Sour-Resistant X65 UOE Line Pipe for Low-Temperature Service

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With the aim of developing sour-resistant API X65 UOE line pipe with good low-temperature toughness, the effects of the aluminum content on the simulated HAZ toughness and the formation of the M-A (martensite-austenite) constituent were examined. It was found that HAZ toughness improves remarkably when the aluminum content is below 0.01 mass %. Reduction in the aluminum content is considered to suppress the formation of the M-A constituent harmful to low-temperature toughness by facilitating the precipitation of Fe₃C from untransformed austenite on cooling after welding. Based on the experimental results, API X65 UOE pipe for sour service was commercially manufactured and its properties were examined. The newly developed API X65 UOE pipe exhibited excellent HIC and SSC resistance, as well as excellent low-temperature toughness at −46°C.

INTRODUCTION

As energy resources are exploited in the Arctic and offshore regions in severe environments, the property requirements for line pipe for transporting oil and gas have become diversified and sophisticated. Heavy-wall API X65 pipe with excellent low-temperature toughness at −30°C and excellent HIC and SSC resistance is commercially used for sour applications in the North Sea (Tamehiro, 1989, 1991). Recently, sour-resistant API X65 pipe has been required even for low-temperature service at −46°C. It is, however, difficult to achieve both excellent HAZ toughness and HIC resistance. In order to improve HAZ toughness, it is important to refine the grain size and suppress the formation of the M-A constituent harmful to toughness (Haze, 1988). Hence, titanium-oxide bearing steel (Ti-O steel), which has improved HAZ toughness by utilizing intragranular ferrite (IGF), has been developed (Chijiiwa, 1988; Nishioka, 1988; Yoshida, 1993). IGF nucleates during austenite-to-ferrite transformation after welding from fine precipitates consisting of Ti₃O₅, TiN and MnS dispersed in steel.

It is difficult to attain both excellent HAZ toughness and HIC resistance because MnS, which facilitates the nucleation of IGF, deteriorates HIC resistance. On the other hand, it is known that a reduction in silicon content improves HAZ toughness by decreasing the amount of the M-A constituent (Ohtani, 1978). However, when the silicon content is lowered, it becomes difficult to attain high strength for sour-resistant line pipe steel containing low carbon and low manganese. Thus, a study was undertaken on the manufacturing technology of sour-resistant API X65 UOE pipe line pipe for low-temperature service at −46°C. In this paper, the effect of the aluminum content on the formation of the M-A constituent in HAZ was investigated from the viewpoint of improving HAZ toughness, and then API X65 UOE line pipe for sour service was manufactured on a mill and its properties and performance were examined.

EFFECT OF ALUMINUM CONTENT ON HAZ TOUGHNESS

Experimental Procedure

Table 1 shows the chemical compositions of the steels used. They are calcium-treated API X65 class steels with a low C-low S-Ni-Mo-Nb system. A to D steels with different aluminum contents were vacuum-melted and cast into 16-kg ingots; these were hot-rolled into 15-mm-thick plates after reheating at 1100°C for 1 h. Simulated weld thermal cycle test specimens—12 mm thick, 12 mm wide and 120 mm long—were machined from the mid-thickness of rolled plates. Peak temperature and cooling time between 800°C and 500°C (ts/5) of the simulated thermal cycle were set to 1400°C and 54 s, respectively. Charpy impact tests of simulated HAZ with A to C steels were carried out, and the formation of the M-A constituent was observed by optical microscope after etching the specimen surface using LePera’s reagent (LePera, 1980). Further, the austenite-to-ferrite transformation temperatures of A to C steels were measured by a dilatometer using cylindrical specimens 3 mm in diameter and 10 mm in length. E and F steels with different aluminum contents were vacuum-melted and cast into 150-kg ingots; these were hot-rolled into 25-mm-thick plates after reheating at 1200°C for 1 h. Simulated thermal cycle test specimens—12 mm thick, 12 mm wide and 120 mm long—were machined from the mid-thickness of rolled plates. The peak temperature and ts/5 of the simulated thermal cycle were set to 1400°C and 21 s, respectively. The HAZ microstructures of E, F and D steels were observed by transmission electron microscope (TEM).

Experimental Results

Figs. 1 and 2 show the effect of the aluminum content on the simulated HAZ toughness and the area fraction of the M-A con-