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Material Design for Grade X65 UOE Sour Linepipe Steels with SSC-resistant Property

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From actual pipe investigations of Grade X65 UOE sour linepipe steels, the inner surface hardness of pipes increased by increasing the volume fraction of the lath bainite (LB) microstructure instead of the granular bainite (GB) microstructure. Four-point bend tests on sulfide stress cracking (SSC) revealed that SSC occurred when the inner surface hardness of a pipe increased by increasing the volume fraction of the LB microstructure over a 1 bar H_2S partial pressure condition. Lowering the surface hardness less than 250 HV0.1kgf at 0.25 mm from the surface by suppressing the LB microstructure led to a good SSC-resistant property over the 1 bar H_2S partial pressure condition.

INTRODUCTION

Linepipe steels for sour service need to have a sufficient resistance to sulfide stress cracking (SSC) under a sour environment. The application of sour linepipes has been expanded toward severe sour environment regions including higher hydrogen sulfide (H_2S) partial pressure conditions over 1 bar. In 2013, actual sour gas pipeline failure occurred as a result of SSC under higher H_2S partial pressure conditions over 1 bar (Newbury et al., 2018). One of the possible root causes of SSC was assumed by the formation of hard spots at the inner surface of linepipe steel. Fairchild et al. (2019) investigated and summarized the three hard zone formation mechanisms including carbon contamination, dual phase microstructure, and local hard zone in a recent paper (Newbury et al., 2019). Therefore, a precise and strict material design is needed in the production of Grade X65 UOE sour linepipe steels for preventing SSC.

The higher cooling rate in the accelerated cooling process after rolling, on one hand, has tremendous benefits for obtaining higher strength and superior toughness, even for thicker plates. It should be noted that the cooling device and process design, such as the thermomechanically controlled process (TMCP), plays quite an important role in realizing well-balanced sour linepipe steels (Tamehiro et al., 1984; Endo et al., 1997; Ishikawa et al., 2012). On the other hand, a higher cooling rate can cause higher surface hardness, resulting in higher SSC susceptibility. In designing a sour gas linepipe, hardness limitations are often required of materials to avoid SSC as specified in the NACE MR0175 standard (NACE International, 2015), which recommends a maximum hardness of 22 HRC, or approximately 250 HV, in carbon and low-alloy steels. The effect of hardness on SSC behavior has been investigated so far mainly in oil country tubular goods (OCTGs), which are quenched and tempered and have relatively higher strength, or welds in which local hardness is likely to be increased (Omar et al., 1981; Pargeter, 2000). However, the effect of surface hardness on SSC behavior in a TMCP sour gas linepipe has drawn much attention recently because of its characteristic hardness distribution along plate thickness, though its strength grade is lower than that of OCTG products. Steel plates for linepipes for sour service are produced by TMCP to ensure fine bainitic microstructure, resulting in excellent hydrogen-induced cracking (HIC) resistance and toughness. To minimize the risk of SSC, a deliberate cooling process design to suppress excessive surface hardness and to ensure homogeneous hardness distribution over a whole plate is required.

By improving cooling homogeneity as well as cooling rate, a wide variety of high-performance plate and pipe products with stringent sour specifications have been made available (Endo and Nakata, 2015). The typical beneficial effect from recent advanced cooling device is homogeneous plate surface hardness by controlling the surface cooling rate (Shimamura et al., 2013). The process window of optimum conditions for controlled rolling and accelerated cooling that balances higher strength, toughness, and moderate surface hardness has been successfully extended.

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KEY WORDS: Linepipe, sour gas, HIC, SSC, TMCP, bainite, hardness.