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Role of residual stresses induced by industrial fabrication on stress corrosion cracking susceptibility of austenitic stainless steel

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ABSTRACT

Effect of residual stress generated during tube fabrication, roll expansion and machining of stainless steel on the stress corrosion cracking (SCC) susceptibility was studied by testing fabricated tubes, tube–tube sheet joint and heavily machined plate of austenitic stainless steel (SS) in boiling $MgCl_2$. U bend samples of machined plate were exposed to acidified $SO_4 + Cl^-$ environment at room temperature to study its ambient temperature SCC behavior. The results correlate the SCC behavior of the SS tubes and roll expanded joints to the nature and magnitude of residual stresses present. The study also highlights the distinct difference in ambient temperature SCC behavior of machined vs. nonmachined surfaces.

1. Introduction

Austenitic SS finds numerous industrial applications due to a good combination of mechanical properties and corrosion resistance. However, it is susceptible to localized forms of corrosion like pitting and stress corrosion cracking. In particular the austenitic SS (300 series of SS) are highly susceptible to chloride SCC which can lead to catastrophic failures and lot of research have been dedicated towards the understanding of its mechanism. SCC occurs as a result of the synergistic action of three factors [1–4]: susceptible microstructure, corrosive environment and tensile stresses present. Depending on the microstructure of the material exposed and the nature of environment, the cracking may be intergranular i.e. passing through the grain boundaries or transgranular i.e. passing through the grain matrix or it may be a mixed mode (transgranular and intergranular) of SCC. In addition to the external stresses working on the components in service, the residual stresses present in the material plays a key role in determining its SCC susceptibility. The sum of all external stresses and internal residual stresses drives the crack initiation and its propagation [5–8]. Residual stresses generated during fabrication process can significantly contribute to SCC in absence of proper control measures. Little research has been focused on defining the exact role of tensile residual stresses in crack initiation and growth. Recent investigation by Beavers et al. [9] showed that residual stresses at the sites of SCC were substantially higher than those measured in adjacent SCC free material. In their study, a valid empirical correlation between residual stress and the incidence of SCC was found. Residual stress by definition is the tensile or compressive force that exists in the bulk of a material without application of an external load. Based on the length scale, residual stresses are often categorized into three types [10]. Type I is the macro-scale residual stresses. Macro-scale residual stresses vary continuously over large distances of at least several grain diameters. Typical sources of Type I residual stresses in pipeline steels may include the bending of steel plate during pipe forming, differential cooling through the wall thickness and along the surface during rolling, and localized plastic deformation during handling. Type II is the micro-scale residual stresses, which vary over the grain scale. Type II residual stresses in pipeline steel are related to the presence of banded microstructures, texture on the surface, and regions with different microstructures. Type III residual stress involves stresses at the atomic scale. These residual stresses are caused by chemical segregations at grain boundaries and small coherent phases in micro-alloyed steels. In the case of manufacturing, e.g. tube manufacturing, residual stresses induced are macro-stresses and fall in Type I category [11]. Nevertheless, the nature and magnitude of residual stress induced in the final tubing depends on the final stages of fabrication and its effect on stress corrosion cracking susceptibility is yet to be understood. The results summarized in the first part of the paper aim to build on understanding of how both magnitude and direction of Type I residual stresses present in industrially fabricated tubes dictate the susceptibility to SCC and the nature of cracking.

The tube to tube sheet joint is a critical element of heat exchangers. Tight, durable fixing of tubes in tube sheets is one of the critical functions in manufacturing heat exchangers for high

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