content is sufficient for stainless steel.

Stainless steels are iron alloys containing a minimum of 10.5wt. % chromium (and ≤ 1.2wt.% C) [BSEN 10088/1]
What makes stainless steel corrosion resistant?

- Passive Film – Chromium Rich Oxide
- Self forming passive film protects the damaged surface
STAINLESS STEEL: THE PASSIVE LAYER (2)

- Metal + air → metal oxide

- Different types of oxide
  - Iron oxide on carbon steel: porous - allows further oxidation
  - Chromium oxide on stainless steel: not porous, is stable and usually prevents further oxidation

- Passive layer is very thin – 1/10000 the thickness of human hair ranges from 2/3 to 10’s of atomic layers thick

- Points to Note!
  - Passivation is accelerated by oxidising acids e.g. citric or nitric
  - Welding can adversely effect the passive film – depletes chromium from surface
  - Chlorides & reducing acids adversely effect the passive layer

- No stainless steel resists all environments
5 TYPES OF STAINLESS STEEL

- Austenitic: most common, ~70% of total usage
- Ferritic: ~20%
- Ferritic-Austenitic (duplex): 3%
- Martensitic: ~5%
- Precipitation Hardened (PH): can be fully austenitic, semi austenitic or martensitic, ~2%
5 TYPES OF STAINLESS STEEL: STRUCTURES

409 Ferritic st/st

316 Austenitic st/st

2205 Duplex st/st

403 Martensitic st/st (x400)

Custom 455 PH Steel (x1000)
# AUSTENITIC STAINLESS STEELS

- A closer look ……

<table>
<thead>
<tr>
<th>No</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Easy to Produce</td>
<td>Subject to price swings – Ni cost variable</td>
<td>Sinks, saucepans, cutlery, cladding, handrails, catering surfaces, chemical, pharmaceutical, food processing, oil and gas, street furniture, hospital equipment, MRI scanners, building products e.g. wallties, furnaces, electrical energy, cryogenic storage vessels, springs, rail carriages, high spec exhaust systems, process piping, medical devices, water tubing, nuclear processing, yacht trim</td>
</tr>
<tr>
<td>2</td>
<td>Formable – stretch forming &amp; deep draw</td>
<td>High alloy grades very expensive</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td><strong>Weldable thick sections</strong></td>
<td>Not heat treatable in bulk</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Low temperature toughness</td>
<td><strong>Low thermal conductivity</strong></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Oxidation resistance</td>
<td>Difficult to machine</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>High alloy grades give high corrosion resistance</td>
<td><strong>High thermal expansion leads to distortion</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Strengthened by cold work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Non-magnetic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### FERRITIC STAINLESS STEELS

#### Advantages

1. Formable – deep drawing
2. Oxidation resistance
3. High alloy grades giving high level of corrosion resistance
4. Price stability – low Ni
5. Similar thermal props. to carbon steels
6. Resistant to stress corrosion cracking

#### Disadvantages

1. Not weldable in thick sections
2. Not as stretch formable as austenitic grades
3. Not as easy to produce
4. Not heat-treatable
5. Poor low temp. toughness

#### Applications

Washing machine drums, automotive exhaust systems, catering equip., microwave oven linings, cheaper cutlery, hot water tanks, internal decorative tubing, automotive trim, induction heating saucepans, window hinges, ventilation ducting, lift panels, electrical enclosures, coal wagons, initial food handling e.g. sugar beet, containers, bus chassis

---

**A closer look ……**
### A closer look ……

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heat treatment gives wide range of props.</td>
<td>Poor weldability in most grades (low carbon grades OK)</td>
<td>Razor strip, high quality knife blades, scalpels, shafts, hydraulic rams, wear resistant plate, oil and gas</td>
</tr>
<tr>
<td>2</td>
<td>High strength with moderate toughness at RT</td>
<td>Poor low temperature toughness</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Good high temperature strength</td>
<td>Process route, more complex than austenitic</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Good for blades</td>
<td>Limited corrosion resistance</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Price stability – low Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Similar thermal props. to carbon steels</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## DUPLEX STAINLESS STEELS

- **A closer look ……**

<table>
<thead>
<tr>
<th>No</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 x strength of austenitics, hence thickness and wt. reduction</td>
<td>Complex metallurgy, difficult processing to achieve phase balance</td>
<td>Chemical processing, subsea oil and gas, structural applications, bridges, hot water tanks, pulp and paper, desalination plants</td>
</tr>
<tr>
<td>2</td>
<td>Moderate low temperature toughness</td>
<td>More care required in welding</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Weldable in thick sections</td>
<td>Higher power needed for forming</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Resistance to Stress Corrosion Cracking</td>
<td>More difficult to machine than austenitics (one exception)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Better price stability than austenitic, particularly lean duplex</td>
<td>Limited to 300 deg C maximum</td>
<td></td>
</tr>
</tbody>
</table>
### PH STAINLESS STEELS

- **A closer look ……**

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very high strength and better toughness than martensitic</td>
<td>Quite expensive</td>
<td>pumps, shafts, valves, critical aerospace components</td>
</tr>
<tr>
<td>2</td>
<td>Better corrosion resistance than martensitic</td>
<td>Complex process route</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Not easy to weld</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Not easy to form</td>
<td></td>
</tr>
</tbody>
</table>
MECHANICAL
AND PHYSICAL
PROPERTIES
TENSILE STRENGTH

- Tensile Properties
  A = Austenitic
  B = Ferritic
  C = Duplex
  D = Martensitic
  E = PH

Stress, MPa vs Strain, %

*Note: The image shows a graph with curves labeled A, B, C, D, and E, each representing different materials with their respective stress-strain properties.*
**TENSILE STRENGTH**

![Graph showing tensile strength and 0.2% Proof/Yield Strength for different materials: Austenitic (316), Duplex (2205), Ferritic (430), Martensitic (H&H-410), 17-4PH (H900-Martensitic), Mild Steel, Aluminium, Brass.](image)

- **Tensile Strength, MPa**
- **0.2% Proof/Yield Strength, MPa**

**Elongation, %**

- Austenitic (316)
- Duplex (2205)
- Ferritic (430)
- Martensitic (H&H-410)
- 17-4PH (H900-Martensitic)
- Mild Steel
- Aluminium
- Brass

18/06/2015

Dr Mike Lewus, BSSA Technical Advisor
• **Toughness**
  ‘Resistance to crack propagation’

Austenitics very tough even at cryogenic temperatures

All other stainless types exhibit prominent ductile-brittle transition, typically at sub zero temperatures
Fatigue Endurance Limit: Austenitic and Duplex

<table>
<thead>
<tr>
<th>Grade</th>
<th>0.2% PS, MPa</th>
<th>UTS, MPa</th>
<th>Fatigue Limit, MPa</th>
<th>Fatigue / UTS Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4301 (304)</td>
<td>210</td>
<td>520</td>
<td>234</td>
<td>0.45</td>
</tr>
<tr>
<td>1.4401 (316)</td>
<td>220</td>
<td>520</td>
<td>234</td>
<td>0.45</td>
</tr>
<tr>
<td>1.4462 (2205)</td>
<td>460</td>
<td>640</td>
<td>384</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Stress for rupture in 1000hr: Martensitic, Ferritic, Austenitic
# THERMAL PROPERTIES

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thermal Expansion ($10^{-6} \text{ K}^{-1}$)</th>
<th>Thermal Conductivity (W m$^{-1}$ K$^{-1}$)</th>
<th>Density (kg m$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4016 Ferritic</td>
<td>10.0</td>
<td>25</td>
<td>7.7</td>
</tr>
<tr>
<td>1.4057 Martensitic</td>
<td>10.0</td>
<td>25</td>
<td>7.7</td>
</tr>
<tr>
<td>1.4301 Austenitic</td>
<td>16.0</td>
<td>15</td>
<td>7.9</td>
</tr>
<tr>
<td>1.4462 Duplex</td>
<td>13.0</td>
<td>15</td>
<td>7.8</td>
</tr>
<tr>
<td>1.4542 PH</td>
<td>10.9</td>
<td>16</td>
<td>7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thermal Conductivity</th>
<th>Thermal Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>304</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>430</td>
<td>3.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
FACTORS AFFECTING WELDABILITY
WELDING ISSUES: ‘SENSITIZATION’ AND IC

C = 0.05%, Cr = 17%  
C = 0.05%, Cr = 18%, Ni = 8%  

18% Cr, 8% Ni  
18% Cr, 8% Ni  
18% Cr, 8% Ni

C = 0.059%, Nb = 0.64%  
C = 0.052%, Ti = 0.40%  

Cr
Si
C
α/γ
N
Mo
Nb
Ti
WELDABILITY OF AUSTENITIC STAINLESS STEEL

• Positive factors
  • Low carbon – reduces risk of sensitization
  • Single phase – no concern about structure changes
  • No preheat or post weld heat treatment
  • Low grain growth - weld toughness retained in large sections

• Negative Factors
  • High thermal expansion and low thermal conductivity
  • Solifidification cracking – composition balanced to give 5-10% ferrite
  • Risk of distortion in thin sections
WELDABILITY OF FERRITIC STAINLESS STEEL

- **Positive factors**
  - Low carbon – reduces risk of carbide formation
  - Single phase
  - Lower thermal expansion and higher thermal conductivity hence lower risk of distortion

- **Negative Factors**
  - High grain growth - loss of weld toughness in thick sections
  - Exception 1.4003 (S40977) – low carbon martensite allows welding of thick sections
WELDABILITY OF DUPLEX STAINLESS STEEL

• Positive factors
  • Part austenitic – relative good toughness in thick sections down to minus 80°C

• Negative Factors
  • Complex metallurgy, for phase balance - tight control of welding parameters required
  • Embrittling phases relatively easy to form
  • Potential for loss of corrosion resistance and mechanical properties
  • Specific weld and welder qualification required
Positive factors
- Low carbon – reduces risk of carbide formation
- Single phase
- Lower thermal expansion and higher thermal conductivity
- Leading to reduced distortion

Negative Factors
- High grain growth - loss of weld toughness in thick sections
- Exception 1.4003 (S40977) – low carbon martensite allows welding of thick sections
WELDING STAINLESS TO STAINLESS: RULES OF THUMB

• Dissimilar Welding
  • Choice of filler usually determined by the more highly alloyed metal e.g. when welding 1.4307 (304L) to 1.4404 (316L) for example, 19Cr12Ni3Mo type filler used

• Ferritic Steels
  • When welding ferritic grades, austenitic fillers are often selected to improve mechanical properties

• Superaustenitic grades
  • For superaustenitic grades, nickel-base fillers over alloyed with molybdenum are often used to compensate for segregation - reduce the amount of intermetallic phases!

• High Temperature Austenitics
  • To avoid the detrimental effect of secondary phases precipitating at 650-960°C specially designed fully austenitic fillers (253 MA-NF) can be used
When Welding Stainless Steel to Mild Steel:-

- To optimise crack resistance use over alloyed and high ferrite electrode (23Cr12Ni or 23Cr12Ni2Mo)

- When welding stainless steel to mild or low alloy steels reduce weld dilution as much as possible. Limit heat input to 1.4kJ/mm and interpass temperature must be <150°C

- Due to risk of pore formation avoid welding to mild steel that has a coating of prefabrication primer

- Where High temperature applications (creep properties) are important use nickel base fillers to minimise carbon diffusion from mild steel into the weld metal – this can reduce strength of HAZ in mild steel
Recommended practice is to clean welds
In practice, many welds are left untreated - very light tinting, non-aggressive environments, invisible applications