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Stress corrosion cracking behaviour of gas tungsten arc welded super austenitic stainless steel joints

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Abstract

Super 304H austenitic stainless steel with 3% of copper posses excellent creep strength and corrosion resistance, which is mainly used in heat exchanger tubing of the boiler. Heat exchangers are used in nuclear power plants and marine vehicles which are intended to operate in chloride rich offshore environment. Chloride stress corrosion cracking is the most likely life limiting failure with austenitic stainless steel tubing. Welding may worsen the stress corrosion cracking susceptibility of the material. Stress corrosion cracking susceptibility of Super 304H parent metal and gas tungsten arc (GTA) welded joints were studied by constant load tests in 45% boiling $MgCl_2$ solution. Stress corrosion cracking resistance of Super 304H stainless steel was deteriorated by GTA welding due to the formation of susceptible microstructure in the HAZ of the weld joint and the residual stresses. The mechanism of cracking was found to be anodic path cracking, with transgranular nature of crack propagation. Linear relationships were derived to predict the time to failure by extrapolating the rate of steady state elongation.

Keywords: Super 304H; Chloride stress corrosion cracking; Constant load test; Gas tungsten arc welding

1. Introduction

Austenitic stainless steels are the desired material for use in high temperatures under highly corrosive environment. Heat exchangers are used in nuclear power plants and marine vehicles which are intended to operate in chloride rich offshore environment. The efficiency of the power cycle is function of the operating temperature and pressure. Development and selection of materials with required high temperature strength and corrosion resistance is vital in further improvement in efficiency of the power cycle [1,2]. Recently developed Super 304H austenitic stainless steel with excellent creep strength and corrosion resistance is mainly used in heat exchanger tubing of the boiler. The addition of 3 wt.% Cu to Super 304H enhances the precipitation strengthening of the alloy by precipitating out fine, stable and coherent Cu rich particles at elevated temperatures [3].

Stainless steels resist general corrosion but are susceptible to localized corrosion such as pitting, and stress corrosion cracking (SCC) in chloride environments [4]. SCC is the most likely life limiting failure in boilers with austenitic stainless steel tubing [5]. SCC is caused by the synergic and simultaneous action of tensile stress, environment and susceptible microstructure [6]. The microstructure depends on the chemical composition and manufacturing methods. Welding is considered as the major manufacturing method for pressure equipments in power plants [7]. Welding may alter the

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Table 1
Chemical composition (wt.%) of parent metal (PM) and filler metal (FM).

	C	Si	Mn	P	S	Cr	Ni	N	Cu	Nb	Mo	B
PM	0.086	0.23	0.81	0.021	0.0003	18.18	9.06	0.095	3.080	0.045	–	0.0039
FM	0.1	0.3	3.3	<0.01	<0.01	18.3	15.7	0.16	2.9	0.5	0.7	–

Table 2
Tensile properties of parent metal and weld joint.

	0.2% yield strength YS/MPa	Ultimate tensile strength UTS/MPa	Elongation in 25 mm gauge length/%	Joint efficiency /%
Parent metal	284.2	575.8	71.8	–
Weld joint	349.6	614.6	52.3	106.7

favorable parent metal microstructure and induce residual stresses in the joints. In some cases the residual stress may exceed the tensile stress of the material, resulting in worsening of SCC susceptibility of the material [4,8]. The addition of Nb to the steel and weld metal is beneficial for stabilizing C in the matrix to avoid sensitization, while the effect of nitrogen on SCC in parent metal is considered beneficial, and for the welds it remains complicated due to their inhomogenous dendritic cast structure [9].

In the absence of analytical approaches to predict SCC, testing becomes vital. In actual conditions, SCC tends occur over long periods of time; hence the SCC tests are accelerated by using highly aggressive environments, constantly increasing the load/strain. The results of accelerated tests can be extrapolated to predict the long term service life of the structure [10]. The test methods for SCC are classified as constant load tests, constant strain tests and slow strain rate tests based on mode of specimen loading [11]. Recent works in Refs. [12,13] on SCC of Super 304H using constant strain method revealed the SCC susceptibility of the Super 304H under larger strain and improper heat treatment conditions.

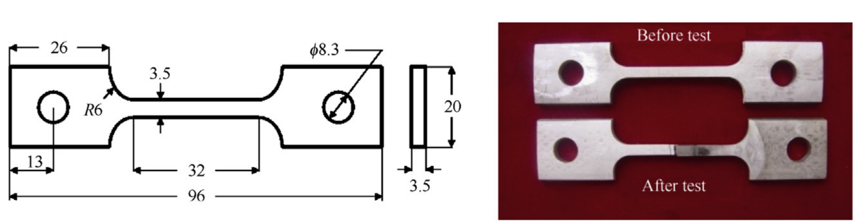
In this present work, the SCC susceptibility of Super 304H parent metal and gas tungsten arc welded (GTA) joints were studied by recording the "corrosion−elongation curves" during constant load tests in boiling $MgCl_2$ solution.

2. Experimental details

The parent metal used in this investigation was Super 304H austenitic stainless steel with distinct addition of 3 wt% of copper. Super 304H was received in annealed condition (1145 °C), in the form of tubes with outer diameter of 57.1 mm and wall thickness of 3.5 mm. For GTA welding, the joints with single 'V' butt configuration were welded with addition of filler metal. Filler metal composition was suitably modified to achieve delta ferrite free weld metal by increasing the Ni content; the resultant weld metal microstructure was fully austenitic, as preferred in high temperature applications [9]. Mo was added to avoid the risk of hot cracking in the fully austenitic weld metal by modifying the S inclusions and enhance the resistance to pitting corrosion [14,15]. The chemical compositions of the parent metal and filler metal are presented in Table 1. The welding was carried out with average heat input of 0.68 kJ/mm, in which argon was used as the shielding and purging gas.

The specimens for transverse tensile test and SCC tests were extracted from the parent metal and weld joints using wire-cut electric discharge machining. The tensile properties of as-received parent metal and weld joints are listed in Table 2. In order to reveal the susceptibility of Super 304H parent metal and weld joint to intergranular corrosion (IGC), the specimens were subjected to oxalic acid etch test as per ASTM A262 practice A. The specimens were probed under light microscope to reveal the level of Super 304H's susceptibility to IGC before and after welding.

The SCC test was carried out using the smooth tensile specimen (shown in Fig. 1) in a custom-built constant load setup with maximum loading capacity of 10 kN. The applied loads are measured using a load cell with an accuracy of ±10 N. The strain measurements were done using an LVDT with measurable range of ±5 mm and an accuracy of <1 μm. The schematic representation of the SCC constant load setup is shown in Fig. 2. The environment for SCC testing of Super 304H was chosen as 45% $MgCl_2$ boiling at 155 °C, and the



(a) SCC Specimen dimensions (b) Photograph of SCC specimen

Fig. 1. Schematic representation of the SCC constant load setup.