Procedure Development on Pressure-Temperature Limit Curve for Shell Region near Geometric Discontinuity

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1. Introduction

Pressure-Temperature limit curve are imposed on the reactor coolant system during several operating conditions to assure adequate safety margins for protection against non-ductile failures. The establishment of pressure-temperature limit curve for RPV shall be calculated in accordance with the rules of KEPIC Code[1,2]. However, the postulated crack was restricted within the special configuration in KEPIC Code. Also, the temperature change shall meet a rate, associated with startup and shutdown, less than about 56℃/hr[3]. Specially, the thermal stress intensity factor with a steep rate (>56℃/hr) can't be calculated by the procedure of Code for the shell region near geometric discontinuities.

In this paper, an evaluation procedure is developed to establish pressure-temperature limit curve for the postulated crack located near geometric discontinuities. To demonstrate the validation of the developed procedure in the present study, the numerical results are compared to those calculated by KEPIC Code.

2. Finite element analyses

2.1 Geometry

The model of RPV considered in the analysis is the SMART-P reactor with the inner diameter of 2494 mm, and the wall thickness of 132 mm as illustrated in Figure 1. The RPV without cladding was considered in the present analysis.

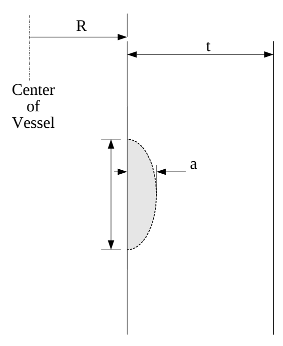

Figure 1. Schematic illustration of postulated crack.

The postulated crack was designed to be located near geometric discontinuities between beltline and lower head. The crack depth ratio(a/t) is 1/4. The crack aspect ratio(a/2c) was selected with 1/6.

2.2 Material Properties

The base metal of RPV is made of MDF A 508 Grade 3 Class 1. The material properties for weld were assumed to be the same as base metal, and no difference was considered for heat affective zone. The material properties used for the analysis are given in Table 1.

2.3 Loading Conditions

The temperature change rate is one of the major parameter determining stress distribution. Therefore, the temperature change rate 56 and 100℃/hr were considered in the analysis to investigate the variation of rate effect.

2.4 Finite element Modeling

The RPV with the postulated crack was modeled with 20-nodes isopametric brick elements using the I-DEAS program. A half of cylindrical vessel was modeled considering the symmetric conditions as shown in Figure 2. Finite element analyses were performed by using ABAQUS program. Stress intensity factors were obtained by converting the J-integral, which was calculated from the deepest point of a semi-elliptical crack.

Table 1. Base metal properties for reactor pressure vessel.

Temperature [$^{\circ}C$]	38	93	149	260	316
Young's modulus E [GPa]	191	187	184	177	174
Poisson's ratio ν	0.3	0.3	0.3	0.3	0.3
Thermal conductivity [$W/m\ K$]	38.1	38.8	38.8	38.1	37.2
Specific heat capacity [$J/kg\ K$]	454	480	502	545	566
Thermal expansion coeff. [$1/K \times 10^{-6}$]	11.7	12.1	12.4	13.1	13.4
Yield strength [MPa]	345	328	318	307	302

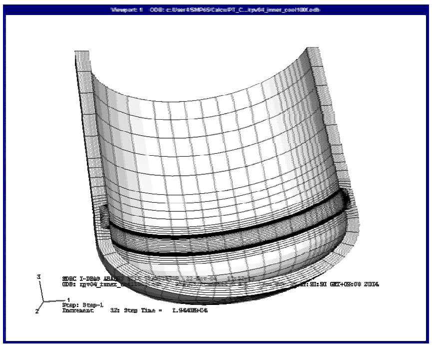

Figure 2. Finite element model.

3. Finite element analysis results

Figure 3 shows pressure-temperature curves to KEPIC Code and FEM result for Heatup 56℃/hr. The results showed overall good agreement. This tendency is similar to cooldown condition(Figure 4). For the temperature change rate 100℃/hr, pressure-temperature curves were compared as shown in Figure 5. The curve of heatup condition is conservative than cooldown condition.

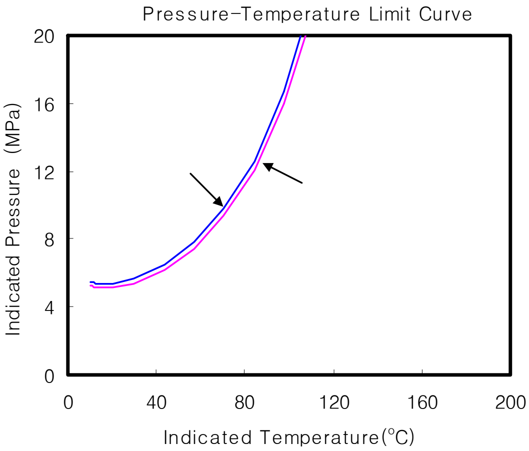

Figure 3. Comparison of P-T curve to KEPIC Code and FEM result (for Heatup 56℃/hr).

4. Conclusion

In this paper, the evaluation procedure is developed to establish pressure-temperature curve for the crack located near geometric discontinuities. In order to demonstrate the validation of the developed procedure, the numerical results are compared to those calculated by KEPIC Code. The results showed overall good agreement.

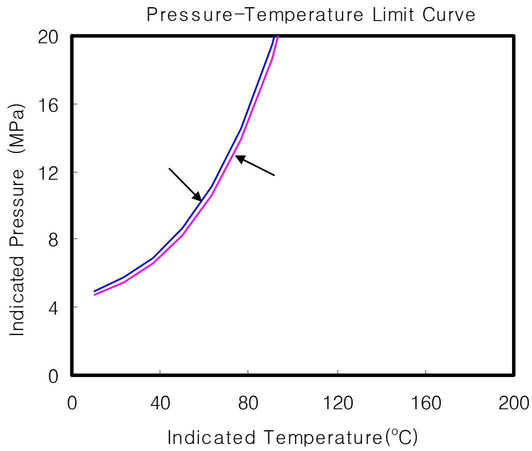

Figure 4. Comparison of P-T curve to KEPIC Code and FEM result (for Cooldown 56℃/hr).

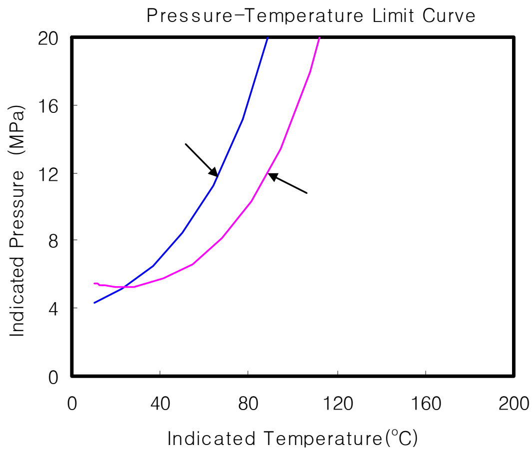

Figure 5. Comparison of P-T curve for various operating condition (temperature change rate 100°C/hr).

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