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Microstructural evaluation of welded fresh-to-aged reformer tubes used in hydrogen production plants

Majid Abbasi[a,*], Ihho Park[a], Yunjo Ro[a], Jingak Nam[b], Youngsu Ji[b], Jaewoong Kim[b], Raghavan Ayer[a]

[a] *Institute of Technology Innovation, SK Innovation, Daejeon 34124, Republic of Korea.*
[b] *SK Energy, Ulsan, Republic of Korea.*

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ABSTRACT

Heat resistant reformer tubes comprise a significant fraction of petrochemical reforming plants cost considering their high alloy content (i.e. 25Cr-35Ni-1Nb-0.1Ti). The bottom portion of tubes experiences the highest temperatures in the furnaces leading to microstructural changes, creep damage, and loss of elongation over their service life which in this case is twenty years. There is a cost- and time-driven motivation to only replace this portion of tubes by welding in contrast with replacing entire set of tubes which is the common industrial practice. However, welding new to aged tubes may lead to reliability issues due to difference in mechanical properties as a result of microstructural differences. In the current study, the microstructure and tensile properties of aged and new tubes have been evaluated in an effort to qualify the mechanical integrity of weldments. Welding trials are carried out to investigate the microstructure of the aged-to-new weldments and correlate it with the tensile properties (particularly elongation). Findings reveal that the heat affected zone of aged tubes is prone to micro-cracking of bulky primary carbides and incipient melting particularly at the inner surface where the root pass is applied. Adopting preheating for the root pass is effective in reducing carbide micro-cracking by decreasing cooling rate which assists in the accommodation of stresses generated by thermal contraction. Despite presence of carbide micro-cracks, tensile elongation is not severely affected as aged-to-new welds exhibit comparable and slightly higher elongation than aged base metals (above 4%). It is proposed that this is partially due to the orientation of micro-cracks in carbides. Further microstructural and tensile property results are presented and discussed.

1. Introduction

Heat resistant austenitic stainless steels have been used as tubulars in reforming plants for decades [1–33]. Alloys such as 25Cr-35Ni-1Nb-0.1Ti (also known as HP50M) offer a good combination of oxidation and creep resistance at elevated temperatures. The oxidation resistance is achieved by the addition of chromium. Ni is required to stabilize the austenite and suppress the formation of detrimental Sigma phase over extended periods of time. Creep strength is mainly achieved by adding Nb to form carbides at elevated temperatures.

These alloys suffer from aging during service. Exposure to the temperature range of 700–900 °C for years introduces microstructural changes such as primary carbide growth and coalescence, transition of Nb-rich MC carbides to G-phase (Ni-silicide rich in

* Corresponding author.
E-mail address: majid.abbasi@sk.com (M. Abbasi).

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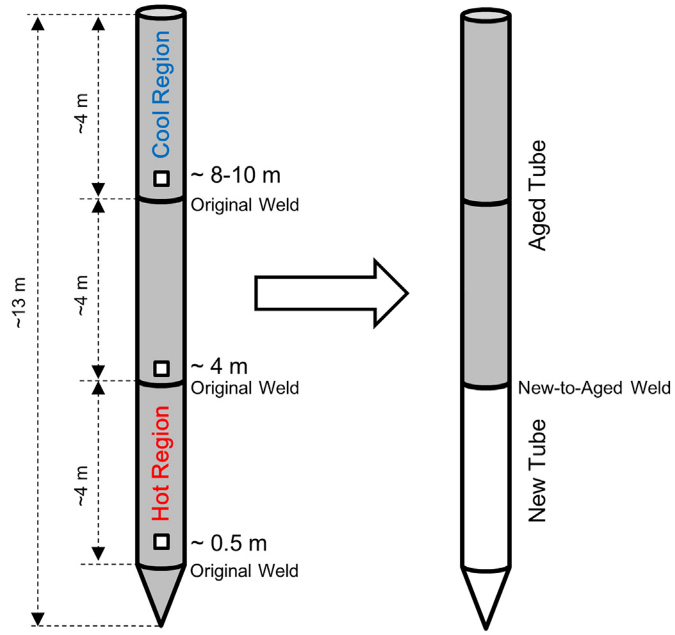

Fig. 1. Schematic of the 20-year aged tube with selected heights for microstructural and welding studies. Replacement of the hottest segment of aged tube with the new tube is intended. Approximate locations of metallographic samples are marked by small white squares on aged tube. Aged and new tube segments are marked in gray and while, respectively.

Nb or Ti), and secondary carbide precipitation [1–33]. Primary carbide growth and coalescence lead to loss of elongation, brittleness, and thermal shock sensitivity. Some studies suggest that MC transition to G-phase decreases creep strength [6]. Addition of Ti has been reported to suppress NbC transition to G-phase [6, 14, 21, 26, 29]. Other studies find G-phase effect on creep strength insignificant as it is deformable at high temperatures and volume fraction is low [34]. Whatever the long-term effect of G-phase on creep may be, it would not affect weldability significantly. Thus, the main welding issue is crack formation due to coarse and continuous network of brittle phases and reduced elongation.

Reformer tubes are typically 13 m long consisting of three segments that are welded by manufacturers (Fig. 1). Although the industry practice during turnarounds is to replace the entire tubes, there is a cost- and time-driven motivation at SK Innovation to only replace the bottom portion of these tubes which have experienced the highest temperature and microstructural changes in contrast with replacing the entire tubes. However, welding new tubes to aged ones may lead to reliability issues due to differences in mechanical properties.

Previous welding and repair welding practices have encountered crack formation in the heat affected zone or weld metal [16–19, 22, 23]. Severe cracking in aged tubes results in little to no weldability. Typically, weldability in the field is judged based on the absence of post-welding macro-cracks [35–38]. Additionally, aged tubes with room temperature total elongation equal or higher than 4% are considered weldable in some technical guidelines [22, 39].

Weldability criteria mentioned above are not fully reliable since detectable crack length and elongation strongly depend on the detection limit of evaluation method and the aged microstructure, respectively. Therefore, careful microstructural analysis as well as mechanical properties assessments of aged tubes and aged-to-new welds are required to evaluate the reliability of welding process.

2. Experiments

Considering that 13 m-long reformer tubes experience a large temperature gradient from top to bottom, microstructure and mechanical properties would be different at each height. This means that weldability of tube will depend on tube height. Therefore, samples from three selected heights in a 20-year aged tube were cut for welding to new tubes. Accordingly, these heights are 0.5 m, 4 m, and 8 m from the bottom of the tube as marked in Fig. 1.

The temperature in 0.5 m height is estimated to be close to 900 °C and therefore, this location experiences the maximum creep and bulging. Heights above 0.5 m experience lower temperatures as feed enters the upper part of the 13 m-long tube at nearly 700 °C and gradually is heated. Temperature measurements at upper parts of the tube are unavailable.

Tube thickness is 12 mm. Sections with 200 mm length from old tubes were welded to new tubes. V-joint groove design with 37° half-angle was used. GTAW with 21Cr-33Ni-5Mn-1Nb-0.3Si-0.1C (UTP A 2133 Mn) filler metal was applied for the root pass. Welding voltage and current were 10–13 V and 80–140 A, respectively. Argon with 99.9% purity was used as shielding and backing gas with 10–15 l/min flow. Liquid penetrant test was performed after the root pass. Five filling passes were applied to fill the seam.

Maximum interpass temperature of 150 °C was maintained between passes. Root pass was applied with and without preheating to