6A-G SUPER DUPLEX

THE MOST SOPHISTICATED MATERIALS
FOR THE MOST DEMANDING APPLICATIONS

NOW
INCLUDED IN
ASTM A995
Standard Specification for Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts

GSC

GOODWIN STEEL CASTINGS LTD
ESTABLISHED 1883

GOODWIN STEEL CASTINGS LTD

Goodwin Steel Castings has developed a reputation in supplying high integrity heavy section stainless steel and nickel alloys over the past 40 years.

We supply large machined castings from 50kg to 40,000kg, with fabricated casting assemblies up to 100,000kg in stainless steels, duplex stainless steels and super nickel alloys for critical duty applications.

Recent research and development at Goodwin has resulted in process techniques and recipes that provide very substantial increased impact properties at both standard low temperature and even lower temperatures than had previously been achievable in cast and forged super duplex stainless steel (SDSS) and corresponding weld metal.

The foundry is supported by its sister company, Goodwin International Ltd, offering CNC machining, fabrication, pressure testing and assembly to meet discerning build to print project requirements in-house.

6A-G SUPER DUPLEX

SOPHISTICATED MATERIALS FOR DEMANDING APPLICATIONS

254 SMO 24"
600 Axial Valves
5,285kg

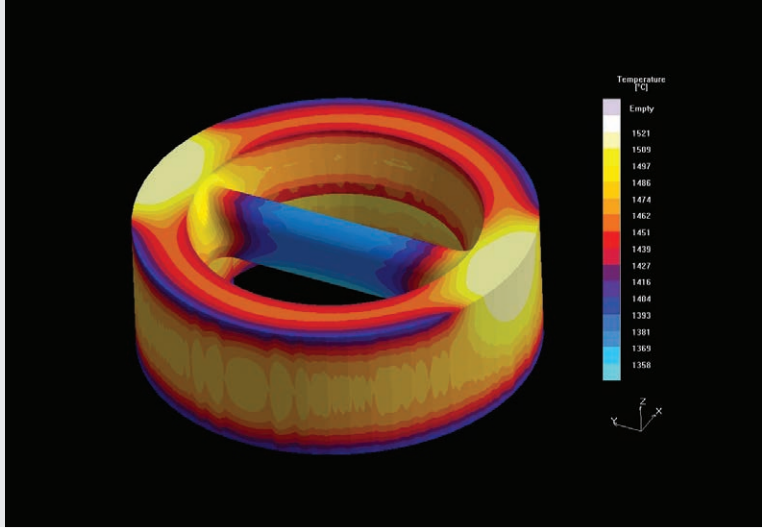
6A-G SUPER DUPLEX BENEFITS

- Low temperature impact properties which meets the Norsok requirements at minus 101°C.
- Corrosion - G48 weight loss values <4g/m2 when tested for 24hrs at 60°C.
- Heavier casting and forging sections greater than 200mm.
- Parent matching welding consumables TIG / TIPTIG / FCAW /SMAW

6A-G 16"
2500 Gate Valves
4,605kg

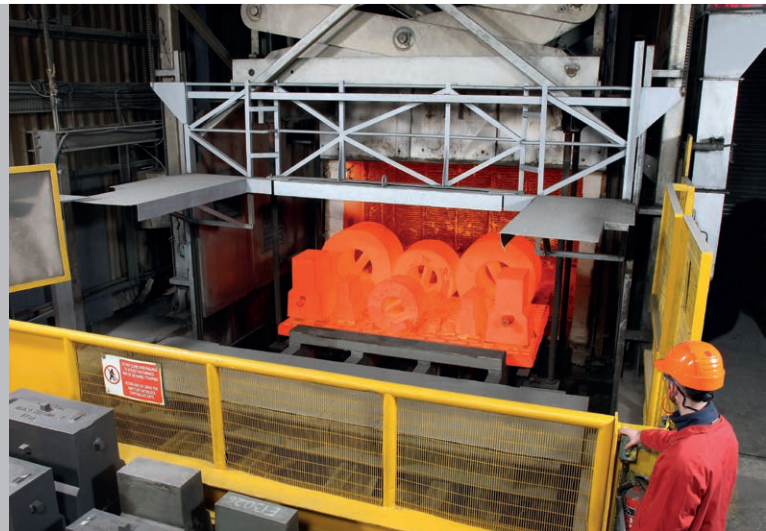
FOUNDRY FACILITIES & CAPABILITY

- Casting Solidification:
  - Fluid flow and stress analysis packages MAGMASOFT™
- Melting & Analysis:
  - Primary Melting Electric Arc and induction furnace melting.
  - Secondary AOD refining vessel with oxygen, argon and nitrogen injection (operating since 1994)
  - Thermofisher 4460 33 channel, Direct reading optical emission spectrometer.
  - Pouring capacity of 80,000 kg
- Heat Treatment:
  - 2 x High temperature water quench furnace (10,000 kg / 50,000 kg)
  - Gas fired low thermal mass bogie hearth furnace (50,000 kg)
  - 3 x Gas fired low thermal mass top-hat furnaces (20,000 kg)
- Riser Removal:
  - Large 3.5m CNC Gantry Saw
- Radiographic Inspection:
  - Varian M9a 9MeV Linatron in a 10m x 8m x 9m Bay with a 70 tonne overhead crane
  - Raytech Super-X 8.5MeV Linac
- Mechanical Laboratory:
  - In-house inspection (Charpy v-notch, tensile, corrosion & metallography)



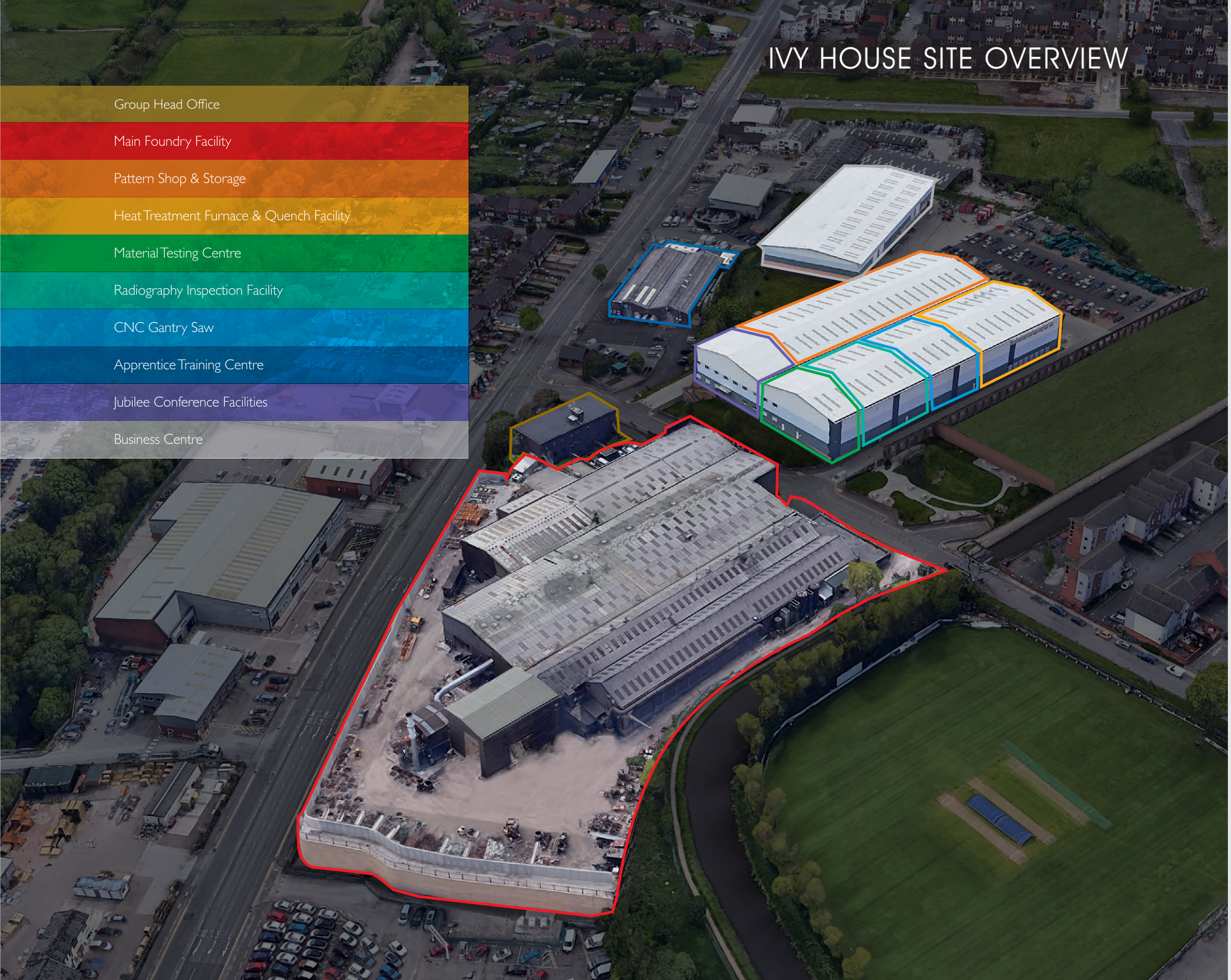
MAGMASOFT™ Solidification Simulation

AOD Secondary Refining



Automated Heat Treatment & Water Quench Facility

IVY HOUSE SITE OVERVIEW



6A-G RESEARCH & DEVELOPMENT

Super duplex steels are often specified for oil and gas, water and desalination industries for their corrosion, tensile and low temperature impact properties. However, these steels can suffer from the formation of deleterious phases which adversely effect both corrosion and impact properties.

With 6A-G material, sigma phase precipitation can be eliminated or significantly reduced leading to dramatic improvements in both low temperature impact properties and pitting corrosion resistance, with no reduction in through section tensile strength.

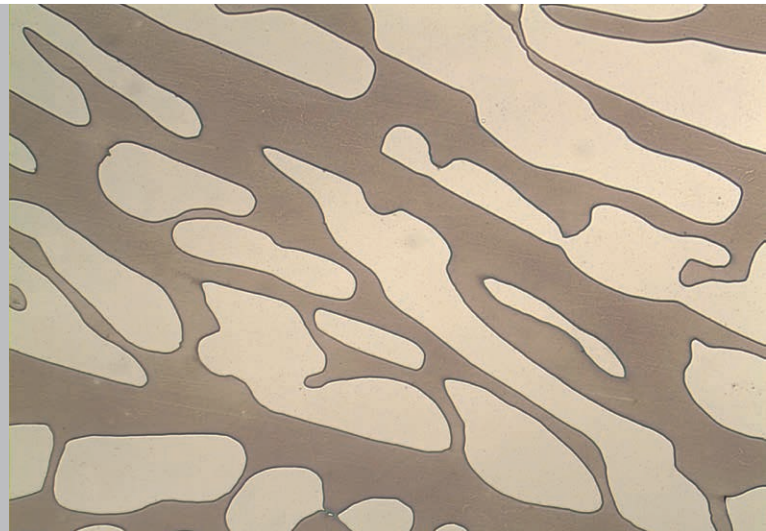
This extends significantly the section size that can be produced. Additionally, previous operational temperature constraints are substantially improved as 6A-G can operate not only in Arctic conditions with excellent impacts at -76°C, but also in seawater corrosion applications above 50°C as high as 60°C.

There is a step change in the improvements of mechanical and metallurgical properties achieved in the parent cast and weld metal when very specific chemistry and process parameters are adhered to during manufacture.

This development work has resulted in the reduction of the section size limitations of SDSS castings, forgings and welds, and the vast improvement in corrosion and impact properties of both heavy and thin section castings and forgings.

Low temperature impact and room temperature tensile testing

Metallographic preparation and inspection facilities



25%Cr Super Duplex micro-structure free from sigma phase

6A-G SUPER DUPLEX

SOPHISTICATED MATERIALS FOR DEMANDING APPLICATIONS

Scanning Electron Microscope with spectrographic EDX facility to analyse cast and forged product up to x30,000 magnification.

WHAT IS 6A-G SUPER DUPLEX?

HOW DOES IT WORK?

Alloy 6A-G has its own special chemistry whilst still being compliant with ASTM A995 6A, casting specification, however providing enhanced technical performance. This is achieved by having far more stringent control than required by conventional specifications.

This change results in much lower levels of sigma (σ) phase in section sizes where conventional 25% Cr SDSS grades have a much higher level of sigma phase resulting in lower impact and corrosion properties. For thicker sections with the conventional super duplex grades, values of 1% or more sigma phase can be expected in the very centre position.

For alloy 6A-G in section sizes ≤200mm, sigma phase will typically be <0.02%. For sections 250mm to 300mm <0.5% can be expected for an equivalent cooling rate constant.

LOW TEMPERATURE IMPACT PROPERTY IMPROVEMENTS

Figure 1 shows the average impact improvements that are achieved in 6A-G (green bars) over conventional ASTM A995 6A SDSS (blue bars) taken from Goodwin's historical database using secondary AOD refinement or remelting of AOD refined material.

Figure 2 shows the 6A-G impact properties tested at -76°C and -101°C for a range of section sizes at the centre ½T position. The graph clearly shows the potential for the 6A-G material to be utilised in Arctic conditions which is normally stipulated as -76°C.

SDSS 6A-G Enhanced Corrosion Resistance

G48 Method 'A' Pitting Corrosion		
Material 50mm Section Tested at ½T	Conventional Test Temperature	New Test Temperature
Parent	50°C →	60°C
Weld 'As Welded'	40°C →	50°C
Weld 'PWHT'	50°C →	60°C
Acceptance	No pitting; weight loss max 4g/m²	

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

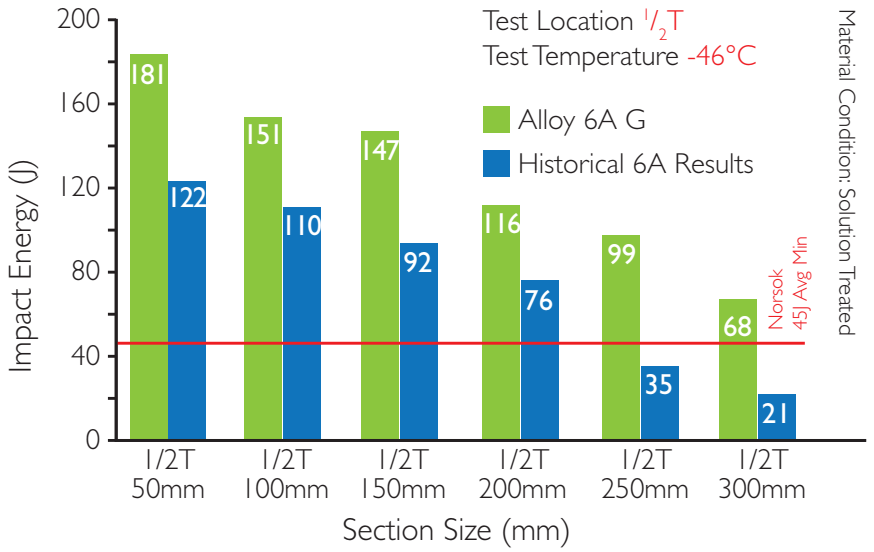


Figure 1: Impact properties of 6A-G duplex parent material compared with conventional 6A SDSS over a range of section sizes from 50mm through to 300mm.

"6A-G achieves dramatically improved impact properties

The 6A-G material has improved pitting resistance due to its enhanced chemistry, cleanliness, and reduction of intermetallic phase precipitation. Two standard corrosion tests are used in the routine production testing of SDSS, ASTM G48 Method A and ASTM A923 method C, the former being the more commonly stipulated.

Both tests use ferric chloride mixed with water (10% Fe3Cl•6H2O) as the corrosion media, and for parent material SDSS the G48 test temperature normally stipulated is 50°C with a duration of 24hrs.

Fig. 3 shows the comparison between the weight loss of 6A-G SSDS compared with the weight loss of conventional 6A SDSS cast material during G48 method A testing at 60°C.

This temperature was selected to test the material beyond the standard test regime of 50°C to demonstrate the enhanced resistance capable with the 6A-G material.

The industry standard maximum allowable weight loss is 4g/m2, figure 3 demonstrates that all 6A-G heats have a weight loss less than the maximum allowable for 50°C, but is achieving this at 60°C. The conventional 6A cast material heats all fail to pass the weight loss restriction by a large margin.

6A-G has enhanced hydrogen induced stress cracking resistance (HISC). For those who are more familiar with this phenomena it will be no surprise that resistance to HISC is improved in the 6A-G material due to significantly superior corrosion resistance at higher temperatures.

SDSS 6A-G Low Temperature Average Impact Properties versus Section Size

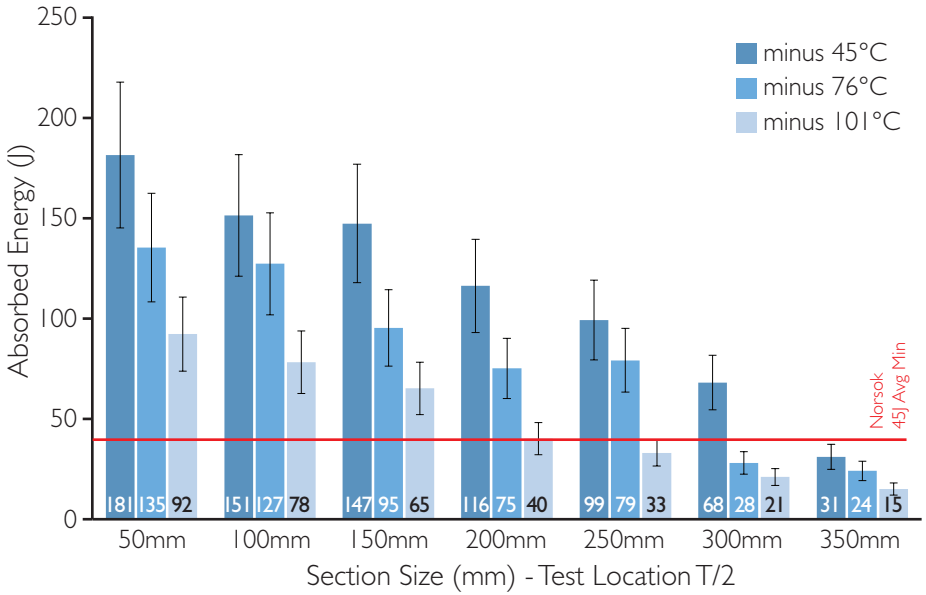


Figure 2: Parent Material 6A-G impact properties at -76°C and -101°C.

SDSS 6A-G ASTM G48 Method 'A'; Temperature 60°C; Duration 24 hrs

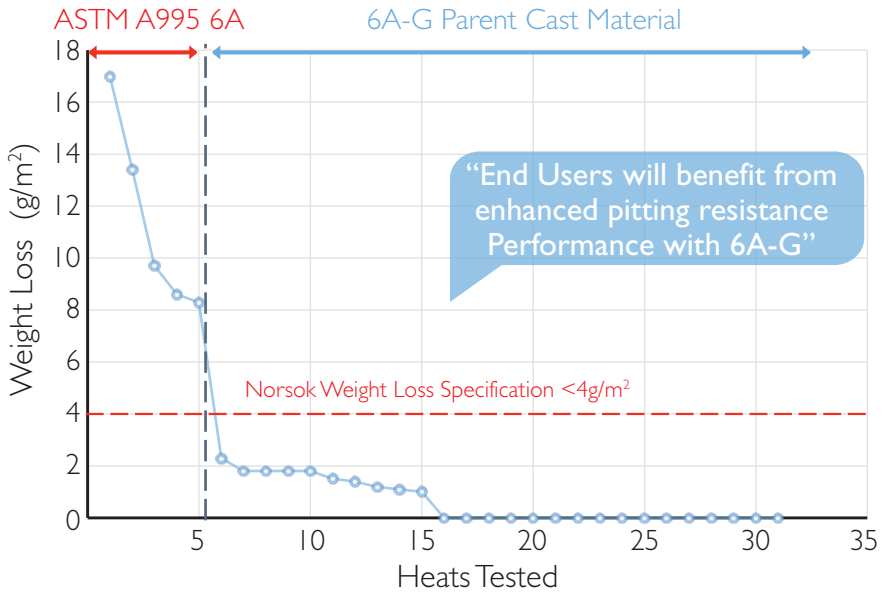


Figure 3: SDSS 6A-G versus conventional 6A G48 Method 'A' Pitting Corrosion Testing.

enabling end-users to utilise 6A-G for Arctic applications whilst achieving remarkable pitting corrosion performance"

6A-G SUPER DUPLEX WELD METAL

Goodwin research and development on SDSS weld metal originally focussed on deep welds in SDSS castings.

Conventional weld qualifications for ASTM weld materials are governed by ASTM A488 where the impact test location is stipulated just below the weld cap. However, Goodwin discovered that after subsequent post-weld heat treatment impact results at depths greater than 35mm dramatically reduced to unacceptable values using conventional commercial fillers, while the parent material was unaffected.

Commercial fillers for 6A super duplex parent material are generally split into two groups, parent matching or over alloyed. During the testing regime, both types of consumable were tested. Upon investigation on multiple thick section tests it was demonstrated that the conventional weld metal responded differently to the parent material during post weld heat treatment and began to precipitate sigma (σ) phase much more quickly than the parent material during quenching from post heat treatment temperatures.

This presented much less of a problem if the weld could be left in the 'As Welded' condition, but where specifications called for mandatory post weld heat treatment (PWHT) this created at the time an insurmountable problem with current commercially available filler metals.

Goodwin worked in conjunction with WB Alloys to develop a filler material that has a quench response with regards to sigma (σ) phase precipitation kinetics much closer to that of the parent material.

Fig 4 shows the marked improvement in 'As Welded' properties using the 6A-G filler metal compared with standard parent matching and over alloyed with nickel consumables.

Fig 5 shows one of the major findings of this work, which is that conventional fillers have a significant drop off in impact properties when welded in thick sections and subsequently post weld heat treated. PWHT is mandated by ASTM A995 for duplex castings with welds of greater depth than 25mm and as a supplementary requirement for the same depth of weld repair for duplex castings to ASTM A890.

SDSS 6A-G Impact Properties in the 'As Welded' condition; Temperature -46°C;

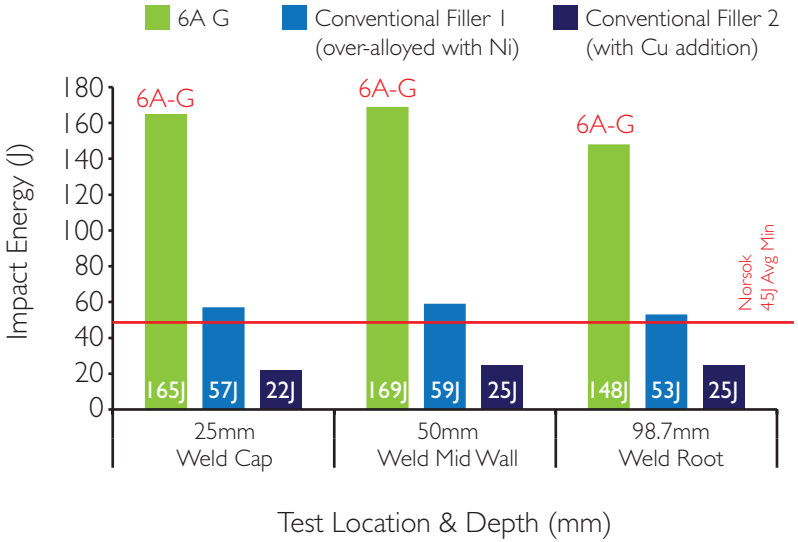


Figure 4: SDSS 6A-G filler metal compared with conventional filler metals in the 'As Welded' condition.

"End-users will benefit from unsurpassed

For conventional fillers at 100mm depth impact values are in single figures as a function of the precipitation of sigma phase in the PWHT condition.

The new 6A-G filler metal also shows a reduction in impact properties as the weld depth increases. However, even at the 100mm depth the impact properties at -46°C are over 1.5x the minimum 45J required by most weld qualification requirements, and at 25mm depth the results are over 4x the value of the conventional filler in the PWHT condition.

This is achieved whilst controlling the interpass temperature to 150°C and with deposition rates more than double current welding rates if the TIP-TIG process is utilised.

Figure 6 shows results of G48 method 'A' pitting corrosion testing for 24hr duration at a variety of temperatures.

G48 method A is specified in the oil industry to validate weld qualification procedural qualifications.

In the 'As Welded' condition the test temperature is specified at 40°C for a duration of 24hrs with a final maximum weight loss of <4g/m2 with no visible pitting allowed.

Now with 6A-G filler in the 'As Welded' condition, this can pass G48 Method 'A' at 50°C with pass data up to 60°C rather than 40°C. In the PWHT condition it can pass at 60°C with pass data up to 65°C where this was previously limited to 50°C.

SDSS 6A-G Impact Properties in the PWHT condition (Solution Treated + WQ)

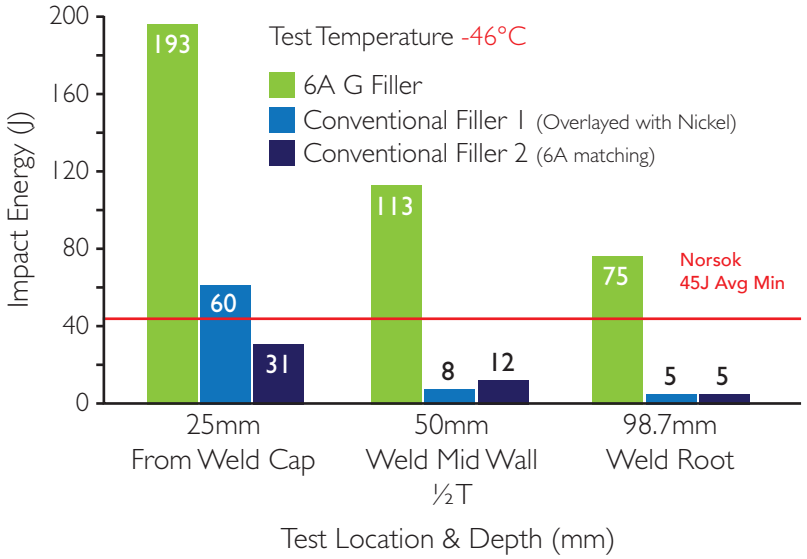


Figure 5: SDSS 6A-G filler metal compared with conventional filler metals in the PWHT condition.

SDSS 6A-G 20mm Thick Butt Weld; G48 Method 'A' Corrosion Results; Duration 24 hours

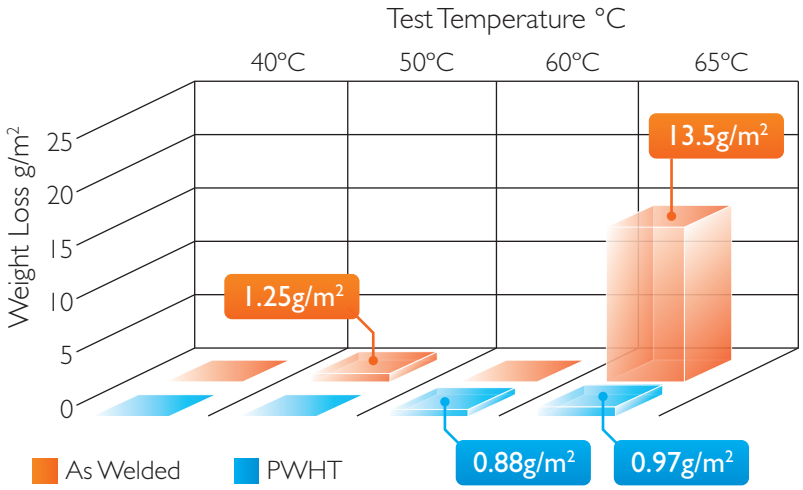


Figure 6: 6A-G Weld Metal G48 method 'A' Testing.

impact and pitting corrosion performance using the newly developed 6A-G welding consumables"

WHAT'S THE ISSUE WITH COMMERCIALLY AVAILABLE FILLERS?

Commercial fillers tested struggle to meet the G48 Method A pitting corrosion requirements when tested at 40°C in the 'As Welded' condition and 50°C when tested in the PWHT condition.

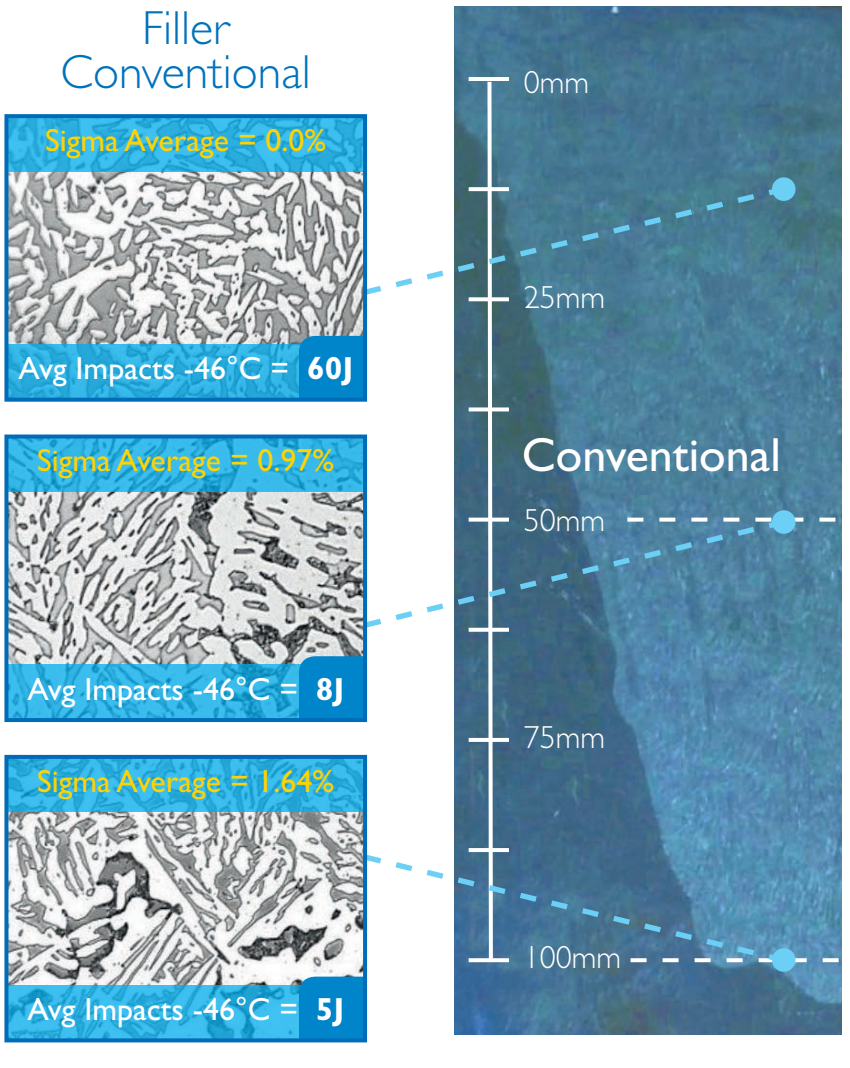
In heavy section welds requiring PWHT, beyond 25mm deep, the commercial fillers tested precipitated sigma phase reducing the impact and corrosion resistance of the weld metal. ASTM A995 stipulates that for castings all weld repairs deemed major are subject to a solution post weld heat treated.

The weld trial depicted demonstrates the significant variance observed in terms of low temperature ductility when a conventional commercially available filler (over alloyed with nickel) is compared through thickness to that of 6A-G consumable within a 100mm weldment and is subject to PWHT.

The dramatic reduction in ductility is a function of sigma phase formation during solution post weld heat treatment which is especially heightened when grain sizes are reduced as a result of the welding processes. The development of 6A-G as a casting alloy is by design less susceptible to sigma formation despite the reduced grain size achieved when welding.

Goodwin developed 6A-G welding consumables in conjunction with WB Alloys in pursuit of weldments that perform in line with the parent material mechanical and metallurgical properties that far exceed today's industry specifications.

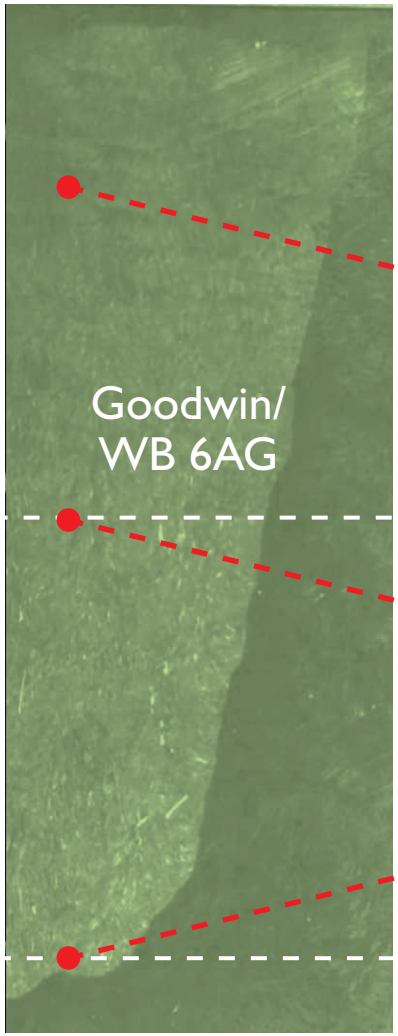
WELDING



100mm Groove weld in a
200mm x 200mm x 330mm Test Block

"End-users will benefit from unsurpassed

TRIALS



Filler
Goodwin / WB 6A-G

Sigma Average = 0.0%

Avg Impacts -46°C = **193J**

Sigma Average = 0.0%

Avg Impacts -46°C = **113J**

Sigma Average = 0.02%

Avg Impacts -46°C = **75J**

Post Weld Heat Treated Condition:
Solution Treated & Water Quenched

impact and pitting corrosion performance using the newly developed 6A-G welding consumables"

6A-G IN SERVICE WELDMENTS & FORGINGS

Goodwin are ASTM committee members who have made a formal proposal in pursuit of a supplementary requirement to ASTM A995 grade 6A to enable specifiers to stipulate enhanced low temperature or corrosion requirements. This supplementary requirement will aid end users in specifying the use of duplex in low temperature artic applications or higher temperature middle east environments over costly super austenitic stainless steels or nickel alloys.

Fig 7 shows in the 'As Welded' condition the 6A-G filler exhibited not only enhanced impact properties when tested at the conventional temperature of -46°C, but also achieved results passing the Norsok 45J avg 35J single specification at -101°C.

Fig 8 shows that forging trials in the new 6A-G material are currently ongoing with early results looking very promising as sections tested up to 100mm at ½T are achieving on average >40% improvement than conventional F55 material tested in the same section sizes.

As a patented material Goodwin is in the process of licensing the technology to select foundries and forges. Any enquiries in relation to 6A-G licensing activity please contact brgoodwin@goodwingroup.com.

A number of petrochemical end users and engineer procurement contractors are presently performing welding qualifications with 6A-G and are reporting enhanced low temperature ductility and reduced susceptibility to corrosion.

6A-G Avg Impact Values 'As Welded' Condition

20mm Thick Weld Test Plate (Test Location T/2)

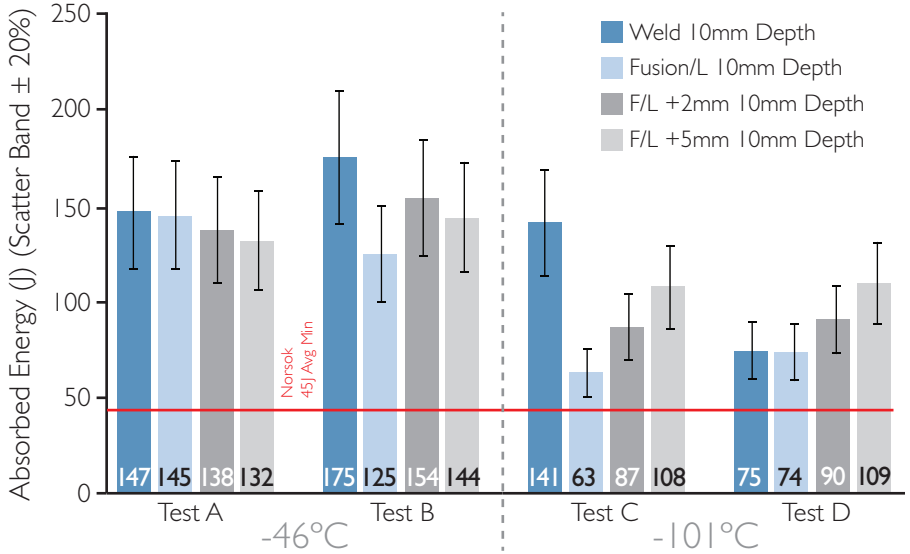


Figure 7: Low temperature ductility inthrough section weldments testing at conventional and Arctic operating conditions.

F55 Compared with 6A-G Forging Data

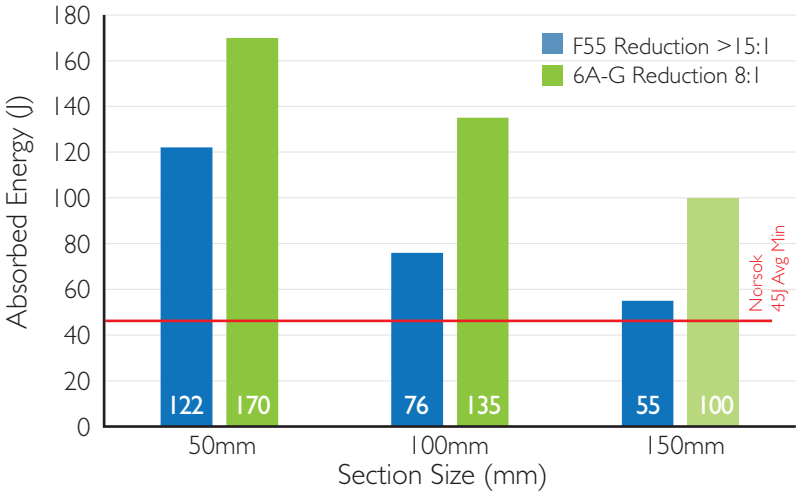


Figure 8: 6A-G forged material comparison with conventional F55 forged product of varying section thickness.

"6A-G achieves dramatically improved impact properties

CONCLUSIONS

1. The performance of the new 6A-G cast and weld metal substantially surpasses what has historically been possible to consistently achieve in terms of low temperature impact and corrosion properties both in the post weld heat treated and 'As Welded' condition.

2. The low temperature performance of this new duplex steel also increases the envelope of operational conditions. The new 6A-G super duplex material can be confidently operated at temperatures down to -76°C for 250mm section and -101°C for 100 mm.

3. Welds made with 6A-G fillers can be successfully made in heavy section components with tested weld depths down to 100mm in the PWHT condition, where previous limitations were between 25mm to 35mm before impact properties reduced to below the industry standard.

4. The pitting corrosion properties have been dramatically improved with the 6A-G material, both for parent and weld metal when tested using standard ferric chloride tests such as ASTM G48 method A and ASTM A923 method C.

5. The enhanced chemistry applies to all 25% Cr type steels be they cast, forged, wrought or weld metal.

OPPORTUNITIES

IMPACT PROPERTIES

- Assisting the guarantee of impact resistance properties.
- To design thicker walled higher pressure pumps & valves in 25% Cr super duplex with cross section >250mm.
- Applications where Arctic low temperature conditions apply.

CORROSION PROPERTIES

- Desalination, oil & gas, offshore & other appliances where line temperatures are >40°C. Previously testing for welds in the 'As Welded' condition was limited to 40°C while for the new 6A-G material this is now 50°C and in the PWHT condition is 60°C, producing an enhancement to the operational envelope.
- The opportunity to lower cost by substituting 6A-G in place of 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.
- To use the full corrosion capacity of 25% Cr super duplex (even in the 'As Welded' condition 50°C corrosion resistance not 40°C).

enabling end-users to utilise 6A-G for Arctic applications whilst achieving remarkable pitting corrosion performance"

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