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論文要約

THESIS OUTLINE

**Thermodynamic Study on Stability of the Late Blooming Phase Precipitating in Nuclear Reactor Pressure Vessel Material**

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**Chapter 1**:

This chapter first introduced the history of reactor pressure vessel (RPV) materials development. Recently, since the relative stakeholders launched the lifetime extension strategy of nuclear power plants, the irradiation embrittlement of the RPV materials after the long-term operation has become an urgently severe problem for nuclear reactor safety. The late blooming phase (LBP) has been believed to trigger the mechanical properties changes of RPV materials. However, there is a lack of reliable thermodynamic data of LBPs. Therefore, the present study aimed to investigate the thermodynamic properties of the LBP by using experimental methods. We focused on the most influential compound of LBP, $Mn_6Ni_{16}Si_7$ phase (G phase).

**Chapter 2**:

This chapter described the design concepts and the principles of all experiments in the present study. We designed different methods for measuring the activity of each component in the G phase: (1) For Si activity, we designed an electromotive force (EMF) method. (2) For the Ni activity, we would calculate its value from the formation energy of $Ni_3Si$ and the measured Si activity. (3) For the Mn activity, we designed a distribution equilibrium method to determine its value by equilibrating the molten Ag and the equilibrium system of Ni, $Ni_3Si$, and G phase.

Moreover, the present study designed two prior experiments: (1) To determine the formation energy of $Ni_3Si$ by an EMF method. (2) To determine the activity coefficient of Mn in various reference metals by an equilibrium method with $CO/CO_2$.

**Chapter 3**:

This chapter introduced one of the prior experiments. we successfully applied the EMF method to determine the standard Gibbs energy of formation for the $Ni_3Si$ phase. We investigated the temperature dependence of the formation energy of $Ni_3Si$ at the experimental temperatures from 1223 K to 1293 K. Meanwhile, we further compared the present results with previous literature. The $Ni_3Si$ showed a better thermal stability than other intermetallic compounds.

**Chapter 4**:

This chapter introduced one of the prior experiments. We determined the activity coefficient of Mn in molten Ag and molten Ag-40 mol% Cu alloy. By establishing the equilibrium of Mn between the molten reference metals and the MnO pellet from 1463 K to 1573 K in a $CO/CO_2$ atmosphere, we successfully determined the temperature dependences of the Mn activity coefficient in various reference metals. The results showed good agreement with the regular model, indicating the reliability of this study.

**Chapter 5**:

This chapter introduced the main experiments. We determined the standard Gibbs energy of formation for the G phase by a series of experiments. The activity of Si was determined by applying an EMF method. The activity of Ni was calculated by combining the Si activity and the formation energy of $Ni_3Si$ obtained in Chapter 3. The Mn activity was determined by performing a distribution equilibrium method with molten Ag and using the Mn activity coefficient data obtained in Chapter 4. Finally, the standard Gibbs energy of formation for the G phase was expressed as a function of temperatures (1243 - 1273 K). The thermal stability of the G phase was discussed by comparing the formation energy of the G phase with other potential G-type phases in the RPV materials. The G phase showed the highest stability among these compounds.

**Chapter 6**:

This chapter discussed the precipitate effects of LBP in RPV materials. By substituting the thermodynamic data of the G phase into a cluster dynamic model, present study investigated the precipitate behaviors of LBPs in a practically operating reactor, R. E. Ginna reactor. The prediction showed: (1) More LBP would be formed in the RPV materials as the operation time was extended. (2) The increase of LBP contents in the RPV matrix would significantly enhance the yield stress shift and the DBTT shift of RPV materials. (3) The RPV materials would be more brittle than the previous predictions after a long-term operation.

Based on these findings, the present study suggested that considering the negative effect of LBPs on RPV materials is necessary during the RPV design and regulation-making process.

**Chapter 7**:

The present study summarized all findings in previous chapters.