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A Study on the Prediction of Welding Distortion of 9% Ni Steel for the Offshore LNG Storage Tank

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ABSTRACT

The purpose of this study is to establish the predictive equations for welding distortion and residual stress in the weldment of 9% Ni steel in consideration of the solid-state transformation. In order to do it, high speed quenching dilatometer is used to evaluate the coefficient of thermal expansion (CTE) of 9% Ni steel with the fraction of martensite. With CTE obtained, an uncoupled thermal-mechanical finite element (FE) model was developed to evaluate the effect of solid-state phase transformation on welding distortion and residual stress of the weldment and verified by comparing with the results of experiment. The variations of welding distortion in the weldment of 9% Ni steel with welding process, welding heat input and plate thickness were investigated. Based on the results, the predictive equations for welding distortion and residual stress in the weldment of 9% Ni steel were formulated as a function of welding heat input and plate thickness. The distributions of welding distortion of the actual welded structure obtained by STEM (Simplified Thermo-Elastic Method, Shin and Lee, 2002) with the predictive equations have a good agreement with the measured results.

KEY WORDS: LNG storage tank; 9% nickel steel; welding distortion; phase transformation; dilatometer; residual stress; FEA

INTRODUCTION

Liquified Natural Gas (LNG) is the world's fastest-growing primary energy source. With an increase in demand for LNG, the number of LNG storage tank has increased. Up to now, most of LNG storage tanks were in-ground or above ground storage tanks with double containers; the inner tank contains LNG and the insulation materials was placed between the inner and the outer tank. Therefore the tanks have some problems related to the productivity due to on-site welding, high construction cost due to the structure reinforcement and so on. For above reason, many researchers have been tried to develop the LNG storage tank of new type. The most representative model is the offshore LNG storage tank. The tank consists of the inner tank of 9% Ni Steel and the outer tank of the gravity based concrete structure. The two inner tanks with prismatic shape were fabricated in the factory and installed inside the outer tank on-site. In case of the storage tank, all of the hydraulic pressures caused by LNG cargo were directly applied to the inner tank. It means that the inner tank of the offshore LNG storage tank should be strong enough to sustain all of the loads. Therefore, the inner tank was designed as panel structure with thin plates strengthened by longitudinal and transverse stiffeners. This is the biggest difference from the previous LNG storage tank and cause new problems related to the excessive distortion.

The excessive distortion affects adversely the productivity and the structural stability of welded structure under the design condition of low temperature. Moreover, straightening by flame heating of the 9% Ni steel was prohibited because metallurgical changes by flame heating deteriorate the cryogenic fracture toughness of the parent material. Thus the welding distortion and residual stress must be controlled during manufacturing process. However it is very difficult to manage the accuracy of LNG storage tank in the production stage due to the deficiency of sufficient data for welding distortion of 9% Ni steel. Especially, welding distortions in the weldment of 9% Ni steel are known to strongly depend on the phase transformation. It is necessary to identify the characteristics of angular distortion, transverse shrinkage and residual stress in the weldment of 9% Ni steel with respect to phase transformation during welding and cooling (Karlsson and Josefson, 1989; Papazoglow and Masubushi, 1981; Andersson, 1978).

This study presents how to predict the angular distortion, transverse shrinkage and distribution of residual stress in the weldment of 9% Ni steel in consideration of the phase transformation using Finite Element Analysis (FEA) and high speed quenching dilatometer tests. From the results obtained by FEA and experiment, the predictive equations of welding distortion and residual stress for the weldment of 9% Ni steel were established and verified by comparing the distribution of distortion measured in the actual welded structure and the predicted results obtained by Simplified Thermal Elastic Method (STEM) and predictive equation.

Experiment and Finite Element Analysis

The chemical compositions of 9% Ni steel are given in Table 1. The carbon equivalent (CE) of the steel calculated using the formula: CE=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15 is 0.77 wt%.