Metallurgical Design and Development of High Deformable High Strength Line Pipe Suitable for Strain-Based Design

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ABSTRACT

Application of high-strength line pipe is beneficial for the reduction of cost of gas transmission pipelines by enabling high-pressure operation. Long-distance gas transmission pipelines from remote areas sometimes pass through discontinuous permafrost, and are subject to ground movement by repeated thaw subsidence and frost heave. In this case, high-deformable line pipe is required for strain-based design. On the other hand, in recent years, demand for high-strength line pipe steels has emerged in which the content of the alloying element is reduced because of the high cost of alloying elements. This paper describes the metallurgical design and development of high-deformable high-strength line pipe without Mo addition suitable for strain-based design. High-deformable high-strength line pipe with cost effectiveness as well as good low-temperature toughness and seam weld toughness was developed.

KEYWORDS: strain-based design, high-strength, line pipe, thermal aging, mechanical properties, alloying element, manufacturing process

INTRODUCTION

Demand for natural gas using pipelines and LNG to supply the world gas markets is increasing as a substitute for oil and coal. The use of high-strength line pipe steels reduces the cost of gas transmission pipelines by enabling high-pressure transmission of large volumes of gas. In particular, high-strength line pipe materials with a yield strength of X80 or higher have been developed over the last few decades around the world. Long-distance gas transmission pipelines from remote areas sometimes pass through discontinuous permafrost, and are subject to ground movement by repeated thaw subsidence and frost heave. In this case, strain-based design has been applied as well as stress-based design. Therefore, high-deformable line pipe is required for strain-based design in order to prevent the pipeline from fracturing (Glover, A, 2002; Denys, R, 1994; Denys, R, 2004; Glover, A, 2004; Al-Sharif, AM, 1996; Hillenbrand, HG, 2002; Liessem, A., 2004). Nippon Steel Corporation has also developed high-deformable high-strength line pipe material suitable for strain-based design (Terada, Y, 2003; Terada, Y, 1997; Shinohara, Y, 2005; Shinohara, Y, 2006; Shinohara, Y, 2008).

High deformability, especially after thermal coating, is required as an important property for line pipes used in a strain-based design. It is necessary to have a narrow range of yield strength and tensile strength. It is also desirable to have a low yield-to-tensile ratio and a high work-hardening rate as well as low-temperature toughness for base metal and seam welds and good field weldability for the steels, which will be used in arctic pipeline.

In recent years, demand for high-strength line pipe steels has emerged in which the molybdenum content is reduced because of the high cost of molybdenum (Mo). Conventionally, high-strength line pipe steel with Mo addition has been developed in order to control the microstructure and to obtain the required pipe properties such as strength and low-temperature toughness (Terada, Y, 2003; Tamehiro, H, 1996; Terada, Y, 1997; Ohm, RK, 2000; Hammond, J, 2000). This paper describes the metallurgical design and development of high-deformable high-strength line pipe without Mo addition suitable for strain-based design. High-deformable high-strength line pipe with a yield strength of X80 or higher as well as good low-temperature toughness and seam weld toughness was developed.

METALLURGICAL DESIGN OF HIGH-DEFORMABLE HIGH-STRENGTH LINE PIPE

Material design of high-deformable high-strength line pipe

Table 1 shows the required properties of line pipe. A specified minimum yield strength (YS) and a specified minimum tensile strength (TS) of the pipe body and seam weld joint in the circumferential direction are required for design against the operating pressure. Excellent toughness of the pipe body, seam weld, and girth weld portion are also required to prevent crack initiation. Crack arrestability of brittle and running ductile fractures is also needed as for high-strength line pipe. A high shear area and high absorbed energy of the pipe body are required in order to arrest fracture even if a crack is initiated. That is, it is necessary to develop high-strength line pipe with excellent low-temperature toughness in the pipe body and seam weld as well as providing excellent field weldability. To obtain a high shear area at the design temperature, it is necessary to have low ductile-to-brittle transition temperature (DBTT). Generally, grain refining is effective for lowering DBTT. In order to achieve high upper-shelf