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ScienceDirect
Defence Technology 11 (2015) 237–243
www.elsevier.com/locate/dt

Microstructure and pitting corrosion of shielded metal arc welded high nitrogen stainless steel

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Received 17 March 2015; revised 20 April 2015; accepted 21 April 2015
Available online 22 May 2015

Abstract

The present work is aimed at studying the microstructure and pitting corrosion behaviour of shielded metal arc welded high nitrogen steel made of Cromang-N electrode. Basis for selecting this electrode is to increase the solubility of nitrogen in weld metal due to high chromium and manganese content. Microscopic studies were carried out using optical microscopy (OM) and field emission scanning electron microscopy (FESEM). Energy back scattered diffraction (EBSD) method was used to determine the phase analysis, grain size and orientation image mapping. Potentio-dynamic polarization testing was carried out to study the pitting corrosion resistance in aerated 3.5% NaCl environment using a G*ill*AC electrochemical system. The investigation results showed that the selected Cr–Mn–N type electrode resulted in a maximum reduction in delta-ferrite and improvement in pitting corrosion resistance of the weld zone was attributed to the coarse austenite grains owing to the reduction in active sites of the austenite/delta ferrite interface and the decrease in galvanic interaction between austenite and delta-ferrite.

Keywords: High nitrogen austenitic stainless steels (HNSs); Shielded metal arc welding (SMAW); Cromang–N (Cr–Mn–N); Field emission scanning electron microscopy (FESEM); Energy back scattered diffraction (EBSD)

1. Introduction

Austenitic stainless steels are generally used where excellent corrosion resistance and good formability are required. The development of austenitic stainless steel with improved properties was initiated in 1960s and became widespread in the 1980s [1]. In general austenitic stainless steels contain nickel as an alloying element to stabilize the austenitic phase and provide corrosion resistance to some extent [2]. Earlier improvements were related to the increase in chromium, molybdenum and nickel contents [3]. Recently much interest has been expressed in raising the level of dissolved nitrogen in the steel. The later development of the so-called high nitrogen austenitic stainless steel (HNS) with nitrogen levels sometimes exceeding 0.5 wt% has resulted in austenitic stainless steel with an exceptional combination of strength, toughness and corrosion resistance. Nitrogen is one of the alloying elements which may be used to replace the Ni addition and has the additional benefits to increase the pitting corrosion resistance and enhance the strength levels of the steel.

In fabricating the structural non magnetic material, welding is one of the most commonly used technique for joining high nitrogen austenitic stainless steels. During welding, it is essential to avoid nitrogen losses which could result in loss of mechanical properties and corrosion resistance. In order to reduce the risk of nitrogen induced porosity, the solubility of nitrogen in the weld metal has to be high enough to accommodate any increase in nitrogen concentration. The defects like porosity and solidification cracking can be overcome by the use of suitable filler wire which produces required amount

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Peer review under responsibility of China Ordnance Society.

http://dx.doi.org/10.1016/j.dt.2015.04.002
2214-9147/

of delta ferrite in the weld metal. Due to the high nitrogen content, welding requires special care to ensure that the nitrogen remains in the metal during welding [4]. Depending on service requirement, delta-ferrite content in stainless steel welds is often specified to ensure that weld metal contains a desired minimum and/or maximum ferrite level [5]. Nitrogen diffusion into the weld metal from the base metal (adjacent to the fusion line) at the elevated temperatures encountered during the weld thermal cycle could also play a role. If the nitrogen level exceeds the limit of solubility at any time during or prior to solidification in welding, the nitrogen bubbles can form in the liquid, thereby increasing the likelihood for nitrogen induced porosity [6]. In order to reduce the risk of nitrogen-induced porosity, the solubility of nitrogen in the weld metal has to be high enough to accommodate any increase in nitrogen concentration. As chromium and manganese are known to increase the solubility limit of nitrogen in austenitic stainless steel, the high levels of these elements are desired in the weld metal when filler wires for welding are selected. Another problem existing in welding a highly alloyed austenitic stainless steel is hot cracking. As a measure to minimize the hot cracking risk, one needs to choose a filler material with low impurity levels (e.g. *S*, *P*) in addition to focus on the least degree of segregation of the major alloying elements and the minimization of the level of intermetallic phase in the weld metal [7]. Nitrogen alloying can also play an important role in retarding the precipitation of intermetallic compounds [8], raising the ferrite/austenite transformation temperature and assisting the formation of austenite phase in heat affected zone of a weldment No matching filler wire is commercially available similar to the composition of the base metal (HNS). In the present work authors made an attempt to study the shielded metal arc welds of high nitrogen austenitic stainless steel using a nearest matching electrode of Cr-Mn-N type as it is presently available. Most of the researchers discussed the pitting corrosion resistance of this type of alloy, but the studies related to the welds are scarce. In view of the above, authors made an attempt to investigate the microstructural changes on pitting corrosion behaviour of weld metals of the high nitrogen stainless steel arc welds in 3.5% NaCl solution and to compare with that of the base metal, namely high nitrogen stainless steel (HNS).

2. Materials and methods

High nitrogen austenitic stainless steel (HNS) plates in cold worked condition are used in the present study. Schematic diagram of joint geometry and plate dimensions are given in Fig. 1. A set of plates with single-V butt joint welded using shielded metal arc welding (SMAW) and an electrode of Cromang-N steel (17Cr–17Mn–0.36N) was chosen in present study, as shown in Fig. 2. The compositions of base metal and electrode are given in the Table 1. The welding parameters, such as welding current and welding speed, were optimized through many welding trials. The optimized welding parameters are given in Table 2. Metallographic examination of samples was performed. The specimen were cut into pieces,

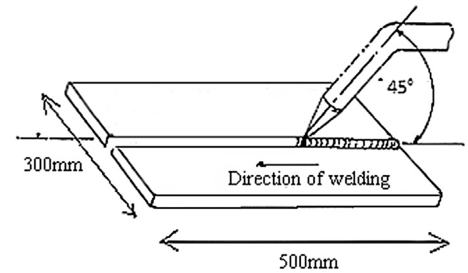

Fig. 1. Schematic diagram of joint geometry and plate dimensions.

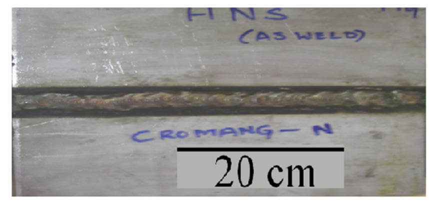

Fig. 2. Weld joint of high nitrogen steel.

which covers fusion zone, partially melted zone and heat affected zone of welds were cut, polished and etched using aqua regia reagent (HCl − 75 vol% and HNO_3 − 25 vol%). Microstructures were recorded using an optical microscope and a field emission scanning electron microscopy (FESEM) was used to examine the structural morphologies. Phases were analyse using X-Ray diffraction technique. Orientation imaging microscope (OIM) studies were done to find the orientation of the grains and the amount of different phases in the various zones of weldment using Energy back-scattered diffraction (EBSD) method. The pitting corrosion resistances of base metal and welds in an electrolyte of 3.5% NaCl were tested using a software based *GillAC* electrochemical system. The exposure area for these experiments was 0.3 mm^2.

3. Results and discussion

Addition of Chromium and Manganese increase the solubility of nitrogen whereas nickel reduces the solubility of nitrogen. Therefore the nitrogen content in Fe–Cr–Ni alloys is much lower than that in Fe–Cr–Mn alloys with comparable

Table 1
Compositions of base metal and electrode.

Material	C	Mn	Cr	N	S	P	Ni	Si	Fe
Base metal (HNS)	0.076	19.78	17.96	0.543	0.007	0.051	–	0.340	Bal.
Electrode (Cromang-N)	0.066	17.36	17.33	0.366	0.017	0.047	0.09	0.522	Bal.

Table 2
Optimized parameters for welding using shielded metal arc welding machine.

Welding current/A	Welding speed/($mm \cdot s^{-1}$)	Electrode diameter/mm	Electrode position	No. of passes	Root gap/mm
110–130	4	3.2	45°	3	1.5