Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 25-26, 2007

The Effect of Flaw on Structural Integrity Assessment of RPV

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1. Introduction

Postulation of defects used in reactor pressure vessel (RPV) integrity assessment is one of the most important parts of the assessment. It significantly affects the results. Postulated defect is usually exactly defined in the applied standard, in some cases in relation to the status of non-destructive testing used in the assessed RPV.

The aim of this study is not to define the parameters of postulated crack, as it is done in the standard, but to explain the influence of individual parameters describing the crack, mostly based on sensitivity studies results.

Several parameters are postulated such as orientation, underclad vs. surface crack, defect depth, defect shape and elliptical vs. semi-elliptical crack, etc. And parametric studies are performed to investigate the influence of flaw parameters on the structural integrity assessment of the reactor pressure vessel during pressurized thermal shock.

2. Postulated Flaw

2.1 Underclad vs. surface

The crack position through the wall thickness is usually postulated as surface one or underclad one. The surface position is more conservative than the underclad one, but it is known, that no flaws in base or weld metal extended up to the inner surface of the RPV (i.e. penetrating the cladding) were found in real cladded RPVs. Moreover, for multi-layers claddings, the probability of presence of surface crack is still lower. The bands of multi-layer cladding are usually welded in such manner to be overlapped.

The position of postulated defect should be based on the standard used. It is well known that the underclad defects exhibit much smaller K_I values and as consequence of it much higher allowable index temperatures (i.e. less conservative solution) than the surface breaking defects exhibit. In the benchmark performed [1], postulating of underclad defect brings the benefit about 40 $MPa.m^{1/2}$ in terms of K_I (reduction on more than 50%) and significant benefit in terms of RT_{PTS}.

2.2 Defect depth

The maximum depth of the postulated crack is very important parameter of the RPV integrity assessment. It should be prescribed by the standard applied. It is usually prescribed directly in the standard (e.g. as ¼ of the wall thickness). According to some recent standards the original (large) prescribed maximum depth of the postulated crack can be significantly reduced on the basis of qualified non-destructive testing results. The crack depth is in this case connected to the plant specific non-destructive testing qualification criteria, along with application of some safety margins.

Concerning the effect of postulated crack depth on the results of PTS analyses, it could seem that the deeper crack is postulated the more conservative solution is obtained, but the situation is not so simple. When assessing the deepest point of the crack only (which is sufficient according to some older standards), the K_I values increase in most cases with increasing crack depth, but at the same time the temperature at the deepest point of the crack also increases with increasing crack depth (and, consequently, also fracture toughness of the material is increasing). Before the calculation, it is not clear which effect prevails. Moreover, if attenuation of the fluence is taken into account, the deeper points may not be so dangerous as points more close to the inner surface. Due to this fact, the standards usually prescribe analysing a set of postulated defects with varying depths.

A little different situation is in case of assessment of the (near) interface point of the crack. The temperature in this point is not changing with increasing crack depth; while the K_I values are increasing, so postulating deeper crack is conservative (from the point of view of assessment of the (near) interface point).

It was shown on some examples [1] that in the cases where with increasing crack depth the assessment of the deepest point gives less conservative results, the deepest point is not the worst one on the crack front and some point closer to the interface becomes the worst (Fig. 1). The assessment at this point gives more conservative results for deeper crack. So, finally, when the assessment is performed for the whole crack front (not only for the deepest point), the deeper crack gives always more conservative solution.

2.3 Defect shape

Another important parameter entering the assessment is shape of the postulated defect. The most usual shape is semi-elliptical one. Some standards prescribe elliptical defects (underclad or partially penetrating the cladding). It has to be mentioned that modelling the elliptical underclad defects in finite element models is difficult task compared to assessing them using simplified codes. Under the term "crack shape" we can also understand the aspect ratio.

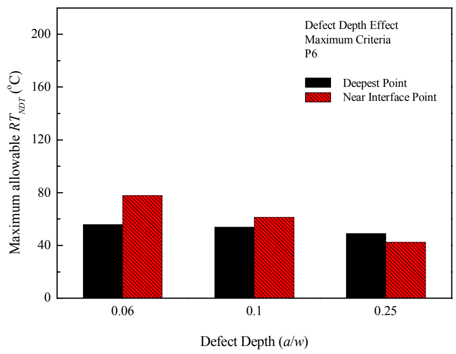

Figure 1. Effect of defect depth on allowable RT_{NDT}

Aspect ratio

The exact shape of the crack is expressed by the aspect ratio parameter, a/c, which means the ratio of the minor semi-axis of the (semi)ellipse, denoted by a, to the crack half length (the major semi-axis of the (semi)ellipse), denoted by c. It has to be mentioned that the semi-elliptical and elliptical cracks with the same depths and aspect ratios have different lengths.

Sensitivity studies show [1] that for the deepest point of the semi-elliptical crack (both surface and underclad), smaller aspect ratios (i.e. the longer crack) produce higher K_I values and, consequently, more conservative solution (lower maximum allowable transition temperature) (Fig. 2). For near interface point, the situation is not so clear and usually smaller aspect ratios produce smaller K_I values. Since in most cases it is not clear (before performing the analyses) which aspect ratio is more conservative, some standards require assessment of several postulated cracks with different aspect ratios selected from prescribed range.

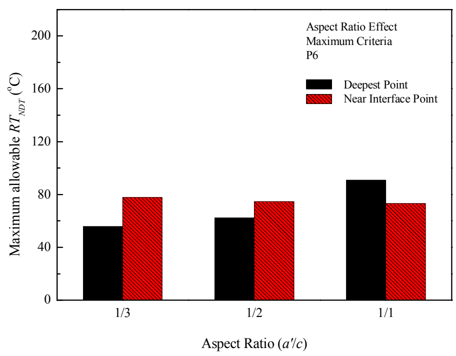

Figure 2. Effect of aspect ratio on allowable RT_{NDT}

Elliptical vs. semi-elliptical underclad crack

It was shown during sensitivity studies that elliptical and semi-elliptical underclad cracks of the same depths and lengths give similar values of K_I in the deepest point. On the other hand, the K_I values in the near interface point differ significantly and more conservative results are obtained for elliptical cracks

Orientation and position (axial/circumferential)

Orientation of postulated defect (axial or circumferential) is very important parameter affecting the results of the assessment. Which orientation is more conservative is strongly dependent on the transient assessed. For transients with no cold plume (axisymmetric cooling) the axial crack is always more conservative due to twice larger circumferential stresses due to pressure (while the thermal stresses are of the same magnitude in both orientations). On the other hand, cold plumes (or other types of non-axisymmetric cooling) give additional axial thermal stresses below the cold plume that may cause that circumferential crack becomes the most conservative one. The ratio between higher circumferential stresses due to pressure and higher axial stresses due to non-axisymmetric cooling cannot be (generally) known before performing the analyses.

Also the position close to large geometry change of the RPV (e.g. change of thickness of RPV wall between beltline and nozzle rings) can affect behaviour of axial and circumferential cracks. For axial crack postulated in thinner part of RPV in the vicinity of its thicker part, the K_I values due to inner pressure are reduced in comparison to crack postulated far from the thickness change. The effect of geometry change on K_I due to thermal shock is not very significant for axial crack. For circumferential crack postulated in thinner part of RPV in the vicinity of its thicker part, the K_I values due to thermal shock are increased. The effect of geometry change on K_I due to inner pressure is not very significant for circumferential crack.

3. Conclusion

The effects of postulated flaws on the structural integrity assessment of the reactor pressure vessel during pressurized thermal shock are addressed in this study, which can be used to suggest some recommendations of best practices and to assure an understanding of the key parameters of this type of approach and will be helpful not only for the benchmark calculations and results comparisons but also as a part of the knowledge management for the future generation of young operators, scientists, computer analysts and regulatory bodies.

REFERENCES

[1] Jhung, M.J., Benchmark calculations of structural integrity assessment for reactor pressure vessels during pressurized thermal shock, KINS/RR-453, Rev.1, Korea Institute of Nuclear Safety, 2007.