

Nitrogen Control during Autogenous Arc Welding of Stainless Steel — Part 1: Experimental Observations

The influence of shielding gas nitrogen content and base metal nitrogen and sulphur concentrations on nitrogen absorption/desorption was investigated

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ABSTRACT. This study deals with nitrogen absorption and desorption during the autogenous welding of stainless steel, investigating the influence of the base metal nitrogen and surface-active element concentrations and nitrogen partial pressure in the shielding gas. The weld nitrogen concentration increases with shielding gas nitrogen content at low nitrogen partial pressures, but at higher partial pressures, nitrogen absorption is balanced by N₂ evolution. This steady-state nitrogen content is not influenced significantly by the base metal nitrogen content in low-sulphur alloys, but in high-sulphur alloys, an increase in the initial nitrogen concentration causes higher weld nitrogen contents over the entire range of partial pressures evaluated. The weld metal saturation limit is reached at progressively lower shielding gas nitrogen contents as the base metal nitrogen level increases. It is postulated that less nitrogen is required in the shielding gas to reach the saturation limit in the high-sulphur alloys because an appreciable fraction of the nitrogen already present in the base metal is prevented from escaping by a higher level of surface coverage.

Introduction

In mild steel, low-alloy steel, and ferritic stainless steel, nitrogen is generally considered an undesirable impurity, causing porosity and the formation of brittle nitrides (Ref. 1). In austenitic and duplex austenitic-ferritic stainless steels, however, nitrogen is often a valued alloying element. In part, this has stemmed from the desire to use nitrogen as a substitute for nickel, thereby reducing alloying element costs. In addition to the fact that the consumption of an expensive strategic metal is reduced, nitrogen is considered to be as much as thirty times as powerful as nickel as an austenite-former (Refs. 2, 3). Nitro-

gen is also an excellent solid solution strengthening element in stainless steel, increasing the yield strength at room temperature and at subzero temperatures (Refs. 4, 5) with no significant decrease in toughness or ductility (Refs. 5, 6). Nitrogen-alloyed austenitic stainless steels, therefore, offer a unique combination of strength and toughness. Nitrogen is also reported to improve the passivation characteristics of stainless steels. It increases resistance to localized corrosion (Refs. 7, 8) and reduces sensitization effects during welding (Refs. 9, 10).

In order to realize the advantages associated with nitrogen alloying, the nitrogen has to be in solution in the metal matrix. Excess nitrogen tends to cause porosity or form brittle nitrides. Iron, mild steel, and low-alloy steel have low solubility limits for nitrogen (the equilibrium solubility of nitrogen in iron at its melting point is only approximately 0.044 wt-% at 1 atm — Ref. 11). It is therefore important to limit nitrogen contamination in these steels. This poses a particular problem during welding, where nitrogen from the surrounding atmosphere can be absorbed by the weld metal in spite of the precautions normally taken to shield the arc and the weld pool from the surroundings by using slag and/or shielding gas. Without the benefits of effective shielding, nitrogen contents as high as 0.2% have been reported in steel welds after arc welding (Ref. 11). These concentration levels are far greater than those in the base and filler metals and indicate the importance of the dissolution of nitrogen into the molten metal from the arc atmosphere during welding.

KEY WORDS

Autogenous GTAW
Nitrogen Alloying
Stainless Steel
Surface-Active Elements

Austenitic stainless steels can accommodate significantly higher levels of nitrogen in solution. In nitrogen-alloyed austenitic stainless steels, the most important problem during welding is often not nitrogen absorption but nitrogen desorption to the arc atmosphere, resulting in lower nitrogen levels in the weld metal. A decrease in nitrogen concentration in the region of the weld has a detrimental effect on the mechanical properties and corrosion resistance of the joint.

In order to control nitrogen absorption and evolution from the molten pool during welding, a fundamental knowledge of the absorption and desorption mechanisms is essential. Over the past years a number of studies have dealt with arc melting experiments under static conditions (stationary arc), and other studies concerned experiments under more realistic welding conditions (traveling arc). The results of these studies show that nitrogen absorption and desorption are complex phenomena, influenced by many factors. Some of these investigations are considered below.

The equilibrium solubility of nitrogen in iron is governed by Sievert's law, which states that the nitrogen concentration in liquid iron is proportional to the square root of the nitrogen partial pressure above the melt — Equation 1 (Ref. 11).

$$N_{eq} = K_{eq} \sqrt{P_{N_2}} \quad (1)$$

where N_{eq} is the nitrogen concentration in liquid iron at equilibrium with diatomic nitrogen (wt-%), K_{eq} is the equilibrium constant for reaction (1), and P_{N_2} is the partial pressure of N₂ in the atmosphere (atm).

Sievert's law implies that the nitrogen solubility limit in iron alloys can be raised by increasing the partial pressure of the diatomic gas above the melt. This approach has been proposed for reducing nitrogen losses and for preventing nitrogen-induced porosity during the welding of nitrogen-containing austenitic stainless steels. The majority of researchers, however, agree that Sievert's law cannot be applied to describe the dissolution of a diatomic gas in liquid metal in the presence