

Inclusion of the achievable properties from the new super duplex Grade 6A-G into the ASTM A995 standard as supplementary requirement S52.
“Additional Requirements for Grade 6A”.

Authors: Steve Roberts ⁽¹⁾, Steve Birks ⁽²⁾; Affiliation: Goodwin Steel Castings Ltd ⁽¹⁾⁽²⁾
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Continuing from the paper presented at Duplex World Conference in Oct 2016 in Düsseldorf titled “*Improving the low temperature properties & corrosion resistance in duplex stainless-steel weld metal and castings*”; this paper focuses on the introduction of 6A-G material and use in the American Society of Testing and Materials standard ASTM A995. For the first-time purchasers and end users can specify the enhanced low temperature impact properties and corrosion properties achieved with the new 6A-G grade for both parent and weld procedural qualification testing.

To facilitate the inclusion of the material in the standard, supporting parent and weld metal data was provided by Goodwin in the form of a comprehensive data package of multiple 6A-G heats and weld tests. This resulted in the American Society of Testing and Materials including the enhanced impact toughness and corrosion resistance properties in ASTM A995 as supplementary requirements S52. “Additional requirements for Grade 6A”; in October 2017.

Since the launch of the 6A-G super duplex steel at the Duplex World Conference in Oct 2016, Goodwin has been manufacturing the new material for our own valve product range, as well as other specific customer contracts requiring enhanced properties. This new material is much less susceptible to cracking when produced in large sections than conventional 5A & 6A grades, which makes the material an excellent choice for both small and indeed larger super duplex components. Section sizes are being successfully produced up to 300mm, which would not be possible with conventional super duplex grades. Conversion to 6A-G has reduced scrap and costly weld repairs, and improved lead times within the Goodwin Foundry for super duplex steel.

Work has also continued with the 6A-G weld consumables in collaboration with WB Alloy Products Ltd, where trial batches have been manufactured and evaluated by multiple organisations, three of which have already approved 6A-G for use on a variety of projects often replacing more expensive fillers such as nickel alloys.

Within ASTM A995 grade 6A only the requirement for tensile testing is mandatory, while test block sizing, impact test temperatures, corrosion testing test regime, ferrite content, specimen locations, weld qualification parameters, and acceptance criteria are not well defined and became the responsibility of the purchaser to separately specify. This resulted in purchasers/ end users having to produce their own technical specifications to outline clear testing and acceptance criteria for the 6A grade, and indeed other grades within the ASTM

A995 standard. Unfortunately this results in many end user specific requirements and little parity between specifications and acceptance conditions.

The intention of this supplementary requirement is to allow purchasers to specify enhanced properties in the 6A grade giving a greater level of confidence and safety margins. This is only possible to achieve by producing grade 6A to specific recipe controls and processed using certain key production parameters changes. Goodwin manufactures this new duplex under the internal designation 6A-G which meets all the requirements of conventional 6A grade but possesses enhanced toughness, corrosion resistance and manufacturability.

To specify 6A-G end users and purchasers can now simply specify ASTM grade 6A and invoke supplementary requirement S52 which is divided into four main sections:

S52.1 Casting Thickness (T)

S52.2 Charpy Impact Test

S52.2.1 Test block thickness for Charpy impact testing

S52.2.2 Charpy test temperature and acceptance criteria for test blocks $\leq 100\text{mm}$ (4").

S52.2.3 Charpy test temperature and acceptance criteria for test blocks $> 100\text{mm}$ (4").

S52.3 Corrosion Testing

S52.3.1 Corrosion specimen removed location.

S52.3.2 Corrosion acceptance criteria for test blocks $\leq 100\text{mm}$ (4").

S52.4 Weld Qualification

S52.4.1 Charpy impact requirements for qualification coupons in the post-welded condition $T \leq 100\text{mm}$ (4").

S52.4.2 Charpy impact requirements for qualification coupons in the as welded condition $T \leq 100\text{mm}$ (4").

S52.4.3 Charpy impact requirements for qualification coupons where $T > 100\text{mm}$ (4")

S52.4.4 G48 Method A pitting corrosion test requirements.

Each of the four main sections or subsections can be specified independently or together if necessary to tailor the requirements to the purchaser's specific needs giving maximum flexibility. Alternatively, the entirety of the supplementary requirement may be specified.

Parent Cast Material Requirements

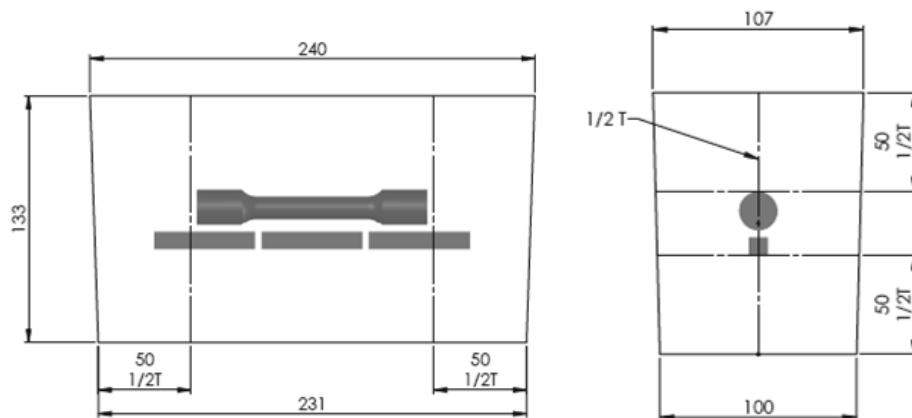
S52.1 Casting Thickness (T)

The casting thickness (T) is one of the most important parameters when manufacturing super duplex products because larger casting sections have slower cooling rates than thinner sections. During quenching from solution temperature all casting sections must be cooled quickly enough to avoid precipitation of secondary phases such as sigma. Phases such as sigma will dramatically reduce the low temperature impact properties and local pitting

corrosion of the material. Consequently, it is important that the test material used to qualify the casting represents the cooling rate of the slowest section to cool in the casting as close as can be practically expected.

S52.1 clearly identifies that (T) is the maximum thickness of the pressure containing wall of the casting exclusive of padding added for directional solidification, flanges, appendages, and sections designated by the designer as non-critical. It is the intention of the standard that the order, inquiry, and/or drawing designate what the dimension (T) is for any individual casting. Once (T) has been specified, the representative test block can be appropriately sized. In the view of the authors, ASTM A703; “Specification for Steel Castings, General requirements, for Parts”, does not adequately specify the section size matching test blocks required for duplex and super duplex steel. Consequently, most purchasers determine that the Norsok datasheet M630 MDS D56 is utilised for test block sizing once (T) has been specified. However, S52.2 stipulates impact testing at $\frac{1}{2}T$ which is more stringent than the Norsok requirements which specifies $\frac{1}{4}T$ testing. An example of test block sizing is detailed in Fig 1.

Fig 1. Example of a 100mm (4”) test block, with specimen locations at the $\frac{1}{2}T$ position



Note: The tensile gauge length and notch positions of impact specimens are a minimum distance of $\frac{1}{2}T$ from any outer surface of the test block and are centred around the $\frac{1}{2}T$ position.

S52.2 Charpy Impact Test

When the thickness of the test block is $\leq 100\text{mm}$ (4”), Charpy impact testing shall be performed at one of the test temperatures detailed in Table 1. The requirement of the standard is that the purchaser specifies one of the impact test temperatures taken from the table. If the test temperature is not specified the default test temperature for impact testing shall be -46°C .

These low temperature impact requirements are higher values than is normally specified for super duplex steel and allow the end user/ purchaser to specify material with higher levels of safety margin and/or guaranteed properties at lower impact test temperatures.

Table 1: Charpy Impact Testing of Base (Cast) Material

Test Temperature °F [°C]	Charpy V-Notch Impact Requirements	
	Energy Value, ft-lbf [J], min value for two specimens and min average of three specimens	Energy Value, ft-lbf [J], min for single specimen
-51 [-46]	103 [140]	77 [105]
-105 [-76]	66 [90]	48 [65]
-150 [-101]	44 [60]	33 [45]

Table 2: Typical mechanical properties of 10 x heats of 6A manufactured by Goodwin Steel Castings Ltd to the Charpy impacts requirements of supplementary requirements S52 (6A-G).

Heat No.	Section (mm)	Location	UTS (N/mm ²)	Yield (N/mm ²)	Elongation (%)	Reduction of Area (%)	Impact Requirements (CVN)											
							Temp (°C)	(Joules)										
								Test [1]	Test [2]	Test [3]	Avg							
ASTM A995 6A	All	-	690 min	450 min	25 min	n/a		n/a	n/a	n/a	n/a							
Supplementary S52.1	≤100mm	1/2T					-46	105 single min			140 avg min							
							-76	65 single min			90 avg min							
							-101	45 single min			60 avg min							
E15660	50mm	1/2T	765	483	36	64	-50	180	172	175	176							
							-76	138	139	133	137							
							-101	65	68	71	68							
E15749	50mm	1/2T	772	552	33	64	-50	158	148	156	154							
							-76	149	136	166	150							
							-101	94	67	103	88							
E15702	50mm	1/2T					-50	148	164	134	149							
							-76	150	128	160	146							
							-101	69	75	72	72							
	100mm	1/2T	767	516	38	59	-46	143	172	167	161							
		1/4T					-46	167	156	148	157							
E15724	50mm	1/2T	746	516	38	59	-50	172	149	160	160							
							-76	127	146	132	135							
							-101	60	61	106	76							
	100mm	1/2T	747	491	34	71	-46	168	142	158	156							
		1/4T					-46	163	146	154	154							
E15780	50mm	1/2T					-50	157	151	158	155							
							-76	154	153	146	151							
							-101	88	92	90	90							
	100mm	1/2T	760	510	40	72	-46	165	166	155	162							
		1/4T					-46	162	154	154	157							
		1/2T					-76	154	92	102	116							
E15839	100mm	1/2T	728	474	33	62	-50	133	144	174	150							
		1/4T					-50	147	143	185	158							
		1/2T					-76	126	134	120	127							
							-101	95	95	118	103							
							G6585	50mm	1/2T	757	456	40	63	-50	180	180	182	181
														-76	100	144	118	121
-101	86	146	105	112														
E15863	100mm	1/2T	753	516	31	50	-46	153	147	139	146							
		1/4T					-46	150	126	140	139							
G6554	50mm	1/2T					742	472	36	50	-50	187	176	180	181			
							-76	165	163	168	165							
							-101	130	96	139	122							
G6590	50mm	1/2T	771	495	39	64	-46	191	181	185	186							
		100mm	1/2T	764	541	33	64	-46	177	178	180	178						
			1/4T					-46	185	184	184	184						

Table 2 details the mechanical properties of 10 x heats of 6A-G where test blocks size ranges between T= 50mm and T=100mm. The chemistry and tensile results from each heat meet the requirements of ASTM grade 6A, while the low temperature impact results far exceed the typical Norsok M650 MDS D56 specification minimum which is 45J avg and 35J single at -46°C. Instead these heats meet the impact values required by the new ASTM A995 S52.2 as specified in table 1. These heats verify that the values required by the new addition to the standard can be achieved provided specific chemistry and process parameter controls are applied.

Table 2A: Typical mechanical properties material of 6A where T=300mm manufactured by Goodwin Steel Castings Ltd

Heat No.	Section (mm)	Location	UTS (N/mm ²)	Yield (N/mm ²)	Elongation (%)	Reduction of Area (%)	Impact Requirements (CVN)				
							Temp (°C)	(Joules)			
								Test [1]	Test [2]	Test [3]	Avg
ASTM A995 6A	All	-	690 min	450 min	25 min	n/a		n/a	n/a	n/a	n/a
E15780	300mm Test Block	1/2T	-	-	-	-	-50	45	37	45	42
G6585	300mm Test Block	1/4T	725	469	25	43	-46	72	73	83	76
G6978	300mm Test Block	1/4T	730	478	27	40	-46	60	59	64	61
	300mm Sacrificial Casting	1/4T	783	490	40	56	-46	42	38	38	39

Table 2A demonstrates what low temperature impact and tensile results can be expected in a 300mm section.

S52.3 Corrosion Testing

Pitting corrosion testing of cast parent material is performed per heat/batch utilising an ASTM G48 Method A ferric chloride pitting resistance test for a duration of 24hrs. This supplementary S52.3 is specified where increased pitting corrosion test temperature of 60°C is required compared with the industry standard test temperature of 50°C. This test confirms the enhanced pitting resistance that can be achieved with the 6A-G material compared with conventional 6A.

The thickness of the test blocks used to extract the corrosion samples for testing shall be equal to the casting thickness (T) and shall be removed from the 1/4T location.

When the thickness of the test block is ≤ 100mm (4") the acceptance criteria for the test shall show no evidence of pitting when examined at x20 magnification and have a weight loss < 4g/m². When the thickness of the test block is >100mm (4"), the test temperature and impact requirements shall be agreed between the purchaser and manufacturer.

Table 3: Typical pitting resistance results of 6A-G production heats produced by Goodwin Steel Castings Ltd

Heat	Section (mm)	Location	ASTM G48 Method A Corrosion Test			
			Duration 24hrs (Weight Loss g/m ²)			
			Tested at 50°C	Tested at 60°C	Tested at 65°C	Comments
E15660	50	1/2T	0	0	0	No pitting observed at x20 Mag
E15749			0	0	5.0	Pitting observed at 65°C
E15702			0	0	5.2	Pitting observed at 65°C
E15724			0	0	0	No pitting observed at x20 Mag
E15780			0	0	0	
E15839			0	0	0	
G6585			0	0	1.0	
E15863			0	0	0	
G6554			0	0	0	
G6590			0	0	0	

S52.4 Weld Qualification

Currently ASME and ASTM welding codes for duplex steel do not take fully into account cooling rates of the component during post weld heat treatment which invariably with duplex steel, means a solution treatment and water quench. This is important for two main reasons, firstly castings often will require some form of weld repair, and secondly, it has been established by the development work performed by Goodwin Steel Castings Ltd, that conventional super duplex filler materials precipitate sigma phase faster than parent material. Consequently, when performing weld qualifications in duplex steel that require post weld heat treatment, the weld qualification must closely simulate the cooling conditions of production components during water quenching.

Weld qualifications which do not take the retardation in cooling experienced when weld repairing large section castings and performing post weld heat treatment may report far better impact and corrosion resistance in the qualification weld metal than will be experienced in actual casting weld repairs. This will result in inaccurate procedural qualifications and safety considerations.

Supplementary requirement S52.4 now takes this into account by ensuring the casting supplier and purchaser agree upon the weld test plate/coupon thickness required for weld procedural record (PQR), but in any event shall be no less than 1.5 times the maximum expected weld repair depth and the weld deposit thickness shall be at least 80% of the maximum expected repair depth.

Weld Test Plate Thickness Worked Example:

- Expected maximum weld depth to be qualified = 50mm (1")
- Weld test plate thickness minimum [1.5 x 50mm] = 75mm
- Weld deposit minimum thickness [0.8 x 50mm] = 40mm

Additionally, S52.4 gives specific weld qualification impact testing requirements for post-weld heat treated coupons and “as welded” test coupons which are invoked when the weld test coupon is $\leq 100\text{mm}$ (4”) [see table 4 & 5]. Just as with the parent material, when the weld coupon thickness exceeds 100mm (4”), the test temperature for impact testing and acceptance criteria shall be agreed between the purchaser and casting supplier.

Table 4: Weld Qualification Impact Testing for Post-weld Solution Treated Coupons

Test Temperature °F [°C]	Charpy V-Notch Impact Requirements	
	Energy Value, ft-lbf [J], min value for two specimens and min average of three specimens	Energy Value, ft-lbf [J], min for single specimen
-51 [-46]	74 [100]	55 [75]
-105 [-76]	44 [60]	33 [45]
-150 [-101]	33 [45]	26 [35]

Note: It is recommended that test temperature selection be determined based on the intended service temperature of the casting.

Table 5: Weld Qualification Impact Testing for As-Welded Coupons

Test Temperature °F [°C]	Charpy V-Notch Impact Requirements	
	Energy Value, ft-lbf [J], min value for two specimens and min average of three specimens	Energy Value, ft-lbf [J], min for single specimen
-51 [-46]	89 [120]	66 [90]
-105 [-76]	44 [60]	33 [45]
-150 [-101]	33 [45]	26 [35]

As shown in table 5, not only is there an enhancement in impact properties in the post-weld treated condition, but there is also a dramatic improvement in impact properties in the as welded condition utilising the 6A-G filler.

Fig.2 Example of a weld test plate showing material to be discarded after post-weld heat treatment

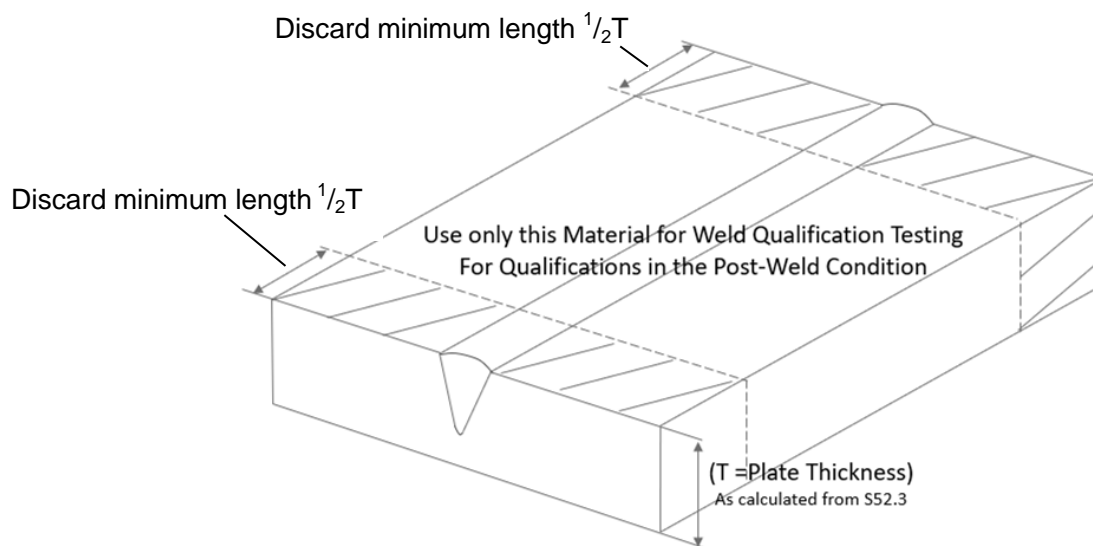
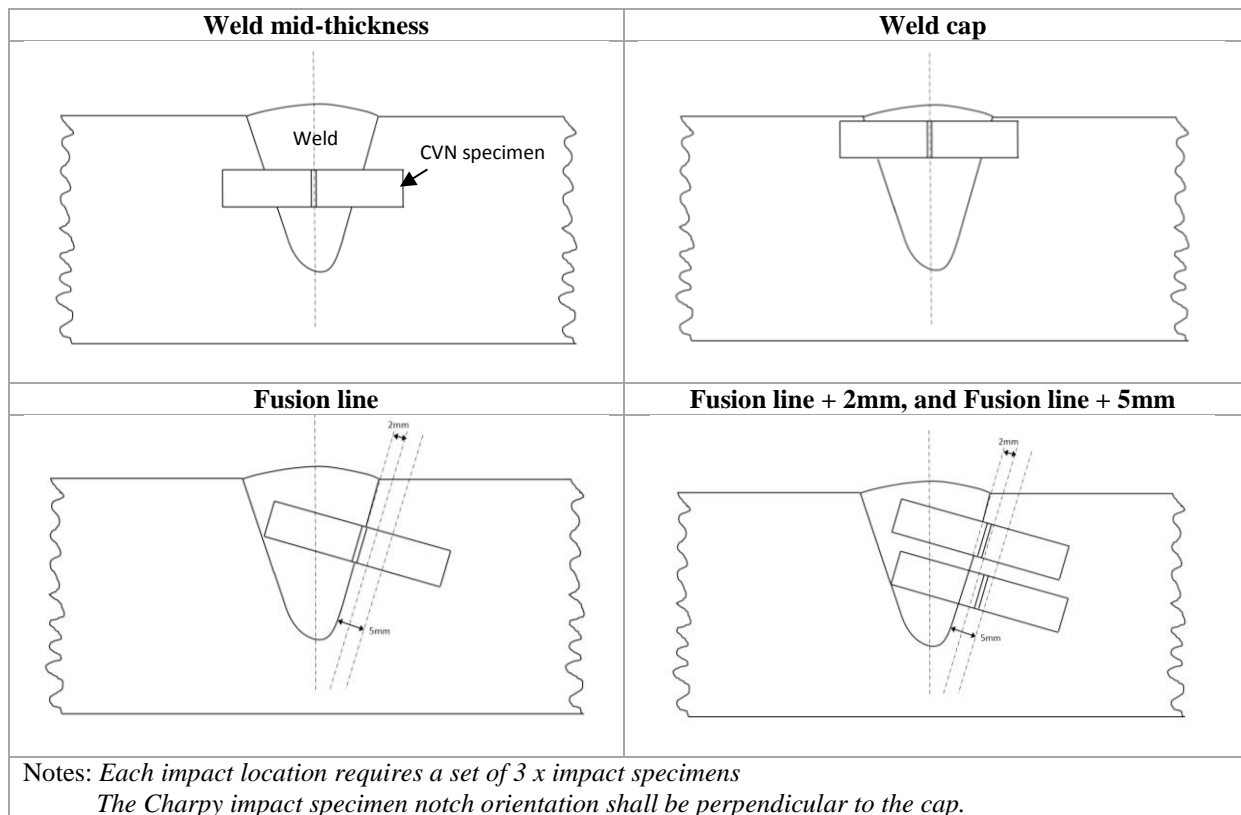


Fig 2 shows the material which is to be discarded from the ends of the weld test coupon so far as to prevent impact testing from being performed in locations close to the edge of the plate which will have accelerated cooling rates during post-weld heat treatment possibly giving exaggerated results.

Fig 3 shows the location of impact specimen sets to be extracted from the weld metal, fusion line and heat affected zone to meet the new supplementary requirement. All locations are required to meet the Charpy impact requirements of table 3 or 4 unless weld coupon thickness is > 100mm (4") in which case the test temperature for impact testing and acceptance criteria shall be agreed between the purchaser and casting supplier.

Weld qualification pitting resistance testing is performed on a sample removed from the weld coupon containing approximately 50% weld metal and 50% base metal. When weld test coupons are subject to post-weld heat treatment the G48 method A test temperature shall be 60°C and 50°C for coupons in the as welded condition.

Fig.3 Impact (CVN) specimen positions as defined by S52.2 for weld qualifications



Example Weld Qualification Test Data

Example 1: Weld repair procedure for minor weld repairs

Tables 6 to 10 shows actual welding parameters and qualification test data in accordance with ASME IX and supplementary requirement S52.4 for a 20mm thick 6A-G weld test plate welded using the GTAW technique and 6A-G filler wire. The weld test plate was tested in the as welded condition. Fig 4 details microphotographs of the weld metal in three positions weld-cap, mid-wall and root.

Table 6. Weld Parameters

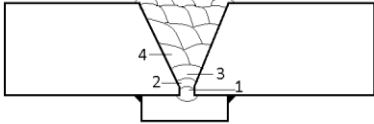
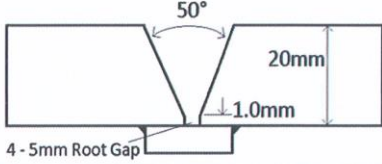
Run Sequence		Joint Design	
 <p>Typical run sequence</p>			
Welding Process:	GTAW	Filler Metal:	6A-G
Type:	Manual	AWS Classification:	A5.9 ER2594
Parent Material:	6A-G	Filler F. No.	6
P. No.:	10H Group 1	Filler Size:	2.4 & 3.2mm
Preheat / Inter-pass:	10°C / 125°C	Shielding:	Ar + N (98/2) 12xLtr/min
Travel Speed:	1.1 -2.7mm/second	Amps:	152-207
Position:	1G (Flat)	Volts:	12.5 – 17.5
Post-Weld Heat Treatment:	None	String or weave bead:	STRING
Organisation:	Goodwin International Ltd	Current/ Polarity:	DC/-VE

Table 7. Actual ASME IX Tensile & Bend Test Data

ASME IX All Weld & Transverse Tensile Testing ASTM E8-14 (9mm diameter)			
Location	UTS (N/mm ²) [Spec 690 N/mm ² min]	0.2% Proof Stress (N/mm ²) [Spec 450 N/mm ² min]	Elongation (%) [Spec 25% min]
All Weld Tensile	962	800	31
Transverse Tensile (1)	801	n/a	23
Transverse Tensile (2)	793	n/a	21
Bend Test – ASTM E190-14 (38mm Former / 65mm Shoulder)			
All weld thickness bend including HAZ (1)		Acceptable	
All weld thickness bend including HAZ (2)		Acceptable	
All weld thickness bend including HAZ (3)		Acceptable	
All weld thickness bend including HAZ (4)		Acceptable	

Table 8. Ferrite Determination

Location	Ferrite Determination ASTM E562-11 Manual Point Count			
	Ferrite (%) [Spec 35%-55%]	Magnification	Etchant	Grid
Weld Cap	36.7	X 500	Electrolytic Sodium Hydroxide (NaOH)	25 Point
Wed Mid-Wall	36.2			
Weld Root	38.4			
HAZ-Cap	38.7			
HAZ Mid-Wall	40.6			
HAZ Root	41.1			

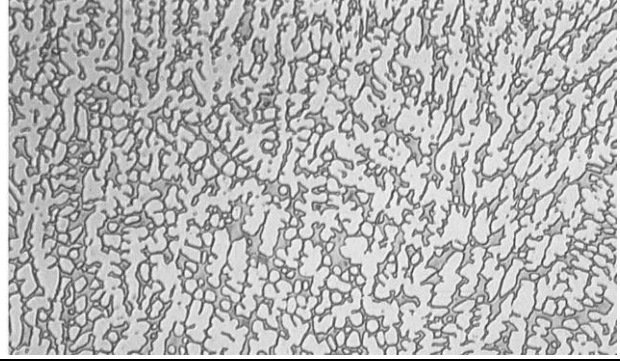
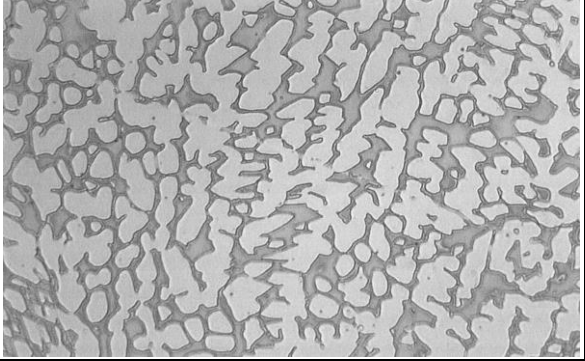
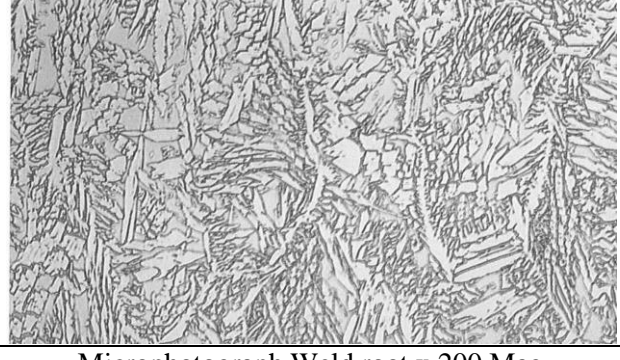
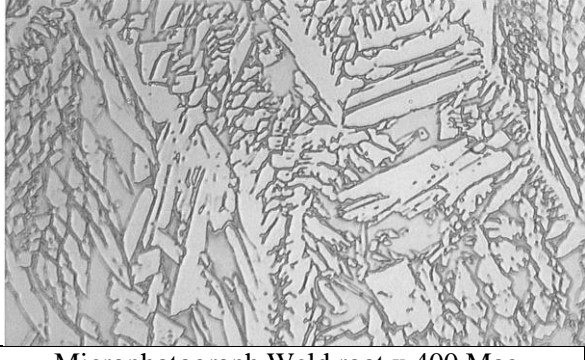


Table 9. Impact Test Data at -46°C & -101°C in conformance with supplementary requirement S52.4

ASME IX Charpy Impact Testing – ASTM E23-12C (Charpy V Notch -10mm x 10mm x 55mm)						
Location	Test Temperature (°C)	Specimen 1 (J)	Specimen 2 (J)	Specimen 3 (J)	Average (J)	Lateral Expansion
Centre-Line	-46°C	168	180	179	175	1.48 mm
Fusion Line		178	82	117	125	1.09 mm
FL +2mm		138	163	161	154	1.41 mm
FL +5mm		144	150	140	144	1.41 mm
Centre-Line	-101°C	136	38	52	75	0.35 mm
Fusion Line		41	74	107	74	0.58 mm
FL +2mm		90	72	109	90	0.57 mm
FL +5mm		110	114	104	109	1.01 mm

Table 10. Pitting Corrosion Test Data at 40°C & at 50°C

Pitting Corrosion ASTM G48-11 Method A – Weld & HAZ					
Test Temperature	Initial Weight	Final Weight	Surface Area	Weight Loss (Spec <4g/m ²)	Pitting (Spec x20Mag- No pitting)
40°C	35.744g	35.744g	1705.882mm ²	0.000g/mm ²	None
50°C	34.593g	34.591g	1601.406mm ²	1.249g/mm ²	None

Fig 4. Weld Qualification Metallographic Examination

Metallographic Examination	
Microstructures are free from deleterious second phases, carbides and nitrides	
Microphotograph Weld cap x 200 Mag	Microphotograph Weld cap x 400 Mag
	
Microphotograph Weld mid-wall x 200 Mag	Microphotograph Weld mid-wall x 400 Mag
	
Microphotograph Weld root x 200 Mag	Microphotograph Weld root x 400 Mag
	

Example 2: Weld repair procedure for major weld repairs

Tables 11 to 15 details actual welding parameters and qualification test data in accordance with ASME IX and supplementary requirement S52.4 for a 200mm thick 6A-G weld test plate welded using the GTAW technique and 6A-G filler wire. The weld test plate was subsequently post-weld heat treated condition (Solution Treated and Water Quenched).

Table 11. Welding Parameters

Joint Design/ Run Sequence			
Welding Process:	GTAW	Filler Metal:	6A-G
Type:	Manual	AWS Classification:	A5.9 ER2594
Parent Material:	6A-G	Filler F. No.	6
P. No:	10H Group 1	Filler Size:	2.4 & 3.2mm
Preheat / Inter-pass:	10°C / 125°C	Shielding:	Ar (99%) 14xLtr/min
Travel Speed:	1.3 -2.9mm/second	Amps: 140-180	Volts 15 – 18
Position:	1G (Flat)	String or weave bead:	STRING
Post-Weld Heat Treatment:	Solution + WQ	Current/ Polarity:	DC/+VE
Test Coupon Thickness:	200mm	Weld Depth:	100mm
Organisation:	Goodwin International Ltd		

Table 12. Actual ASME IX Tensile & Bend Test Data

ASME IX All Weld & Transverse Tensile Testing ASTM E8-14 (9mm diameter)			
Location	UTS (N/mm ²) [Spec 690 N/mm ² min]	0.2% Proof Stress (N/mm ²) [Spec 450 N/mm ² min]	Elongation (%) [Spec 25% min]
Transverse Tensile (1)	743	n/a	33
Transverse Tensile (2)	741	n/a	25
Parent Tensile	757	496	39
Bend Test – ASTM E190-14 (38mm Former / 65mm Shoulder)			
All weld thickness bend including HAZ (1)	Acceptable		
All weld thickness bend including HAZ (2)	Acceptable		
All weld thickness bend including HAZ (3)	Acceptable		
All weld thickness bend including HAZ (4)	Acceptable		

Table 13. Ferrite Determination

Location	Ferrite Determination ASTM E562-11 Manual Point Count			
	Ferrite (%) [Spec 35%-55%]	Magnification	Etchant	Grid
Weld Cap	45.3	X 400	Electrolytic Sodium Hydroxide (NaOH)	25 Point
Weld Root	40.3			
Parent	46.0			

Table 14. Impact Test Data at -46°C in conformance with supplementary requirement S52.4

ASME IX Charpy Impact Testing – ASTM E23-12C (Charpy V Notch -10mm x 10mm x 55mm)						
Location	Test Temperature (°C)	Specimen 1 (J)	Specimen 2 (J)	Specimen 3 (J)	Average (J)	Lateral Expansion
Cap C/Line	-46°C	198	194	207	199	2.20 mm
Mid Wall C/Line		106	104	91	100	1.09 mm
Root C/Line		89	115	102	102	1.06 mm
Cap F/Line		176	186	166	176	1.75 mm
Mid Wall F/Line		160	189	174	174	1.79 mm
Root F/line		141	165	114	140	1.33 mm
Mid Wall F/L +2mm		160	183	165	169	1.71 mm
Mid Wall F/Line +5mm		166	175	170	170	1.69 mm
Parent		126	139	162	142	1.43 mm

Table 15. Pitting Corrosion Test Data at 40°C, 50°C, 60°C and 65°C.

Pitting Corrosion ASTM G48-11 Method A – Weld & HAZ & Parent		
Duration: 24hrs		
Test Temperature	Weight Loss (Spec <4g/m ²)	Pitting (Spec x20Mag- No pitting)
40°C	0.000g/mm ²	None
50°C	2.969g/mm ²	None
50°C	0.0g/mm ²	None
50°C	0.0g/mm ²	None
60°C	0.0g/mm ²	None
60°C	0.9g/mm ²	None
65°C	0.0g/mm ²	None
65°C	1.0g/mm ²	None

Conclusion

The inclusion of the properties achievable with the 6A-G super duplex steel into the ASTM A995 standard is a step change for purchasers and specifiers of super duplex steel castings. For the first time the enhanced impact toughness and corrosion resistance of the 6A-G material can be specified with very specific acceptance criteria. This enables the purchase of these castings with a much greater level of confidence and safety factor as the impact and corrosion property acceptance criteria are much higher than current industry norms. In addition to this, lower temperature impact testing temperatures can be specified for applications requiring operation temperatures lower than -46°C, for example in arctic conditions.

In the authors' opinion, current welding codes such as ASME IX and ASTM A488 do not capture adequately within their requirements the effect of cooling rate on weld qualification test coupons during post weld heat treatment. This can result in weld material qualification with weld impact properties that exceed what is achieved in the actual casting weld repair and can present obviously safety considerations.

This has been addressed in the new supplementary requirement S52.4 where defined weld test coupon minimum thickness is stipulated along with minimum weld deposit depths and exact sample extraction locations. It is expected that these new acceptance criteria will give greater confidence to

end users to specify super duplex castings for application in heavier sections, colder application temperatures, and where enhanced pitting corrosion is required.