Nitrogen retention/enrichment of 316LN austenitic stainless steel welds.

Alexander M Galloway, University of Strathclyde, Glasgow, United Kingdom
Norman McPherson, BAE Systems – Naval Ships, Glasgow, United Kingdom

Introduction

The development of nitrogen enriched austenitic stainless steels has been a source of recent interest due to the abundant availability of nitrogen and by the manner in which nitrogen contributes several beneficial material property effects over a wide service temperature range. It is widely recognised that, in the case of nitrogen enriched 316L, improvements in mechanical property and corrosion resistance are derived from the interstitial influence of nitrogen within the matrix. Consequently, having the best combination of strength, toughness and corrosion resistance relationships found in any group of steels, nitrogen strengthened austenitic stainless steels have tremendous scope for application in areas as diverse as the cryogenic, nuclear, power generation and chemical transportation industries.

For some time it has been known that when welding nitrogen enriched austenitic stainless steels that denitration of the weld metal occurs. The resultant depletion of nitrogen from the weld region results in a reduction of the unique property relationship referred to previously. This requires the loss of base metal nitrogen to be compensated for by an increase in the nickel and manganese content of the welding wire. As there is a constant focus on the cost of nickel due to market fluctuations, and given that the cost of nickel basically governs the cost of stainless steel, there is a strong economic case for controlling the degree of nitrogen loss from the weld region during welding.

Weldability studies have been conducted on 316LN by varying the arc shielding gas composition during autogenous GTAW and FCAW. Mechanical property and corrosion resistance data will be discussed. Additionally, computational fluid dynamic (CFD) modelling of the arc plasma as a function of shielding gas composition will be highlighted.

Procedure

The test plate material used in this work was a standard 12mm thick AISI 316LN, which is a nitrogen enriched, molybdenum bearing austenitic stainless steel. Autogenous bead on plate GTAW was used to assess factors such as geometry of the welds being produced. However, the main work was carried out using a solid 1.2mm diameter 316L welding wire with the FCAW process using an electrode positive polarity.

Welding parameters were in the range 25-35 volts, and 225-300 amps, with a spray transfer mode. Typical analysis of the welding wire and the plate are shown in Table 1, where the overmatching of nickel can be seen. Also included is the overall weld metal analysis for each variation of the shielding gas used. From that, calculation of the chromium and nickel equivalents required to determine the Primary Solidification Mode (PSM), were carried out.

The weld preparation was a 60° inclusive angle with a 2.5mm root face, a 2mm root gap and a ceramic backing tile on the root face. Five mechanized passes were used to complete the welds. The shielding gases used have been detailed in Table 2, utilising a base case of 100% argon. Thereafter the nitrogen content was maintained at 15%, with variations in the

Table 1. Chemical analysis (wt%) of 316LN plate; 316L welding wire; weld metal for different shielding gases.

	12mm steel plate	Welding wire		Weld	Metal	
			Type 1	Type 2	Type 3	Type 4
Carbon	0.013	0.016	0.013	0.013	0.013	0.013
Silicon	0.51	0.51	0.50	0.60	0.60	0.60
Sulphur	0.007	0.005	0.005	0.005	0.005	0.005
Phosphorus	0.024	0.019	0.018	0.018	0.018	0.018
Manganese	1.15	1.81	1.50	1.40	1.40	1.40
Nickel	10.1	12.40	11.5	11.7	11.7	11.6
Chromium	17.37	19.00	17.4	17.8	17.7	17.7
Molybdenum	2.72	2.95	2.90	2.90	2.90	2.90
Nitrogen	0.13	0.039	0.0770	0.140	0.147	0.153

Table 2. Shielding gas mixtures used.

Shielding Gas	% argon	% nitrogen	% helium
Type 1	100	0	0
Type 2	85	15	0
Type 3	80	15	5
Type 4	65	15	20

argon and helium contents. Weld metal nitrogen contents were determined, using a LECO analyzer, on samples taken from various positions in the weld.

Mechanical testing was carried out using standard techniques, and corrosion resistance was assessed against The Strauss Test (BS EN ISO 3651-2). Weld metal ferrite content was established using an image analysis technique and Ferritescope equipment. Solidification cracking resistance was determined using a circular patch test. Plate temperature was measured using two methods, thermographic imaging and with thermocouples attached to the plate. Microhardness was determined using a Vickers Microhardness Tester, with a load of 100g.

Results and Conclusions

FCAW trials on 316LN provided favourable weldability conditions for all the shielding gas conditions investigated. The addition of nitrogen and helium to the argon carrier gas led to improvements in the mechanical and corrosion properties compared to the base case of 100% argon. Absorption of nitrogen by the weld metal was found to increase with nett increases in the shielding gas helium content and this was attributed to the higher ionization potential associated with the helium containing arc plasma. However, nitrogen absorption was not found to obey Sievert’s Law.

The increase in weld metal nitrogen level resulted in a decrease in the weld δ-ferrite level. This was not unexpected as nitrogen, like nickel, has an austenite stabilizing effect. Such levels of δ-ferrite would normally result in a tendency for solidification cracking. However, as the resultant weld metal weld impurity levels (P + S = 0.023%) were significantly low, the occurrence of this form of cracking was not identified. PSM's were found to be ferrite-austenite in all cases and this has positively contributed to the absence of solidification cracking in the fully austenitic weld metal. Intermetallic phases or carbides were not observed during this study.

CFD analysis of the weld region showed an increased temperature in the weld plasma as the nitrogen and helium content of the shielding gas increased. Increased velocity magnitudes were observed as the shielding gas nitrogen and helium levels increased and this led to turbulence of the gas column and stirring of the weld pool, which has created favourable conditions for nitrogen absorption into the weld metal.

This work has shown that potential exists to retain/increase the nitrogen content of 316L weld metal. The effects derived from the ionisation potentials of nitrogen and helium have been shown to increase the weld plasma temperature, which has been verified by plate temperature increases. Consequently, the increased nitrogen content of the weld metal has produced highly favourable combinations of mechanical properties and corrosion resistance.