

PTS Integrity Study in Japan (Part 2)

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ABSTRACT

Japanese Pressurized Thermal Shock (PTS) integrity study has been carried out to get a public acceptance for reactor pressure vessels (RPVs) integrity against PTS events and to provide the data base for their life extension. This paper introduces our research plan and the interim results as the second report.

1. Introduction

The RPVs used for Japanese PWR plants have lower copper contents and preliminary research showed that no PTS concern existed on Japanese RPVs during their design service lives. But, it is required to get public acceptance about the integrity by analyses and experiments and it is very useful to establish an analytical method and a data base for Japanese RPVs life extension. Japanese PTS integrity study is scheduled to be carried out from FY 1983 to FY 1989 as a national project by Japan Power Engineering and Inspection Corporation (JAPEIC) under the contract with Ministry of International Trade and Industry (MITI) in cooperation with LWR utilities and vendors.

2. Research Program and Interim Results

This program is composed of fracture mechanics test which includes PTS transient study and model test.

This paper introduces mainly our research plan and interim results of our model test.

2.1 Fracture Toughness Test and Study on Irradiation Embrittlement

Five kinds of base metal plates and two kinds of weld metals were produced. Chemical compositions of these materials were selected to simulate actual RPVs and to evaluate the effect of chemical compositions on irradiation embrittlement. Material test items and chemical compositions are shown in the previous paper (Okamura et al, 1987).

Irradiated and unirradiated material properties have been investigated. Prediction method of irradiation embrittlement was developed for Japanese RPV materials and the predictive equations were shown as follows (Ishino et al, 1988).

(Base Metal)

$$RT_{NDT} = (-16 + 1230P + 215Cu + 76\sqrt{Cu \cdot Ni}) \cdot (f/10^{19})^{0.27} \quad (1)$$

$\sigma = 12, X = 0$

(Weld Metal)

$$RT_{NDT} = (27 - 23Si - 58Ni + 290\sqrt{Cu \cdot Ni}) \cdot (f/10^{19})^{(0.21 - 0.09\log(f/10^{19}))} \quad (2)$$

$\sigma = 16, X = 0$

P, Cu, Ni, Si : Contents of chemical composition (Wt.%)

f	:Neutron fluence(n/cm^2 , $E>1MeV$)
σ	:Standard deviation (K)
\bar{X}	:Average (K)

2.2 Model Test

The model test is planned to investigate crack behavior under PTS conditions, using flat plate specimens with an actual vessel thickness.

(1) Basic concepts of the test

Stress distribution through the thickness of the test specimens shall be comparable to that of an actual vessel wall. By using flat plate specimens with the same thickness as an actual RPV, simulation methods are planned as follows(Fig.1):

- 1 Thermal bending stress, which will be induced by thermal moment, will be simulated by mechanical bending load.
- 2 Local thermal stress will be simulated by thermal shock of test specimen with almost the same thickness as that of an actual vessel wall.
- 3 Internal pressure will be simulated by mechanical tensile load.

(2) Test items

Preliminary analyses were done to develop the model test items. According to these results, the following items are selected.

(a) PTS preliminary test

* Verification of fracture mechanics analytical method and our model test methodology by brittle crack initiation test.

(b) Step A test

- * Verification of no crack initiation under PTS events at the end of design life.
- * Verification of no crack initiation under PTS events at the extended plant life.
- * Investigation of crack depth margin for fracture initiation.

(c) Step B test

* Investigation of crack behavior at the upper shelf region and Elastic Plastic Fracture Mechanics (EPFM) method.

(d) Step C test

* Investigation of crack arrest behavior by using of toughness gradient material.

(3) PTS preliminary test result

Test material for the preliminary PTS test specimen is A533B C1.1 modified and its chemical composition and mechanical properties are shown in Table 1 and Table 2, respectively.

Dimensions of the specimen are shown in Fig.2. An initial semielliptical surface crack was prepared by electrical discharge machining and cyclic bending load. The crack depth and crack length are $22.5 \times 10^{-3}m$ and $90.5 \times 10^{-3}m$, respectively.

Initially the specimen was heated at 536 K and insulated. Tensile load of 8.14 MN was applied and kept constant during the test.

Ethylene glycol was cooled at 273 K and stored in the storage tank.

The specimen surface with the initial crack was thermally shocked and the four-point bending load was applied to the specimen simultaneously. The bending load was monotonically increased in order to avoid the warm prestressing effect until brittle fracture took place. The specimen was failed at 2500 s after the start of thermal shock.

Fig.3 shows the temperature distribution through the thickness during the test. Quenching was disturbed at the initial stage of thermal shock because of low flow rate of $0.017 m^3/s$ as shown in Fig.3.

Fig.4 shows thermal stress distribution through the thickness and this stress corresponds to the induced stress of the plate without restriction subjected to thermal shock.

Fig.5 shows the trajectories of stress intensity factor(K_I) during the test and K_{IC} data by 1TCT specimens. Disturbance of K_I at the surface edge of the crack corresponds to the temperature disturbance at the initial stage of thermal shock as shown in Fig.3.

K_I and the temperature at the deepest point of the crack at the onset of brittle fracture are about $107\text{MPa}\sqrt{\text{m}}$ and 348 K, respectively. Also those at the surface edge of the crack at the time are about $99\text{MPa}\sqrt{\text{m}}$ and 330 K, respectively.

K_I value at the onset of brittle fracture was higher than the lower bound of K_{IC} data obtained by 1TCT specimens. It means that brittle fracture takes place when K_I is greater than or equal to the lower bound of K_{IC} .

Brittle failure appearance was shown on the whole fracture surface and it is estimated that brittle fracture initiated somewhere between the deepest and surface edge of the initial crack.

3. CONCLUSION

Our research is progressed on schedule. In near future, the integrity of Japanese RPVs against PTS will be verified and useful results will be introduced.

REFERENCES

Ishino, S., Kawakami, T., Hidaka, T. and Satoh, M.(1988) The Effect of Chemical Composition on Irradiation Embrittlement. 14th MPA-Seminar, Vol,1,pp.13.1-13.15.

Okamura, H., Yagawa, G., Kawakami, T. and Funada, T.(1987) PTS Integrity Study in Japan. 9th International Conference on Structural Mechanics in Reactor Technology, Vol.G, pp.395-400.

Table 1 Low Fracture Toughness Steel for Preliminary PTS Model Test (A533B Cl.1 Modified)

	C	Si	Mn	P	S	Ni	Mo	RT _{NOT} (K)	σ_y (MPa)
Intended	≤ 0.25	0.13 ~ 1.00	1.07 ~ 1.62	≤ 0.090	≤ 0.040	0.37 ~ 0.73	0.10 ~ 0.64	≥ 403	≥ 686
Mill Analysed	0.21	0.58	1.48	0.058	0.006	0.55	0.15	520	768

Table 2 Mechanical Properties

Test Material		Tensile Strength			Charpy Value.					Drop Weight Test	RT _{NOT} (K)	
		σ_u (MPa)	σ_s (MPa)	E _L (%)	*1 vTr30 (K)	*2 vTr50 (K)	*3 vTr35 mils (K)	*4 vTrs (K)	*5 USE (J)	T _{CV,33} (K)		T _{NOT} (K)
Low Fracture Toughness Steel	Measured	806	957	16.4	458	>573	>573	444	—	>573	388	>573
	Intended	≥ 686	—	—	—	—	—	—	—	—	—	≥ 403

*1 41J (30ft-1b) transition temperature

*2 68J (50ft-1b) transition temperature

*3 9×10^{-4} m (35mils) transition temperature

*4 50% shear transition temperature

*5 Upper shelf energy

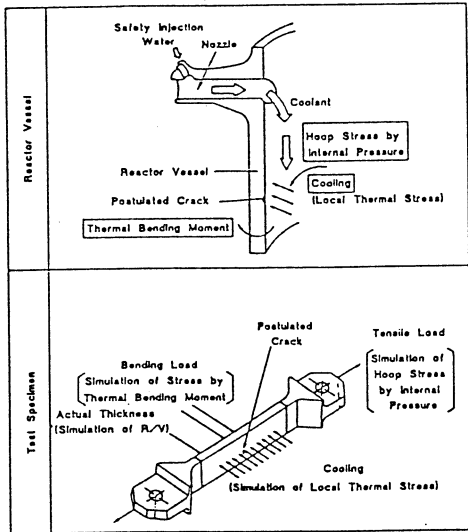


Fig.1 Simulation by Flat Plate Specimen

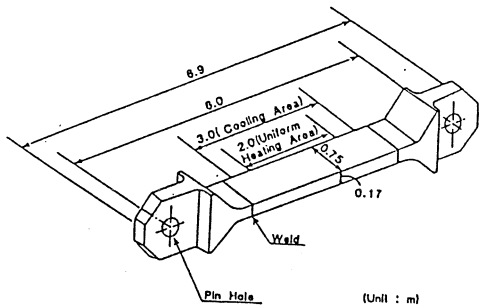


Fig.2 Detail of Model Test Specimen

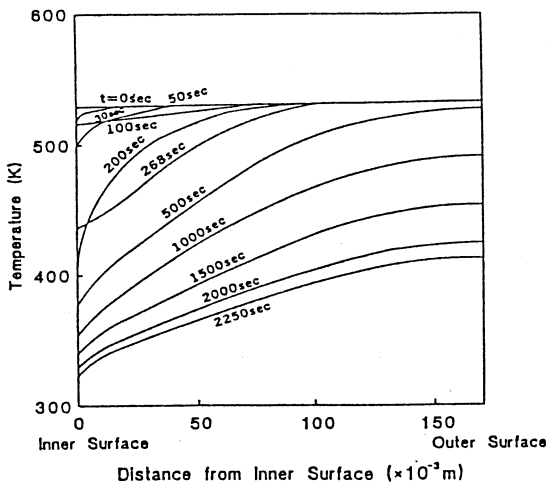


Fig.3 Time History of Temperature Distribution through the Specimen Thickness

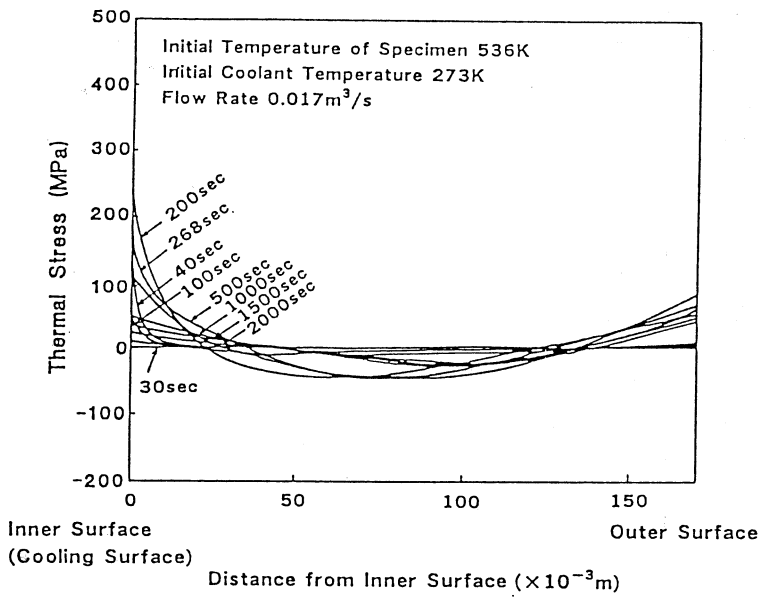


Fig.4 Time History of Thermal Stress Distribution through the Specimen Thickness

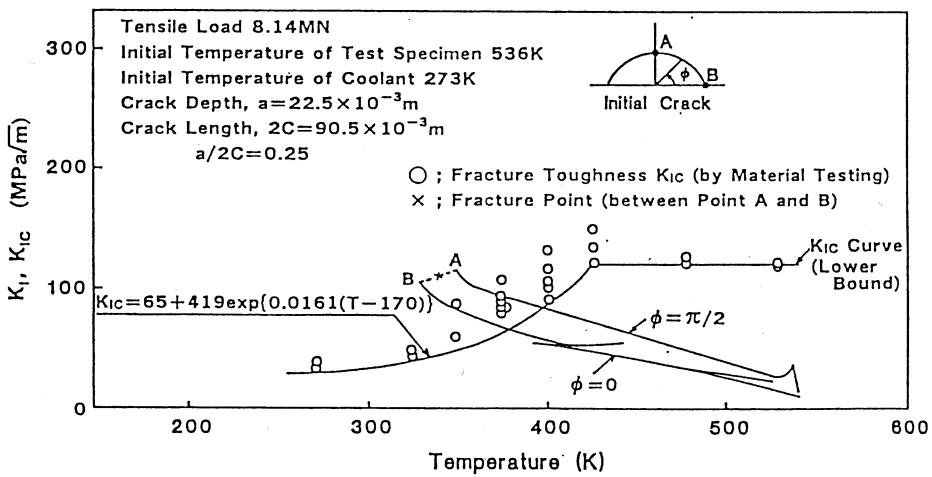


Fig.5 PTS Transition Curve for Preliminary PTS Model Test