

OLAC (On-Line Accelerated Cooling)-Based X65 Linepipe with Low Surface Hardness for Severe Sour Environment

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ABSTRACT

TMCP (Thermo-mechanical controlled process) large diameter linepipes have been used since a long time for high-strength and severe sour application, but recently Sulfide Stress Cracking (SSC) caused by local hard zones has become a concern. In this paper, material design concept to prevent SSC was firstly introduced. In the author's organization, Advanced-OLAC-based cooling rate control for surface and mid-thick area can achieve uniform and low hardness at the surface portion while maintaining high strength with lean chemistry. By improving cooling homogeneity as well as surface cooling rate control, homogeneous granular bainite microstructure is obtained, resulting in a stable low surface hardness at pipe inner surface. Developed OLAC-based Grade X65 LSAW Linepipe showed no SSC even for severe sour environment over than 1bar H₂S while tested as per both four-point bend test and full ring test. The surface hardness limit in full ring SSC tests gave good agreement with that of 4PB SSC tests in 1bar and 16bar H₂S partial pressure condition. The effect of H₂S partial pressure condition on surface corrosion behavior and SSC crack propagation behavior is also discussed.

Key words: linepipe; sour gas; sulfide stress cracking; Thermo-mechanical controlled processing; Bainite; hardness; SSC crack propagation.

INTRODUCTION

Application of sour linepipes has expanded towards severe sour environment regions including high H_2S partial pressure conditions. In 2013, actual sour gas pipeline failure occurred due to SSC¹. One of the possible root cause of SSC was assumed to be a formation of hard spots in a surface region of the steel. Fairchild et al² investigated and proposed three hard zone formation mechanisms including carbon contamination, dual phase microstructure and heat transfer variation in a recent paper^{1,2}. Therefore, precise and strict material design should be needed in a production of sour linepipe steels for preventing SSC.

In designing sour linepipe steels, hardness limitation is required to avoid SSC as specified in NACE MR0175 / ISO 15156 standard³ which specifies a maximum hardness of 22HRC or approximately 250HV in carbon and low alloy steels⁴. Steel plates for Grade X65 sour linepipes are usually produced by Thermo-Mechanical Controlled Processing (TMCP) to ensure fine bainitic microstructure, resulting in excellent HIC resistance and toughness. To minimize a risk of SSC, a deliberate cooling process to suppress excessive surface hardness and to ensure homogeneous hardness distribution over the whole plate is required.

In the previous paper⁵, 4PB SSC tests as per NACE TM 0316⁶ revealed that SSC occurred when the inner surface hardness exceeds the limit as a function of H_2S partial pressure. Surface hardness of pipe increased with increasing volume fraction of lath bainite (LB) microstructure. In the case of 1 bar or higher H_2S partial pressure condition, the surface hardness limit was approximately 250 HV0.1kgf at 0.25mm from pipe inner surface⁵. Advanced online accelerated cooling (OLAC) system achieved uniform and low hardness at the plate surface while maintaining high strength with lean chemistry. By improving cooling homogeneity as well as surface cooling rate control, homogeneous granular bainite microstructure is obtained, resulting in stable low surface hardness.

In this paper, the material design concept to prevent SSC was firstly introduced. Then, SSC test results of four-point bend test and full ring SSC test were introduced under the H_2S partial pressure up to 16bar in order to clarify the hardness limit of SSC occurrence using Grade X65 pipes.

SURFACE MICROSTRUCTURE AND HARDNESS CONTROL FOR SSC RESISTANT PROPERTY

SSC behavior in TMCP sour gas linepipe has been focused recently due to 'hard spot' shown at the pipe inner surface. The inner surface area of the pipe corresponds to the top surface area of the source plate. Figure 1 shows the schematic illustration of the cooling curve at plate surface and mid-thickness position. In a typical TMCP process using accelerated cooling device, the cooling rate of the plate surface is higher than that of the plate at mid-thickness location. Therefore, the surface cooling rate should be controlled carefully to obtain lower surface hardness. Advanced online accelerated cooling (OLAC) system can achieve improved cooling homogeneity and low surface cooling rate without large cooling rate decrease at mid-thickness location. So, the developed pipes achieved uniform and low hardness at the plate surface while maintaining target strength.

Figure 2 summarizes the material design concept used for achieving lower surface hardness at the inner surface of X65 UOE sour pipes. When the surface cooling rate is above 200 °C/sec, the surface microstructure is mainly hard lath bainite (LB). When the surface cooling rate is around 100 °C/sec, the surface microstructure is composed from soft granular bainite (GB) and LB. When the surface cooling rate is less than 50 °C/sec, the surface microstructure becomes mainly GB microstructure.

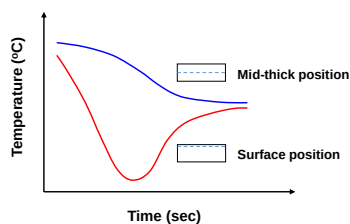


Figure 1: Schematic illustration of cooling curve in steel plate.

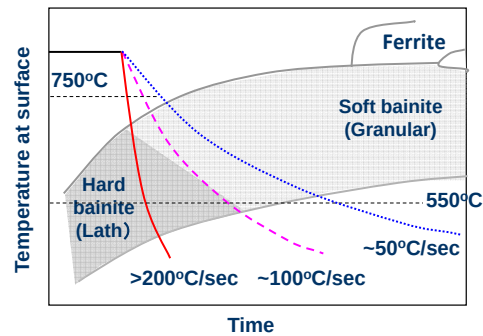


Figure 2: Ideal lower surface cooling curve of steel plate for Grade X65 UOE sour linepipe.

EFFECT OF SURFACE COOLING RATE ON MICROSTRUCTURE AND HARDNESS OF AGED PIPE

Detailed microstructure observations were conducted for several pipe samples manufactured with different cooling pattern as mentioned in previous section. Figure 3 shows the effect of cooling rate on the surface microstructure. In X65 sour linepipe steels, surface microstructure is usually composed of a bainite microstructure. Bainite microstructure is categorized into two types including lath bainite (LB) and granular bainite (GB), depending on the transformation temperature. The inner surface hardness of pipe increases with increasing the volume fraction of LB microstructure in replacement of GB microstructure as the surface cooling rate is increased. Detailed hardness distributions were measured at inner surface area of aged pipe after 1hr heating at 250 °C. Figure 4 shows examples of hardness distribution in each pipe samples with different cooling rates. In order to measure the cross-section hardness at a distance as close as 0.1mm from surface, 0.1kg force load was used in HV measurements. Higher cooling rate samples over 100 °C/sec showed higher hardnesses covering larger cross section areas in both through thickness and width direction. On the other hand, lower cooling rate samples of less than 50 °C/sec showed lower hardnesses values spread in both through thickness and width direction.

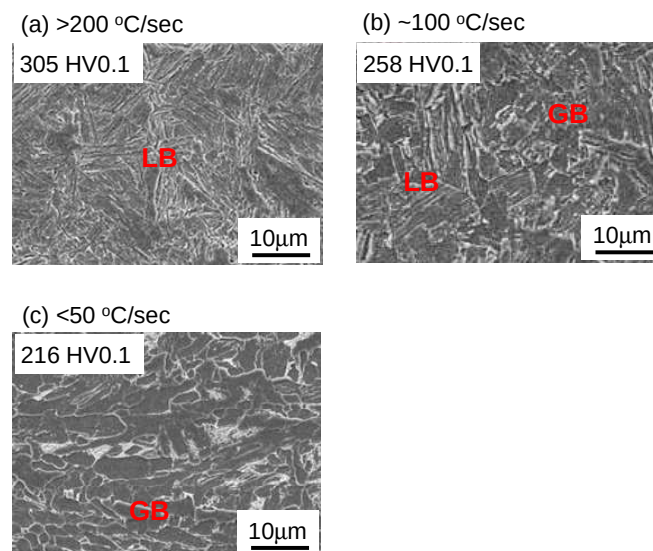


Figure 3: Effect of surface cooling rate on surface microstructure.