suitable for welding AL 2003 alloy to type 304L, 316L, carbon steels or low alloy steels.

An example of a typical weld procedure on AL 2003 plate at 17mm (0.668 inch), using the submerged arc process (SAW) for filler in combination with gas tungsten arc welding (GTAW) for root passes is given in the appendix. The resultant weld showed 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 seen in nickel has prompted many end users to consider AL 2003 alloy as a replacement for 316L. With higher strength and corrosion resistance, AL 2003 duplex alloy can allow for reductions in thickness, making it not only a superior alloy choice, but an economic choice. Since the alloy resembles a lean version of 2205 with only a slight reduction in corrosion resistance, AL 2003 alloy has gained considerable attention from design engineers looking to reduce project costs.

Specifications

The most commonly used ASTM specifications for duplex stainless steels, including AL 2003 alloy 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
AL 2003™ Duplex Stainless Steel

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 (150ºF) 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, 20º included tip angle
Gas Cup Diameter:	12.7mm (½")

Root Welds - Parameters

Wire Feed Angle:	15º - 20º 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

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

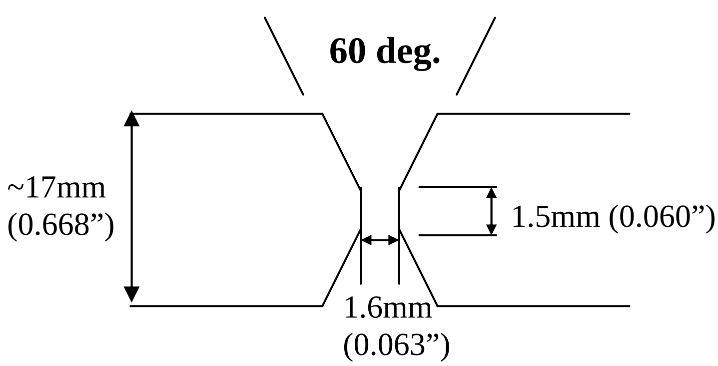


Figure 1 – Experimental Weld Joint Design

Filler Welds - Equipment Set-up

Process:	Submerged Arc Welding
Welding Position:	1G (Flat)
Preheat Temp:	Room Temperature
Interpass Temp:	66°C (150ºF) 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 DCEP)	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

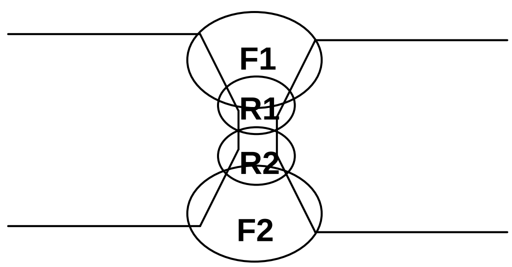


Figure 2 – Experimental Root & Filler Weld Passes.

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% HNO_3 – 3% HF solution at 60°C (140^{o}F) for 5 minutes in preparation for testing. Test results showed that the samples passed the test at 5^{o}C (41^{o}F) and failed at 10^{o}C (50^{o}F).

Metallographic Analysis

Macrostructure

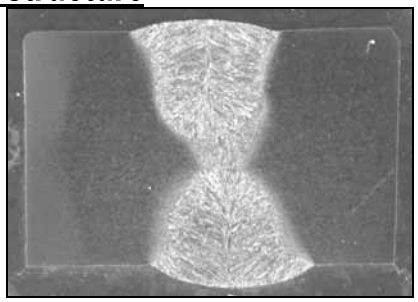


Figure 3 – Photomacrograph of a Full-Thickness Weld Cross-Section. Complete fusion was obtained between the weld beads and the base metal.

Microstructure

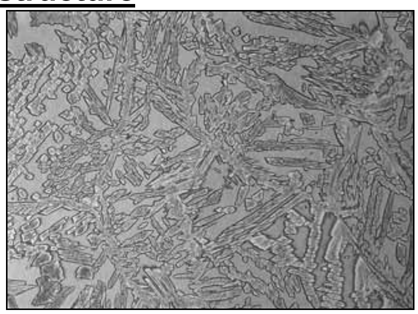


Figure 4 – Photomicrograph of a Root Weld Fusion Zone. Finely dispersed austenite in a ferrite matrix
(200X, KOH etch)

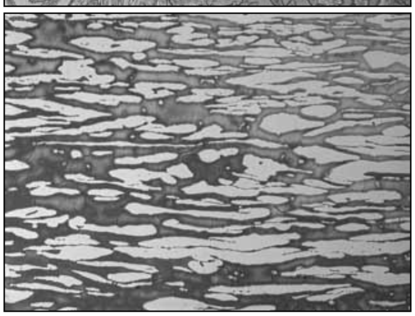


Figure 5 – Photomicrograph of a Root Weld Heat-Affected Zone. Islands of austenite in a ferrite matrix. (200X, KOH etch)

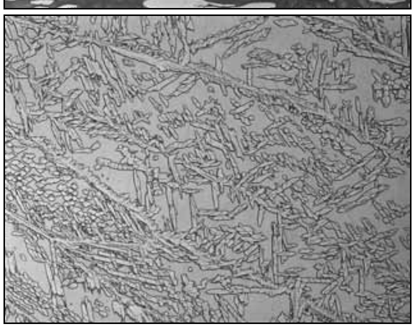


Figure 6 – Photomicrograph of a Filler Weld Fusion Zone. Finely dispersed austenite in a ferrite matrix.
(200X, KOH etch)

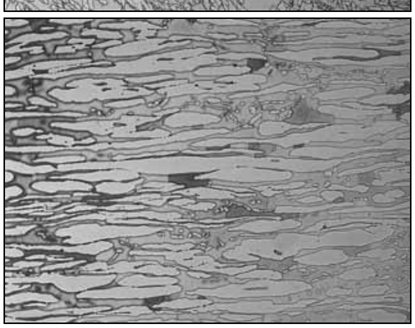


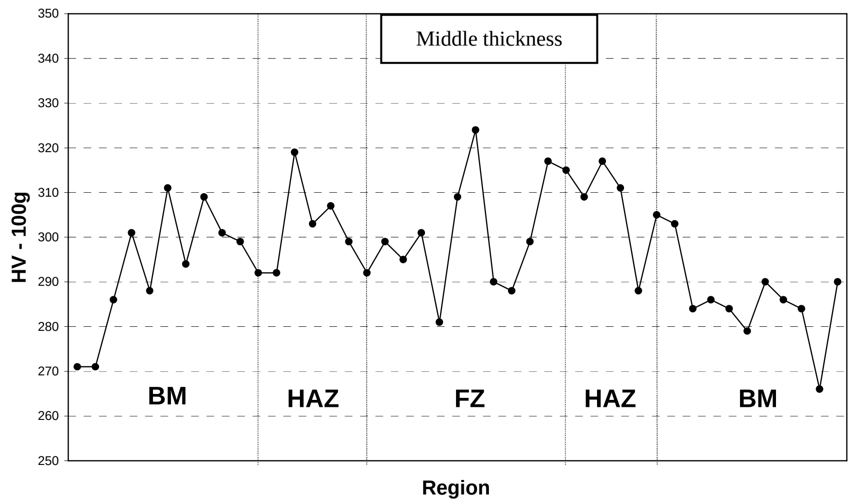
Figure 7 – Photomicrograph of a Filler Weld Heat-Affected Zone. Islands of austenite in a ferrite matrix. (200X, KOH etch)

Ferrite Measurements

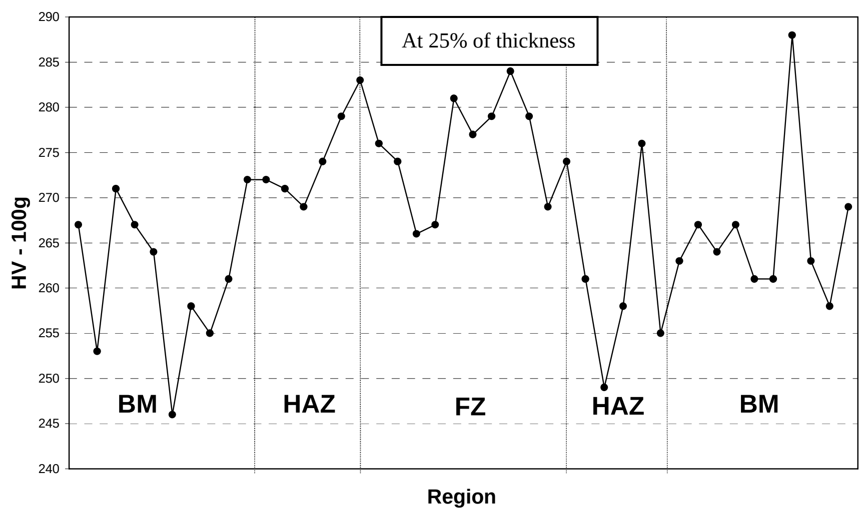
Percent Ferrite	Root Weld	Filler Weld
Fusion Zone[1]	50.3%	54.7%
Heat-Affected Zone[2]	49.2%	50.0%

Microhardness Profiles

Root Weld Microhardness Profile



Filler Weld Microhardness Profile



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

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.

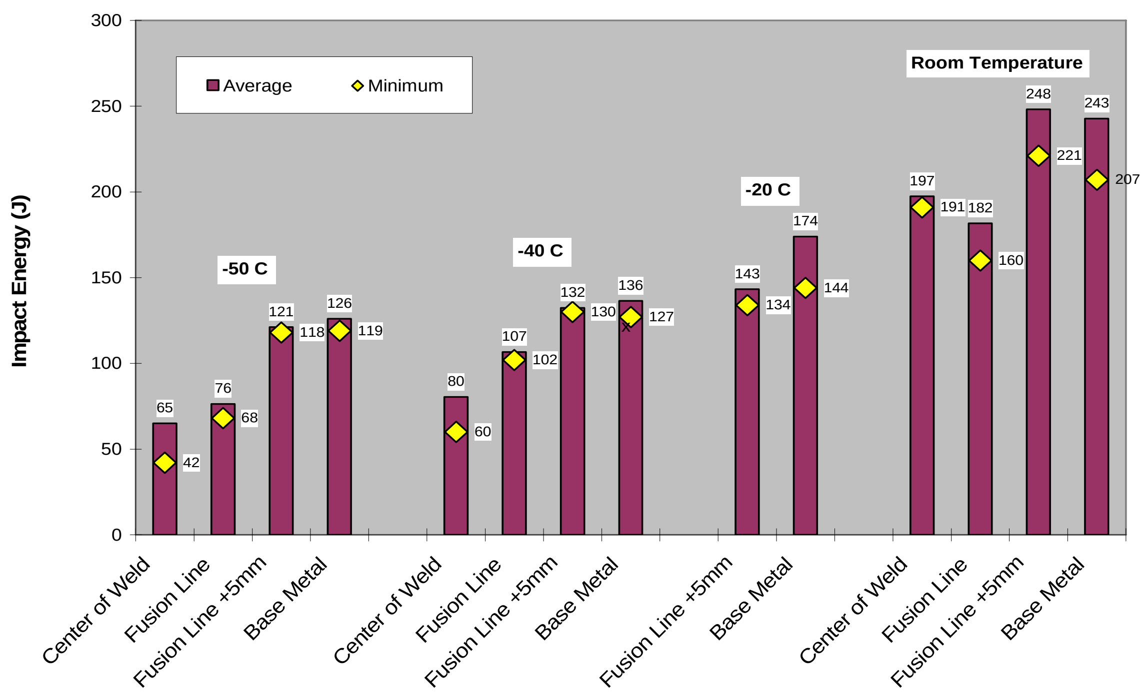
Mechanical Properties

Excellent results were obtained from mechanical testing of the combination of the AL 2003™ weld zone, HAZ and base metal as follows:

Impact Test

T-L Orientation in accordance with ASTM E399.

AL 2003 Welded Plate Charpy Impact Test Results



Tensile Test

	WELDED	NON-WELDED
0.2YS	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

Bend Test

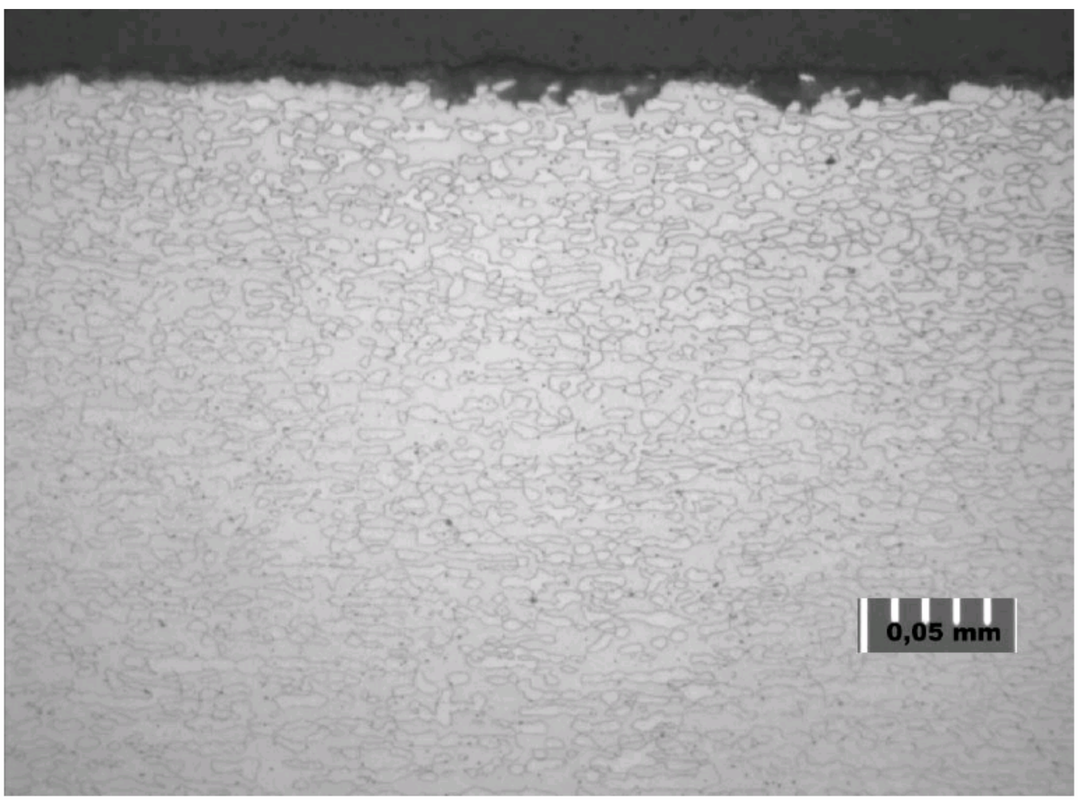
- ⇒ Face bend passed at 180° around a radius of 2 times the thickness
- ⇒ Side bend passed at 180° around a radius of 3 times the thickness

SCC & SSC Testing

Chloride Stress Corrosion Cracking (CSCC) resistance was evaluated on strip samples at 1.8mm thickness, from heat 813394. Testing was performed by SINTEF's Corrosion Test Laboratory in Trondheim, Norway. The test was performed in a saturated chloride solution at 82°, 100° and 115°C (177°, 212°, 239°F), for periods up to 2200 hours. The salt mixture and concentration are comparable to compositions obtained when seawater dries on a high temperature surface, such as top side piping on an offshore platform.

The specimens suffered slight general corrosion of the surface, with the highest temperature having the most corrosion. However, none of the AL 2003 specimens exposed at any of the three test temperatures showed any sign of chloride stress corrosion cracking. As reference points, SINTEF results for more highly alloyed super duplex and 6Mo alloys showed CSCC limits of 110° and 120°C respectively. 316L and 22%Cr duplex limits are 60° and 100°C (140° and 212°F) respectively.

In conclusion, the resistance of AL 2003 alloy to CSCC is considered very good in comparison to other alloys.

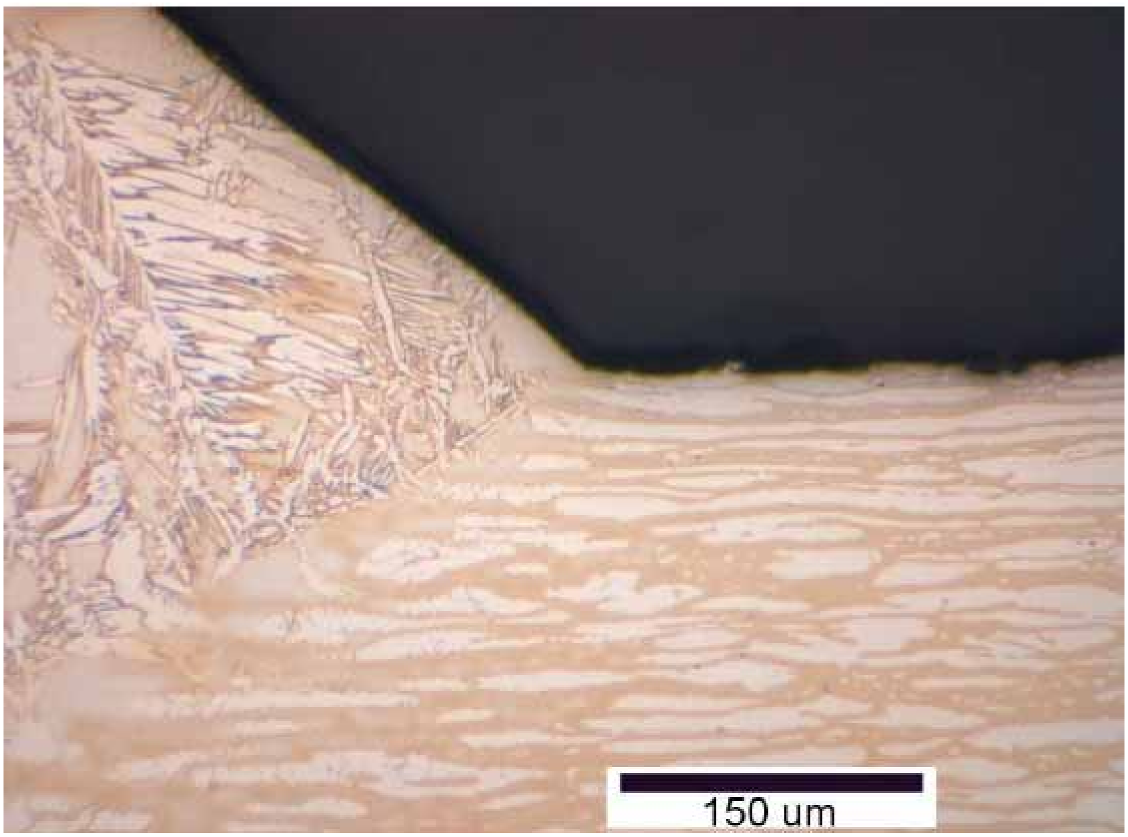


A cross-section of the tensioned surface of AL 2003™ alloy after CSCC testing at 115°C for 2208 hours. General corrosion was observed at the surface but no cracking or crack initiation was present.

Sulfide Stress Cracking (SSC) resistance was evaluated on 17mm thick welded plate samples from Heat 511511. Welds were prepared in accordance with the procedure previously described in this report, consisting of root passes using GTAW and filler passes using SAW with ER2209 wire. Four Point Bend (FPB) tests were performed at SINTEF in accordance with EFC Document No. 17.

Testing was carried out for 720 hours at room temperature and 160°C (320°F) in formation water of 5.8pH to simulate the conditions at the Kristin Field in the North Sea. The test gas was 10mbar H_2S with CO_2 as the balance at a pressure of 7.4 bar.

No cracking or pitting was observed during FPB testing, indicating that in formation waters simulating actual North Sea conditions, AL 2003 welds were not sensitive to pitting nor stress corrosion cracking.



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

About Allegheny Technologies

Allegheny Technologies Incorporated is one of the largest and most diversified specialty metals producers in the world with revenues of $4.9 billion during 2006. ATI has approximately 9,500 full-time employees world-wide who use innovative technologies to offer growing global markets a wide range of specialty metals solutions.

Our major markets are aerospace and defense, chemical process industry/oil and gas, electrical energy, medical, automotive, food equipment and appliance, machine and cutting tool, and construction and mining.

Our products include titanium and titanium alloys, nickel-based alloys and superalloys, stainless and specialty steels, zirconium, hafnium, and niobium, tungsten materials, grain-oriented silicon electrical steel and tool steels, and forgings and castings.

Data shown are typical, and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.