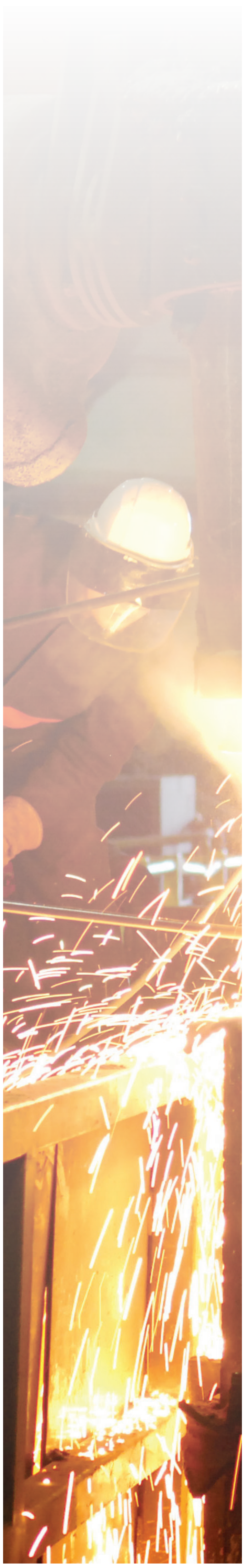
Forging ahead with improvements in impact properties & corrosion resistance

GOODWIN STEEL CASTINGS LIMITED



Abstract

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.

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	

Enhancements include:

1) Dramatically improved low temperature impact properties in parent metal castings, forgings and weld metal.

2) Improved G48 method 'A' corrosion resistance in parent and weld metal.

3) Much greater safety margin than has traditionally been achieved with SDSS.

4) The low temperature performance of this new SDSS increases the envelope of operational conditions. The new 6A-G super duplex material can be confidently operated as low as -76°C for 250mm section and to -101°C for 100mm section.

5) Enhanced hydrogen induced stress cracking (HISC) resistance properties.

6) Crucially enables heavier sections to be successfully produced while maintaining excellent impact strength and corrosion performance in centre sections.

Introduction

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, the 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 artic conditions with excellent impacts at -76°C, but also in seawater corrosion applications above 50°C.

This article describes the step change improvements of properties achieved in the parent cast and weld metal when very specific chemistry and process parameters are observed in the manufacture of product.

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.

How does it work?

Alloy 6A-G has its own special chemistry whilst still being compliant with ASTM A995 6A, it provides the enhanced technical performance. This is achieved by having far more stringent chemistry 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 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.

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

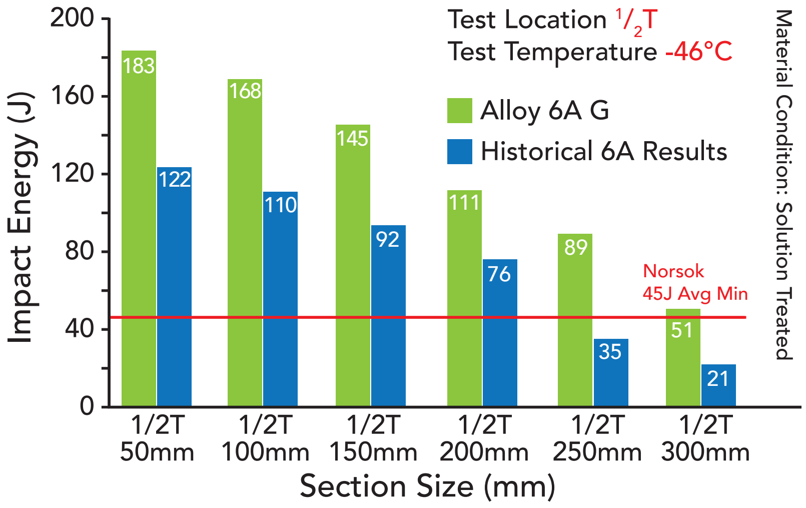
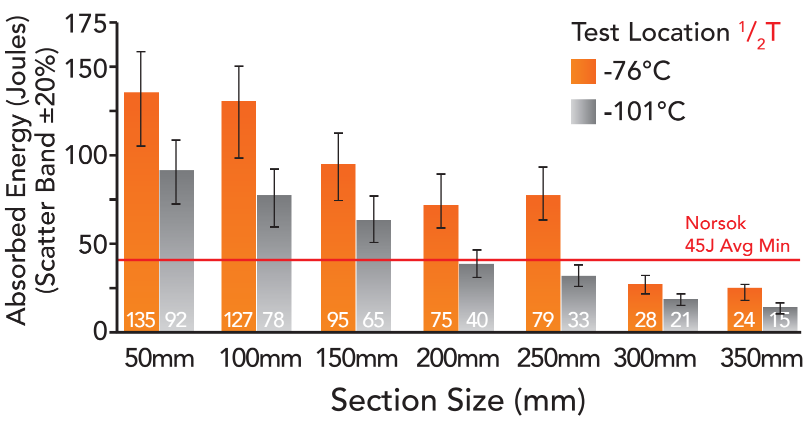


Figure 2 shows the 6A-G impact properties tested at -76°C and -101°C for a range of section sizes at the centre ½T position. The graph clearly shows the potential for the 6A-G material to be utilised in arctic conditions which is normally stipulated as -76°C.

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

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



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 SDSS compared with the weight loss of conventional 6A SDSS cast material during G48 method A testing at 60°C.

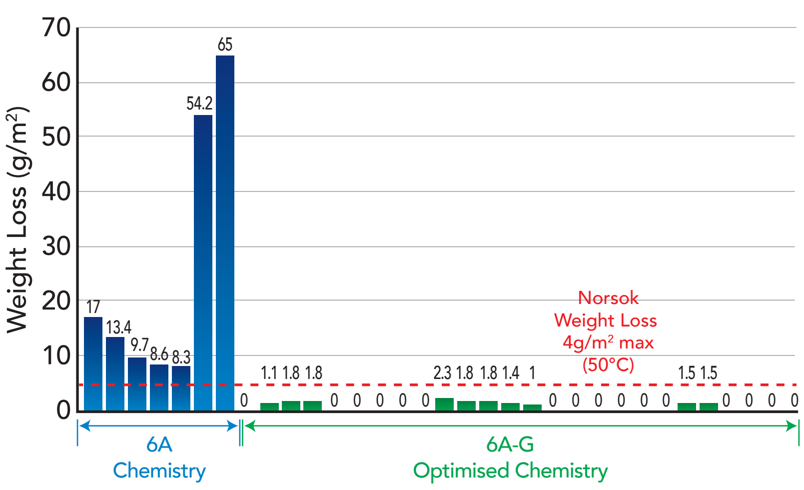
This temperature was selected to test the material beyond the standard test regime of 50°C to demonstrate the enhanced resistance capable with the 6A-G material.

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.

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

ASTM G48 Method 'A'; Temperature 60°C; Duration 24 hrs



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Super Duplex Steel 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.

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

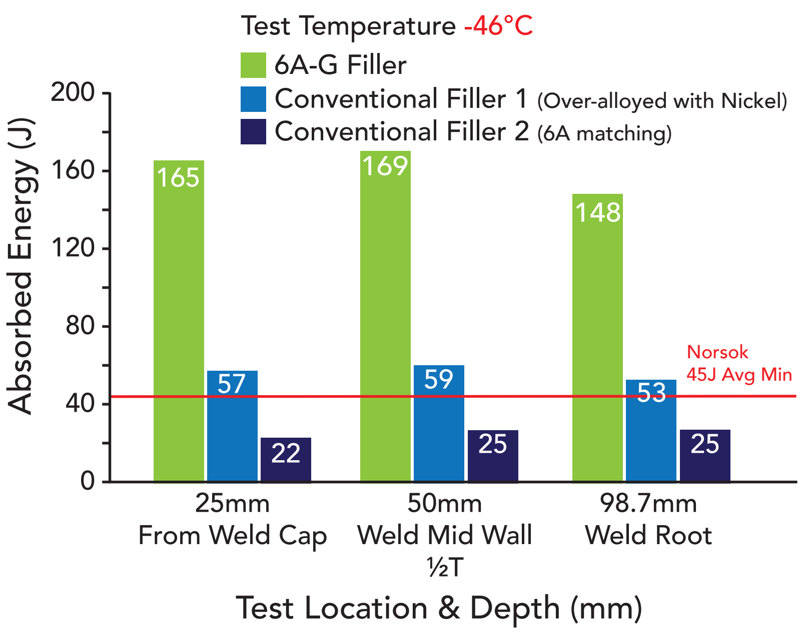
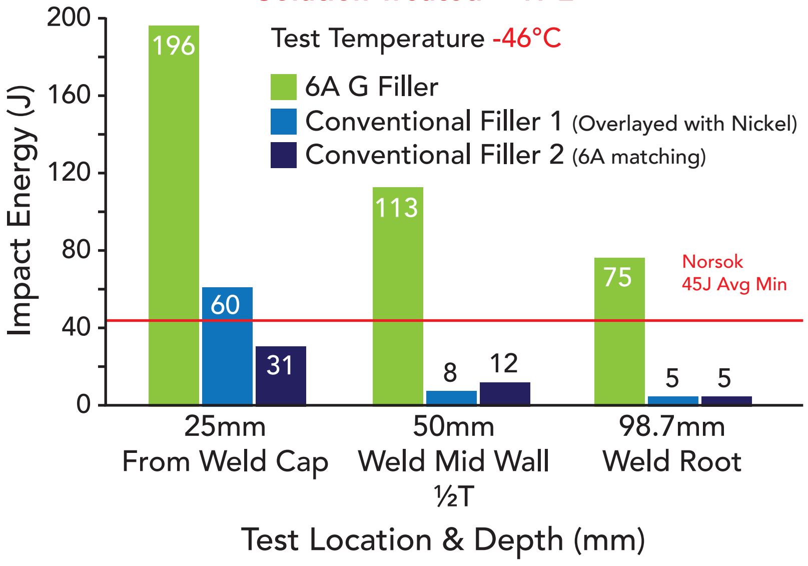


Fig 4 shows the marked improvement in as welded properties using the 6A-G filler metal compared with standard parent matching and over alloyed with nickel consumables.

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.

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.

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



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.

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.

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.

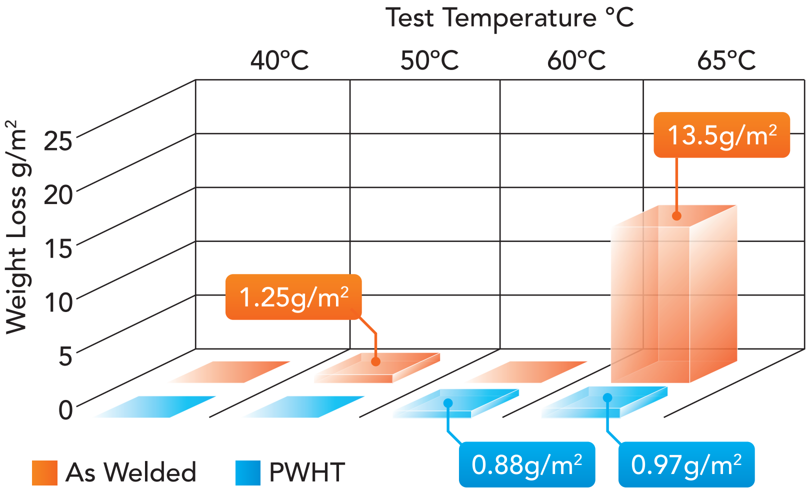
2. The low temperature performance of this new duplex steel also increases the envelope of operational conditions. The new 6A-G super duplex material can be confidently operated at temperatures down to -76°C for 250mm section and -101°C for 100 mm.

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

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



Opportunities

- Countries where ambient out of the sun temperature is >40°C.
- 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.
- Assisting the guarantee of impact resistance properties.
- To use the full corrosion capacity of 25% Cr super duplex (even in the "as welded" condition 50°C corrosion resistance not 40°C).
- To design thicker walled higher pressure pumps & valves in 25% Cr super duplex with cross section > 250mm.
- 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.
- Applications where arctic low temperature conditions apply.