# DUPLEX SEMINAR & SUMMIT Oct 2016

## "Improving the low temperature impact properties & corrosion resistance in super duplex stainless steel weld metal and castings"

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# Contents

# Super Duplex 25% Cr Castings
# Key manufacturing problems facing the Industry

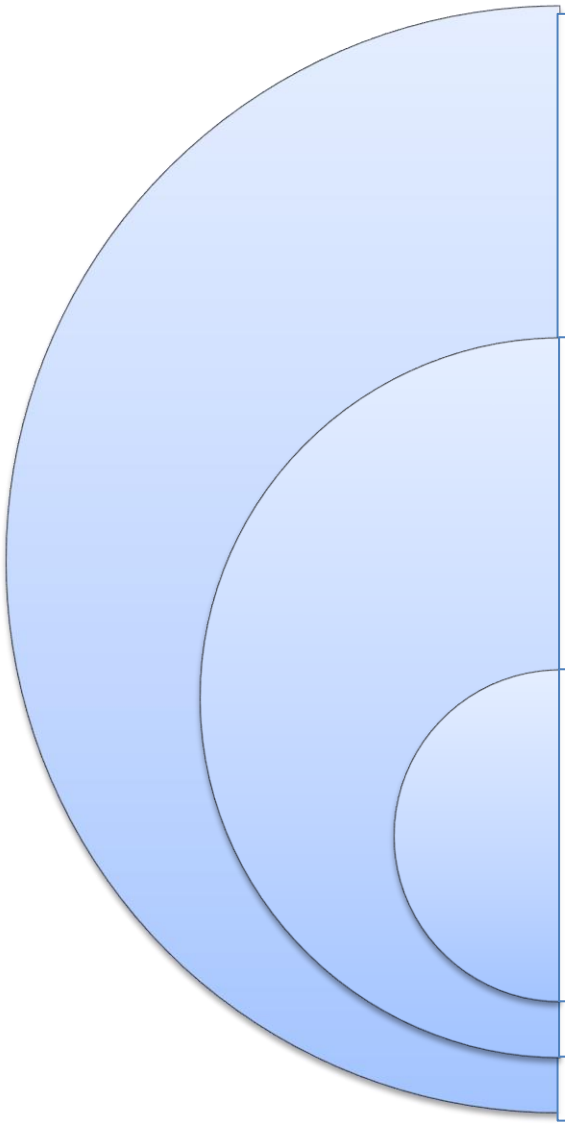
- Poor impact properties in heavy sections due to intermetallic phases, limiting the section sizes that can be produced.
- Poor corrosion resistance of both parent and weld metal.
- Castings can crack in the mould or on heat treatment, especially in heavy section casting.
- Cracks can propagate from drill holes through heavy sections.
- Desalination plants can not run at temperatures above 40°C as this creates an environment for high corrosion.
- For castings, feeder head removal is difficult by conventional thermal cutting techniques without risk of sigma precipitation and cracking.
- For castings & forgings over 200mm wall thickness there is difficulty in obtaining acceptable T/2 mechanical impact properties.

- Traditionally PREn has been the industry guiding bench mark for corrosion resistance, but this presentation is to help individuals to appreciate that cast & forged duplex ST/SL can perform much better than is traditionally known if by chemistry control sigma phase can be virtually eliminated.

- It is the sigma phase in a duplex stainless steel that is the culprit for relatively low and/or inconsistent impact properties and lower than possible corrosion resistance.

# 6A-G Parent Casting Material Testing Results

Benefits of 6A-G over Conventional ASTM A890/A995 Grade 6A Super Duplex Castings



| | |
|---|---|
| **Vastly Improved Impact properties** | • Vastly enhanced low temperature impact properties over the conventional 25% Cr duplex steel grades giving a greater level of safety. Impact values meet the Norsok requirements at minus 101°C. |
| **Increased Section Sizes** | • Crucially enabling heavier sections greater than 250mm to be successfully produced both in castings and forgings, while maintaining excellent through section impact strength and corrosion performance. |
| **Improved Corrosion Resistance** | • Offers enhanced G48 method A pitting corrosion resistance values over conventional grades of 25% duplex steel on like for like sections with weight loss values <4g/m2 when tested for 24hrs at 60°C. |
| | |
| | |

- **6A-G HOW DOES IT WORK?**

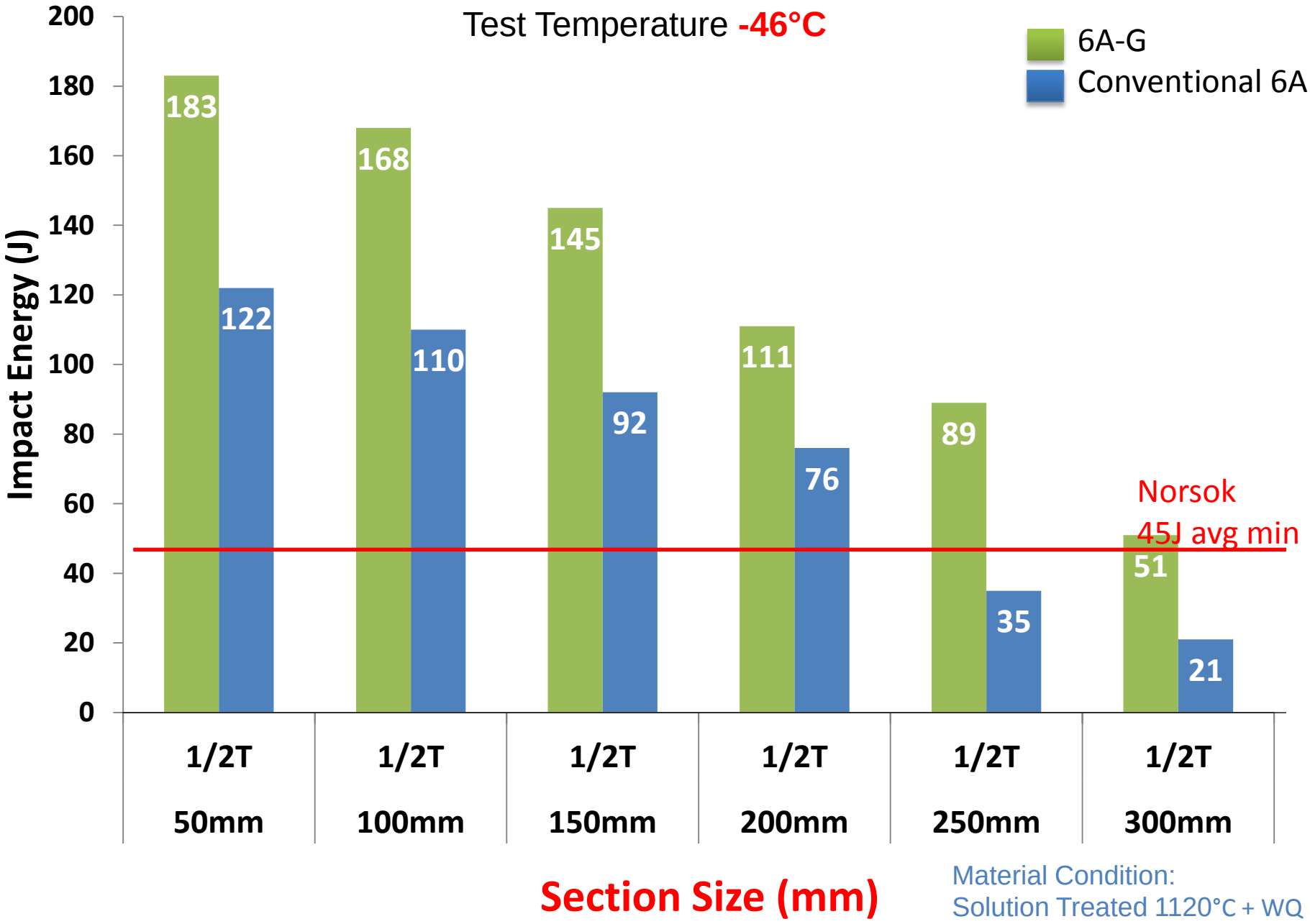
- Alloy 6A-G whilst still being compliant with the chemical requirements of A995 6A has its own special chemistry that focusses on the sweet spot and provides the very much enhanced technical performance.

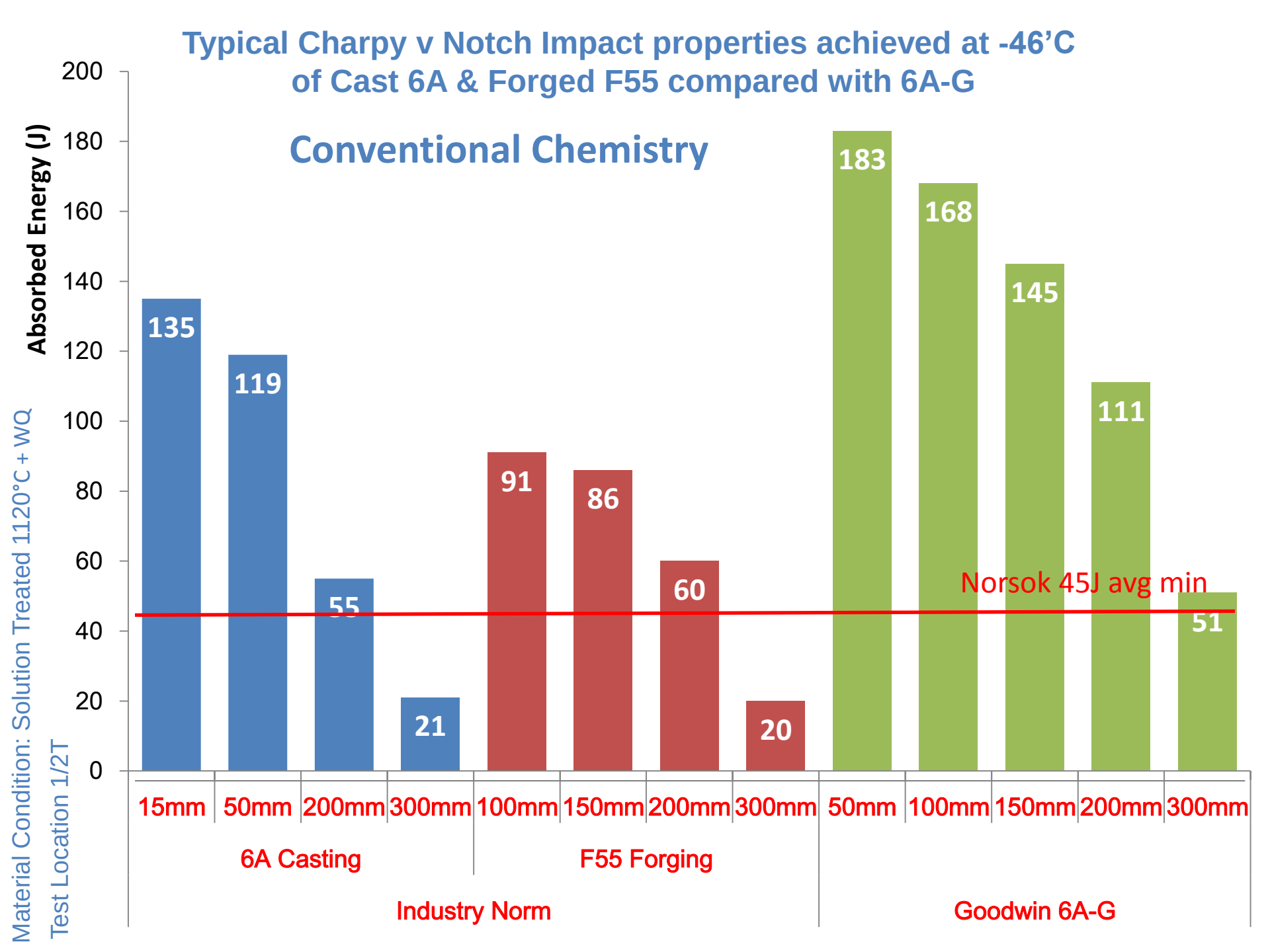
- This is achieved by having a far more stringent chemistry control than required by conventional specifications. The fundamental difference in results is due to the very low levels of sigma phase in thick sections, where in conventional 25% Cr duplex grades a much higher percentage of sigma phase will be found in the thicker section.

- For thicker sections with the conventional 25% Cr super duplex, 0.5% to 1% sigma phase can be expected in the very centre position.

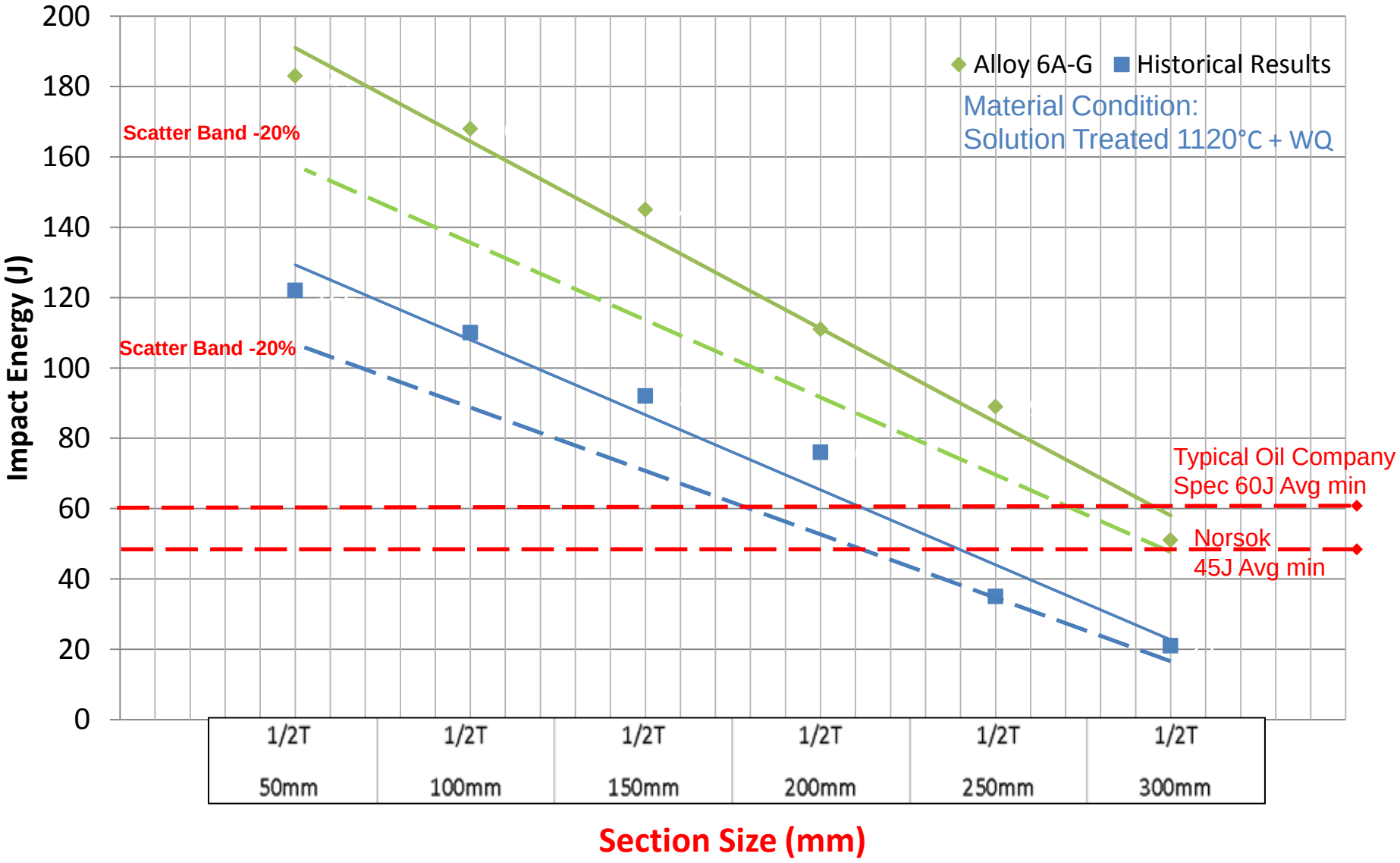
- Alloy 6A-G in section sizes ≤200mm, sigma phase will typically be <0.01%, for sections 250mm to 350mm <0.5% can be expected.

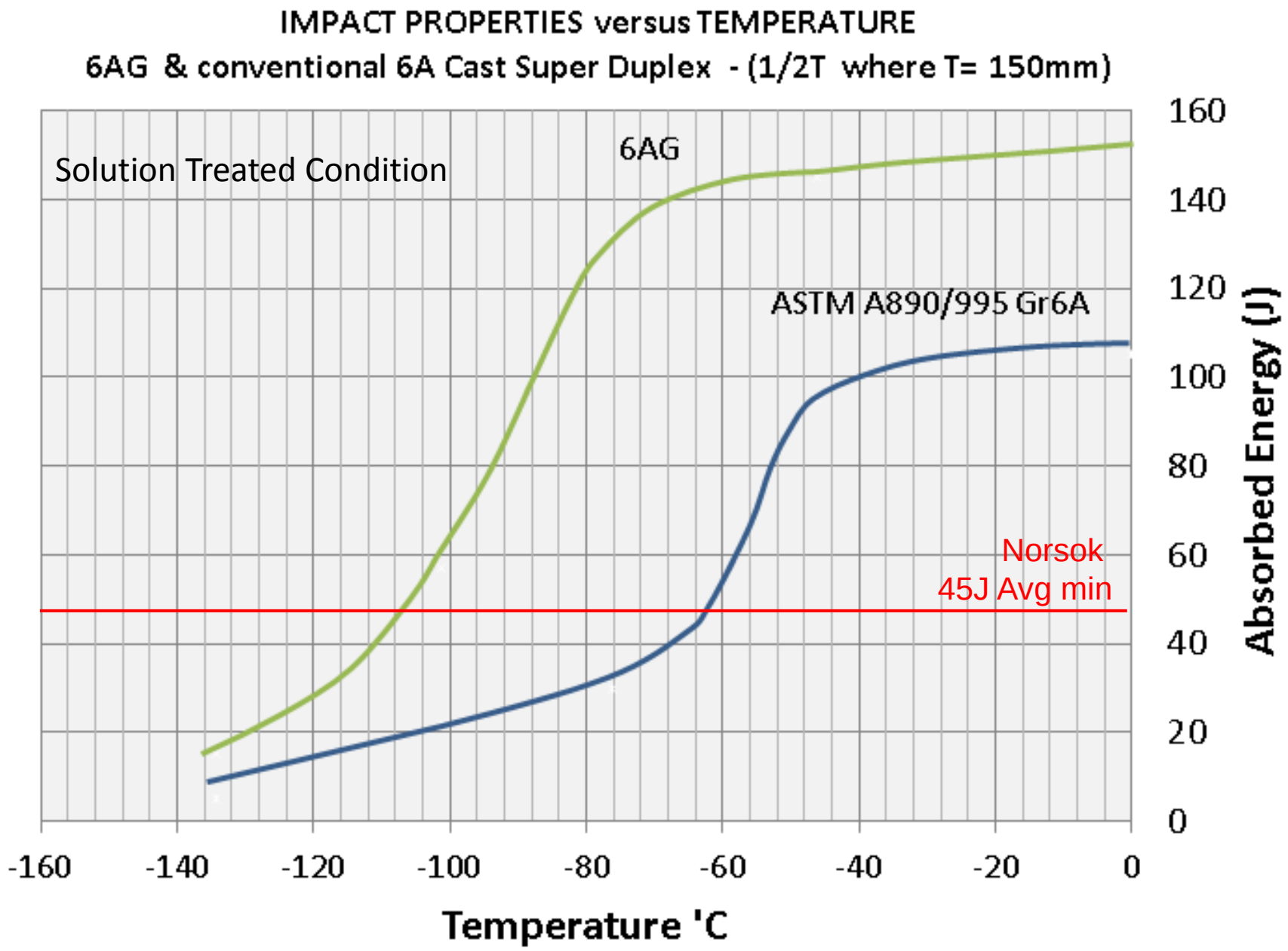
# Historic 6A versus 6A-G Average Impact Properties

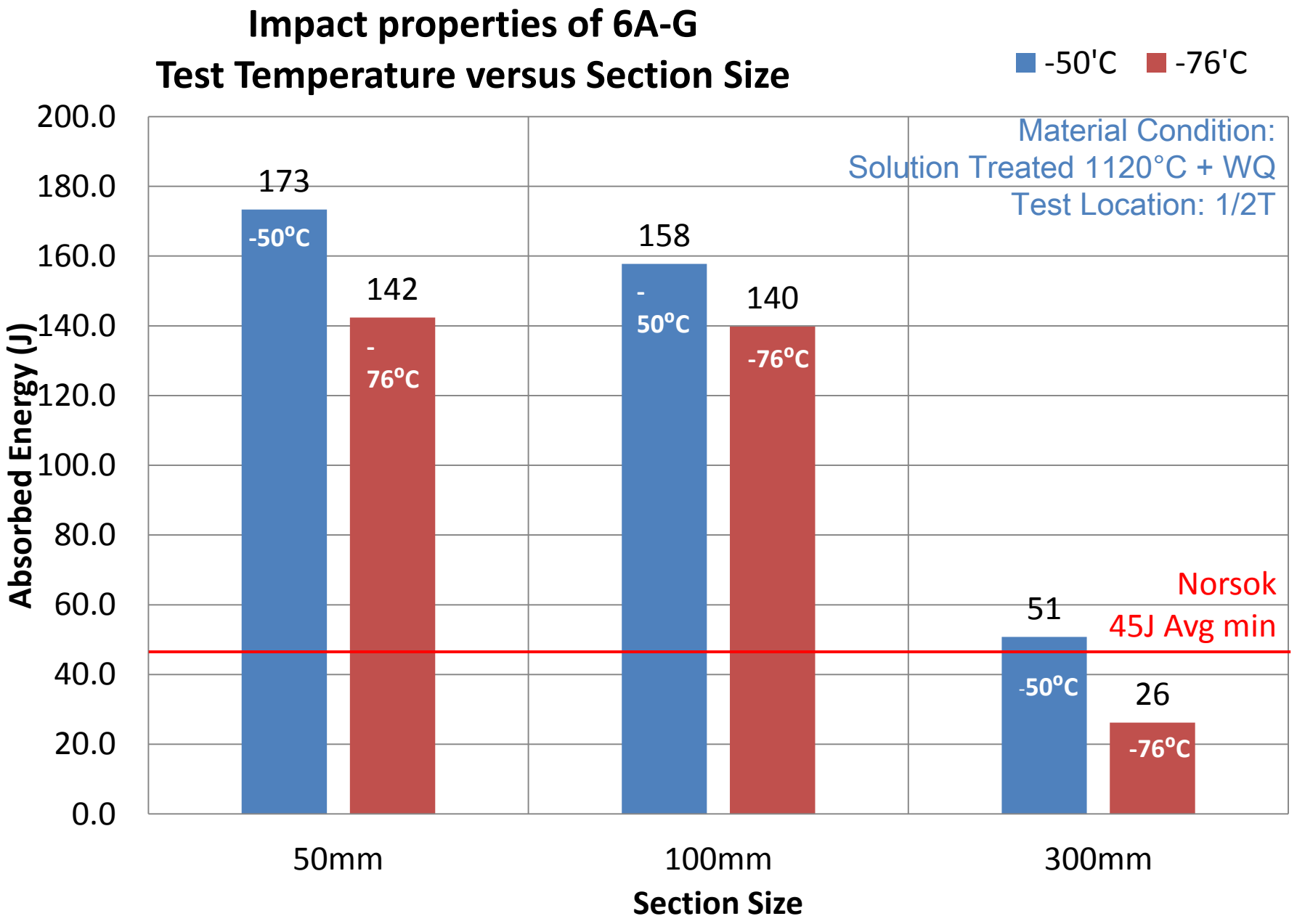



Typical Charpy v Notch Impact properties achieved at -46'C
of Cast 6A & Forged F55 compared with 6A-G
Conventional Chemistry
Absorbed Energy (J)
200
180
160
140
120
100
80
60
40
20
0
135
119
55
21
91
86
60
20
183
168
145
111
51
Norsok 45J avg min
15mm
50mm
200mm
300mm
100mm
150mm
200mm
300mm
50mm
100mm
150mm
200mm
300mm
6A Casting
F55 Forging
Industry Norm
Goodwin 6A-G
Material Condition: Solution Treated 1120°C + WQ
Test Location 1/2T

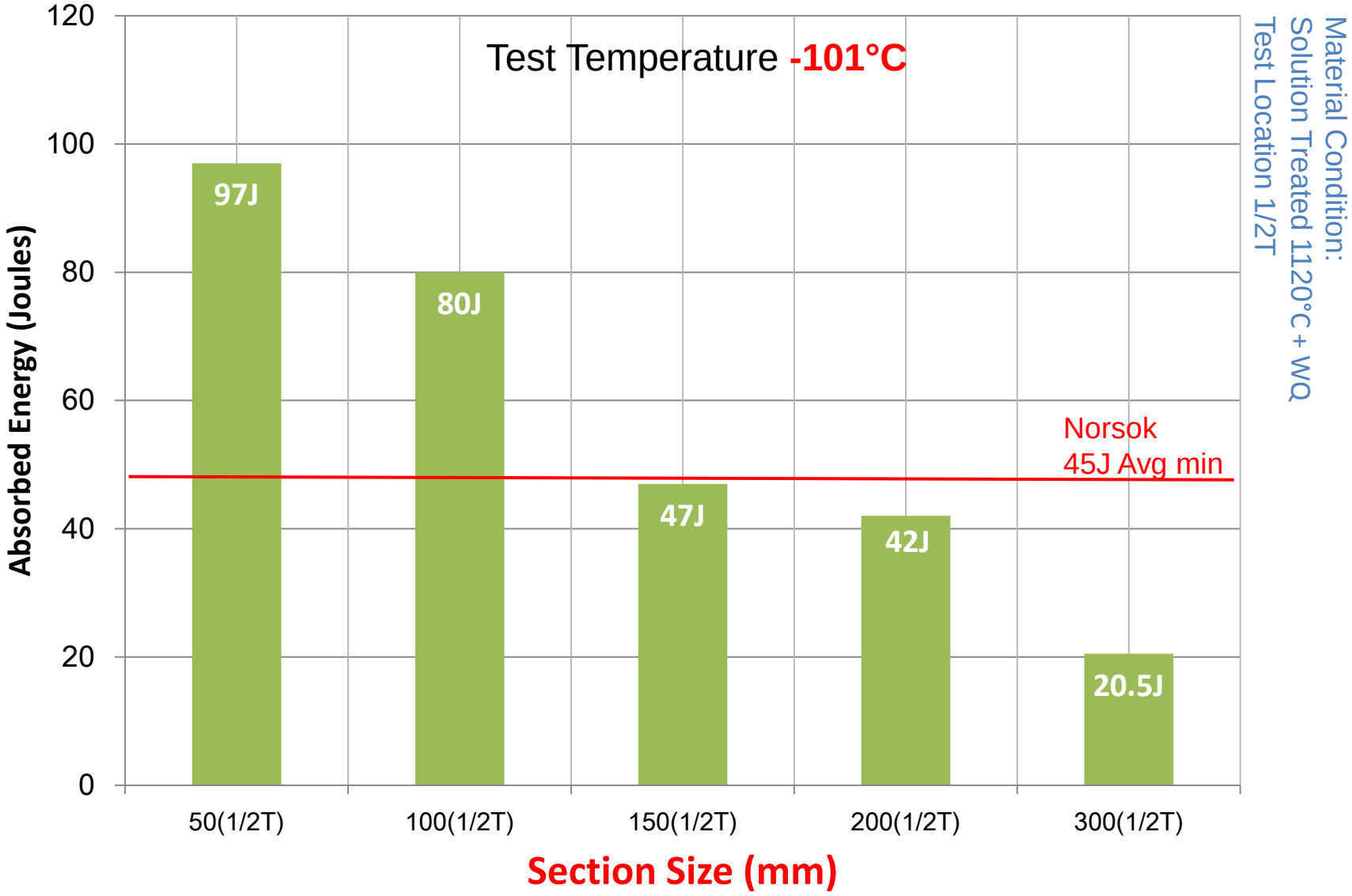
# 1/2T Parent ASTM A995 Gr 6A
## Goodwin Historic 6A versus 6AG Average Impact Properties



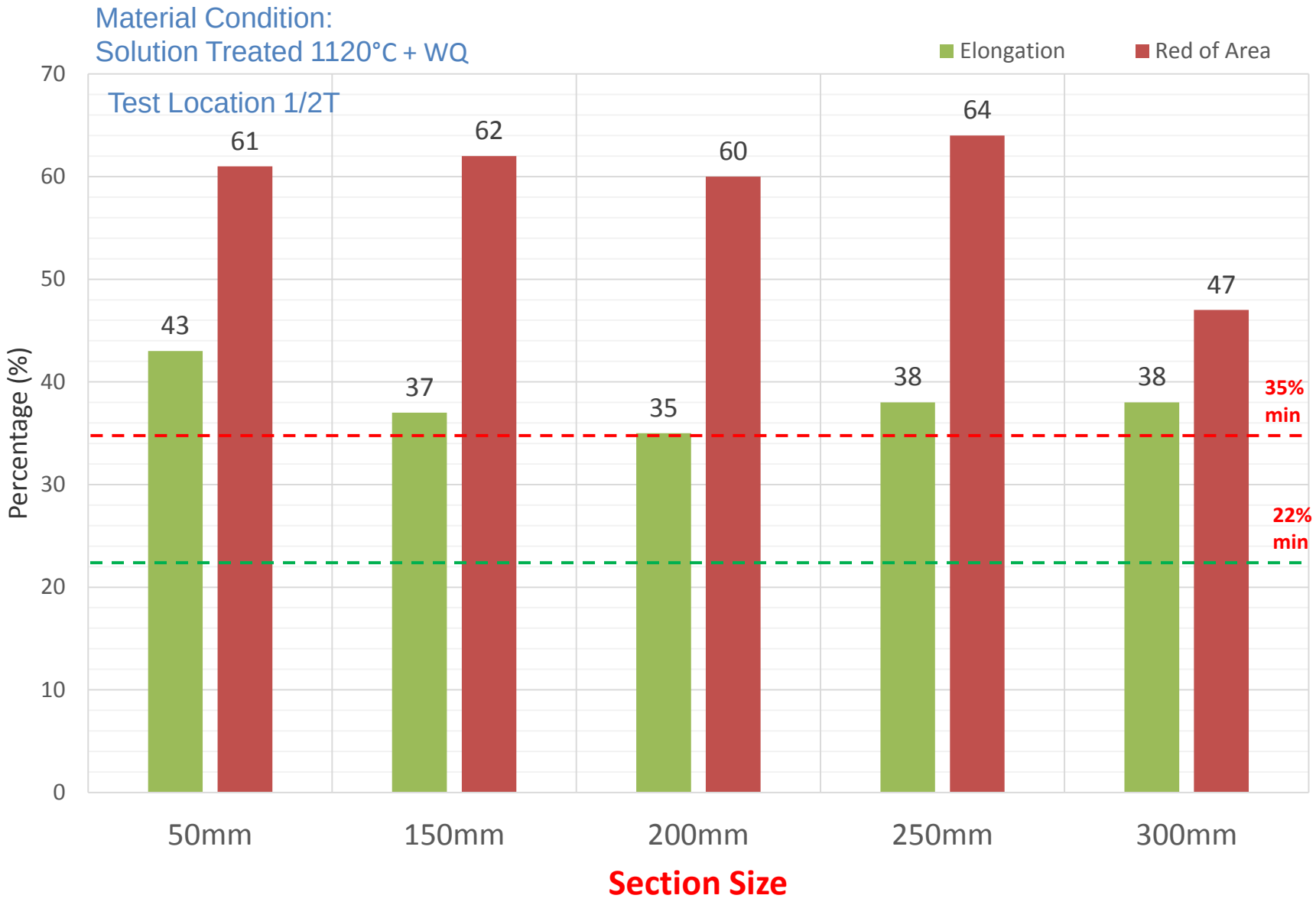

IMPACT PROPERTIES versus TEMPERATURE
6AG & conventional 6A Cast Super Duplex - (1/2T where T= 150mm)
Solution Treated Condition
6AG
ASTM A890/995 Gr6A
Norsok
45J Avg min
160
140
120
100
80
60
40
20
0
Absorbed Energy (J)
-160
-140
-120
-100
-80
-60
-40
-20
0
Temperature 'C

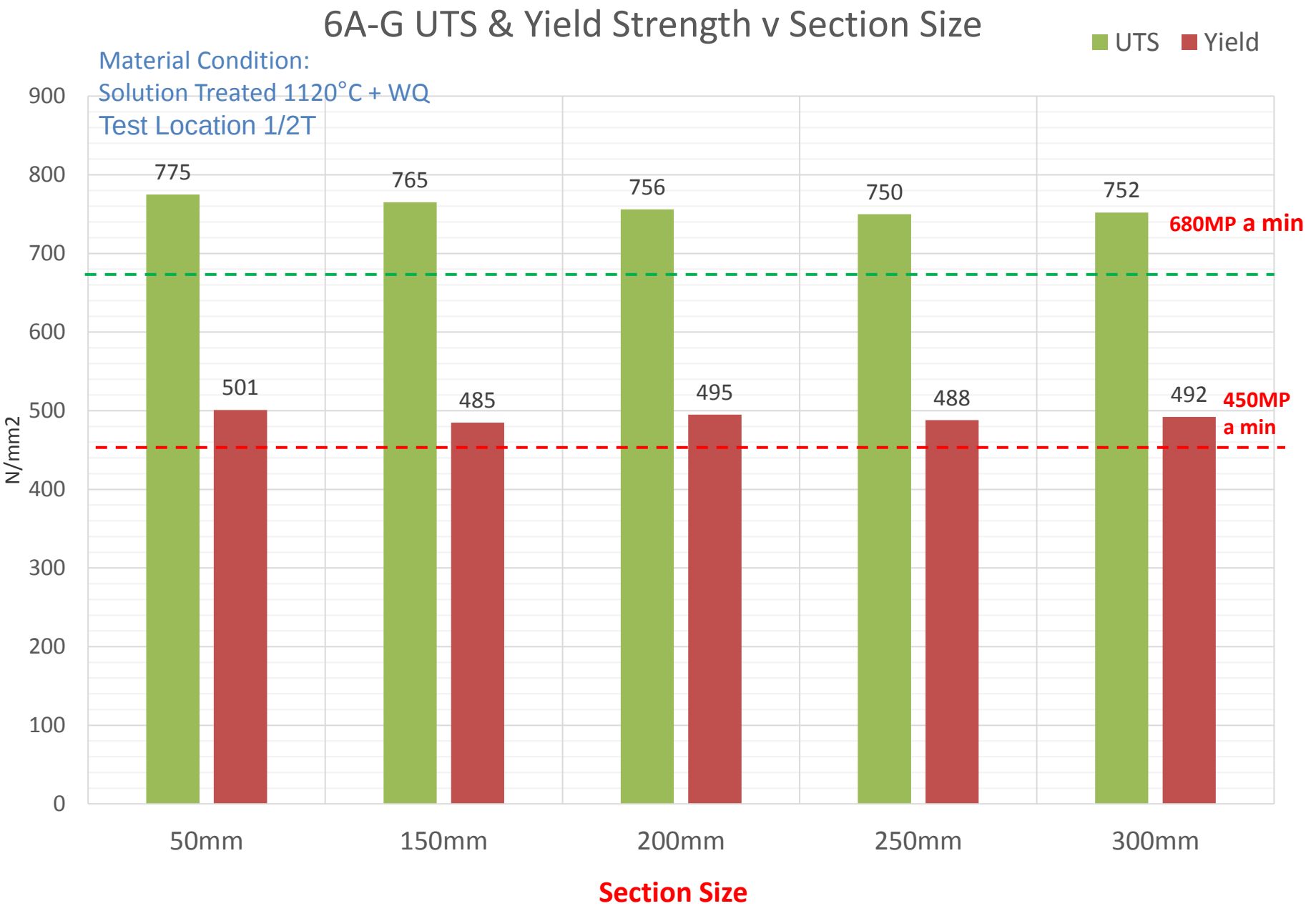

Impact properties of 6A-G
Test Temperature versus Section Size
-50'C
-76'C
Material Condition:
Solution Treated 1120°C + WQ
Test Location: 1/2T
Absorbed Energy (J)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
173
-50°C
142
-76°C
158
-50°C
140
-76°C
51
-50°C
26
-76°C
Norsok
45J Avg min
50mm
100mm
300mm
Section Size

# 1/2T Parent 6A-G - Avg Impacts tested at -101°C



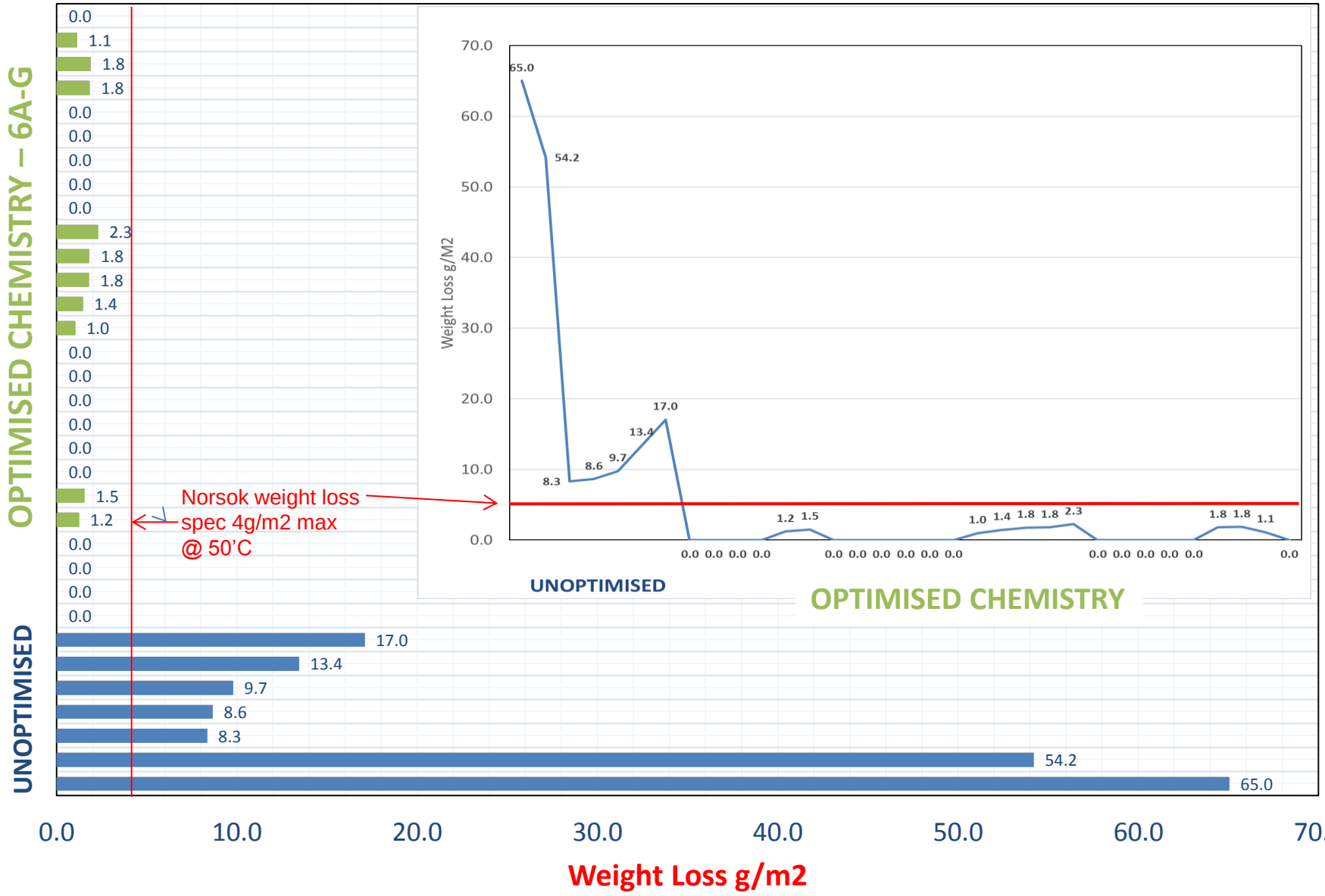
# 6A-G Elongation & Reduction of Area v Section Size




6A-G UTS & Yield Strength v Section Size
UTS
Yield
Material Condition:
Solution Treated 1120°C + WQ
Test Location 1/2T
900
800
700
600
500
400
300
200
100
0
N/mm2
775
501
765
485
756
495
750
488
752
492
680MP a min
450MP a min
50mm
150mm
200mm
250mm
300mm
Section Size

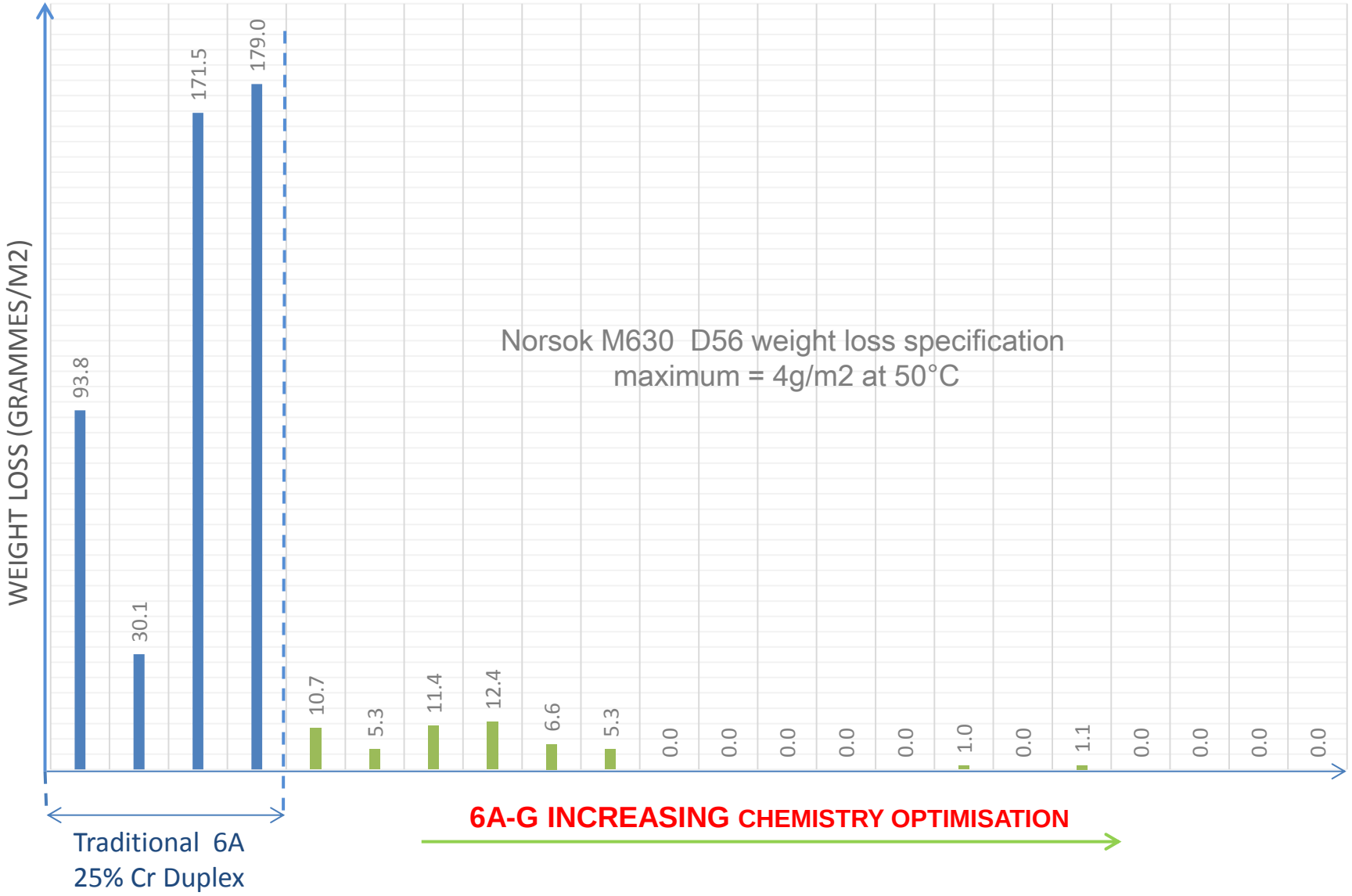
# CORROSION TESTING – Parent Cast Material

## ASTM G48 Method A, Temperature: 60'C, Duration: 24hrs

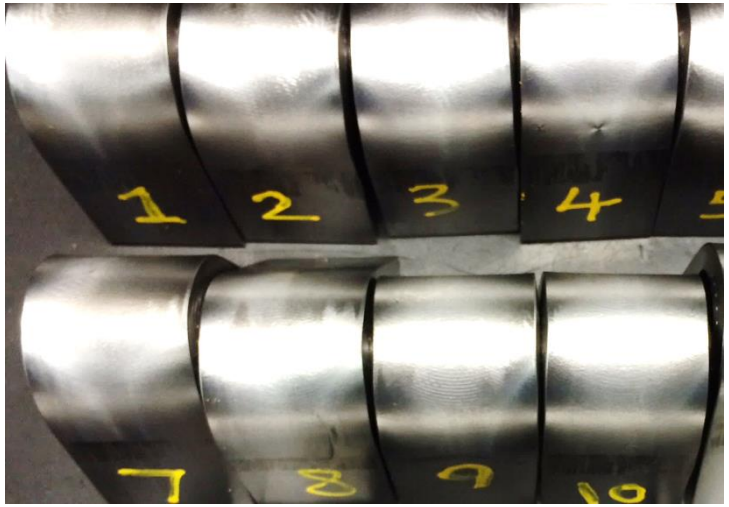


# PARENT CAST MATERIAL

## G48 METHOD A - TEST TEMPERATURE 65'C - DURATION 24HRS



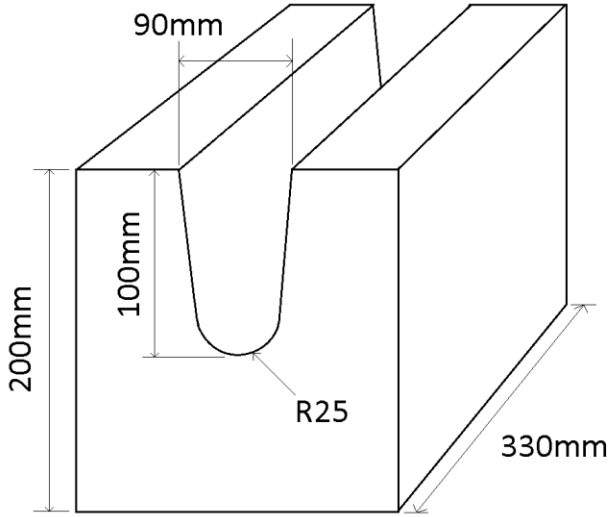
# 6A-G Weld Filler Metal Development



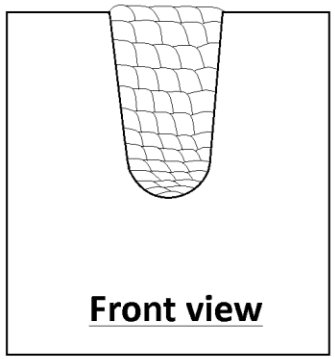

GTAW, SMAW, TIP TIG

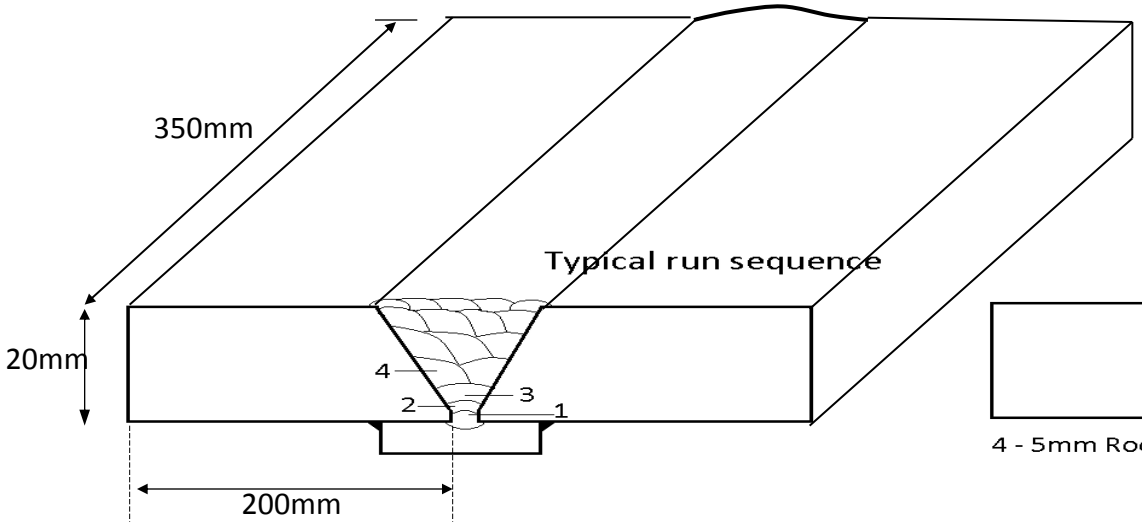
# Geometry of Test Blocks and Weld Plates used to develop weld test data

(A)
Heavy Section
Test Block

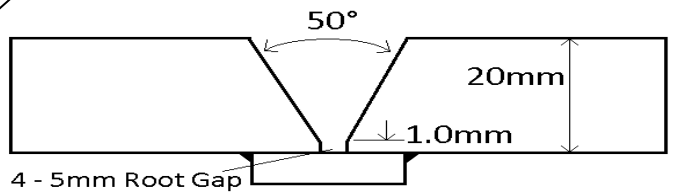



Typical run sequence



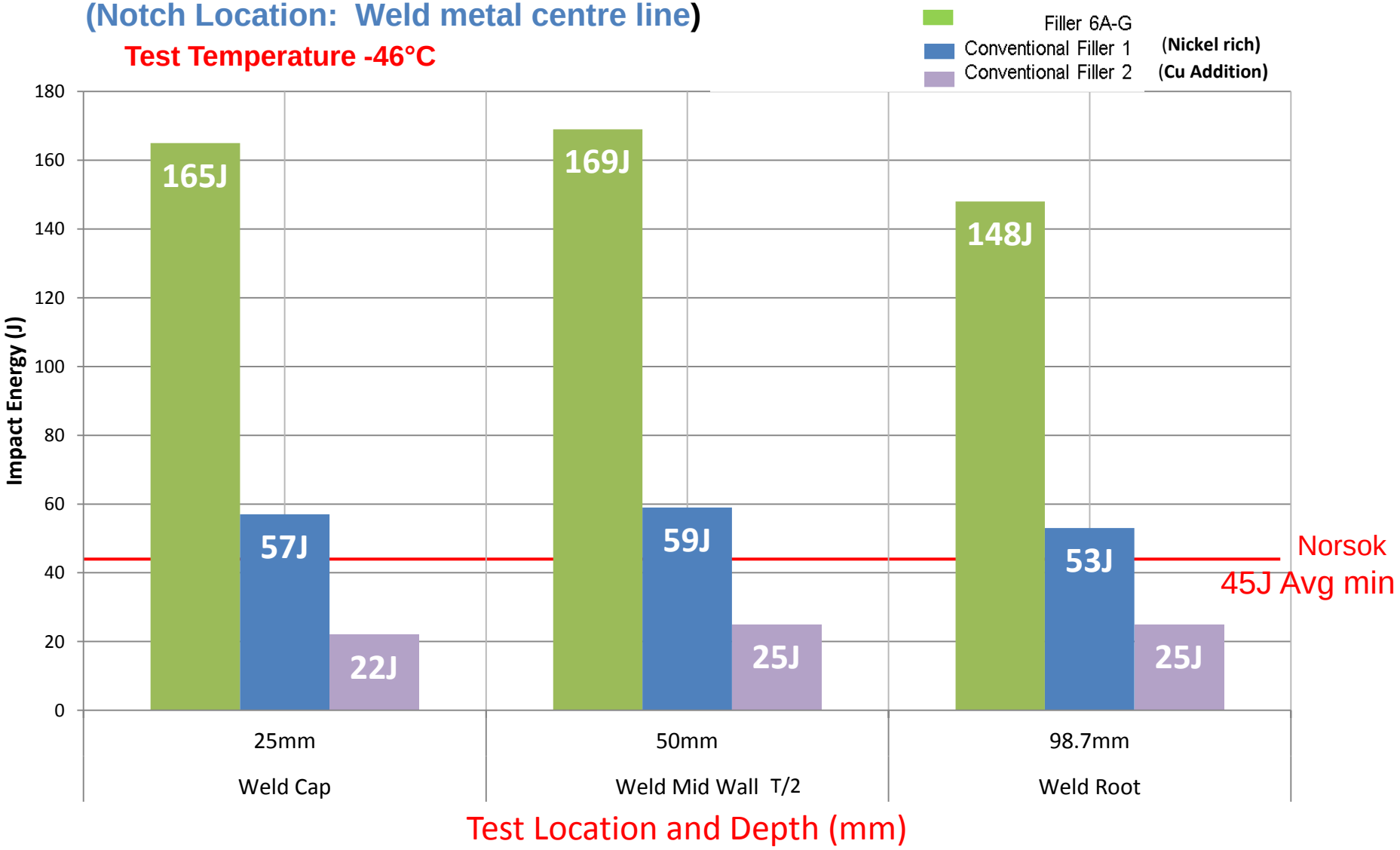



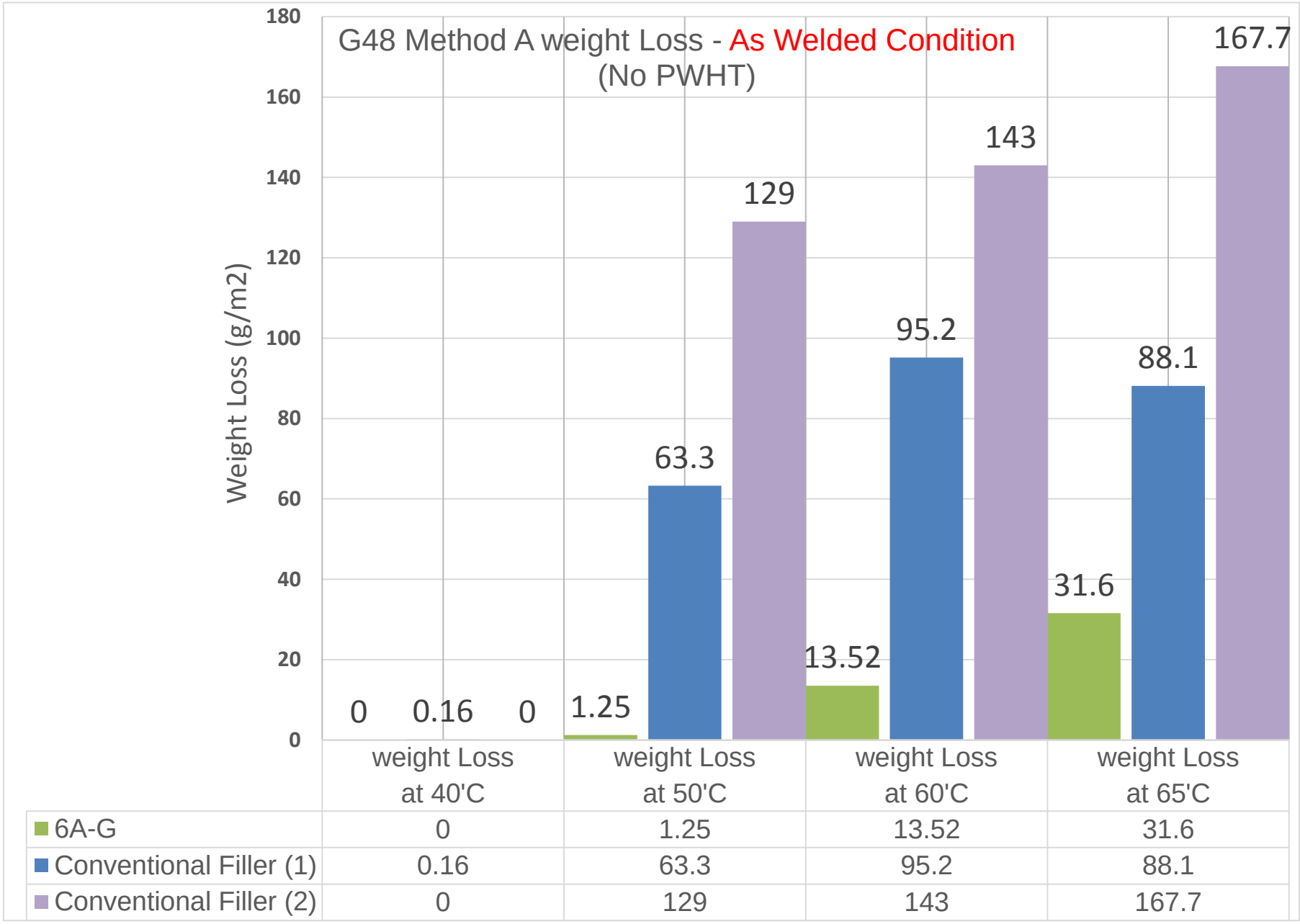

(B)
Weld Test Plate



## Impact properties in the "As-Welded" condition (Notch Location: Weld metal centre line)

**Test Temperature -46°C**



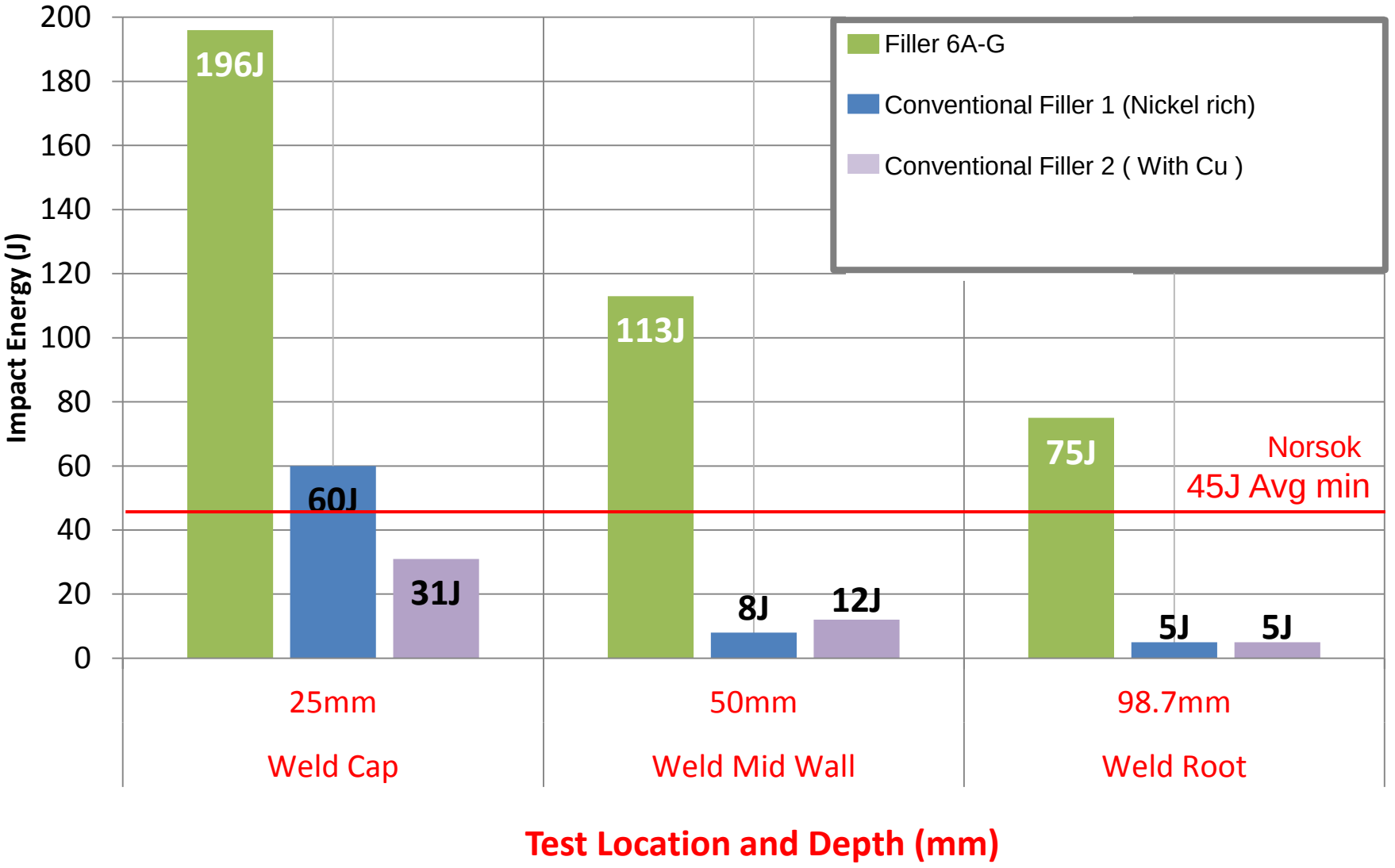


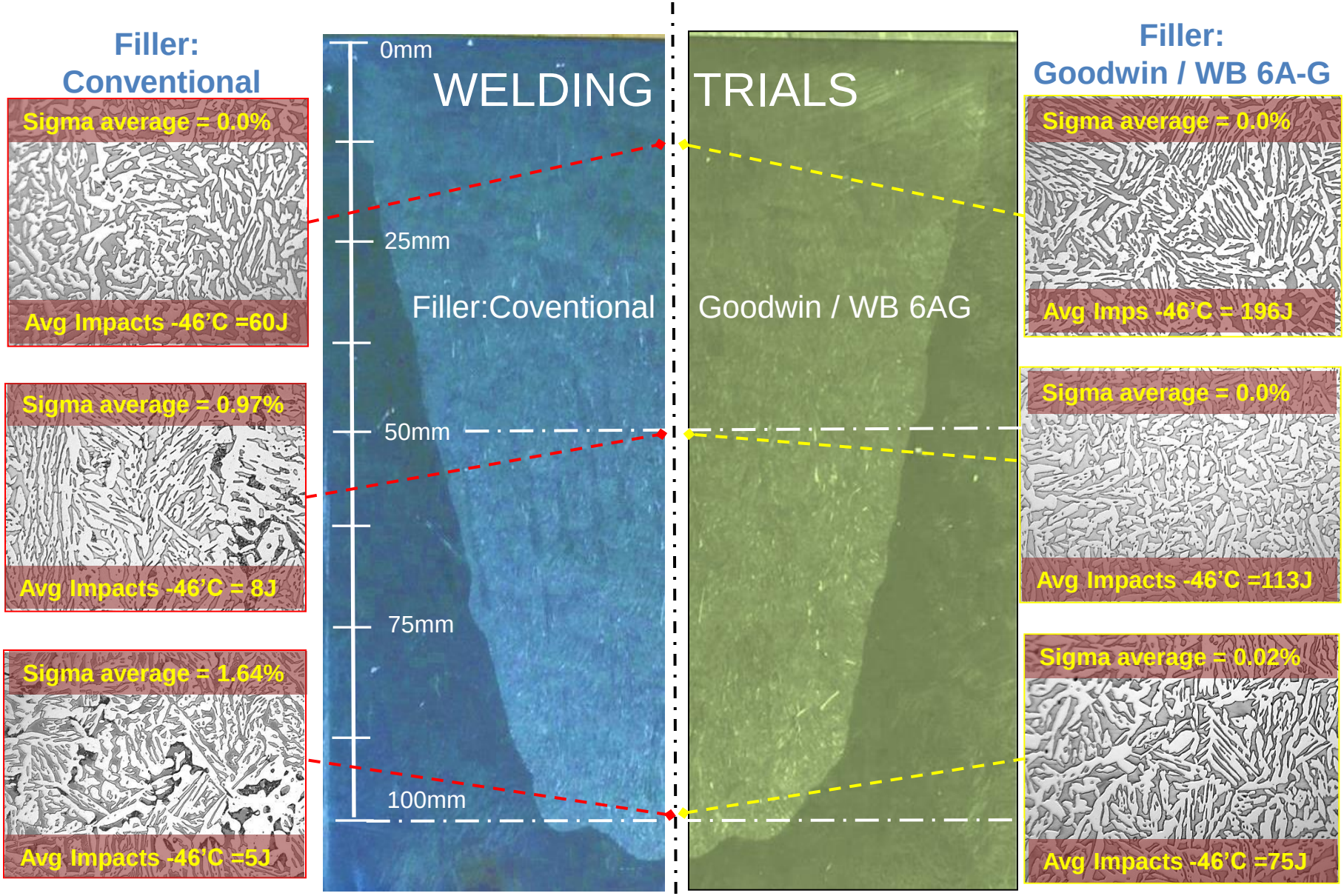

| | weight Loss at 40'C | weight Loss at 50'C | weight Loss at 60'C | weight Loss at 65'C |
|---|---|---|---|---|
| 6A-G | 0 | 1.25 | 13.52 | 31.6 |
| Conventional Filler (1) | 0.16 | 63.3 | 95.2 | 88.1 |
| Conventional Filler (2) | 0 | 129 | 143 | 167.7 |

## Impact properties in the PWHT condition - Solution Treated + WQ

As mandated by ASTM A995 for depths over 25mm

(Notch Location - Weld Metal Centre Line)

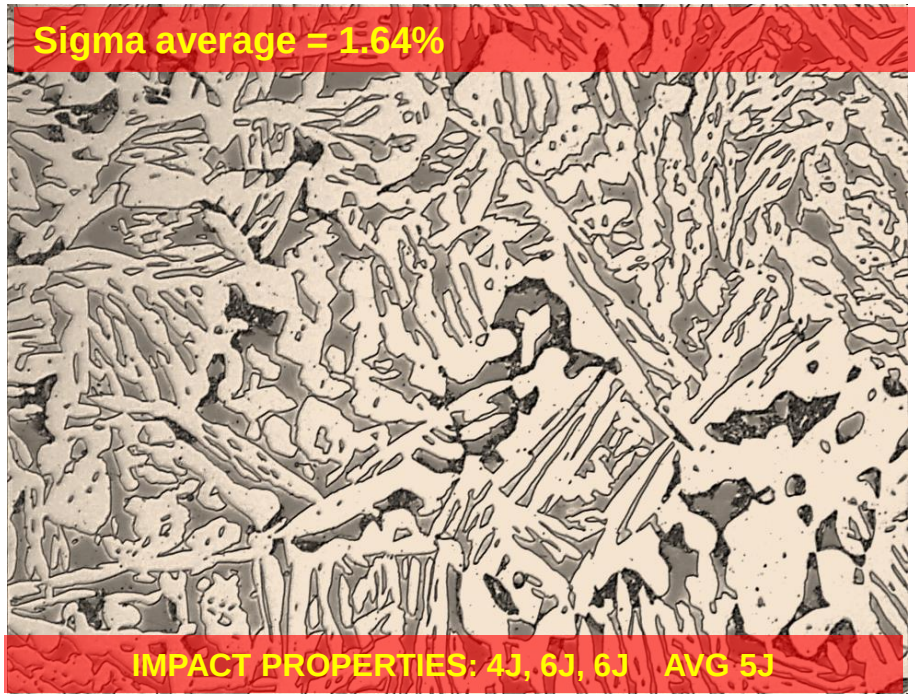





**Post Weld Heat Treated Condition: Solution Treated & Water Quenched**
**100mm Groove weld in a 200mm x 200mm x 330mm Test Block**

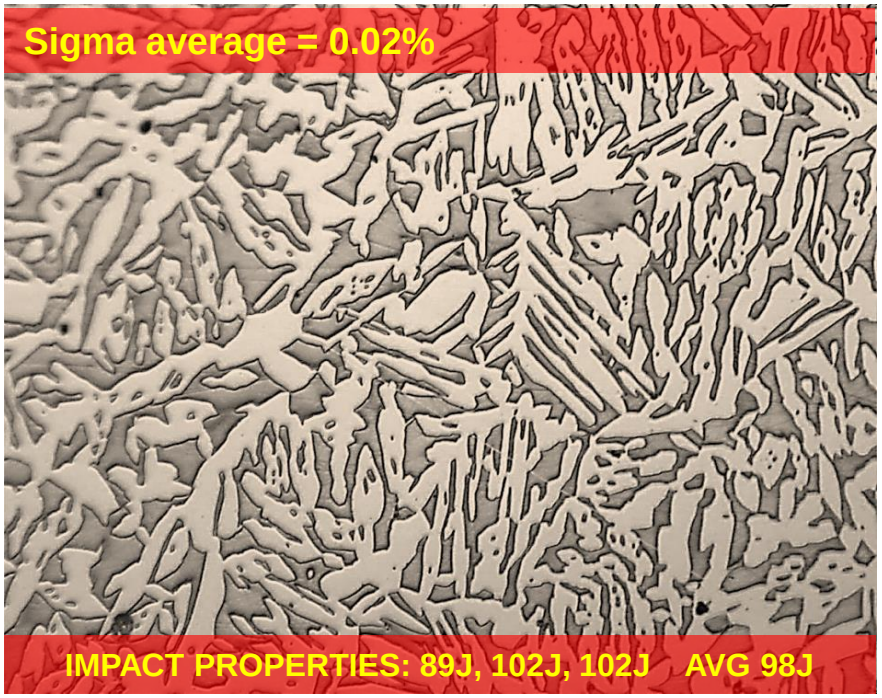
# T/2 Section 100mm deep weld

Filler: Conventional




Magnification : x200
Etchant: electrolytic NaOH

Filler: Goodwin / WB 6A-G



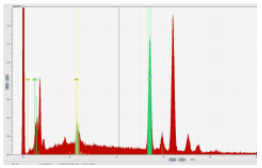

Magnification : x200
Etchant: electrolytic NaOH

Weld metal responds differently to the parent metal during PWHT
Precipitation kinetics are increased leading to sigma phase precipitation with conventional composition filler metals in heavy section welds.

6A-G composition retards the sigma phase precipitation.

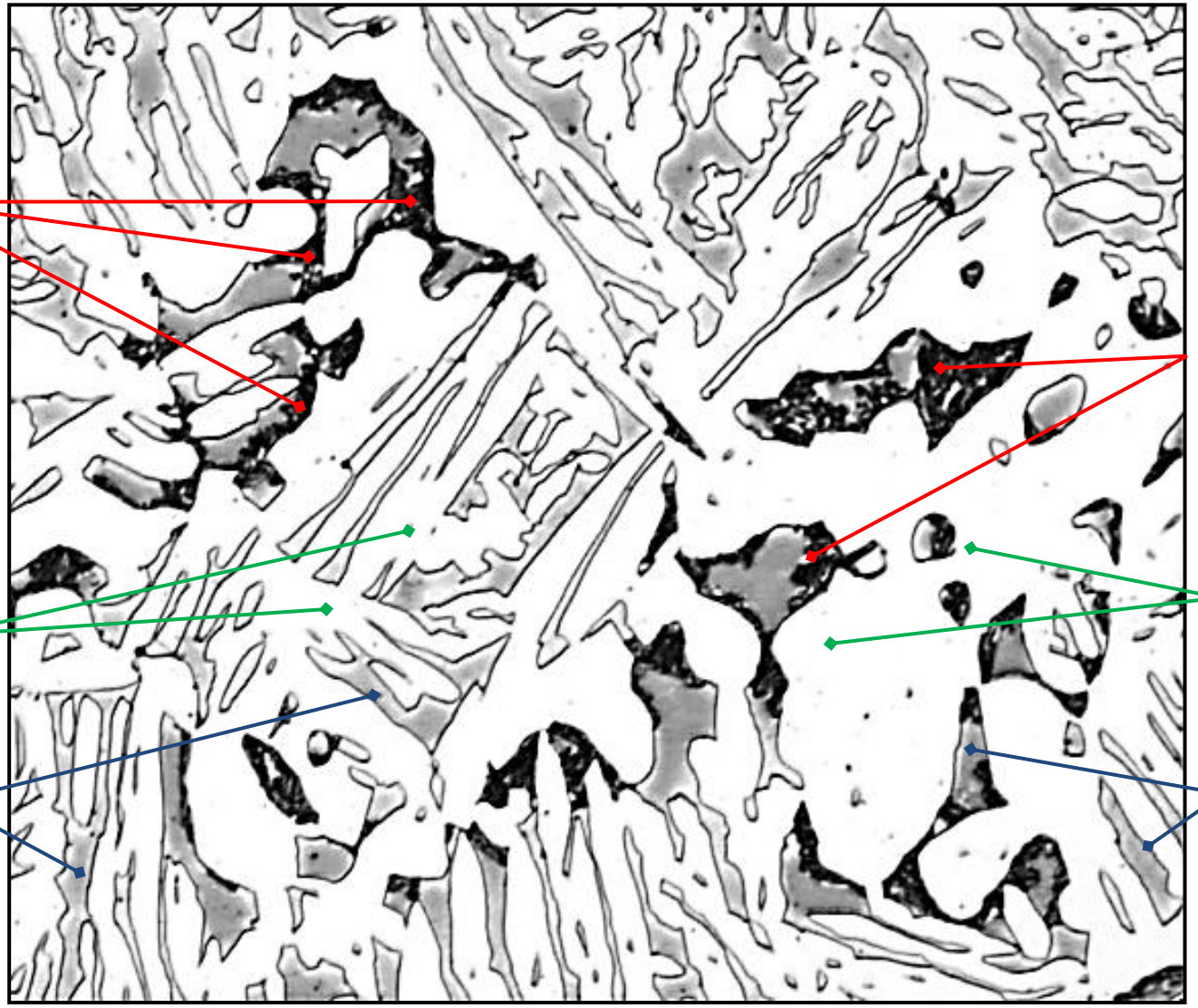
# Impact Properties ≤5J (tested at -46°C)

**Sigma phase**



Composition of intermetallic phase in weld metal is : 31% Cr ; 4.6% Mo.

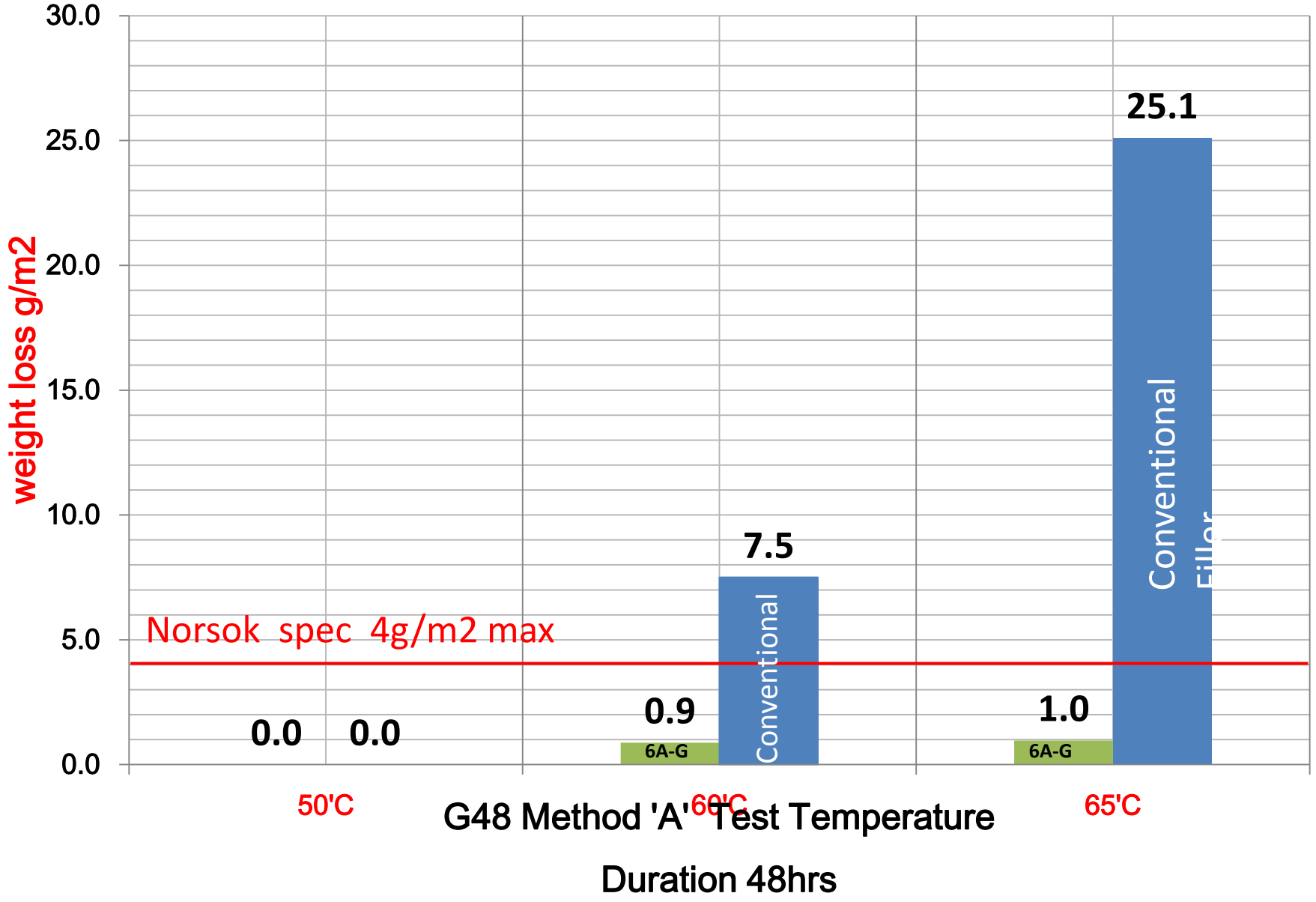
Typical sigma phase composition in super duplex steel typically ranges from 30%–60% Cr; 4%-10% Mo.




Magnification : x400
Etchant: electrolytic NaOH

**Filler: 2507XKS weld deposit at 98.5mm depth**

# 6A-G filler versus conventional filler – after post weld heat treatment



# Conclusions

- The performance of the new cast, wrought, forged and weld metal material substantially surpasses what has historically been possible to consistently achieve in terms of….
    a) Low temperature impact properties.
    b) Pitting corrosion properties.

Both in the post weld heat treated and as welded condition.

- The low temperature performance of this new duplex steel also increases the envelope of operational conditions.

- The new 6AG super duplex material can be confidently operated at temperatures down to -101ºC.

# Conclusions continued……

- 6A-G can also be used at temperature's up to 65ºC for PWHT fabricated items and 50ºC for non PWHT fabricated items.

- The sweet spot recipe applies to all 25% Cr type steels be they cast, forged, wrought or weld metal.

# Market Opportunities

- Countries where ambient out of the sun temperature is >30$^{0}$C.
- Desalination, oil & gas offshore & other appliances where line temperatures are > 40°C.
- Assisting the guarantee of  impact resistance properties.
- To use the full corrosion capacity of 25% Cr super duplex (even in the “as welded” condition 50ºC corrosion resistance not 40ºC).
- To design thicker walled higher pressure pumps & valves in 25% Cr super duplex with cross section > 250mm.
- The opportunity to lower cost by substituting more nickel rich alloys such as 6%Mo Austenitic steels and obtain similar corrosion resistance & much lower component weight due to the higher strength of super duplex.

# Thank You

More information at goodwinsteelcastings.com