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Evaluation of the Precipitation Behavior in SA508 Gr. 4N Low Alloy Steel Using a Thermodynamic Calculation

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1. Introduction

Low carbon low alloy steels, used as nuclear pressure vessels, steam generators and so on, hold a large portion of materials for nuclear power plants, and they are very important materials since they determine the safety and the life span of nuclear power plants. In addition, they are utilized for a long period under very severe conditions such as a high pressure, high temperature, neutron irradiation and corrosion, so they need a good combination of strength and toughness, a good weldability and an excellent neutron irradiation resistance and so on. SA508 Gr.3 steel shows the upper bainite microstructure, which is a less tough, so the steel is more difficult to obtain good toughness than to have good strength. And then, if a loss of toughness due to a neutron irradiation during service is considered, above all improving the toughness is important when a pressure vessel is fabricated

It is known that a higher strength and fracture toughness of low alloy steels could be achieved by increasing the Ni and Cr contents. In this study, we have performed a thermodynamic calculation based on the microstructure of SA508 Gr.4N low alloy steel which has higher Ni and Cr contents than SA508 Gr.3 low alloy steel. Based on the microstructure/property relations obtained from literature research experimental works on SA508 Gr.4N steels, and by predicting the constitutional changes with alloying elements (such as Mn, Cr) during individual steps of a steel making process a using thermodynamic calculation, fundamental information for an alloy design have been discussed.

2. Experimental Procedure

The chemical compositions of the steels used in this study are given in Table 1. A model alloy with a typical composition of the SA508 Gr. 4N steel was prepared as a nominal alloy (labeled as 'R'). It was also intended to make the cementite precipitates become substituted by $M_{23}C_6$ type carbides by increasing the chromium content. It was intended to increase or decrease the hardenability of SA508 Gr. 4N, by changing the manganese content. Base metal was austenitized at 880℃ for 2 hours followed by an air cooling, and then tempered at 660℃ for 10 hours.

The phase equilibria of the tested alloys over a temperature range of 200℃ to 1600℃ were calculated by ThermoCalc. In the ThermoCalc, the Gibbs energies of the individual phases are described using thermodynamic modes. Then, the calculations of the phase equilibria are performed based on minimum-Gibbs-energy criterion, for example, the Hillert's equilibrium condition[1]. By this method, the equilibrium amounts and compositions of individual phases are calculated under a given temperature and overall composition.

Microstructure observations at a low magnification were conducted using optical microscopes and scanning electron microscopy (SEM). Metallographic specimens for these specimens for these observations were prepared by a grinding and polishing to 0.25 μm powder then etched in 3 pct Nital.

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

	C	Mn	Ni	Cr	Mo
1	0.2	0.3	3.5	1.0	0.5
2	0.2	0.3	3.5	2.5	0.5
3	0.2	0.1	3.5	1.8	0.5
4	0.2	0.5	3.5	1.8	0.5
R	0.2	0.3	3.5	1.8	0.5

3. Experimental Results and Discussion

Thermodynamic calculation results of steel 1 and steel 2 over a temperature range of 200℃ to 1600℃ are shown in Fig. 1 and Fig. 2. By comparing Fig. 1 with Fig.2 it is seen that when tempered at 660℃ the carbides such as $M_{23}C_6$ and M_7C_3 in steel 2 are well precipitated while those in steel 1 are less precipitated.

It is also seen that steel 2 seems to maintain much more carbides after a tempering treatment than those in steel 1. By these result, it could be predicted that most

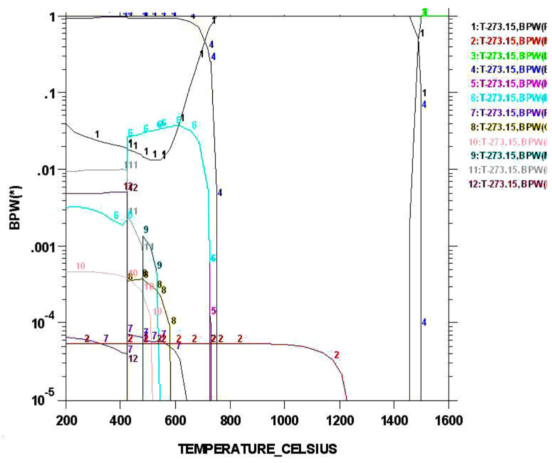

Fig. 1 Calculation results of alloy (1).

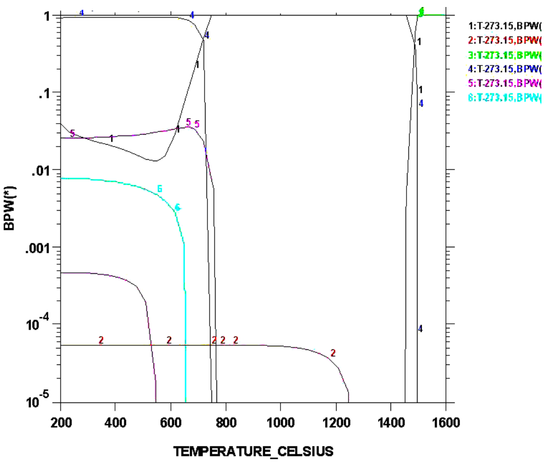

Fig. 2 Calculation results of alloy (2).

of the cementite carbides are substituted by $M_{23}C_6$ type carbides or other carbides during a tempering treatment.

Alloys may not reach a full equilibrium after a tempering for 10h in 660℃, but we believe they are very near to it and the thermodynamic calculation presents real microstructure well. For example, in a high chromium alloy (alloy 2), cementite particles are not observed after a tempering.

Fig. 3 and Fig. 4 show the calculation results of steel 3 and steel 4, respectively. In these results, MnS precipitating temperature is decreased in steel 3 remarkably. In general, it is known that MnS is precipitated in an austenite single phase and brings about a grain refining in SA508 Gr.4N steel by a pinning effect during a forging process. (Forging temperature is about 1250℃.) Thus, to make the pinning effect more efficient, we need to make the MnS precipitating point near forging temperature, about 1250℃. In the calculated result, it is clear that the MnS precipitating temperature depends on the amount of manganese. However, the calculation results have shown that the MnS precipitating temperature is not changed very much when the amount of manganese is over 0.3 pct. The MnS precipitating temperatures are similar in all other steels except for steel 3. Consequently, the amount of manganese in the SA508

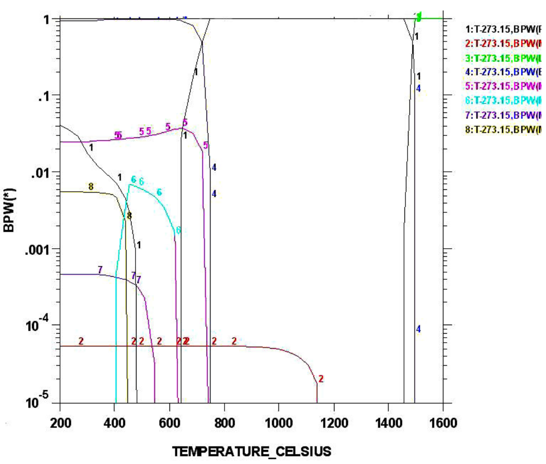

Fig. 3 Calculation results of alloy (3).

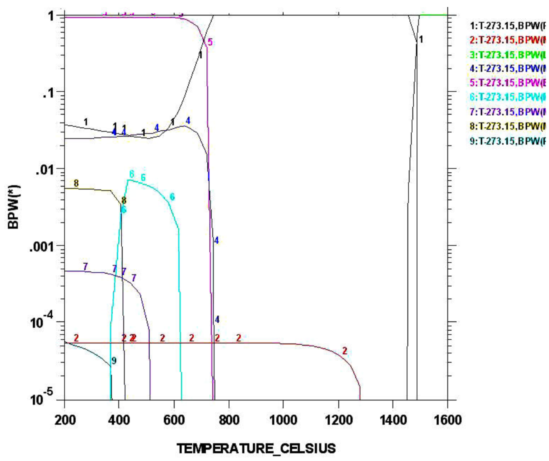

Fig. 4 Calculation results of alloy (4).

Gr.4N steel is required to be more than 0.3 pct to create an effective the grain refining during the forging process.

4. Summary

From the thermodynamic calculation result, a high chromium content steel precipitates the carbides such as $M_{23}C_6$ well, which suppresses the precipitation of cementite. A fraction of this cementite can be reduced by increasing the chromium content and changing it into $M_{23}C_6$ carbides owing to an increasing Cr content. The calculation result that the temperature for the MnS precipitation of a lower manganese steel (steel 3) is lower than that of a higher manganese steels (more than 0.3 pct manganese). This reduces the pinning effect of SA508 Gr.4N, which causes a grain refinement.

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REFERENCES

[1] M. Hilert, Phys. B 103 (1981) 31.
[2] Young-Roc Im, Yong Jun Oh, Journal of nuclear materials 297 (2001) 138-148
[3] P. Bowen, S.G. Druce, J.F. Knott, Acta Metall. 34 (1986) 1121
[4] ASME, SA508-S77, 607
[5] X.Z. Zhang and J.F. Knott, Acta Mater., 47 (1999) 3483