

# Development of High-Strength Steel Line Pipe for SBD Applications

Yasuhiro Shinohara, Eiji Tsuru\* and Hitoshi Asahi  
Technical Development Bureau, Nippon Steel Corporation, Futtsu City, Chiba, Japan

Takuya Hara and Yoshio Terada  
Kimitsu R&D Laboratory, Nippon Steel Corporation, Kimitsu City, Chiba, Japan

Naoki Doi and Naoshi Ayukawa  
Kimitsu Works, Nippon Steel Corporation, Kimitsu City, Chiba, Japan

Masahiko Murata  
Pipe & Tube Sales Division, Nippon Steel Corporation, Chiyoda Ward, Tokyo, Japan

**A strain-based design (SBD) has been widely discussed in recent years. Line pipes for the design applications are required to have high deformability as well as toughness and weldability. We studied how to simultaneously improve toughness and deformability in high-strength steel line pipes through laboratory work. A dual-phase (bainite/ferrite) microstructure was effective, and the optimized volume fraction and grain size of polygonal ferrite were confirmed. In addition, we revealed that the accelerated cooling condition in hot rolling absolutely correlated with thermal aging during anti-coating treatment. Based on the experimental results, we experimentally manufactured X80 UOE pipes for SBD.**

## INTRODUCTION

A strain-based design (SBD) has been discussed for pipeline construction in discontinuous permafrost areas (Glover, 2002). The design aims to prevent any fracture of the pipe through plastic deformation due to ground movement. For SBD, we need to consider the tensile strain limit and the compressive strain limit.

The relation between the pipe and the girth weld properties is important for the tensile limit. We should first estimate the allowable defect size and required toughness (Denys, 2002), and then control the yield strength (YS) and flow stresses (FS) at a 2% strain or lower in a pipe's longitudinal direction to achieve an overmatch of the girth weld strength.

The compressive strain limit is affected by many factors, such as operation conditions, pipe size and mechanical properties in a pipe's longitudinal direction (Glover, 2004). Because the yield-to-tensile strength (Y/T) ratio, uniform elongation (U.El) and stress-strain (S-S) curve shape affect the compressive strain limit, it is important to control these properties.

A line pipe is normally coated for corrosion protection. While there are many types of coating treatment methods, the use of a fusion bonding epoxy (FBE) type has increased. In the case of an FBE coating application, a pipe is heated at 200°C and higher. The coating treatment causes thermal aging because of cold pipe forming (Shinohara, 2005; Timms, 2005). The mechanical properties such as Y/T ratio, YS, FS at lower strain and S-S curve shape may change due to thermal aging.

In this paper, we studied how to simultaneously improve toughness and deformability in high-strength steel line pipes through

laboratory research. In addition, we considered the means to control change in mechanical properties due to thermal aging during anti-corrosion coating treatment.

Basic study in a laboratory indicated that a dual-phase (DP) microstructure with bainite and fine polygonal ferrite was effective for simultaneously improving deformability and toughness instead of a bainite single microstructure. Beyond that, the absorbed energy in the drop weight tear test (DWTT) was improved when the microstructure changed from bainite single microstructure to a DP microstructure with fine polygonal ferrite. We confirmed the optimized volume fraction and grain size of polygonal ferrite to achieve excellent elongation, Y/T ratio and DWTT property to a line pipe for SBD applications. Further, the basic study indicated that an accelerated cooling condition in hot rolling was strongly correlated with thermal strain aging during the coating treatment.

Based on the experimental results, we experimentally manufactured in a commercial mill X80 UOE pipes for SBD with low Y/T ratio, high U.El, good Charpy impact and DWTT properties.

## LABORATORY TEST

### Experimental Procedure

Table 1 shows the chemical compositions of steel used in this study. A continuous cast slab melted in a 300-ton LD converter was used for the study. Small slabs, 280 mm wide, 250 mm long and 240 mm thick, were cut from the large cast slab. From these small slabs, 23-mm-thick plates were made through a thermomechanical controlled and accelerated cooling process, using a rolling simulator in a laboratory. Two types of steels with different microstructures, ferrite/ bainite DP steel and bainite single-phase steel, were made due to the change in the accelerated cooling condition. Tensile specimens, DWTT specimens and Charpy V-notched (CVN) specimens were machined from the rolling plates. JIS No. 5 full thickness specimens were used for a tensile test. Two types of DWTT methods were used in this study: One was press notched DWTT (PN-DWTT); the other, precrack

\*ISOPE Member.

Received February 12, 2008; revised manuscript received by the editors August 4, 2008. The original version (prior to the final revised manuscript) was presented at the First SBD Symposium of the 17th International Offshore and Polar Engineering Conference (ISOPE-2007), Lisbon, July 1–6, 2007.

KEY WORDS: Line pipe, UOE pipe, high-strength steel, deformability, toughness, thermal aging.