Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

A Basic Study on the Failure of Lower Head of Nuclear Reactor Vessel by Molten Core in Severe Accident

JongRea Cho[a*], KwangHyun Bang[a], JiHoon Bae[b], ChangSung Kim[b], JongWon Jeon[b]
[a]*Division of Mechanical & Energy System Eng., Korea Maritime University, Busan, Korea*
[b]*Graduate School, Mechanical Eng., Korea Maritime University, Busan, Korea*
[*]Corresponding author: cjr@hhu.ac.kr

1. Introduction

The purpose of this study is to develop the analysis techniques of the reactor vessel lower head under in-vessel pressure loads and thermal loads in severe accident. First, the temperature distribution in accordance with time using the thermal loads imposed on the lower head inner wall for simplified 2D model and 3D model respectively was analyzed. Second, the pressure applied on the lower head inner wall, was calculated by using the simplified 2D model and 3D model respectively. And The results of the analysis are indicated by equivalent von-mises stress and sum of the displacement, respectively. Third, the creep model and parameters used in the calculation were selected as well as the curve fitting of the experimental creep data.

The plastic strain is the major cause of failure of the reactor pressure vessel. However, it can be calculated in this study that creep is not an important factor of failure of the reactor pressure vessel given the above mechanical and thermal loads.

2. Assessment of ICI Nozzle

2.1 Integrity Assessment Process

The structure analysis of head and nozzle was analyzed for thermal effect and was conducted by boundary condition considering the melting area.

Through the creep experiment, the creep coefficient was obtained. The coefficient is used for analysis and studies of creep effectiveness. This paper will show the comparative analysis of strain and displacement due to the existence of creep.

2.2 Failure Criteria

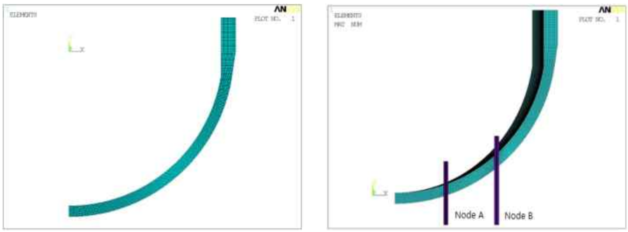
Failure criteria used by Bohl and Butler[2] and Berman et al.[3] were phenomenologically based on the continuum mechanics. Each criterion based on failure on equivalent plastic strain which is defined in terms of the principal plastic strains by the following equation.

$$\overline{\varepsilon_p} = \frac{\sqrt{2}}{3}\left[(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2\right]$$

According to Bohl and Butler, failure tends to occur at 12% of equivalent plastic strain. Berman et al. on the other hand, placed this criterion at 18%.

The failure criteria has to be evaluated conservatively. For this purpose, the mechanistic ideas of ductile failure were used based on the void nucleation, growth, and with particular reference to the work of Shockey et al.[4]. It was found that the voids nucleate predominantly on included particles, and that the threshold strain of 11% is needed for nucleation.

2.3 Finite Element Modeling



(a) (b)

Fig. 1 (a) FE model of lower head in 2D analysis
(b) FE model of lower head in 3D analysis

2.3 Conditions of Heat and Structure Analysis

The heat flux is applied to the inside of pressure vessel, and The convection is applied to the outside of pressure vessel. considering for melting area, structure analyses were applied to the value of dropped pressure status 1MPa as shown in. fig.2.

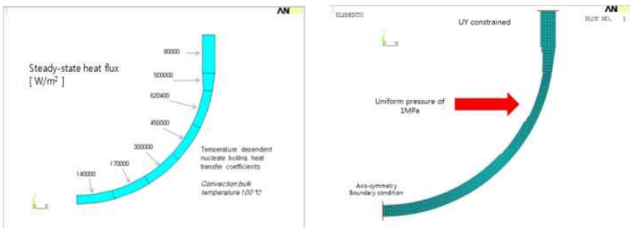


Fig. 2 Input heat and pressure load on the surface of lower head

2.4 Structure analysis for creep

Creep is the tendency of a solid material to move slowly or deform permanently under the influence of stresses. This paper focus on primary status of creep in order to check the creep effect.

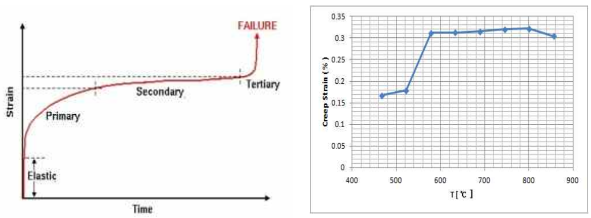


Fig.3 Strain for Creep area and temperature

$$\sigma = \sigma_0 e^{\varepsilon}$$

$$LMP = b \ln \frac{\sigma_0}{\alpha}$$

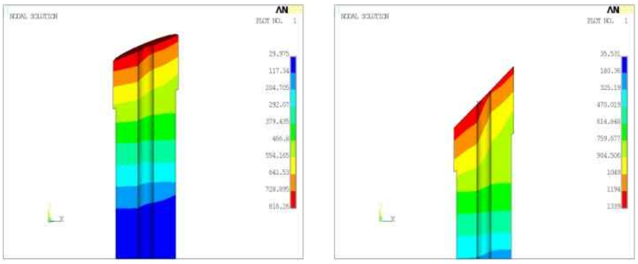
$$\Delta LMP = 0.001T = b(\ln \frac{\sigma_0}{\alpha} - \ln \frac{\sigma}{\alpha})$$

$$\varepsilon_{eff} \geq 0.874 \times 10^{-4}\ T$$

strain is calculated by first Creep model equation, this value is using for calculate effective creep strain. According to the result of calculation, the effective strain is 15%, and if the strain is same or bigger , rupture occurs.

3. Results and Discussions

Fig.3 shows the distribution of temperature for each nozzle. The nozzle and head is not separated, since the nozzle temperature dose not exceed melting temperature. Fig.4 show the distribution of temperature on the lower head. Due to the exceeding of melting temperature, the head and nozzle are melted. Additionally, Fig.5 shows the structural strain and fig.6 shows the result of creep effective.



(a) (b)

Fig. 3 Distribution of temperature frome nozzle A and B

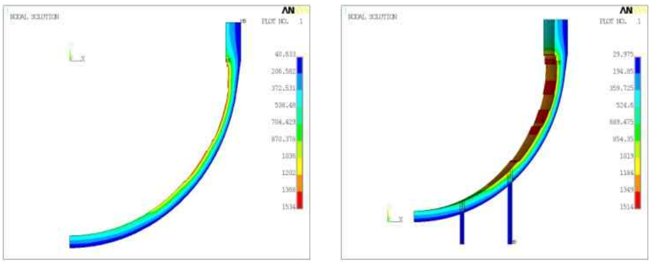


Fig. 4 Temperature distribution of lower head

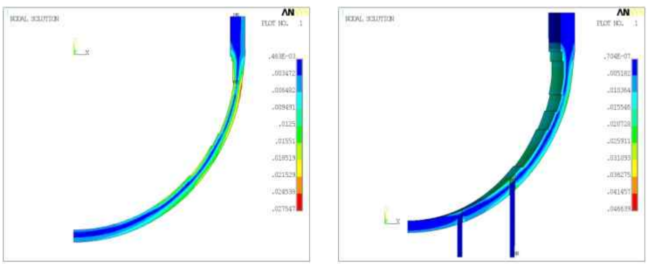


Fig. 5 Equivalent strain distribution of lower head

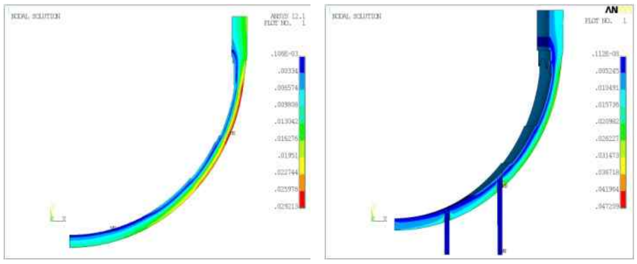


Fig. 6 Equivalent strain distribution considering the creep of lower head

4. Conclusions

This paper is analyzed by transient analysis for eight hours. Thermal conditions were carried out to interpret the data obtained from the existing experiment, and the pressures analyses were conducted considering pressure drop by applying the 1MPa. According to the analysis, a portion of the nozzle and the head is soluble, while nozzles and heads were not separated.

This structural analysis has a comparative analysis of strain and displacement due to the existence of creep. Without the creep effect, strain shows 2.7% in 2D model and 4.6 % in 3D model. And, strain shows 2.9% in 2D model and 4.7 % in 3D model, in creep effect condition. Both case is satisfied to allowable strain. When comparing both analyses about creep effect, strain differences are 0.2% in 2D model and 0.1% in 3D model. Thus, it can be seen that in these analyses, the effect that creep has is minor.

REFERENCES

[1]Martin Abendroth et al, 2005. Modeling of in-vessel retention after Relocation of corium into the lower plenum. Forschungszentrum Rossendorf; FZR-437

[2]T.G. Theofanous et al, 1997. IN-VESSEL COOLABILITY AND RETENTION OF A CORE MELT.
Nuclear Engineering and Desin.

[3]M. Berman, D.V.Swenson and A.J. Eickett, 1984. " An Uncertainty Study of PWR Steam Explosions" Sandia National Laboratories. SAND83-1438, NUREG/CR-3369.

[4]Walter Villanueva et al, 2011. Coupled thermo-mechanical creep analysis for boiling water reactor pressure vessel lower head. Nuclear Engineering and desin

[5]ASME Boiler & Pressure Vessel Design Code Section VIII, Div.2, ASME, 2010.

[6]A.M.J.M VAN HEE, 1995. IN-VESSEL CORE DEBRIS RETENTION THROUGH EXTERNAL FLOODING OF THE REACTOR PRESSURE VESSEL. State-of-art report. ECN-R-95-022