Parametric Study on Sub-Critical Growth of Crack Present in Core Belt and Nozzle Crotch Region of a Pressure Vessel

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ABSTRACT

Sub-critical growth under accidental transients like those caused by LOCA or steam line break are analysed. The cracks are assumed to be present in highly stressed nozzle crotch region or in core belt region where embrittlement due to neutron fluence($E >$ 1 Mev) takes place. Different sizes of cracks are analysed for their dormancy or growth. Also for core belt region effect of parameters like material chemistry, fluence etc. are studied.

1 INTRODUCTION

The integrity of pressure boundary of Reactor Pressure Vessel under postulated overcooling accident conditions is of concern. The events like Rancho Seco Transeitn(1978) which can cause cold pressurisation of vessel wall get added importance. The vessel failure could result after a transient if pressurised with relatively cold water. The likelyhood of vessel failure depends on the materials, irradiation and severity of cool down transient.

In this paper the results of a parametric study relating to sub-critical growth of cracks, when located in highly stressed nozzle crotch region and core belt region are presented. Two cases of accidental transients are studied. First, due to occurance of loss of coolant accident (LOCA) and second, due to steam line break accident. At nozzle location no deterioration in material due to neutron embrittlement is considered (fluence $<$1.0E18 nvt). For core belt region parametric study has been done for neutron embrittlement with different chemistry and fluence levels.

2. ACCIDENTAL TRANSIENTS

Postulated over cooling accident transients are plant specific. For the transient occuring due to LOCA, the pressure and temperature at inner wall of the pressure vessel are assumed to vary as shown in fig-1a(Transient-1). For steam line break accident repressurisation of pressure boundary may take place at lower temperature. One such occurance is reported for Rancho-Seco reactor in 1978. Fig.1b gives the transient analysed

SMiRT 11 Transactions Vol. G (August 1991) Tokyo, Japan, © 1991

under steam line break in present study (Transient-2). The approximation is not necessarily conservative. Both these transients are taken from reference-1.

3. THERMAL AND STRESS ANALYSIS

Core belt region of pressure vessel is a cylinder with base metal radius of 1000mm and wall thickness (t) to radius ratio of 0.122. Geometry of nozzle region is given in Fig. 2. The base metal thickness (w) at crotch region is 425 mm. The base metal is SA 508c13 and is cladded with stainless steel at inside surface. Thickness of cladding is 7mm.

Mechanical properties for base metal and cladding are taken from ASME B&PV code (ref-2).

Finite element method is used for temperature and stress calculations. For core belt region axisymmetric temperature distribution is calculated using the code DOT (ref-3) and stress analysis is done using the code PLAXIS(ref-4). For nozzle region temperature and stresses are calculated using code PAFEC(ref-5). Nozzle in cylinder is simulated by a sphere having inner radius equal to 3.2 times that of actual cylinder. Fig-2 also gives the finite element mesh used. Typical hoop stress variation at nozzle region under transient-1 is given in Fig-3 after 500 sec from start of transient.

Reference stress free temperature for stress calculation is 30C.

4 FRACTURE ANALYSIS

A preliminary analysis done with a semielliptical crack at nozzle crotch region shows that cracks become circular under transient stresses. In the present study, therefore, only circular cracks are assumed to be present.

For core belt region, a semielliptical crack at inner surface having major to minor axes ratio of 3:1 is assumed to be present in base metal. The defects in highly ductile stainless steel cladding are not considered. The cracks are observed to be more circular with major to minor axes ratio tending to become 2:1. The residual stress distribution in cladding and base metal affect the crack growth. Studies have been done with differet assumed distributions for residual stresses (ref-6,7). However, explicit accepted distribution for analysis are to be established.

Fracture calculations are done using code BIGIF(ref-8). Influence function technique is used.

5. MATERIAL PROPERTIES

Material fracture properties are taken from Appendix A of ASME B&PV code Section XI (ref-9). The attenuation of neutron fluence at any point 'x'cm away from the inner wall is given by (ref-10):

$F = Fo.\exp(-0.0094\ x)$ $(E > 1\ \text{Mev})$

Fo = Incident fluence at inner surface.

The shift in reference nil ductility temperature (RTNDT) dependsupon fluence level and chemistry of base metal (or weld metal). As nozzle is quite away (Fo $<$ 1.0E18 nvt, E $>$ 1 Mev) no shift in RTNDT is assumed.

For core belt region parametric study has been done with different chemistry Cu=0.1 and 0.2, Ni = 0.8, P=0.012 and fluence levels of 1.0E19 and 2.0E19 nvt ($E \geq 1$ Mev.) Following law is used to predict the shift in RTNDT(ref-10)

Shift (deg F) =[31+82 Cu+339 SQRT (Cu.Ni)] (F/1.0E18)**K
with K=[0.298-0.041 ln (f/1.0E19)]

USNRC regulatory guide 1.99 rev 02 gives similar relation with chemistry factor based on Ni and Cu content.

At any instant of time stress intensity factor, KI, is compared with KIa and KIc. If KI $\leq$ =KIa, crack remains dormant. If KI $\geq$ KIc, crack initiation takes place. KI is calculated by combination of stresses due to pressure and temperature loadings at particular instant of time.

6. RESULTS AND DISCUSSIONS

Fig-4 shows the propagation behaviour of circular cracks at nozzle crotch under transient-1. Various defects having a/w=0.04, 0.056, 0.067, 0.08 and 0.113 are studied (a= radius of crack, w=wall thickness at nozzle crotch). The stress intensity factor and fracture toughnesses are plotted with temperature (time). Following can be concluded.

1. Cracks upto a/w=0.113 get arrested.
2. KI value increases initially and again drops down. This is due to fall of thermal stresses.
3. KI value is always lower than KIc indicating no crack initiation.

Fig.5 gives the behaviour of cracks under transient-2. Following can be concluded.

1. No initiation takes place for cracks upto a/w=0.113.
2. The value of KI becomes maximum and then drops to that corresponding to pressure loading.
3. KI values are lower than those resulting under transient-1.

Fig.6a and 6b show the behaviour of semielliptical crack with a/t=0.123 in core belt region. Fig. 6a gives the effect of fluence at inner surface while fig 6b gives the effect of chemistry. Figs. 7a and 7b show the corresponding results for a/t=0.45. Following can be concluded.

1. KI is more for transient -1 compared to that for transient-2 for smaller cracks. The picture reverses for larger cracks. This is due to high tensile thermal stresses seen near inner surface under cooldown.
2. Cracks having depth upto 45 percent of wall thickness remain dormant.
3. When chemistry and fluence are adversely combined, margin between KI & crack initiation fracture toughness, KIa, becomes quite small. A more detailed investigation for such situations is needed in practice.

7 CONCLUSIONS

The fracture calculation done for the nozzle crotch region shows that cracks upto a/w = 0.113 get arrested in the more ductile base material under the transients caused by LOCA. These are dormant under transient caused by guillotine type rupture of the steam line. However, under transient caused by LOCA, the margins between KIc and KI is small.

Cracks in longitudinal-radial plane of core belt region remain dormant under both types of transients studied. Under the transient stresses the initially semielliptical crack with major to minor axis ratio of 3:1 tends to acquire deeper shape with major to minor axis approaching 2:1. This will lead to leak before break condition. The effect of chemistry and fluence is to lower the margin between KI and KIa for core belt region.

8. REFERENCES

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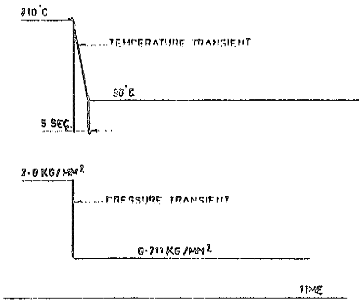

FIG. 1(a) VARIATIONS OF PRESSURE AND TEMPERATURE DURING A LOSS OF COOLANT ACCIDENT (TRANSIENT-1) (Ref-1)

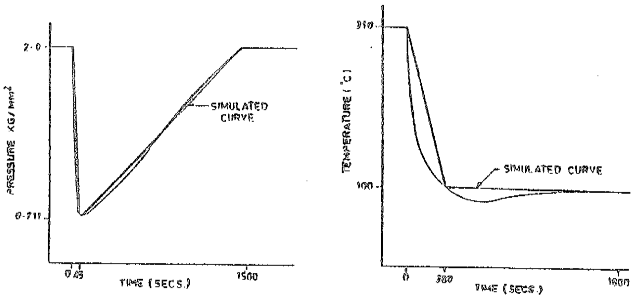

FIG. 1(b): VARIATION OF PRESSURE AND TEMPERATURE UNDER STEAM LINE BREAK TRANSIENT (TRANSIENT-2) (Ref-1)

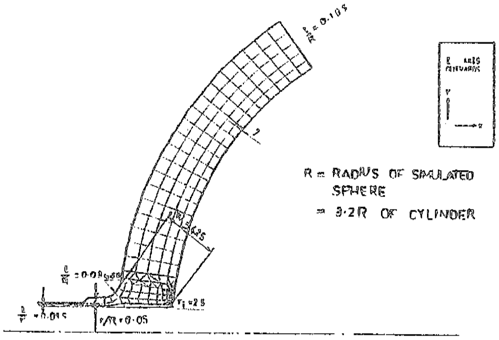

FIG-2 DIMENSIONS & FINITE ELEMENT DISCRETIZATION OF NOZZLE

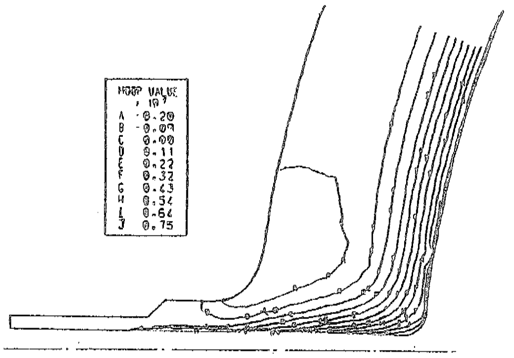

FIG-3 HOOP STRESS CONTOUR FOR TRANSIENT-1 AT 500.0 SEC.

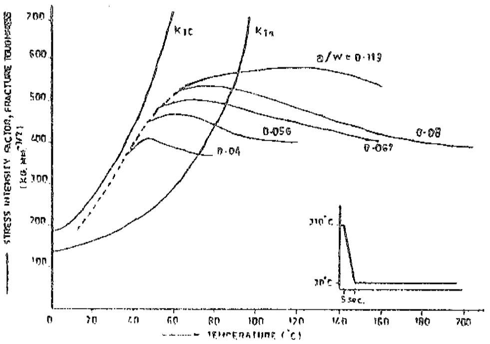

FIG. 4 CRACK PROPAGATION AT NOZZLE CROTCH UNDER EMERGENCY COOL DOWN TRANSIENT (TRANSIENT-1)

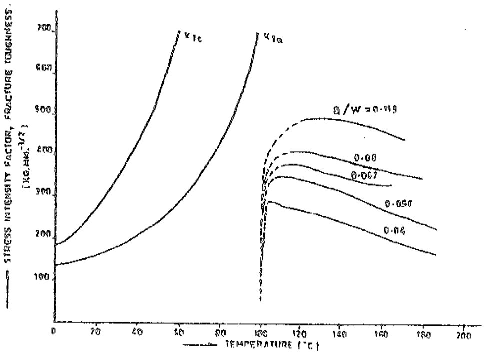

FIG. 5 CRACK PROPAGATION AT NOZZLE CROTCH UNDER EMERGENCY COOL DOWN TRANSIENT (TRANSIENT-2)

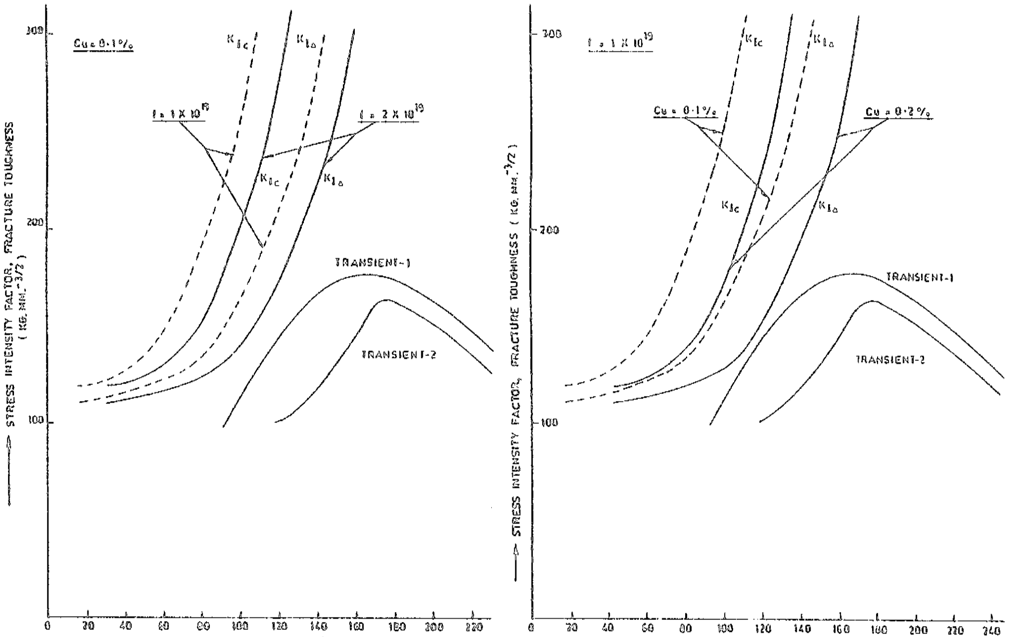

FIG. 6A EFFECT OF FLUENCE

FIG. 6B EFFECT OF CHEMISTRY

CRACK PROPAGATION IN CORE BELT REGION (CRACK DEPTH a/t = 0·123)

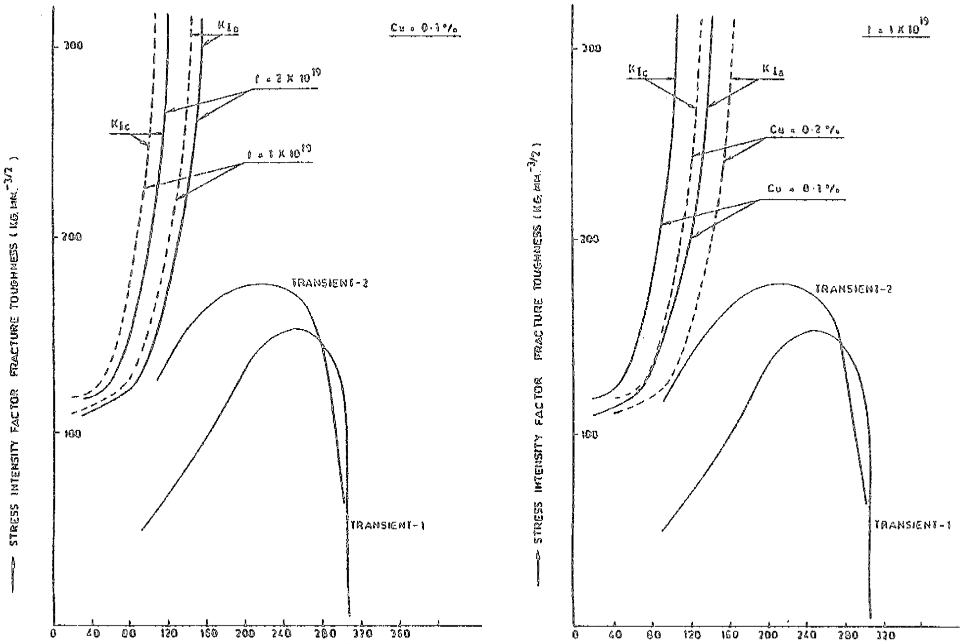

FIG. 7A EFFECT OF FLUENCE

FIG. 7B EFFECT OF CHEMISTRY

CRACK PROPAGATION IN CORE BELT REGION (CRACK DEPTH a/t = 0·45)