Structural Evaluations of the Reactor Vessel Head at Elevated Temperature

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1. Introduction

A reactor pressure vessel is one of the most important structures in the nuclear power plants. Thus, the choice of the material for such main component is significant work, which is made by the considerations such as industrial experience, R&D information available and operating conditions.

The high operating temperature for the reactor vessel in next generation nuclear plants necessitates the use of a high-Cr steel such as modified 9Cr-1Mo as the material of the reactor vessel, which provides good creep resistance at higher temperature. Also, the modified 9Cr-1Mo steel is the candidate material of the next generation nuclear reactor, which is covered by ASME NH for class 1 components up to 371 ^{o}C.

The purpose of this paper is to study the elevated temperature structural evaluation for 60 years for the reactor vessel head structure designed by modified 9Cr-1Mo steel, which is one of the main structures in Gen-IV class 1 components. The design integrity of a reactor vessel head to sustain the given thermal and mechanical loads in Service Level A condition is demonstrated through the comparison of their structural responses with the ASME Code stress limits and the structural deformation limits according to ASME-NH Code rules[1,2].

2. Modeling of a Reactor Vessel Head

A reactor vessel head is a single unit composed of a duct, an upper head and an integrated flange. Fig. 1 shows the configuration of the reactor vessel head at elevated temperature modeled by using the ANSYS software[3]. The inner diameter and the height of a reactor vessel head as shown in Fig. 1 are 285 cm and 317 cm, respectively. Its thicknesses are various at the different regions of the surface as shown in Table 1. Fig. 2 shows the thermal and mechanical boundary conditions for a reactor vessel head.

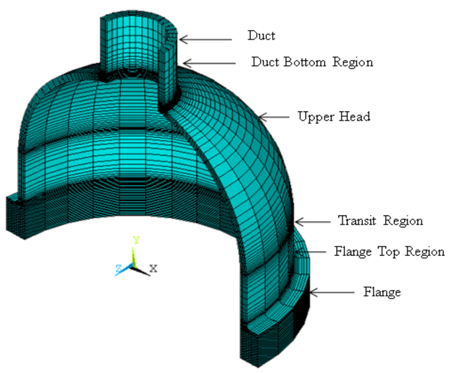

Fig. 1 Finite element model of the reactor vessel head with elevated temperature

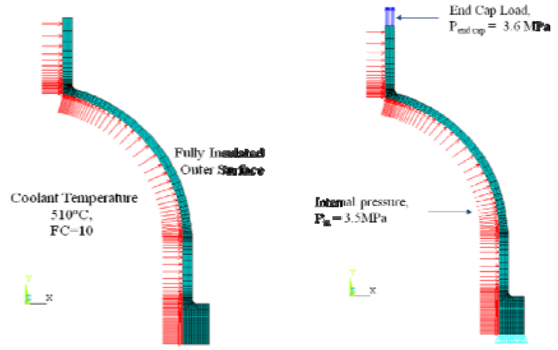

Fig. 2 Thermal and mechanical boundary conditions for a reactor vessel head

The total design lifetime for the structural evaluation is assumed as 60 years. Fig. 3 shows the coolant temperature distribution for two cycle types. In this figure, the maximum and minimum coolant temperatures are 510 ^{o}C and 204 ^{o}C, respectively.

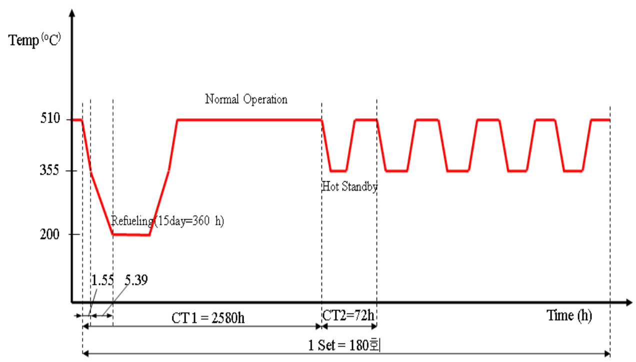

Fig.3 Coolant temperature distribution for two cycle types

3. Results and Discussions

Fig. 4 shows the evaluation cross sections of a reactor vessel head. In this figure, we can see that the maximum stress intensity occurs at the flange top region of A1 section. Fig. 5 shows the temperature distributions along elevations during the heat-up operation of cycle type-1. As shown in this figure, we can see that the temperature gradients through the thickness are largest in the flange top level along the elevation.

Fig. 6 shows the linearized stresses in A1 section at the end of cool-down. As shown in this figure, the maximum bending stress intensity occurs at the outer surface of the reactor vessel head.

Table 1 Design Parameter

Inside pressure of reactor vessel head	3.5 MPa
End cap load of reactor vessel head	3.6 MPa
Coolant temperature in reactor inside (full power/refueling)	510/204 ^{o}C
Inside diameter of reactor vessel head	285 cm
Height of reactor vessel head	317 cm
Vessel thickness	203 mm
- Duct region	8.5 cm
- Upper head region	7.5 cm
- Flange top region	8.5 cm

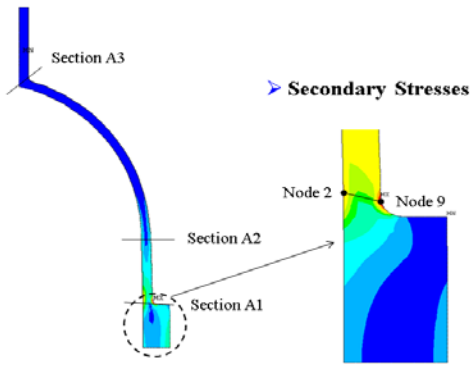

Fig. 4 Evaluation cross sections of a reactor vessel head

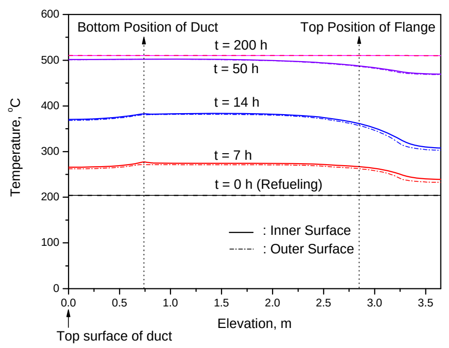

Fig. 5 Temperature distributions along elevations during the heat-up operation of cycle type-1

Total six points in a reactor vessel head were calculated for the structural integrity check, and the most critical position was at the outer surface of the flange top region(A1 section). Table 2 shows the structural integrity check results at such position. The primary stresses induced by the internal pressure and the end cap load are acceptable with enough margins against the allowable stress limit of ASME-NH rules.

The inelastic strain check results by the elastic approach satisfy the deformation and strain limits of ASME-NH rules. For the check results of the creep fatigue limit, the calculated fatigue damage is negligible, but the maximum creep damage is 54.8 at the outer surface of A1 section. In this section, it is evaluated the creep damage is very large.

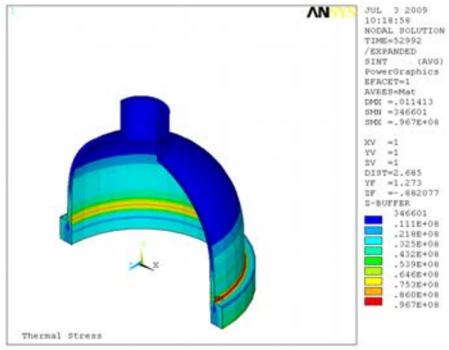

Fig. 6 Linearized stresses in A1 section for cooldown (Minimum stress time point)

Table 2 Structural Integrity check results(section A1)

Evaluation Items		Calculated	Limit value	Check
❑ Primary Stress Limits				
Membrane		41.4 MPa	110 MPa	OK
Membrane + Bending		45.5 MPa	110 MPa	OK
❑ Inelastic Strain Limits				
Elastic Approach	Inner	0.57 %	1.0 %	OK
	Outer	0.51 %	1.0 %	OK
Simplified Inelastic Approach	Inner	0.00 %	1.0 %	OK
	Outer	0.00 %	1.0 %	OK
❑ Creep-Fatigue Limits				
Fatigue Damage	Inner	0.00	0.04	OK
	Outer	0.00	0.00	OK
Creep Damage	Inner	0.60	1.00	OK
	Outer	54.8	1.00	Not OK

4. Conclusions

Three sections of a reactor vessel head structure were evaluated for the mechanical and thermal loads for the load combination of two cycle types. The outer surface of A1 evaluation section located in the flange top region doesn't satisfy the creep fatigue design limits of ASME-NH rules. For an acceptable design, it can be considered to modify the design for the fillet joint and the configuration of the flange or to change the thermal loading data.

Acknowledgements

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REFERENCES

[1] ASME Boiler and Pressure Vessel Section II, Part A, Part D, ASME, 2004.
[2] ASME Boiler and Pressure Vessel Code Section III, Subsection NH, ASME, 2004.
[3] ANSYS User's Manual for Revision 11.0, ANSYS Inc.