Part 2: Mechanical Property Attributes and Metallurgical Behaviour of AS 1548 Pressure Vessel Plate Steels

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November 2010
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1. The effect of heat treatment and Normalising temperature range definition
Schematic of hot rolling, Normalising and stress relieving thermal path

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
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<tbody>
<tr>
<td>1200°C</td>
<td></td>
</tr>
<tr>
<td>900°C</td>
<td></td>
</tr>
<tr>
<td>Ar₃ ≈750°C</td>
<td></td>
</tr>
<tr>
<td>Ac₃ ≈850°C</td>
<td></td>
</tr>
<tr>
<td>600°C</td>
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</table>
Effect of heat treatment on strength for AS 1548-5-490

Stress relieving
Temperature

Normalising
Temperature range

Yield Strength
Tensile Strength
Ac1
Ac3

Heat Treatment Temperature (°C)

Strength (MPa)
Effect of heat treatment on Charpy toughness at -50°C for AS 1548-5-490

[Diagram showing Charpy toughness as a function of heat treatment temperature]

- Stress relieving
- Normalising Temperature Range

[Graph with charpy energy on the y-axis and heat treatment temperature on the x-axis]
Normalising summary

• Once the steel has been fully austenitised by heating into the Normalising temperature range and air cooled, the resultant mechanical properties in AS 1548 for the grade should be realised.
• Excessive heating leads to grain growth which greatly affects the toughness.
• Failure to fully austenitise the steel leads to low strength and very poor toughness.
• Cooling rate affects the driving force for ferrite nucleation during transformation. Air cooling aids ferrite grain refinement.
• Minimum Mn content has been incorporated into AS 1548 to depress Ac3 which aids final ferrite grain size.
2. The effect of stress relieving (PWHT) heat treatment on the parent plate mechanical properties
Stress relieving – effect on parent plate mechanical properties

• Carried out after welding to relieve any residual stresses that may have built up during fabrication and welding, as well as temper the weld heat affect zone to improve toughness.
• The stress relieving temperature range also allows carbon to diffuse which can significantly affect the parent plate mechanical properties.
• As it is a diffusion process it is temperature and time dependent.
• BlueScope Steel undertake a heat treatment of 600°C for 3 hours to simulate the stress relieving stage of fabrication for all our pressure vessel mechanical test specimens.
• In response to industry questions, BlueScope Steel has undertaken an investigation into long stress relieving times and the effect of multiple stress relieving treatments on the parent plate mechanical properties.
• Stress relieving temperatures of 550-650°C
• Times 1hr - 96 hrs
• Effect of multiple 3 hour treatments at 600°C
Effect of stress relieving – time and temperature on tensile strength
Effect of stress relieving – time and temperature on Charpy toughness
Schematic of microstructural changes during stress relieving/PWHT heat treatment

As-Rolled: Ferrite + Pearlite → Stress Relieved

- C diffuses out of Pearlite
- C Precipitates as Carbides on G.B.
- Deposits as thin films on G.B.
- Net affect is a reduction in strength and toughness

C speriodised in pearlite, lower volume fraction
Carbides
Carbide films
Microstructural changes with increased stress relieving

- As Rolled
- 600°C / 3 hrs
- 650°C / 72 hrs
- 600°C / 8 hrs
Combination of time and temperature

• The effect of both time and temperature can be combined by the Holloman-Jaffe Tempering Parameter

• \[ TP=10^{-3}(T+273)(20+\log(t)) \]
  – Where \( T \) is temperature in °C and \( t \) is time in hours.
  – 600°C for 3 hours: \( TP = 17.88 \)
Effect of the Holloman-Jaffe Parameter on tensile strength

TP = 17.88; 600°C for 3 hours

AS1548-7-490N

AS1548-7-460N
Effect of the Holloman-Jaffe Parameter on Charpy toughness

TP=17.88; 600°C for 3 hours
Comparison of multiple 3 hour stress relieving heat treatments with a continuous treatment

Grade: AS 1548-7-490N
Stress relieving summary

- Stress relieving is a diffusion process which is both temperature and time dependent.
- The effect of time and temperature can be combined into one parameter: the Holloman-Jaffe Tempering Parameter (TP).
- For TP > 17.5 there is a gradual degradation in both tensile strength and toughness due to the microstructural changes that are occurring.
- AS 1548 requires all mechanical tests to be given a simulated stress relieving heat treatment using a TP = 17.88.
- Multiple stress relieving treatments can be considered as additive in terms of time when compared to continuous treatments.
- Stress relieving conditions set by AS4458 are covered by TP = 17.88 in AS 1548-2008.
3. The revision of elevated temperature Yield Strength values
Elevated temperature Yield Strength of AS 1548 grades

- The AS 1548-1995 elevated temperature Yield Strength values were derived from historical performance of BlueScope Steel product and based upon the three standard deviation lower bound value.
- EN and ASME apply a ratio of the room temperature Yield Strength derived from experimental data.
- Recognise that the elevated temperature Yield Strength is a function of the room temperature Yield Strength for any particular elevated temperature.
- This approach was adopted for AS 1548-2008 after considerable confirmatory research with BlueScope Steel.
Relationship between elevated temperature and room temperature Yield Strength for various test temperatures.
Relationship between elevated temperature and room temperature Yield Strength for various test temperatures

ETT 0.2% Proof Stress (MPa) vs. Room Temperature Yield Strength (MPa)

- 200°C
- 300°C
Relationship between elevated temperature and room temperature Yield Strength for various test temperatures

- 200°C
- 300°C
- 400°C
Relationship between 0.2% PS and room temperature Yield Strength for AS 1548 grades

Test Temperature (°C)

ETT 0.2%PS/RT YS

5/490
7/460
7/490
Relationship between elevated and room temperature YS for ~160 plates examined by the BSCC*

*British Steel Creep Committee
Trend curve from the BSCC superimposed on the AS 1548 data

![Trend Curve from BSCC data](image-url)
Comparison of the trend curve from the BSCC data and BSL AS 1548 grade data
Trend curve from the BSCC superimposed on the AS 1548 data

Trendline based upon 2 Std Dev. from average.
Trend curve from the BSCC superimposed on the AS 1548 data

Trendline based upon 2 Std Dev. from average.
Comparison of the elevated temperature Yield Strengths for 460 grades in AS 1548 (1995 and 2008)
The change in elevated temperature Yield Strength for the 460 grade between AS 1548 (1995 and 2008)
4. Consolidating 5-490 and 7-490 into PT490 grade
Consolidation of AS 1548-5-490 and AS 1548-7-490 into AS 1548-PT490

• AS 1548-5-490: Nb microalloyed
  – supplied in normalised condition only
  – higher Yield Strength than AS 1548-7-490

• AS 1548-7-490: plain C-Mn-Si steel type
  – supplied in R, T and N conditions
  – lower Yield Strength than AS 1548-5-490
Consolidation of AS 1548-5-490 and AS 1548-7-490 into AS 1548-PT490

- AS 1548-PT490: maintains higher Yield Strength of AS 1548-5-490
- Allows Nb microalloying, but maximum restricted for weldability
- Supply conditions are NR, T and N
- Charpy toughness testing @ -20°C introduced to ensure reasonable toughness of base grade
- Nb additions to PT430 and PT460 also only allowed for impact tested variants.
5. Comparison of strength levels for Normalised Rolled and Normalised conditions
Comparison of the strength levels for AS 1548-7-460 R and N grades

- AS 1548-7-460R has higher strengths than AS 1548-7-460N
- Normalising R/NR grades will not replicate the actual plate strength levels of the R/NR plate, but will achieve the grade strength requirement
- The definition of inter-changeability in AS 1548-1995 and Normalised Rolled in AS 1548-2008, is based upon minimum strength specification for the grade; not actual strength levels of individual plates
6. Attributes of XLERPLATE® pressure vessel steels
## Typical chemistries for XLERPLATE® pressure vessel steels

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>Ni</th>
<th>Cu</th>
<th>Nb</th>
<th>Ti</th>
<th>CEQ (IIW)</th>
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<td>0.15</td>
<td>1.35</td>
<td>0.35</td>
<td>0.012</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.018</td>
<td>0.39</td>
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<td>0.012</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.022</td>
<td>0.018</td>
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<tr>
<td>PT490</td>
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<td>1.50</td>
<td>0.45</td>
<td>0.012</td>
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<td>0.30</td>
<td>0.015</td>
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<td>0.415</td>
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<td>0.9-1.70</td>
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<td>0.50</td>
<td>0.40</td>
<td>0.01/0.05</td>
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<td>0.85-1.20</td>
<td>0.15-0.40</td>
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<td>0.4</td>
<td>0.4</td>
<td>0.02</td>
<td>0.03</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Tensile properties of AS 1548-7/460R / PT460
XLERPLATE® pressure vessel steels and attributes

- All XLERPLATE® pressure vessel steel plate is produced via continuous slab casting – improved chemical composition homogeneity, steel cleanliness and soundness.
- Carbon and alloy levels well below maximum levels to aid weldability and AS 1548 Carbon levels are lower than some overseas pressure vessel plate standards (0.22-0.27% Carbon).
- All steels are Titanium treated in addition to Aluminium fully killed to aid weldability.
- All grades are tested in the simulated stress relieved condition.
- AS 1548-2008 provides for some level of Charpy testing of all grades and variants to ensure a certain level of toughness.
- Not all overseas material standards include Charpy testing of base grades or mechanical testing in stress relieved condition.
7. What do the changes to AS 1548 mean to me?
What does this mean to me?

• Careful control of temperatures is essential to avoid significant decreases in strength and toughness of pressure vessel steels during Normalising
  – Toughness decreases more rapidly than strength with incorrect Normalising temperatures, hence verification testing of toughness (e.g. Charpy testing) is strongly recommended following Normalising.

• The affects of a number of stress relieving heat treatment cycles on steel properties is cumulative
  – Care needs to be taken to ensure that the properties of pressure vessel steels are not reduced below specifications by excessive stress relieving.
  – Guidance is provided by the Holloman-Jaffe equation or can be discussed with BlueScope Steel.
What does this mean to me?

• Changes to the Elevated Temperature Proof Stress in the 2008 version of AS 1548 have resulted in an increase in the design stress up to and including 80mm thick XLERPLATE® steel (but a decrease for above 80mm thick).

• Consolidation of AS 1548-7-490 and AS 1548-5-490 grades into the AS 1548-PT490 has provided a 490 grade with the advantages of both grades:
  – high design strengths due to the higher minimum Yield Strength
  – good weldability due to restrictions on Niobium levels
  – Good toughness due to Charpy testing required of all delivery options
Reference information

- General enquiries contact BlueScope Steel Direct 1800 800 789
- Distributor Locator available on website
Thank you and keep in touch!

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Date published: November 2010
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