Failures in stainless steel welds – examples and causes

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Overview of a few real-life examples

1. Intermetallic precipitation – Sigma phase
2. HAZ Liquidation cracking
3. Solidification cracking
4. Stress corrosion cracking (SCC)
5. Heat tint
1. Sigma phase

Case Study A Loss of corrosion resistance
Case Study B Embrittlement
Superduplex stainless steel

- Subsea spoolpiece
- Weld metal/HAZ crack
- Hydrogen embrittlement
Pitting corrosion and preferential phase corrosion due to sigma phase
Causes of Failure

- Superduplex stainless steel
- Girth weld repair
  - High heat input
- Sigma phase precipitation
- Pitting corrosion
- Hydrogen embrittlement crack
  - Hydrogen from corrosion
  - Tensile stress
Sigma Phase

Case Study B
Duplex stainless steel

- Dye penetrant showing weld metal/HAZ crack
Brittle fracture due to sigma phase
Duplex stainless steel Microstructure

Sigma phase
Composition of phases
EDX spectrum

Sigma phase (white)
Rich in Cr and Mo
Causes of failure

- Duplex stainless steel
- Sigma phase precipitation
- Incorrect heat treatment of forging
- Tensile stress
  - Residual stress
  - Applied stress during hydrotest
2. HAZ Liqutation cracking
Short intergranular cracks:
- In high-temperature zone of the HAZ, or
- In previously deposited weld metal, during a subsequent run

Due to formation of grain boundary liquid films at temperatures below the alloy melting temperature

On cooling this liquid is unable to accommodate tensile strains, caused by contraction, and cracks may form

http://www.twi.co.uk/technical-knowledge/knowledge-summaries/liquation-cracking/
HAZ Liquation Cracking

1a) Photomacrograph of HAZ liquation cracking in austenitic stainless steel cladded with a nickel alloy weld metal. Location of liquation cracking indicated by arrows;

1b) Liquation cracking in AISI 316 austenitic stainless steel weld metal, reheated by subsequent weld bead. Location of liquation cracking indicated by arrows;

1c) HAZ liquation cracking in AISI 310 austenitic stainless steel (Magn. x 114);

1d) Scanning electron micrograph of liquated film on liquation crack surface in an AISI 316 austenitic stainless steel weld metal (Magn. x 1800)
Factors affecting liquation cracking

- Resist Cracks
  - $\delta$-ferrite content of HAZ
  - Scavengers for harmful trace elements, e.g., Mn and rare earths
  - Mo
- Promote Cracks
  - Residual and trace elements, principally B, C, N, Si, S & P
  - Grain size
  - Weld arc energy
3. Solidification Cracking
Solidification crack

- Butt weld
- Repair weld

- Solidification crack arrowed
Solidification crack fracture face
Causes of failure

- Duplex stainless steel
  - Less common than austenitic

- Bend test failure

- Factors involved in solidification cracking
  - Tensile stress
  - Delta ferrite content
  - Sulphur

- Cause - Unusually wide weld bead due to weaving?
4. Stress corrosion cracking (SCC)
Stress corrosion cracking

- Austenitic stainless steel, pipe girth weld
Stress corrosion cracking

- Austenitic stainless steel
- Branched, transgranular cracks
Causes of Failure

- Chloride-containing environment
- Residual tensile stresses from welding
- Weld profile
  - Difficult to drain – liquid collection
  - Concentration of chlorides
- Elevated temperature (55-60°C)
5. Heat tint
Pitting and crevice corrosion

- Lowered corrosion resistance
- Corrosion pits in heat tint
- 304L stainless steel welded pipe
- Pitting corrosion much larger under the surface than visible on the surface
Causes of failure

- Oxidation of the root bead + adjacent HAZ during welding of SS.
- Cr-rich scale is formed, the surface becomes Cr-depleted which impairs corrosion resistance.

- Avoid heat tint:
- Need good shielding and backing (purging) gas.
  - Shield: Ar, Ar/He, Ar/N mixtures.
  - Purge: Ar or N₂.
- Use several volumes of purge gas before welding.
- Maintain purge for 3 or 4 weld passes in multi-pass weld.
- May also pickle and passivate
Welding can introduce or promote various failure mechanisms

Best practice for welding should be followed

For further guidance:

http://www.twi-global.com/technical-knowledge/
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