Effects of the phase fractions on the carbide morphologies, Charpy and tensile properties in SA508 Gr.4N High Strength Low Alloy RPV Steel

Sang Gyu Park[a], Min-Chul Kim[b], Bong Sang Lee[b], Dang Moon Wee[a]
*a KAIST, Material Science & Engineering., Guseoung-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea**
b KAERI, Nuclear Materials Research Division.,Deogjin-dong, Yuseong-gu, Daejeon, 305-353, Republic of Korea
sg121243 @ kaist.ac.kr

1. Introduction

To improve the strength and toughness of RPV (reactor pressure vessel) steels for nuclear power plants, an effective way is the change of material specification from tempered bainitic SA508 Gr.3 Mn-Mo-Ni low alloy steel into tempered martensitic/bainitic SA508 Gr.4N Ni-Cr-Mo low alloy steel [1]. It is known that the phase fractions of martensitic/bainitic steels are very sensitive to the austenitizing cooling rates. Kim [2] reported that there are large differences of austenitizing cooling rates between the surface and the center locations in RPV due to its thickness of 250mm. Hence, the martensite/bainite fractions would be changed in different locations, and it would affect the microstructure and mechanical properties in Ni-Cr-Mo low alloy steel. These results may lead to inhomogeneous characteristics after austenitizing. Therefore, it is necessary to evaluate the changes of microstructure and mechanical properties with varying phase fractions in Ni-Cr-Mo low alloy steel.

In this study, the effects of martensite/bainite fractions on microstructure and mechanical properties in Ni-Cr-Mo low alloy steel were examined. The changes in phase fractions of Ni-Cr-Mo low alloy steel with different cooling rates were analyzed, and then the phase fractions were correlated with its microstructural observation and mechanical properties.

2. Experimental Procedure

A model alloy of SA508 Gr.4N low alloy steel was selected for this study. The chemical composition of the steel is given in Table 1. The model alloy of KL4 with a typical composition of the SA508 Gr.4N steel was arranged as a reference alloy within ASME specified composition. Model alloy was austenitized at 880℃ for 2 hours followed by different cooling rates (16℃/s, 0.47℃/s, 0.11℃/s and 0.05℃/s), and then tempered at 660℃ for 10 hours. Each sample was named on the dependence of cooling rate. 16℃/s is named as WQ, 0.47℃/s is named as AC, and 0.05℃/s is referred to FC.

The dilatation curves of the different cooling rates were measured by the Dilatronic III and the DIL402C dilatometer. The specimens were heated at 880℃ and held for 3 minutes in a vacuum. The specimens were than cooled to room temperature at cooling rates from 16 to 0.05℃/s.

The observations of the microstructure were conducted using an optical microscope (OM) and a scanning electron microscope (SEM). The specimens were examined using an SEM-5200 scanning electron microscope.

Tensile properties were evaluated using MTS universal static testing machine. Yield strength was determined by 0.2% strain offset stress, or by lower yield stress. Impact transition curves were obtained using standard Charpy V-notched specimens and using an SATEC-S1 impact test machine with maximum capacity of 406J in a temperature range of -196℃ to 150℃. The index temperatures were determined from fitted Charpy curves as the temperature corresponding to the Charpy energy values of 48J and 68J.

Table 1. Chemical compositions of steels. (wt%)

	C	Mn	Ni	Cr	Mo	Fe
KL4	0.20	0.30	3.64	1.80	0.49	Bal.

3. Experimental Results and Discussion

The dilatometric curves of the SA508 Gr.4N with the various cooling rates are shown together in Fig. 1. The starting temperature of martensite transformation is decreased with an increase of cooling rates. From the dilatometer curves, the phase fractions of the each cooling rates are analyzed. The volume fractions of martensite are 93% in WQ, 70% in AC, and 0.5% in FC.

Fig. 2 shows the SEM images of the tempered samples. WQ reveals the tempered martensitic microstructure, while the upper bainitic microstructure

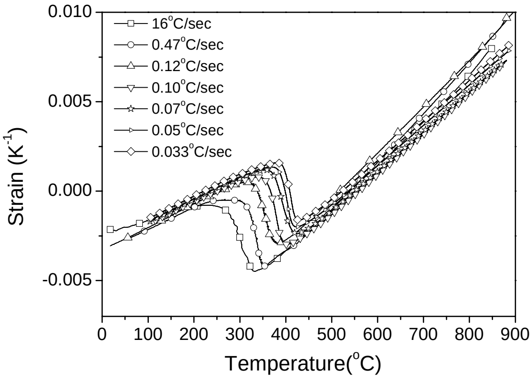
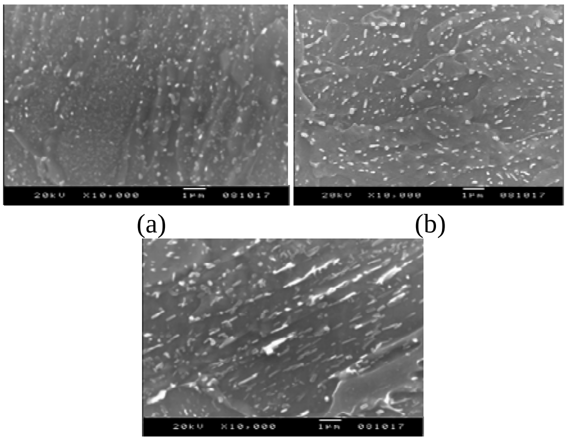


Fig. 1 Dilatometric curves measured at different cooling rates after heating at 880℃ for 3min.



(a) (b)

(c)

Fig. 2 SEM images of the tempered (a) WQ, (b) AC, and (c) FC

is observed in FC. The AC shows a mixed microstructure of martensite/bainite. Relatively coarse carbides were distributed along the laths in the FC, whereas small carbides were observed to be distributed homogeneously in WQ and AC.

Fig. 3 shows the Charpy impact test results of the WQ, AC and FC. FC shows the lowest Charpy impact properties. Its index temperature, T_{41J}, was elevated by nearly 27℃ relative to the -90℃ reading of AC, and the USE (Upper shelf energy) value was decreased by 24J from the 224J of AC. This result may have caused by the difference morphologies of carbides; the carbides in FC were much larger than those of WQ and AC. It has been reported that coarse carbides can cause a decrease in the Charpy impact properties [3]. The increased martensite fractions improve the Charpy impact properties up to 65% martensite. However, the samples that have exceeded martensite fractions over 65% show similar DBTT. This result also can be explained by the similarity of carbide morphology in WQ and AC.

The yield strength of alloy is linearly increased with an increase of martensite fraction, because the morphology of lath structures refined as the fractions of martensite increase [4]. The relations between the martensite fractions and mechanical properties in the viewpoint of microstructures will be discussed with the results of Image analyzer and EBSD in detail.

4. Summary

The effects of phase fractions on microstructure and mechanical properties in Ni-Cr-Mo low alloy steel have been evaluated. The yield strength is increased with martensite fraction. When the fraction of bainite is increased, the coarse carbides are observed and it causes the elevation of Charpy transition temperature. Ductile-brittle transition temperature is decreased with an increase of martensite fraction, but the transition behaviors are similar over 65% martensite due to the similarity of precipitation behavior.

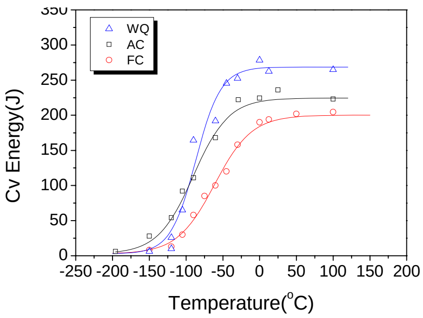


Fig. 3 Charpy transition curves with different cooling rates

Acknowledgement

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

REFERENCES

[1] S.G. Park, M.C. Kim, B.S. Lee, D.M. Wee. J. of the Kor. Inst. Metal. Mat. 46 (2008) 771

[2] J. T. Kim. H. K. Kwon, Y. B. Il, H. S. Jang. J. Kor. Soc. of Mech. Eng. 37, (1997) 43

[3] G. P. Gibson, M. Caple and S. G. Druce, Defect Assessment in Components, Mechanical Engineering Publications, Inc., 1991

[4] J. P. Naylor Metall. Trans. A, 10A (1979) 861