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著者(和文)	LIJiajun
Author(English)	Jiajun Li
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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	材料 材料	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 工学 ）
学生氏名： Student's Name	Li Jiajun		指導教員（主）： Academic Supervisor(main)	小林 能直	
			指導教員（副）： Academic Supervisor(sub)		

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The title of this thesis is "Thermodynamic Study on Stability of the Late Blooming Phase Precipitating in Nuclear Reactor Pressure Vessel Material". This thesis contains 7 chapters.

In Chapter 1, we introduced the background and proposed the research objectives of this study. After the long-term operation of nuclear reactors, the irradiation embrittlement of the reactor pressure vessel (RPV) materials will become one of the most critical problems for nuclear reactor safety. The Ni-rich precipitate, namely late blooming phase (LBP), has been found to trigger the mechanical properties changes of RPV materials, resulting in the irradiation embrittlement. However, the stability of LBP and the precipitate behavior in RPV materials were still unclear. There is still a lack of experimental research on the thermodynamics of LBPs. Therefore, the present study aims to investigate the thermodynamic properties of the LBP by using experimental methods. The present study focused on the most influential compound of LBP, $Mn_6Ni_{16}Si_7$ phase (G phase). A series of experiments were designed to investigate the standard Gibbs energy of formation for the G phase.

In Chapter 2, we 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 the Si activity, we designed an electromotive force (EMF) method in the equilibrium system of Ni, Ni_3Si, G phase, and SiO_2. (2) For the Ni activity, we decided to calculate its value by using the formation energy of Ni_3Si and the measured Si activity. (3) For the Mn activity, we decided to determine its value by a distribution equilibrium method, equilibrating the molten Ag and the equilibrium system of Ni, Ni_3Si, and G phase. Since the standard Gibbs energy of formation for the Ni_3Si phase and the activity coefficient of Mn in molten Ag were unclear. We designed two prior experiments. The former one was to determine the formation energy of Ni_3Si by an EMF method. The latter one was to measure the activity coefficient of Mn in reference metals by a chemical equilibrium method with CO/CO_2.

In Chapter 3, we applied the EMF method to determine the standard Gibbs energy of formation for the Ni_3Si phase. By measuring the oxygen partial pressure in the equilibrium system of Ni, Ni_3Si, G phase, and SiO_2, we subsequently determined the formation energy of Ni_3Si at the experimental temperatures from 1223 K to 1293 K. We further compared the present results with previous literature, indicating that Ni_3Si showed a better thermal stability than other intermetallic compounds. Finally, we decided to use the results obtained in this chapter to Chapter 5 to determine the activity of Ni in the G phase experiment.

In Chapter 4, we determined the activity coefficient of Mn in two different molten reference metals, Ag and Ag-40 mol% Cu alloy. A distribution equilibrium of Mn between the molten reference metals and the MnO pellet from 1463 K to 1573 K was established by holding the samples under a CO/CO_2 atmosphere for 24 hours. By measuring the concentration of Mn in the molten reference metals, we 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. Finally, we decided to apply the results of Mn in molten Ag to Chapter 5 to determine the activity of Mn in the G phase experiment.

In Chapter 5, we determined the standard Gibbs energy of formation for the G phase by a series of experimental methods. Firstly, we measured the Si activity by applying an EMF method for the equilibrium system of Ni, Ni_3Si, G phase, and SiO_2. Combining the Si activity and the formation energy of Ni_3Si obtained in Chapter 3, we determined the activity of Ni. Secondly, we made a pellet of mixed powders including Ni, Ni_3Si, and G phase, and then established a distribution equilibrium of Mn between the molten Ag and the equilibrated pellet under an Ar atmosphere from 1243 K to 1273 K. We measured the concentration of Mn in the molten Ag and determined the activity of Mn by combining the results and the activity coefficient of Mn in molten Ag presented in Chapter 4. Finally, we determined the formation energy of the G phase at the experimental temperatures from 1243 K to 1273 K. The present data showed about 70 - 300 kJ/mol lower than the previously computed data because of the uncertainty of the crystal structure and the ignoration of temperature effects. In addition, we compared the thermal stability of the G phase with other potential G-type phases in the RPV materials (e.g., $Mo_6Ni_{16}Si_7$ or $Cr_6Ni_{16}Si_7$). The result showed that the G phase was the most stable phase among these compounds.

In Chapter 6, we discussed the precipitate effects of LBPs in RPV materials. we substituted the thermodynamic data of the G phase to a cluster dynamic model to investigate the precipitate behaviors of LBPs. We performed a primary prediction for a practically operating reactor, R. E. Ginna reactor. The prediction showed that more LBPs would be formed in the RPV materials if the operation time was extended. Based on the predicted results, we further evaluated the longitudinal changes of the RPV mechanical properties, indicating that the increase of LBP contents in the RPV matrix would enhance the yield stress shift and the DBTT shift of RPV materials. Also, we found that the RPV materials would be more brittle than the previous predictions after a long-term operation. Based on these findings, the present study emphasized that the negative effect of LBPs on RPV materials should not be neglected in the RPV design and regulation-making process.

In Chapter 7, we summarized all findings in previous chapters.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
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