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An Assessment of Through Thickness Mechanical Properties in Forged Thick Section Mod. 9Cr-1Mo Steel .

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1. Introduction

Ferritic/martensitic steel, modified 9Cr-1Mo 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 microstructure stability [1]. These steels are also the primary candidate for the RPVs(Reactor Pressure Vessels) of High Temperature Gas-Cooled Reactors. Currently, many studies has been conducted in laboratory-scale for mod. 9Cr-1Mo steels. However, there is a lack of the study on forged thick- section for RPVs [2].

The differences in characteristics including the through thickness microstructure and mechanical properties between internal and external locations may occur during cooling after austenitization, because the thickness of RPVs is over about 200mm. Therefore, in order to use ferritic/martensitic steel as RPVs, a detailed assessment of the through thickness properties is needed [3].

The purpose of this study is to investigate the effects through thickness on the mechanical properties in mod. 9Cr-1Mo steel for RPVs. Additionally, differences in mechanical properties are discussed in viewpoints of microstructural features.

2. Experimental Procedure

The chemical composition of materials is listed in Table 1. The steel was austenitized at 1050℃ for 11 hours followed by air cooling, and tempered at 780℃ for 7.4hours. Post-weld heat treatment (PWHT) was conducted at 730℃ for 42 hours.

Specimens were taken from the surface, 1/4T and 1/2T. Impact transition curves were obtained using standard Charpy V-notched specimens (10 x 10 x 55 mm^3) in a temperature range of -150℃ to 100℃. Tensile tests were carried out using plate type tensile specimens with 18mm gage length and 1mm thickness over the temperature range from room temperature to 600℃.

To investigate the difference of through thickness microstructure, the samples were etched in Vilella's reagent (1g picric acid + 5 ml HCl + 100 ml ethyl alcohol) and then microstructure was observed by optical microscope and scanning electron microscope (SEM). Thin foil samples were prepared for TEM examination by conventional jet electropolishing methods, in 60ml perchloric acid, 600ml ethanol, and 300ml butyl cellosolve at -20℃ and 35V. 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).

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

Chemical composition (%)						
Specimens	**Cr**	**Mo**	**C**	**Nb**	**V**	**Fe**
P91	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.

3. Results and Discussion

Table 2. shows the results of through thickness tensile tests at the range from room temperature to 600℃. The yield strength and ultimate tensile strength gradually decrease with increasing test temperature in all specimens. The total elongations decrease until about 400℃ and then increase with increasing test temperature. At all test temperatures, both the yield strength and ultimate tensile strength of surface specimens are lower than those of specimens from 1/4T and 1/2T.

Table 2. Tensile properties of the specimens

Specimens	T_{test} (℃)	YS (MPa)	UTS (MPa)	TE (%)
Surface	R.T	426	594	26.1
	300	340	476	17.9
	400	319	457	16.5
	500	283	384	22.6
	600	195	240	36.2
1/4T	R.T	459	621	24.1
	300	393	515	16.8
	400	357	485	15.5
	500	320	414	19.5
	600	251	282	28.4
1/2T	R.T	461	613	18.2
	300	372	505	11.9
	400	353	469	10.6
	500	313	402	14.5
	600	242	277	17.9

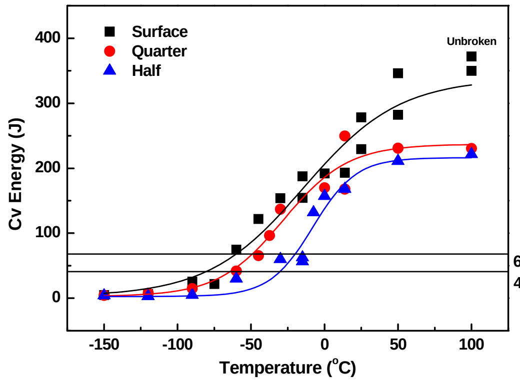

Fig. 1. Variation of Charpy impact energy in the temperature range from 150℃ to 100℃.

Fig. 1 shows the Charpy energy transition curves for the mod. 9Cr-1Mo steels. It is shown that the impact toughness of surface is higher than those of the other locations. In the case of index temperature (T_{68J}) which characterizes the transition behavior, that of specimens from 1/2T is about 45℃ higher compared to those of specimens from 1/4T and surface. Also, upper shelf energy is decreased depending on the depth from the surface. Therefore, the toughness of surface is superior to those of the others.

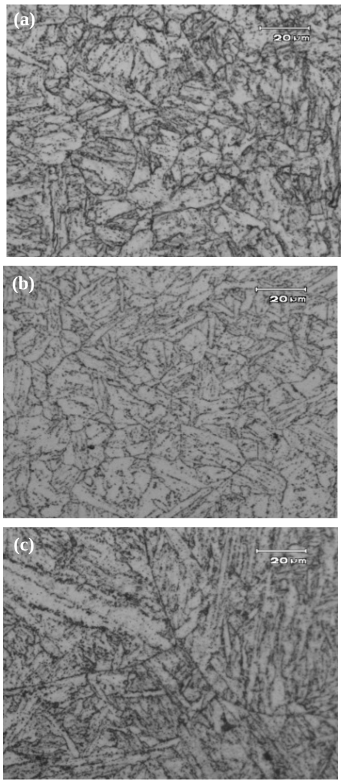

Fig. 2. Optical Micrographs of Mod..9Cr-1Mo steel at representative locations
(a) surface, (b)1/4T , (c) 1/2T

To determine the cause of variation of through thickness mechanical properties, microstructural features of all specimens are compared. Fig 2 shows the optical micrographs of mod. 9Cr-1Mo steel at the through thickness. At the locations of 1/4T and surface, the microstructures are typical tempered martensite while 1/2T specimens is composed of tempered martensite and a few proeutectoid ferrite (α-Fe). The prior austenite grain size is increased according to the depth from the surface. In the previous work, it has been concluded that the prior austenite grain size essentially determines the impact toughness properties of the normalized and tempered high-chromium martensitic steels [4]. The effects of the proeutectoid ferrite on the tensile properties and toughness are being evaluated. Additionally, assessments of the fracture toughness variations with through thickness are ongoing.

4. Summary

In this study, the effects of through thickness on the mechanical properties in mod. 9Cr-1Mo steel for RPVs are investigated. Both the yield strength and ultimate tensile strength of surface are lower than those of other locations. It is shown that the impact toughness of surface is superior to those of other specimens. Overall, the toughness is developed increasingly toward outside.

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