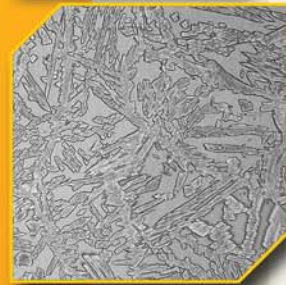




ATI 2003[®]
Lean Duplex Alloy

Weld Procedures
and Evaluation



ATI



ATI 2003® (S32003) Lean Duplex Stainless Steel with Molybdenum

Weld Procedures & Evaluation

ATI 2003® LEAN DUPLEX STAINLESS STEEL WITH MOLYBDENUM

ATI 2003 (UNS S32003) alloy is a molybdenum-enhanced Lean Duplex Stainless Steel (LDSS) that was developed to fill the performance gap between Type 316L (UNS S31603) and 2205 duplex (UNS S32205) stainless steels. ATI 2003 LDSS has reduced alloy content, which makes it less costly than 2205 duplex, yet ATI 2003 LDSS retains the high strength level characteristic of duplex grades. Compared to Type 316L, ATI 2003 LDSS has increased strength, better corrosion resistance, and greater cost stability.¹ These and other factors make ATI 2003 LDSS an attractive alternative for a variety of applications. This brochure addresses questions on the welding of ATI 2003 LDSS that are often asked by fabricators and end users.

WELD PROCESSES

ATI 2003 LDSS can be welded by most of the methods used to weld stainless steels. A good duplex weld practice will generate a sufficient amount of austenite in both the weld and the heat-affected zone to impart good impact strength while maintaining the desired corrosion resistance. Such practices are well established for 2205 and can be considered as good reference points for ATI 2003 LDSS, which has similar elemental constituents and phase balance. In fact, ATI 2003 LDSS is considered more forgiving than 2205 and 13% Cr martensitic alloys because it has a greater tolerance for the heat input and cooling variations that are sometimes experienced in field and fabrication welds. Even so, a good welding practice for ATI 2003 LDSS should limit the total exposure time in the range of 650 to 1000°C (1200 to 1830°F) to minimize precipitation of deleterious phases which may degrade its corrosion resistance or mechanical properties, while at the same time achieving a well-balanced austenite to ferrite ratio.

Autogenous Welds

Autogenous welding will increase the amount of ferrite present in the weldment and adjacent areas of the base metal. An addition of 2-5% nitrogen is recommended for autogenous welding to preserve corrosion resistance and strength. Post weld heat treatment (PWHT) in the range of 1010 to 1100°C (1850 to 2010°F) followed by rapid cooling is suggested to restore the phase balance. While 2205 is not recommended for use in the as-welded condition without the use of filler metal, such a weld on ATI 2003 LDSS may be satisfactory for some end uses because of the alloy's greater resistance to sigma phase formation.²

Filler Metal Welds

Commercially available filler metals are used for welding ATI 2003 LDSS. AWS ER2209 wire contains extra nickel to produce a balanced microstructure in the weld, similar to that in the base metal. AWS ER309L or ER309MoL wires are suitable for welding ATI 2003 LDSS to type 304L, 316L, carbon steels, or low alloy steels.

An example of a typical weld procedure for 17mm (0.668 inch) ATI 2003 plate, using gas tungsten arc welding (GTAW) for the root passes and submerged arc welding (SAW) for the filler passes, is given in the appendix³. The resultant weld had excellent mechanical properties, corrosion resistance, and microstructure as evidenced in the tables and figures in the appendix.



COST CONSIDERATIONS

Volatility in the cost of raw materials, as recently seen in nickel and molybdenum, has prompted many end users to consider ATI 2003 LDSS as a replacement for Type 316L. The higher strength of ATI 2003 LDSS may allow for reductions in thickness, making it not only a more corrosion resistant alloy choice, but also an economical choice. Since the alloy resembles a lean version of 2205 with only a slight reduction in corrosion resistance, ATI 2003 LDSS has gained considerable attention from design engineers looking to reduce project costs.

SPECIFICATIONS

The most commonly used ASTM specifications for duplex stainless steels, all of which include ATI 2003 LDSS (UNS S32003), are as follows:

- A240 (Stainless Plate, Sheet and Strip)
- A480 (General Requirements for Flat Rolled Stainless)
- A789/790 (Duplex Tube and Pipe)



Appendix

Experimental Welding Procedure ATI 2003® Lean Duplex Stainless Steel with Molybdenum

Root Welds - Equipment Set-up & Joint Details

Material:	Heat 511511, UNS S32003, ASTM A240 Plate
Thickness:	17mm (0.668")
Process:	Gas Tungsten Arc Welding with Cold Wire Feed
Welding Position:	1G (Flat)
Preheat Temp:	Room Temperature
Interpass Temp:	66°C (150°F) max.
Weld Joint:	Butt with gap
Groove Type:	Double-V
Filler Wire:	ER2209, 1.6mm (0.063") diameter
Gases:	Shielding gas, backing gas, and trailing shield gas are all 95% Ar – 3% He – 2% N ₂ .
Tungsten Electrode:	EWTh-2, 3.2mm (0.125") diameter, 20° included tip angle
Gas Cup Diameter:	12.7mm (½")

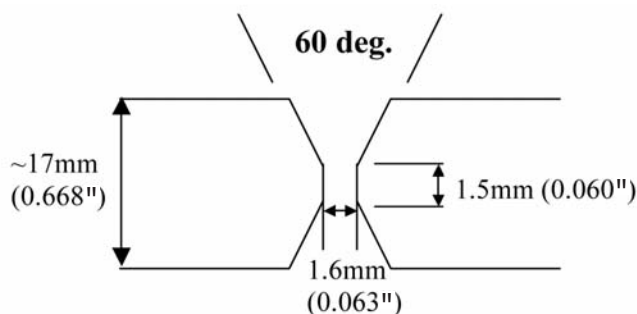
Root Welds - Parameters

Wire Feed Angle:	15° - 20° from the horizontal
Shielding Gas Flow:	9.5 l/m (20 cfh)
Trailing Gas Flow:	9.5 l/m (20 cfh)
Backing Gas Flow:	7 l/m (15 cfh), with a 30-second purge before welding
Cooling:	AC
PWHT:	None

Root Welds - Parameters

Weld Pass	Wire Feed Speed (cm/m)	Current (amps)	Voltage (volts DCEN)	Travel Speed (cm/m)	Heat Input (kJ/mm)
Root 1 (R1)	20	220	12	10	1.6
Root 2 (R2)	15	320	12	20	1.1

Figure 1 — Experimental Weld Joint Design



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Filler Welds - Equipment Set-up

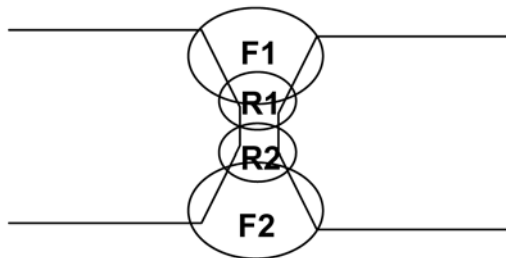
Process: Submerged Arc Welding
 Welding Position: 1G (Flat)
 Preheat Temp: Room Temperature
 Interpass Temp: 66°C (150°F) max.
 Weld Joint: Butt
 Groove Type: Double-V

Filler Wire: ER2209, 1.6mm (0.063") diameter
 Flux: Avesta 805 (highly basic)
 Tip-to-work distance: ~19mm (¾")
 Cooling: AC
 PWHT: None

Filler Welds - Parameters

Weld Pass	Wire Feed Speed (cm/m)	Current (amps)	Voltage (volts DCEN)	Travel Speed (cm/m)	Heat Input (kJ/mm)
Filler 1 (F1)	953 – 1016	360 – 375	30	51	1.3
Filler 2 (F2)	953 – 1016	360 – 375	30	51	1.3

Figure 2 – Experimental Root & Filler Weld Passes



METALLOGRAPHIC ANALYSIS

Macrostructure

Figure 3

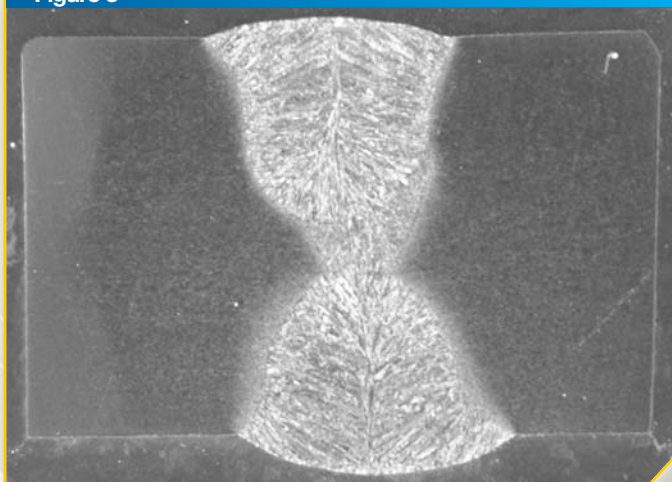


Figure 3 – Photomicrograph of a Full-Thickness Weld Cross-Section. Complete fusion was obtained between the weld beads and the base metal.



Microstructure

Figure 4

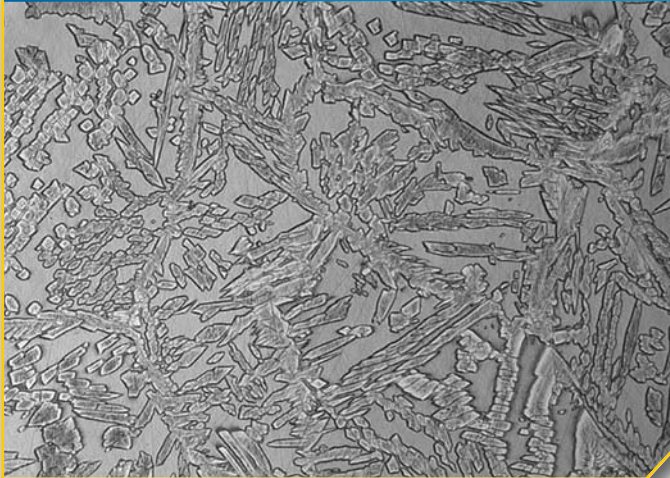


Figure 4 – Photomicrograph of a Root Weld Fusion Zone. Finely dispersed austenite in a ferrite matrix. (200X, KOH etch)

Figure 5

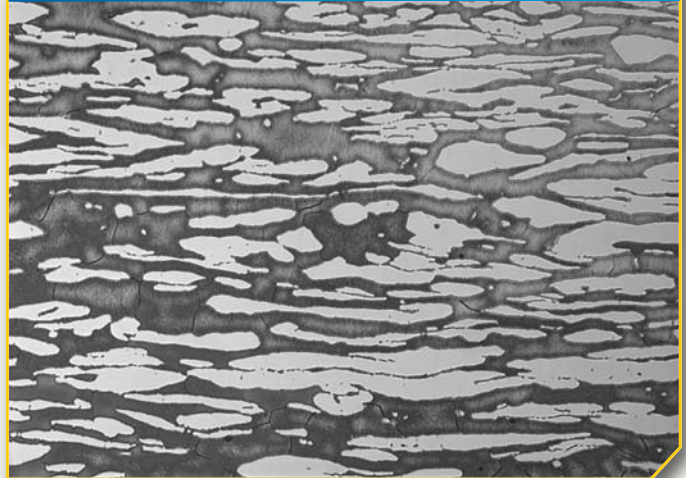


Figure 5 – Photomicrograph of a Root Weld Heat-Affected Zone. Islands of austenite in a ferrite matrix. (200X, KOH etch)

Figure 6



Figure 6 – Photomicrograph of a Filler Weld Fusion Zone. Finely dispersed austenite in a ferrite matrix. (200X, KOH etch)

Figure 7

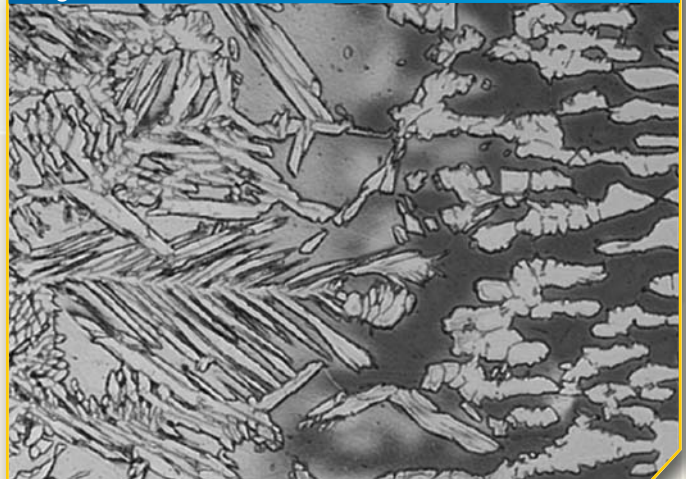


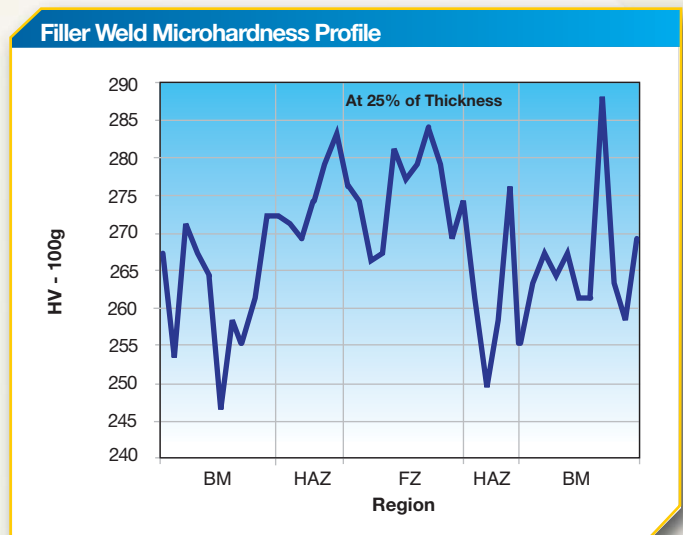
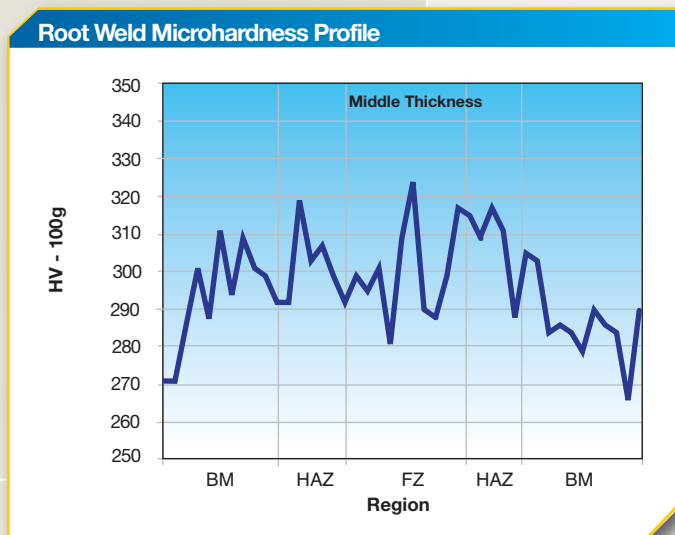
Figure 7 – Photomicrograph of a Filler Weld Heat-Affected Zone. Islands of austenite in a ferrite matrix. (200X, KOH etch)



Ferrite Measurements

Percent Ferrite	Root Weld	Filler Weld
Fusion Zone¹	50.3%	54.7%
Heat-Affected Zone²	49.2%	50.0%

Microhardness Profiles



1 Determined magnetically with a calibrated Fischer Feritscope, Model MP3C.
 2 Determined by ASTM E562 Optical Point-Counting Method.

ATI 2003® LDSS Base Metal Chemistry

Ht. 511511									
C	Mn	P	S	Si	Cr	Ni	Mo	N	Fe
0.016	1.32	0.025	0.0002	0.32	21.59	3.80	1.82	0.18	Bal.

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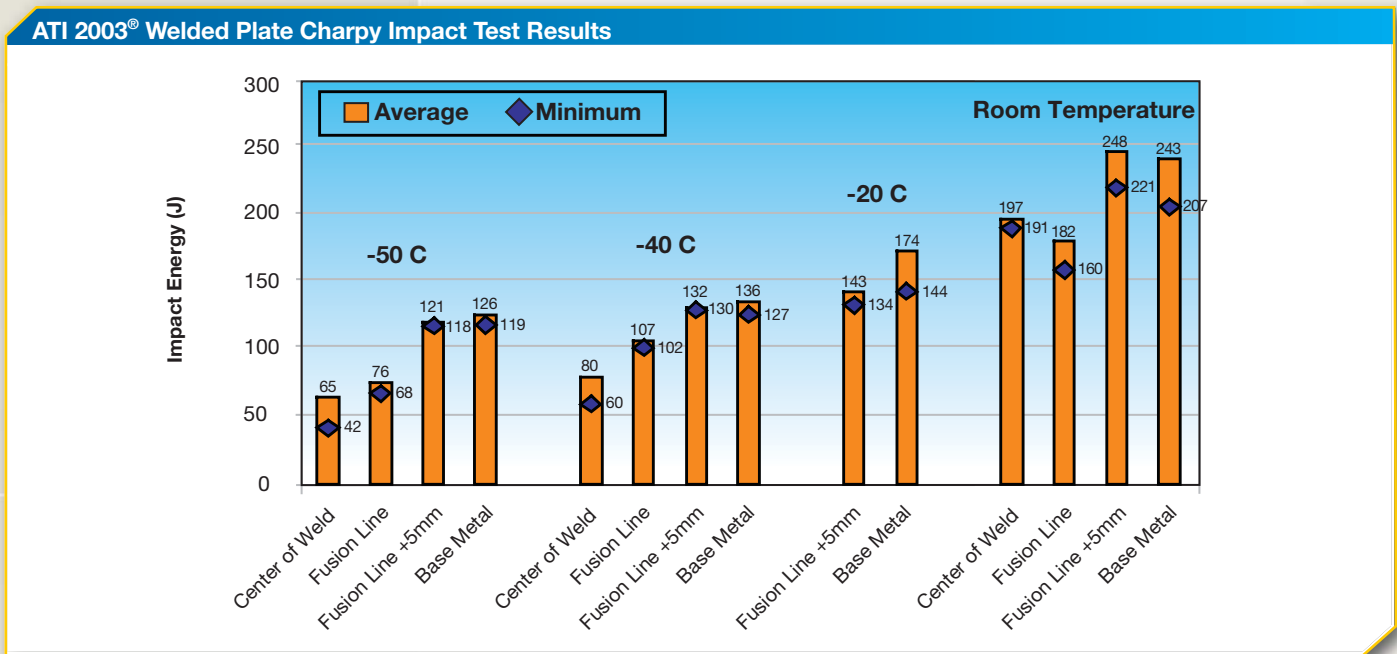


Mechanical Properties

Excellent results were obtained from mechanical testing of the ATI 2003® weld, HAZ, and base metal as follows:

Charpy Impact Testing

Samples were tested in the T-L orientation in accordance with ASTM E399. The V-notch was centered at the locations shown in the plot below.



Tensile Test

Tensile Testing		
	Welded	Non-Welded
0.2% YS	538 MPa (78 ksi)	534 MPa (77.5 ksi)
UTS	738 MPa (107 ksi)	745 MPa (108 ksi)
Elongation	39%	40%
Break Location	Base Metal	Base Metal

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Bend Testing

- Face bend passed at 180° around a radius of 2 times the thickness
- Side bend passed at 180° around a radius of 3 times the thickness

Corrosion Testing

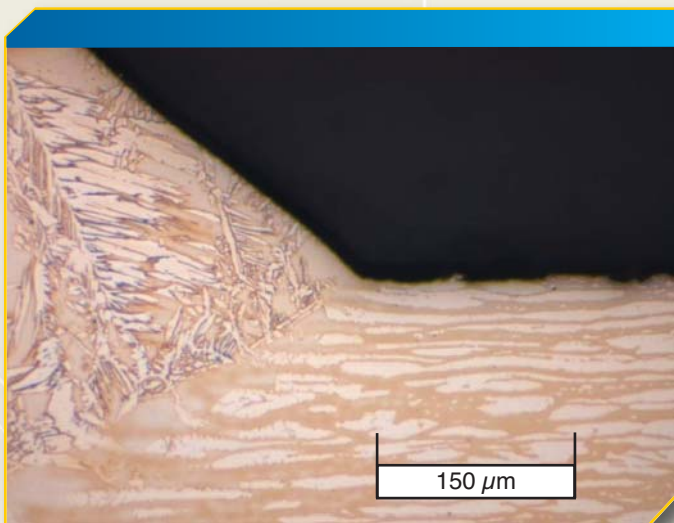
Welded samples were corrosion tested according to ASTM G48 Practice C for 72 hours. The samples were sand blasted and pickled in a 10% HNO₃ – 3% HF solution at 60°C (140°F) for 5 minutes in preparation for testing. The samples passed the test at 5°C (41°F) and failed at 10°C (50°F).

Stress Corrosion Cracking Resistance

Sulfide Stress Cracking (SSC) resistance was determined by testing at SINTEF⁴ and Bodycote^{5,6} using the Four Point Bend (FPB) test method in accordance with EFC 17⁷. All welds were prepared in accordance with the procedure previously described in this report, consisting of root passes made by GTAW and filler passes made by SAW with ER2209 wire. Triplicate testing was carried out for 30 days at a load equal to 100% of the yield stress under the conditions shown in the table below. These conditions were chosen to simulate various well streams encountered in offshore oil and gas production. Under these conditions, no cracking or pitting was observed on any of the as-welded or base metal samples of ATI 2003 material that were tested. Testing has shown that ATI 2003 LDSS also has excellent resistance to Chloride Stress Corrosion Cracking (CSCC)⁸.

Four-Point Bend Test Conditions

Four-Point Bend Test Conditions					
Temperature	pH ₂ S	pCO ₂	pH ₂ O	pH	Solution
68°F (20°C)	0.01 bar	7.4 bar	6.1 bar	5.8	87.4g/l NaCl and 1.26 g/l NaHCO ₃
194°F (90°C)	0.1 bar	1.9 bar	0.7 bar	3.5	20% NaCl (120,000 ppm Cl ⁻)
194°F (90°C)	0.1 bar	39.9 bar	0.7 bar	3.0	1000 ppm Cl ⁻ and 500 ppm CH ₃ COOH
320°F (160°C)	0.01 bar	7.4 bar	6.1 bar	5.8	87.4g/l NaCl and 1.26 g/l NaHCO ₃



A cross-section of a sample of ATI 2003® alloy after SSC testing, showing no signs of cracking in the Weld, HAZ, or Base Metal.



REFERENCES

- ¹ATI Allegheny Ludlum Technical Data Sheet, “ATI 2003® (UNS S32003) Lean Duplex Stainless Steel with Molybdenum”, ATI Allegheny Ludlum Technical Publication, 2010.
- ²P. Woolin and B. K. Holmes, “Welding of Lean Duplex Stainless Steel”, Stainless Steel World 2008 Conference Proceedings, KCI Publishing, 2008.
- ³K. J. Schott, “ATI 2003 Weld Procedure”, Internal ATI Allegheny Ludlum Report, 2004
- ⁴A. Mikkelsen and T. G. Eggen, “SSC/SCC testing of GTAW welded lean duplex alloy UNS S32003”, Sintef Report, Trondheim, Norway, Dec. 2004.
- ⁵P. N. Dent and R. Farnell, “Bodycote Test Certificate C700820/C” Bodycote Testing, West Midlands, UK, Aug. 2007.
- ⁶P. N. Dent, R. Farnell, and P. Williamson, “Bodycote Test Certificate C7010230/C” Bodycote Testing, West Midlands, UK, Dec. 2007.
- ⁷European Federation of Corrosion Publication 17, “Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H₂S Service,” Maney Publishing, London, 2002.
- ⁸T. G. Eggen, “Chloride Stress Corrosion Cracking Test of Allegheny Ludlum – Lean Duplex Steel”, Sintef Report, Trondheim, Norway, Sept. 2004.





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