Dissolution of Nb(C,N) During Post-weld Heat-Treatment of Electric Resistance Welded X70 Line Pipe

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The effect of peak temperature for post-weld heat treatment (PWHT) on the dissolution of Nb-rich carbonitrides, Nb(C,N), in the weldline of an electric resistance welded (ERW) X70 grade pipeline steel was investigated. Selected-area electron diffraction patterns and corresponding electron energy loss spectroscopy mappings revealed both Nb-rich carbonitrides and Ti-rich nitrides, (Ti,Nb)N, in the sample heat-treated to 1080 °C peak temperature. However, only Ti-rich nitrides were revealed in the sample heat-treated to 1220 °C peak temperature. During continuous heating to higher than the Ac3 temperature, *i.e.*, near 1100 °C temperature, the dissolution of Nb(C,N) was observed in dilation and derivative of dilation. This experimental result agreed with the predictions by a DICTRA model. Furthermore, a phenomenological model was developed to explain the volume shrinkage during the dissolution of Nb(C,N) precipitates.

https://doi.org/10.1007/s11661-024-07496-4

I. INTRODUCTION

ELECTRIC-RESISTANCE welded (ERW) line pipe of X65 and X70 grade steels is widely used for oil and natural gas transportation across large distances and is recently considered for renewable energy transportation; therefore, impact toughness and hydrogen embrittlement requirements at low temperatures (below − 30 °C) become an important factor.[1–3] In ERW line pipe, it is widely reported that the impact toughness at the weldline is considerably lower than in the pipe body or base metal.[2,3] Depending on the chemical composition and thermo-mechanically controlled processing (TMCP) parameters, pipeline steels can form different microstructure constituents, such as polygonal ferrite (PF), quasi polygonal ferrite (QF) acicular ferrite (AF), and bainitic ferrite (BF), with second-phase precipitates such as carbides, nitrides, and carbonitrides of Nb, Ti, and V. Such complex microalloying and microstructure contribute significantly to the impact toughness.[4]

Due to the rapid heating, instant upsetting, and fast cooling involved in the ERW manufacturing process, the microstructural constituents of the base metal will be altered at the weld joint. In the as-welded condition, the ERW weldline consists of a solute-depleted ferrite and solute-enriched martensite-austenite (M/A) constituents.[2,5] The coarse-grained heat-affected zone (CGHAZ), adjacent to the weldline, consists of mostly bainitic ferrite with a minor fraction of retained austenite (RA). Sharma *et al.*[5] proved that the ferrite-austenite interface in the as-welded HAZ followed a negligible-partitioning local-equilibrium (NPLE) kinetics of bainite transformation. Han *et al.*[6] showed that due to the rapid thermal cycle and deformation in ERW, tensile residual stresses were developed in the weld region. Therefore, the as-welded ERW line pipe does not comply with the low-temperature toughness requirements imposed by the standards such as American Petroleum Institute (API) Specification 5L—Line Pipe, Canadian Standards Association (CSA) Z245.1:22—Steel Pipe.[1,2,7–9] To improve the low-temperature toughness, the as-welded ERW line pipe usually needs

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Manuscript submitted May 14, 2024; accepted June 15, 2024.

Published online: 26 June 2024