

# SSC / SCC Testing of Lean Duplex AL 2003™ (S32003) Welds

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## ABSTRACT

A weld procedure was established for AL 2003™ lean duplex stainless steel (UNS S32003), with optimum ferrite content and alloy content to give enhanced, low temperature impact strength. The welded specimens were evaluated for resistance to environmentally induced stress cracking from exposure to aqueous environments containing H<sub>2</sub>S. Room temperature Sulphide Stress Cracking (SSC) and elevated temperature Stress Corrosion Cracking (SCC) tests were performed at an independent laboratory on as-welded plates, in an environment simulating the formation water of produced fluids, for a North Sea oil field. Additional SSC constant load testing was performed at a lower pH to establish threshold criteria.

## INTRODUCTION

UNS S32003 alloy is a newly established lean duplex stainless steel with similar strength to 22%Cr duplex, and improved corrosion resistance over 316L stainless steel (Table 1). The alloy is commercially known as AL 2003™ duplex stainless steel, and is currently under consideration for use in the Oil & Gas industry. A main concern by the industry relates to the potential of an alloy to stress corrosion crack. Cracking concerns can extend beyond the base material, to other high stress areas such as welds.

It was the purpose of this experiment to first establish a weld procedure for AL 2003 material that demonstrated sufficient as-welded toughness and pitting corrosion resistance, and then expose welds and non-welded sections to SCC environments common in industry. Three environments were chosen as follows:

- Chloride-induced Stress Corrosion Cracking (CSCC), to simulate top side exposures where sea spray is continually evaporated on the surfaces of warm piping systems, creating salt concentrations,
- Room temperature Sulphide Stress Cracking, correlated to a typical subsea field environment,
- Elevated temperature Stress Corrosion Cracking correlated to a typical subsea field environment.

## **WELD PROCEDURE & RESULTS**

Commercially produced AL 2003 plate was prepared with a double-V groove for welding, according to Figures 1 and 2.<sup>1</sup> ER2209 wire was utilized in the Gas Tungsten Arc Welding of the root passes and the Submerged Arc Welding of the filler passes. For the root passes, a shielding gas containing 95%Ar – 3%He – 2%N<sub>2</sub> was used. The resulting weld structure is shown in Figure 3. Ferrite measurements were in the range of 49 to 55% for Base Metal, HAZ, and Fusion Zone (Table 2).

Mechanical tests performed to evaluate the integrity of the welds included tensile, bend, Charpy, and microhardness tests. Tensile test results for the welded specimens were close to the results obtained for the base metal (Table 3). Impact properties showed the HAZ easily met the Norsok requirements of 45 J average (35 J minimum value), for 22Cr material at -46°C (Figure 4).<sup>2</sup>

Based on these results, it was concluded that an acceptable weld procedure had been established for AL 2003 alloy. Further corrosion testing was warranted to characterize the alloy for field-welded applications.

## **CORROSION TESTING RESULTS**

### **Critical Pitting Temperature (CPT)**

The CPT was determined for AL 2003 in an acidified ferric chloride solution in accordance with ASTM G48, Practice C for 72 hours.<sup>3</sup> Results showed that the as-welded samples of AL 2003 alloy passed the test at 5°C and failed at 10°C. As a reference point, Type 316L would be expected to fail in this test at approximately 0°C.<sup>4</sup>

### **Sulfide Stress Cracking (SSC) & Stress Corrosion Cracking (SCC)**

Resistance to SSC and SCC was determined using the Four Point Bend (FPB) test method in accordance with EFC 17.<sup>5</sup> Triplicate testing was carried out for 720 hours under two separate conditions: one at room temperature and one at 160°C. This higher temperature in combination with the following conditions was used to simulate formation water conditions from the Kristin Oil field in the North Sea.<sup>6</sup>

- $p_{\text{H}_2\text{S}} = 10 \text{ mbar}$ ,  $p_{\text{CO}_2} = 7.4 \text{ bar}$ ,  $p_{\text{tot}} = 13.5 \text{ bar}$  at 160°C
- 5.8pH
- 87,400 mg/l NaCl, 1,261 mg/l NaHCO<sub>3</sub> formation water
- 100% of YS

Under these conditions, no cracking or pitting was observed for the as-welded AL 2003 material, as evidenced in the micrograph of Figure 5. Thus, AL 2003 welds were found to be not sensitive to SSC / SCC conditions in simulated formation water from an actual North Sea condition.

## **Chloride Stress Corrosion Cracking (CSCC)**

CSCC resistance was evaluated on non-welded strip samples, which is customary for this type of test. The test was performed in a saturated chloride solution at 82, 100, and 115°C for periods up to 2200 hours. The salt mixture and compositions are comparable to conditions expected from sea spray of a top side piping system.<sup>7</sup> At the higher temperature, some general surface corrosion was evident on the AL 2003 material, but no cracking occurred (Figure 6). 316L material is limited to 60°C in this test, while the 22Cr alloy is limited to 100°C.<sup>8</sup> Thus, AL 2003 alloy can be considered to have very good CSCC resistance in comparison to some commonly used alloys for top side applications.

## **CONCLUSIONS**

An acceptable weld procedure was established for AL 2003 alloy. Further corrosion testing was warranted to characterize the alloy for field-welded applications.

No cracking or pitting was observed during SSC/SCC testing of the as-welded AL 2003 material. Thus, AL 2003 welds were found to be not sensitive to cracking under conditions simulating formation water from an actual North Sea condition.

AL 2003 alloy can be considered to have very good CSCC resistance in comparison to some alloys commonly used for top side applications.

## **RECOMMENDATIONS**

Further SCC testing appears appropriate at an intermediate or more moderate pH range of 3.5 – 4.5. Determining the effects of Hydrogen Induced Stress Corrosion Cracking (HISC) with respect to both environmental and microstructural effects, particularly in the weld and HAZ is also prudent.

## **ACKNOWLEDGEMENTS**

ATI Allegheny Ludlum would like to recognize the efforts of Trond Rogne and Andre Michelson at Sintef for their guidance in selecting appropriate test criteria.

Group	Alloy	UNS No.	R <sub>p0.2</sub>	R <sub>m</sub>	Cr	Ni	Mo	N	PREn
Austenitic	304L	S30403	170 MPa	485 MPa	18.2	8	-	-	18
Austenitic	316L	S31603	170 MPa	485 MPa	16.2	10	2.2	-	24
Lean Duplex	AL 2003™	S32003	450 MPa	620 MPa	21.5	3.6	1.8	0.16	30
Standard Duplex	2205	S32205	450 MPa	655 MPa	22.5	5.5	3.3	0.16	36

Table 1 Alloy comparisons.

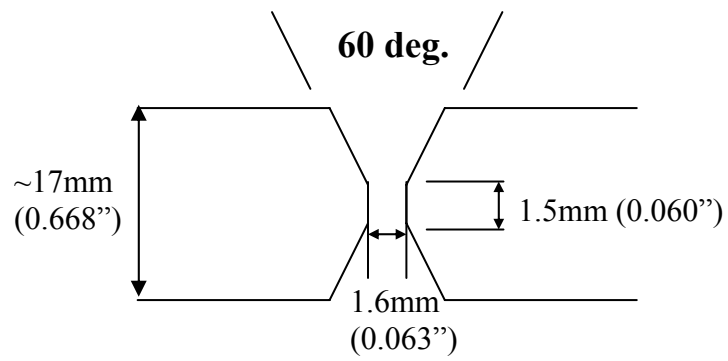


Figure 1 Experimental Weld Joint Design.

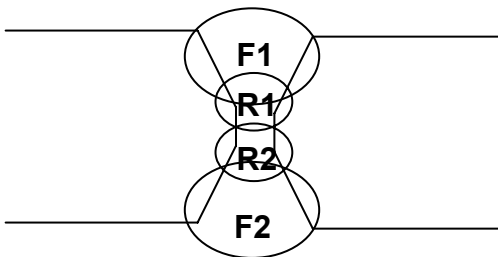


Figure 2 Experimental Root & Filler Weld Passes.

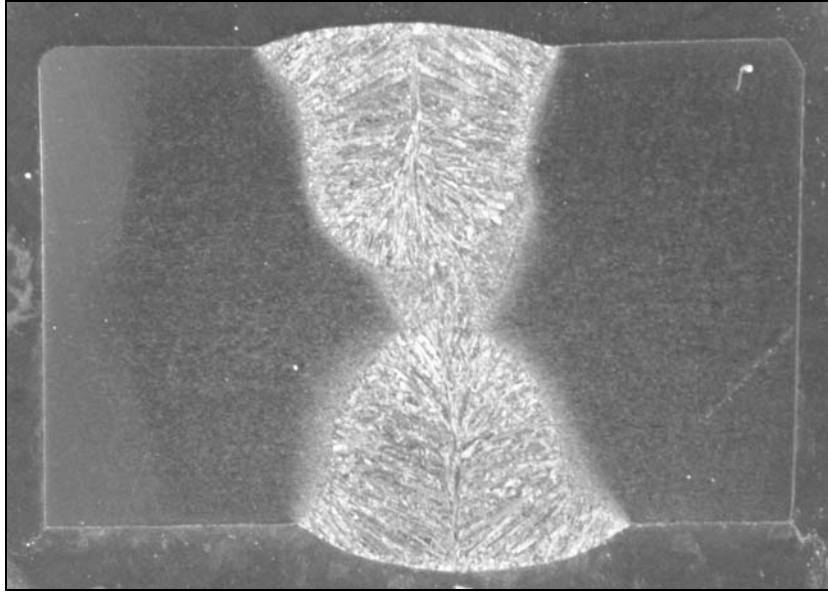


Figure 3 S32003 weld cross section microstructure profile.

<b><i>Percent Ferrite</i></b>	<b>Root Weld</b>	<b>Filler Weld</b>
<b>Fusion Zone</b>	50.3%	54.7%
<b>Heat-Affected Zone</b>	49.2%	50.0%

Table 2 Ferrite measurements in the AL 2003 weld.

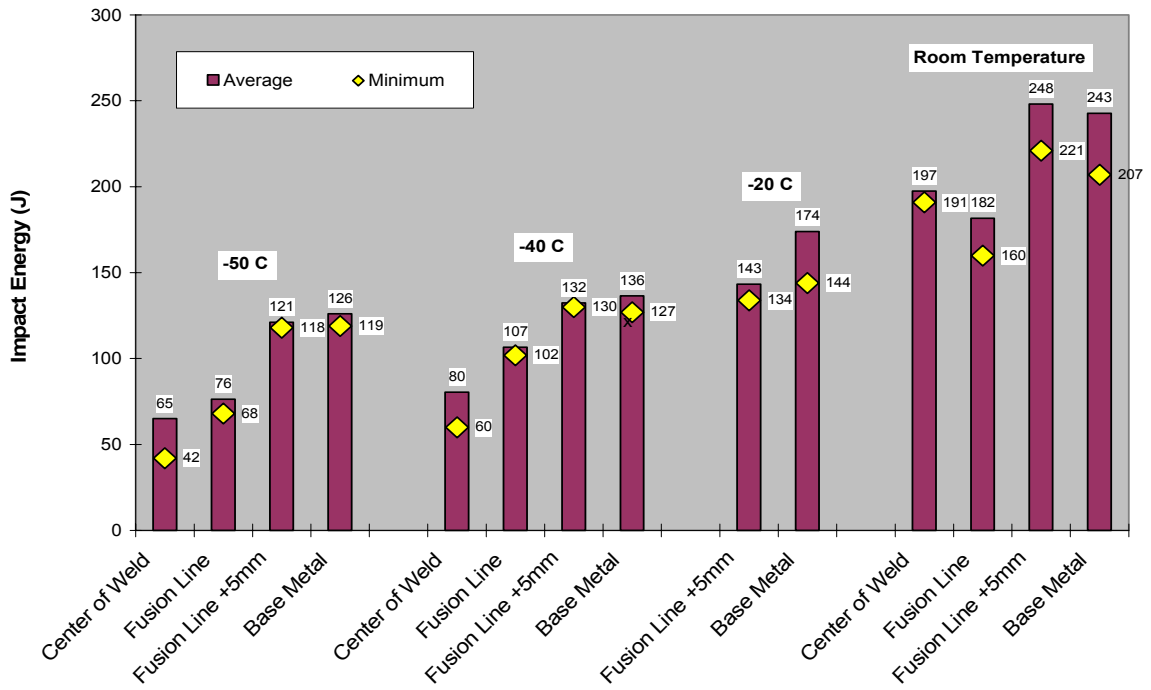


Figure 4 Welded AL 2003 Charpy impact test results.

	<b>Welded</b>	<b>Non-Welded</b>
<b>0.2YS</b>	538 MPa (78 KSI)	534 MPa (77.5 KSI)
<b>UTS</b>	738 MPa (107 KSI)	745 MPa (108 KSI)
<b>Elongation</b>	39%	40%
<b>Break Location</b>	Base Metal	Base Metal

Table 3 Welded and non-welded AL 2003 tensile test results.

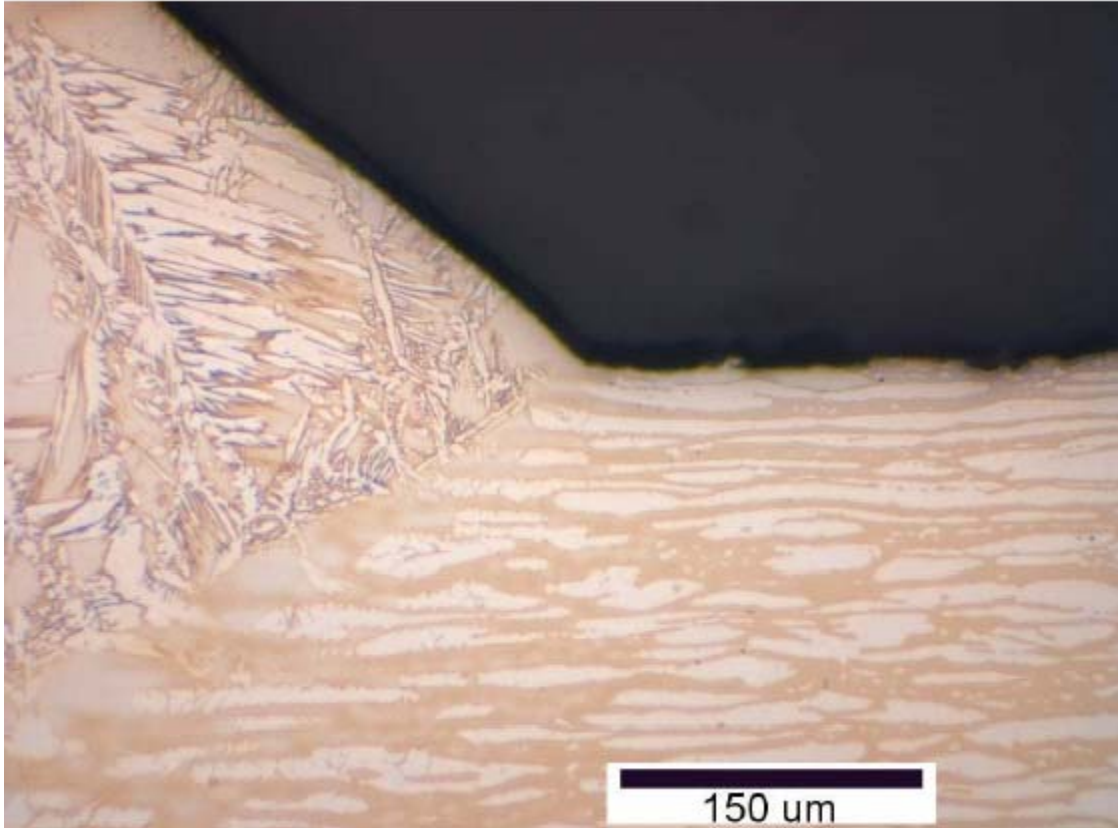


Figure 5 Micrograph showing no cracking of an AL 2003 weld after SSC /SCC testing.



Figure 6 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.

## REFERENCES

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