Transactions of the Korean Nuclear Society Fall Meeting
Gyeongju, Korea, October 24-26, 2012

Evaluation of through thickness microstructure and mechanical properties in a thick forged 9Cr-1Mo-1V steel and its welds

Min-Chul Kim*, Sang Gyu Park, Ki-Hyoung Lee, Bong Sang Lee
KAERI, Nuclear Materials Research Division, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: mckim @ kaeri.re.kr*

1. Introduction

The High Temperature Gas-Cooled Reactors (HTGR), which is one of future nuclear energy systems, will be operated at higher temperature over 800°C to increase energy efficiency. Hence, it needs superior high temperature mechanical properties, stability for long-term operation, and excellent neutron irradiation resistance. Ferritic/martensitic steel, 9Cr-1Mo-1V steels have been used most extensively in the power-generation industry throughout the world due to having superior high temperature properties such as high strength, creep resistance, and good stability of microstructure [1]. These steels are also one of candidates for the RPVs(Reactor Pressure Vessels) of HTGR.

Currently, many studies have been conducted in laboratory-scale for 9Cr-1Mo-1V steels. However, there is a lack of the study on forged thick-section for RPVs [2]. The differences in microstructure and mechanical properties between internal and surface locations may occur during cooling after austenization, because the thickness of RPVs is over 200mm[3]. Therefore, in order to use ferritic/martensitic steel as RPVs, a detailed assessment of the through thickness properties is needed Hence, the study on 220mm thick plate for RPV application is being performed in KAERI [4].

The purpose of this study is to investigate the microstructure and the mechanical properties in G91 steel and its weld. The tensile properties at elevated temperatures and ductile-brittle transition behaviors were evaluated at the surface, 1/4T, and 1/2T locations of the 220mm thick section. The microstructure and mechanical properties of the weld metal were also evaluated from the lower and upper region of the weld.

2. Experimental Procedure

The base material used in this study is a forged 9Cr-1Mo-1V steel in the form of 220mm thick plate with the typical composition of G91 based on the ASME A-336 [8]. The chemical composition of the steel is given in Table 1. Table 2 shows the detailed heat treatment conditions. The specimens for microstructural and mechanical evaluation were obtained from the locations of surface, 1/4T, and 1/2T along the through-thickness depth of the heat-treated steel.

Narrow gap welds was produced by Submerged Arc Welding (SAW) with two different welding speeds using PF200S welding flux and US9CB(for SAW) or TGS9CB(for GTAW) welding wire. The weld root region (205mm~220mm region from surface) were welded by Gas Tungsten Arc Welding (GTAW) in 1~14 passes with a rate of 14~18cm/min(12~16V, and 120~160A). Then Submerged Arc Welding (SAW) was applied with a rate of 30~35cm/min for 15~89 passes (78~205mm region from surface), and with a rate of 28~32min/sec for 90~128 passes (region from surface to 78mm)(28~32V, 480~520A).

Table 1. Chemical composition of G91 steel (wt%)

	Chemical composition (%)					
Specimens	**Cr**	**Mo**	**C**	**Nb**	**V**	**Fe**
G91	**8.96**	**0.92**	**0.11**	**0.075**	**0.2**	**Bal.**
ASTM standard	**8.0 ~9.5**	**0.85 ~1.05**	**0.08 ~0.12**	**0.06 ~0.10**	**0.18 ~0.25**	**Bal.**

Table 2. Heat treatment conditions

Heat treatment	**Normalizing**	**Tempering**	**PWHT**
Condition (°C / h)	**1050 / 11**	**780 / 7.4**	**730 / 42**

The microstructure was observed by optical microscope and scanning electron microscope (SEM). In order to examine the morphology and structure of the precipitates in detail, a carbon extraction replica was prepared and examined by transmission electron microscopy (TEM).

Impact energy transition curves were obtained using standard Charpy V-notched specimens (10 x 10 x 55 mm^3) in a temperature range of -150°C to 100°C. Tensile tests were carried out at a strain rate of 1.11×10^{-3}/s using MTS Static Insight 50 using plate type tensile specimens with 18mm gage length and 1mm thickness over the temperature range from room temperature to 600°C. The yield strength and tensile strength were determined by a 0.2% strain offset stress and maximum loading point. Two or three specimens under identical conditions were tested.

3. Results and Discussion

Fig. 1 shows the optical micrographs of 9Cr-1Mo-1V steel at the surface, 1/4T, and 1/2T locations. The prior austenite grain size increased as the sampling locations were deeper. At the surface and 1/4T locations, the size of prior austenite grains were about 20μm and it was significantly increased in 1/2T location measuring a few tens to several hundred micrometers.

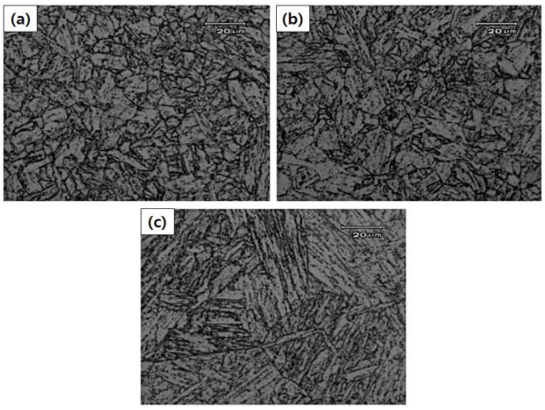

Fig. 1. Overall microstructures at representative locations in forged thick section; (a) surface, (b) 1/4T and (c) 1/2T

The optical micrographs of 9Cr-1Mo-V weld metals in the upper (a) and lower (b) welds are presented in Fig. 2. In the case of the upper region, relatively coarse solidification microstructures are observed due to the larger amount of heat input. The microstructure of the lower region is finer than the upper weld due to the decrease in the amount of heat input by higher welding speed.

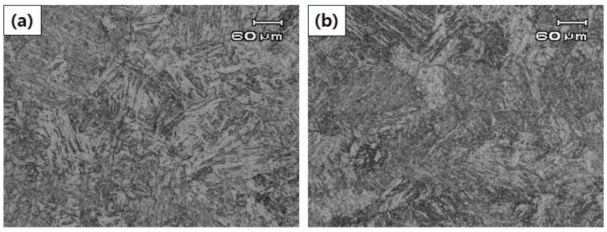

Fig. 2. Optical micrographs at different locations in 9Cr-1Mo weld metal; (a) Upper region and (b) Lower region

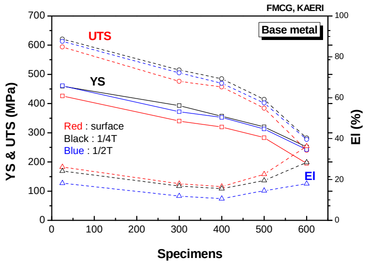

Fig. 3. Tensile properties of the base metal in the temperature range from R.T to 600°C

Fig. 3 show the results of tensile tests with test temperature. The yield strengths of specimens taken from center and 1/4T location were higher than that from surface in all test temperatures by 30MPa. Elongation also decreased with test temperature, while it increased from 500°C. In the case of Charpy properties, the impact toughness of surface is higher than those of the other locations.

Fig. 4 shows the results of tensile tests with test temperature. There is no significant difference in strength of upper and lower welds, but the elongations of the upper weld are slightly larger than those of the lower weld.

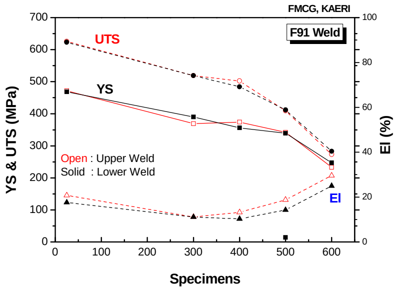

Fig. 4. Tensile properties of the weld in the temperature range from R.T to 600 °C

The lower weld shows comparatively better impact toughness than the upper weld caused by the relatively smaller size of weld beads and finer microstructures due to lower heat input by increased welding speed. The relations between the thickness direction and mechanical properties, and the properties of welds will be discussed in detail.

4. Summary

This study focused on the variation of microstructural and mechanical properties along the thickness direction in a heavy section of G91 steel and its weld. Both the yield strength and ultimate tensile strength of surface are lower than those of other location. It is shown that the impact toughness of surface is superior to those of other specimens. Overall, the toughness is developed increasingly toward outside. The lower weld shows better impact toughness caused by the relatively smaller size of weld beads and finer microstructures

Acknowledgement

This work was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy.

REFERENCES

[1] F.W. Noble, B.A. Senior, L.B. Eyre. Acta Metall. Mater. 38 (1990) 709

[2] Research Report, KINS / RR-613 / 2008

[3] J.T. Kim, B.I. Yang, H.K. Kwon, H.S. Jang, Journal of Mechanical Science and Technology, 43 1997.

[4] S.H. Lee, S.G. Park, M.C. Kim, B.S. Lee, S.J. Kim, Trans. of KPVP 7 (2011) 1