

Improved Collapse Resistance of UOE Line Pipe with Thermal Aging for Deepwater Applications

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UOE pipe has a strength anisotropy and distribution developed by cold forming. Since a decrease in the compressive yield stress in the circumferential direction causes lower collapse resistance, the fabrication factor should be allowable for pipeline design. The collapse resistance of UOE pipe with and without thermal aging was evaluated using the full body collapse test and numerical simulation by finite element analysis (FEA). The results show that decreased yield stress is recovered by thermal aging during anticorrosion coating, and it exceeds the specified yield stress for the specially designed material.

INTRODUCTION

UOE pipe is used in gas pipelines for intercontinental transportation. In such deepwater projects, collapse resistance to external pressure is required for the line pipe, so its wall thickness is determined from collapse resistance in various design factors (Torselletti et al., 2003). Accordingly, the improvement of collapse resistance directly leads to the reduction of material cost.

Collapse resistance is affected by the compressive stress vs. strain behavior in the circumferential direction in addition to the pipe's ovality. However, the strength anisotropy is induced by the cold strain in the UOE pipe forming process and distributed in the pipe cross-section. Pipe expansion—that is, the final process in UOE pipe—forming develops tensile stress in the circumferential direction. The tensile stress decreases the compressive yield stress in the circumferential direction (C-YS), in the Bauschinger effect (Kyriakides and Corona, 1991). The DNV defines 0.85 as the fabrication factor (α_{fab}) for UOE pipe for the estimation of C-YS reduction (DNV OFFSHORE STANDARD OS-F101, 2000). However, the C-YS distribution has not been clarified in a whole pipe with heavy wall thickness despite the difference in the forming strain in the pipe locations. Further, some studies have investigated the effect of orthogonal anisotropy on collapse resistance (Marewski et al., 2004; DeGeer et al., 2004).

After UOE pipe forming, the anticorrosion coating is applied to the line pipe when it is heated in the pre-treatment. The heating temperature of the most popular coating type, fusion-bonded epoxy coating, typically ranges from 200°C to 250°C. The temperature rise during the coating increases C-YS and collapse resistance is improved (Stark and McKehehan, 1995; Al-Sharif and Preston, 1996). The increase in yield stress (YS) results from thermal aging, depending on the heating temperature and the applied strain intensity (Tsuru and Asahi, 2004).

The objectives of this study are to clarify YS distribution before and after the thermal aging, and to determine the dominant factors

for collapse pressure using a full-scale test and finite element analysis (FEA).

In this study, the collapse resistance of UOE pipe was verified by the full-scale test. The results revealed the influence on collapse pressure of the change in the mechanical properties. A commercially available finite element program was used for predicting collapse pressure and solving the collapse mechanism, considering the C-YS distribution.

As a result of the tests, the C-YS in the middle of and outside the thickness was found to be lower than inside. After thermal aging, the larger recovery of the C-YS appears for the inner and outer wall. The YS increase was dependent on the manufacturing process of a UOE pipe under the same heating pattern. The collapse tests verified that the high collapse of the UOE pipe meets 1.1 of α_{fab} after the simulated coating operation.

In the numerical simulation, the collapse pressures were predicted within the error between -10% and $+3\%$. Accuracy was achieved by modeling the pipe geometry as the ellipse, disregarding the anisotropy and residual stress. In addition, the FEA results were useful for converting from the measured collapse pressure to the pressure in the capped end conditions.

TEST PIPES

Table 1 summarizes the pipes used in the collapse tests. The collapse modes were classified into plastic, transition and elastic collapse, judging from D/t (pipe diameter/thickness) and YS. In these modes, the pipe used in deepwater projects belongs to the plastic collapse mode. The pipes in this mode were manufactured by 2 processes: M1 is the conventional method; M2, the high collapse method. The plate rolling process of M2 is mainly modified to utilize the positive effect of strain aging during the coating.

Fig. 1 shows the transient temperatures on the outer and inner surface of the pipes during the heat treatment, using the induction heater and water-cooling system. Three heating patterns were determined for the thermal aging process. T1 means that the steady state temperature ranges from 230°C to 240°C for 5 min, and it simulates the typical fusion-bonded epoxy coating process. For T2, after over-heating the outer surface to 450°C, the pipe was cooled from the inner surface using water spray as soon as

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Received June 9, 2007; revised manuscript received by the editors August 15, 2007. The original version (prior to the final revised manuscript) was presented at the 16th International Offshore and Polar Engineering Conference (ISOPE-2006), San Francisco, May 28–June 2, 2006.

KEY WORDS: Pipeline, line pipe, UOE pipe, collapse, yield stress.