Duplex Stainless Steel Fabrication

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International Molybdenum Association
Promoting molybdenum - as a material with superior properties and performance in a wide variety of metallurgical, chemical and other product applications

Expanding the applications in which molybdenum is used via:

- Market development programs
- Co-operation with consumers, end-users and allied organizations
- Technical brochures and training seminars to explain the advantages of using molybdenum-containing products in various industries
Presentation Overview

• What is Duplex Stainless Steel?
• Chemical Composition
• Mechanical Properties
• Cutting
• Forming
• Machining
• Welding
• Post-Fabrication Cleaning
## Types of Stainless Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austenitic</td>
<td>Type 316</td>
</tr>
<tr>
<td>Ferritic</td>
<td>Type 430</td>
</tr>
<tr>
<td>Duplex</td>
<td>Type 2205</td>
</tr>
</tbody>
</table>
## Chemical Composition

<table>
<thead>
<tr>
<th>Type</th>
<th>%Cr</th>
<th>%Ni</th>
<th>%Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>316 (austenitic)</td>
<td>17</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>430 (ferritic)</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2205 (duplex)</td>
<td>22</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>
## ASTM Mechanical Properties (Minimum Limits)

<table>
<thead>
<tr>
<th>Type</th>
<th>Yield (ksi)</th>
<th>Tensile (ksi)</th>
<th>Elong. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>304L</td>
<td>25</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>316L</td>
<td>25</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>2205</td>
<td>65</td>
<td>95</td>
<td>25</td>
</tr>
</tbody>
</table>
What is Duplex Stainless Steel?
Duplex Stainless Steels Consist of Austenite and Ferrite
## Duplex Stainless Steel Types

<table>
<thead>
<tr>
<th></th>
<th>Type</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lean</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2304</td>
<td>23% Cr, 4% Ni</td>
</tr>
<tr>
<td></td>
<td>LDX 2101</td>
<td>21% Cr, 1% Ni</td>
</tr>
<tr>
<td></td>
<td>2202</td>
<td>22% Cr, 2% Ni</td>
</tr>
<tr>
<td></td>
<td>2102</td>
<td>21% Cr, 2% Ni</td>
</tr>
<tr>
<td><strong>Standard</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2205</td>
<td>22% Cr, 5% Ni</td>
</tr>
<tr>
<td><strong>Super</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2507</td>
<td>25% Cr, 7% Ni</td>
</tr>
</tbody>
</table>
Advantages of Duplex

- Strong
- Stress corrosion cracking resistant
- Pitting / crevice corrosion resistant
- Erosion resistant
- Fatigue resistant
- Cost effective (lower nickel contents)
Cutting Stainless Steel
Cutting Duplex Stainless Steel

- Mechanical
  - Sawing
  - Shearing
  - Abrasive wheel cutting
  - Water-jet cutting

- Thermal
  - Plasma cutting
  - Laser cutting
Cutting: Sawing

- Similar to austenitic stainless steel
- Powerful machine
- Proper blade alignment
- Coarse toothed blade
- Slow to moderate cutting speed
- Heavy feed
- Generous flow of coolant
Cutting, Mechanical Shearing

- More force and heavier equipment will be required to shear stainless steel compared to carbon steel.
- Carbon steel - 1/2” thick shear limit.
- Austenitic stainless steel - 1/4” max.
- Duplex stainless steel - 3/16” max.
Mechanical Shearing

- A general clearance guide is to use a clearance of 5% of the metal thickness between shear knives.
- To counter the shearing force required for duplex stainless steel, the hold down pressure on the clamps may have to be increased.
- BLADES MUST BE SHARP!
Abrasive Cutting

- Abrasive wheels, rotating at high speed can be used for straight line cutting of sheet and thin gauge plate and for cut-off operations on relative small sections
- Thick section cut-off operations are usually done wet
- Use uncontaminated vitrified or resin-bonded wheels
- DO NOT INDUCE OVER-HEATING
Cutting: Plasma and Laser

- Same equipment as for 304/316
- Optimum parameters vary slightly
Bending - Springback

• Duplex stainless steels, with their higher strength and higher rate of work hardening, require more power to bend than carbon steel

• Duplex stainless steel must be bent further than carbon steel to result in the same angle since there is more springback
Minimum Bending Force

- **Bending Force (kN)**
  - 2205
  - 2304
  - 316L

**Stainless Steel Grades**
Forming Stainless Steels

- Duplex stainless steels have high work hardening rates - the strength increases as they are formed
- Greater springback than carbon steels
- Avoid contamination from tooling: Use dedicated tooling, or provide surface protection
Avoid Iron Contamination!
Avoid Contamination from Tooling During Forming

- Ensure particles such as carbon steel or rust are not pressed into the surface
- Adopt some combination of the following guidelines:
  - Use dedicated tooling
  - Clean all contamination from the surface of tooling before use
  - Do not use carbon steel tooling - use tool steel or stainless steel or hard chrome plated tooling
  - Protect the surface of the stainless steel
Cold Forming

- Duplex ductility lower than austenitic
  - avoid sharp bend angle
  - bend radius at least twice the thickness
- Duplex much stronger than austenitic
  - higher forces necessary
  - more spring-back
- Duplex cold works readily
  - Requires more annealing stages than austenitic
Hot Forming

- Avoid critical temperature range for sigma phase (1300 - 1800°F)
- Duplex is very soft between 1750 and 2100°F
  - easy to hot form
# Hot Forming Temperature Range

<table>
<thead>
<tr>
<th>Grade</th>
<th>Hot Forming Temperature Range</th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>2205</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1100 to 950</td>
<td>2010 to 1740</td>
</tr>
<tr>
<td>25 Cr Duplex</td>
<td></td>
<td>1150 to 980</td>
<td>2100 to 1795</td>
</tr>
<tr>
<td>2507</td>
<td></td>
<td>1200 to 1025</td>
<td>2190 to 1875</td>
</tr>
<tr>
<td>Types 304/316</td>
<td></td>
<td>1205 to 925</td>
<td>2200 to 1700</td>
</tr>
</tbody>
</table>
Hot Forming

- Lower temperature can cause cracking
- Higher temperature can cause tearing
- Full solution annealing after hot forming
# Minimum Annealing Temperature

<table>
<thead>
<tr>
<th>Grade</th>
<th>Minimum Annealing Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>2205</td>
<td>1040</td>
</tr>
<tr>
<td>25 Cr Duplex</td>
<td>1040</td>
</tr>
<tr>
<td>Superduplex</td>
<td>1025 to 1100</td>
</tr>
<tr>
<td>(depending on grade)</td>
<td></td>
</tr>
</tbody>
</table>
Machining
Machining Duplex

- High work hardening
- Low thermal conductivity
- High toughness
- “sticky”
- Poor chip breaking
General Rules for Machining

- Good edge sharpness
- Cutting tool with high edge strength
- Sufficient cutting depths
- Frequent insert replacement
Comparison
Austenitic - Duplex

Alloy content $\uparrow \Rightarrow$ machinability $\downarrow$

- Duplex: harder
- Duplex: faster strain hardening
- Higher tool wear
- Lower machinability
# Face Milling with Cemented Carbides

<table>
<thead>
<tr>
<th>Stainless Steel or machining data</th>
<th>Roughing</th>
<th>Finishing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed (m/min)</td>
<td>Speed (s/min)</td>
</tr>
<tr>
<td>Lean duplex (2304)</td>
<td>100-130</td>
<td>330-425</td>
</tr>
<tr>
<td>2205</td>
<td>50-80</td>
<td>165-260</td>
</tr>
<tr>
<td>Superduplex</td>
<td>30-50</td>
<td>100-165</td>
</tr>
<tr>
<td>Feed (per tooth)</td>
<td>0.2-0.4 mm</td>
<td>0.008-0.075 in.</td>
</tr>
<tr>
<td>Depth of cut</td>
<td>2-5 mm</td>
<td>0.080-0.200 in.</td>
</tr>
<tr>
<td>Carbide Grade</td>
<td>2304, 2205: ISO P20-P40</td>
<td>2304, 2204: ISO P10-P25</td>
</tr>
<tr>
<td></td>
<td>Superduplex: ISO P25-P40</td>
<td>Superduplex: P20-P30</td>
</tr>
</tbody>
</table>
Summary

• Machinability generally lower than standard austenitic grades (300-series)
• Higher forces necessary for machining and forming
• Adjust parameters to optimize
Duplex Stainless Steel Welding
Similarities: Austenitic vs. Duplex

- **Same pre-weld joint cleaning**
  - Remove all debris, dirt, paint and oil
  - Remove water or moisture

- **Same joint preparation**
  - Remove heavy oxides
  - Remove rough grinding burrs
  - Same edge geometry
  - Machine or grind edge profile

- **Similar joint design**
  - Provide backing gas shielding
  - Ensure full penetration weld
Differences: Austenitic vs. Duplex

Duplex weld / HAZ sensitive to:

- Excessive ferrite
- Sigma phase

“You can’t tell from the outside”
Differences Austenitic vs. Duplex

• Qualification extremely important
  • Appearance of weld gives no indication of quality
  • Written procedures and trial welds necessary to assure quality
Differences Austenitic vs. Duplex

- Less thermal expansion - less distortion
- Less hot cracking
- Sensitive to H₂-cracking
  - Remove moisture from joint
  - Store electrodes at elevated temperature
  - Avoid hydrogen in backing or shielding gas
Metallurgy: Phase Balance

- Don’t quench too quickly
- No wash passes or spot welds
- Intermediate heat input
- Filler metal mandatory
- Nickel over-alloyed filler
- Nitrogen in shielding gas is beneficial
- Remove tack welds in final fabrication
Metallurgy:  Sigma Phase

- Don’t cool too slowly
- Avoid high heat input
- Inter-pass temperature < 300°F
- Heat input 15 - 60 KJ/inch (2205)
- Qualify all welding procedure
- Qualify weld repairs
Welding Processes for Duplex Stainless Steel

- Shielded Metal Arc Welding: SMAW, covered electrodes, “stick”
- Gas Tungsten Arc Welding: GTAW, “TIG”
- Gas Metal Arc Welding: GMAW, “MIG”
- Flux Core Arc Welding: “FCAW”
- Submerged Arc Welding: “SAW”
2205 Welding

- Always use filler metal, even for repair
- Use 2209 (7 - 9% nickel) filler metal
- Preheating is not necessary
- **Heat input 15 - 60 kJ/inch**
- Interpass temperature below 300°F
- Post-weld heat treatment is not normally necessary. Above 600°F alpha prime precipitation is a concern (885 embrittlement)
Superduplex Welding

- Always use filler metal, even for repair
- Use 25Cr-10Ni-4Mo-N filler metal
- Preheating is not necessary
- Heat input 15 - 40 kJ/inch
- Interpass temperature below 200°F
- Post-weld heat treatment is not normally necessary. Above 600°F alpha prime precipitation is a concern (885 embrittlement)
Dissimilar Metal Welds

- Duplex can be welded to austenitic stainless steels and carbon steels
  
  - E309LMo/ER309LMo or E2209/ER2209 filler used when welding to austenitic stainless steel

- E309L/ER309L or E309LMo/ER309LMo filler used when welding to carbon steels
## Welding Consumables Used for Dissimilar Metal Welding

<table>
<thead>
<tr>
<th></th>
<th>2304</th>
<th>2205</th>
<th>25 Cr</th>
<th>Superduplex</th>
</tr>
</thead>
<tbody>
<tr>
<td>2304</td>
<td>2304 2209</td>
<td>2209</td>
<td>2209</td>
<td>2209</td>
</tr>
<tr>
<td>2205</td>
<td>2209</td>
<td>2209</td>
<td>25Cr-10Ni-4Mo-N</td>
<td>25Cr-10Ni-4Mo-N</td>
</tr>
<tr>
<td>25 Cr</td>
<td>2209</td>
<td>25Cr-10Ni-4Mo-N</td>
<td>25Cr-10Ni-4Mo-N</td>
<td>25Cr-10Ni-4Mo-N</td>
</tr>
<tr>
<td>Superduplex</td>
<td>2209</td>
<td>25Cr-10Ni-4Mo-N</td>
<td>25Cr-10Ni-4Mo-N</td>
<td>25Cr-10Ni-4Mo-N</td>
</tr>
<tr>
<td>304</td>
<td>309LMo 2209</td>
<td>309LMo 2209</td>
<td>309LMo 2209</td>
<td>309LMo</td>
</tr>
<tr>
<td>316</td>
<td>309LMo 2209</td>
<td>309LMo 2209</td>
<td>309LMo 2209</td>
<td>309LMo</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>309L 309LMo</td>
<td>309L 309LMo</td>
<td>309L 309LMo</td>
<td>309L 309LMo</td>
</tr>
</tbody>
</table>
Welding Consumables

- Always use a recommended welding product
- Duplex stainless steel weld fillers are slightly overalloyed compared to the base material
- Composition of consumables is chosen to produce correct Austenite/Ferrite balance in duplex stainless steel welds
### Duplex Stainless Steel Shielding Gases

<table>
<thead>
<tr>
<th>Method</th>
<th>Shielding Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIG</td>
<td>Ar or Ar + 2 - 3% N₂ or Ar + 30% He</td>
</tr>
<tr>
<td>MIG</td>
<td>Ar or Ar + 2 - 3% N₂ or Ar + 30% He + 1 - 3% CO₂ or Ar + 2 - 3% CO₂</td>
</tr>
<tr>
<td>FCAW</td>
<td>Ar + 18 - 25% CO₂ or 100% CO₂</td>
</tr>
</tbody>
</table>
Good Welding Qualification

- Toughness
- Corrosion resistance
  - e.g., ASTM A 923
- ASME requirements
- Metallography

→ Service relevant properties are most important
Post Weld Heat Treatment
Only full solution anneal acceptable!

- Not normally necessary, except:
  - Autogenous weld (not recommended)
  - Thick weld section with multiple passes

  to remove sigma phase and restore phase balance
Post-Fabrication Cleaning

- Main Objectives are:
  - Remove heat tint
  - Make sure there is no surface contamination, such as smeared or embedded iron
  - Ensure there is a strong, continuous, protective chromium-rich oxide layer all over the surface
Post-fabrication cleaning treatments

- **Blasting** (eg. glass beads)
  - Local or large area cleaning
- **Grinding** (abrasive discs or flapper wheels)
  - Do not smear (eg. wire brushes) or overheat the surface (eg. worn abrasives or excessive pressure)
- **Pickling** (mixed nitric-hydrofluoric acids)
  - Immersion, spray or paste
- **Electropolishing** (electrocleaning)
  - Site or shop treatment
Pickling

- Chemical treatment to remove heat tint, and the underlying chromium-depleted layer and surface contamination
- Covered by: ASTM A 380
Spray Pickling
Pickling

Before

After
Publication was revised in 2009 and will be printed by IMOA

New duplex stainless steel grades are included in the revision