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ORIGINAL RESEARCH ARTICLE

Metallurgical and Mechanical Failure Investigations of a Welded Duplex Stainless Steel Flange–Elbow Joint

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Abstract
This paper investigates duplex stainless steel failure in welded process piping systems, focusing on the microstructural and mechanical properties related to welding corrosion. The detailed examination involved the following tests: optical microscopy, field-emission scanning electron microscopy with electron dispersive spectroscopy, tensile test, bend test, V-notch impact test, and Vickers microhardness test. The KNN supervised machine learning algorithm was employed as an image processing technique for microscopic image segmentation and quantification of presented phases. The weld zone indicated an imbalance in microstructural metallurgical phases where the ferrite content was 24%. This resulted in localized corrosion in weld zones; precisely because its composition is predominately austenitic structure; which is the root cause of duplex steel's reduced resistance (localized corrosion initiation and progressive damage) against aggressive piping system's transferred fluid (oily sour water extracted from oilfields reservoirs and separated from crude oil via gravity-assisted 2-phase separation process in a high-pressure unfired vessel). Mechanical testing results showed that welding tensile properties complied with the minimum requirements; the weld metal had higher yield and tensile strengths than the base metal. The bend test, however, disclosed a root bend specimen failure, attributed to surface cracks along the weld root. Toughness results from impact testing were satisfactory and thus did not indicate any embrittlement. Microhardness tests revealed a slight hardness decrease within the weld zone compared to the HAZ and base metal zone, which was largely due to microstructural changes and a higher cooling rate in HAZ.

Keywords Corrosion · Environmental attack · Microstructural analysis · Mechanical properties · K-nearest neighbor

Introduction

Environmental attacks, in particular corrosion, seriously threaten the durability and structural integrity of stainless steel components during its service life. Several factors may induce corrosion, relating to the material's composition, environment, or mechanical stresses. Generally, stainless steels are corrosion-resistant due to high chromium content (compared to other types of steel alloys); however, under proper conditions, they are still subject to some heavy degradation caused by local forms of corrosion such as pitting, crevice corrosion, or stress corrosion cracking [1, 2].

Duplex stainless steels, consisting of equal amounts of austenite and ferrite phases, exhibit superior strength compared to either phase individually, possessing yield strengths that are double that of standard austenitic grades while retaining commendable ductility. Their thermal expansion and heat transfer properties are midway between ferritic and austenitic stainless steels. Nonetheless, welding might considerably affect their performance. Given the necessity of preserving a balanced microstructure and preventing the emergence of undesired metallurgical phases, it is imperative that welding parameters and filler metals are precisely defined and meticulously monitored. The welding temperature cycle will influence the balanced microstructure of the base material, characterized by equal quantities of austenite and ferrite. A substantial alteration in balance, resulting in dissimilar proportions of the two phases, can lead to a pronounced deterioration of material qualities. A reduced

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