Modelling of surface cracks in piping tee junction

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ABSTRACT

The tee pipe junction at the inlet and outlet headers of Pressurised Heavy Water Reactor (PHWR) is a highly stressed area under internal pressure due to geometrical discontinuity. Therefore to investigate the crack growth an initial semi-elliptical surface crack is postulated at corner inner surface of piping tee junction. This paper deals with modelling of piping tee along with different sizes of surface cracks oriented in two different directions. Stress intensity factors obtained by finite element analysis are presented.

1 INTRODUCTION

The leak-before-break (LBB) approach has become well accepted to reduce the conservatism and cost without compromising safety. According to this approach, a part through wall crack should be postulated at highly stressed region of a pressurized component and then it should be demonstrated that it will not grow through wall during the entire service life of plant. This requires fatigue crack propagation studies using stress intensity factors.

In the Pressurised Heat Transport (PHT) system, the steam generator inlet and outlet pipes are connected to header in such a way that pipe axes are perpendicular to each other thereby constituting Piping Tee. The stress gradient is very high at inner surface of Tee corner due to internal pressure. Therefore, the surface crack is postulated at piping tee corner. The published results available on the determination of SIF for piping tees are very limited. Therefore, the present result may provide a useful reference for fracture mechanics work on piping tees.

2 GEOMETRY OF PIPING TEE

The geometry of 500MWe reactor outlet header tee, made of carbon steel SA350 grade LF2, considered for present study, is shown in figure 1. A crack is postulated at the corner inner surface of Tee. The shape of surface crack is taken as semi-elliptical as per ASME
code guidelines [1]. The axial as well as circumferentially oriented surface crack is postulated. The axial crack is assumed to be running along the run pipe to branch pipe, while the circumferential crack is considered to be at intersection line of two pipes. The location and orientation of surface crack, considered in the analysis, is shown in figure 2.

3 FINITE ELEMENT MODELLING

A three dimensional finite element model is prepared using eight noded thick shell elements. Half the geometry is modelled due to symmetry for all the cases under study. The symmetric plane passes through the axis of run pipe and branch pipe. The surface crack is modelled using line spring elements. The finite element modelling with the line spring is validated in earlier work by the present authors[2,3]. The results for tee were validated by comparing the results with those available in literature[4] as shown in Table 1. For the present analysis computer code ABAQUS [5] is used. The curvature discontinuity in the crack front at the corner of tee junction makes finite element results sensitive to mesh and element grading. Therefore, the convergence study is also carried out by reducing the element size locally near the surface crack. The converged mesh is used in the final analysis. Figure 3 shows the finite element model of the reactor header piping tee with corner surface crack. The enlarged view of the model near crack location is shown in figures 4 and 5 for axial and circumferential surface crack respectively. Analysis is carried out for internal pressure of 1.0 Kg/sq.mm.

4 AXIAL SURFACE CRACK

Limited literature is available for fracture mechanics of piping tee. In Ref.[4] the surface crack in run pipe close to tee corner is considered. Other possible locations are crack in branch pipe or a crack running across both the pipes. Therefore, to understand the behaviour of axial surface crack three different crack configurations located at corner of tee are studied using linear elastic fracture mechanics. These crack configurations are shown in figure 6. In the first case, the surface crack is assumed to be located in branch pipe while in second case the crack is considered to be in run pipe. In the third case the crack is assumed to be running along the branch and run pipe. In all the three cases the elliptical crack profile is assumed (crack depth/thickness = 0.25). Only internal pressure is considered for the study. The distribution of stress intensity factors for these three cases is shown in figure 8. The comparative study shows that third case envelopes the first and second case. Also the SIF for third case is higher than other two cases. Therefore, it is decided to postulate the surface crack running along branch and run pipe.

In this case, the geometry of tee is symmetric on two sides of crack plane. Therefore three noded symmetric line spring elements are used. The crack depth to thickness ratios considered in the analysis are 0.125, 0.25, 0.5 and 0.75. The crack front length to crack depth ratio is taken as 6 for all the cracks as per ASME Section XI [1]. At corner of tee wall local thickening of the wall was accounted by varying the thickness of line spring elements depending on the location along crack front. If this variation in thickness is not considered, the computed SIF is higher or in other words conservative but unrealistic as seen from the comparison of SIF distribution with and without taper modelling in figure 8.
Therefore the variation of wall thickness is considered by supplying the thickness variation for line spring elements. Based on this thickness and crack depth the program calculates the stiffness of line spring elements. The SIF distribution for various crack dimensions is presented in figure 9 and 10. It can be seen that there is sharp gradient of SIF near corner of tee. The SIF distribution unsymmetric in branch and run pipe for shallow cracks (a/t=0.125, 0.25). The distribution shows slightly higher SIF in branch pipe as compared to run pipe for these cracks. However, for deep cracks (a/t=0.5, 0.75) the SIF distribution is almost symmetric in branch and run pipe.

5 CIRCUMFERENTIAL SURFACE CRACK

The analysis of piping tee is also carried out with circumferential surface cracks at corner. Semi-elliptical surface crack profile is simulated at intersection line of run and branch pipe. Since structural geometry is not symmetric on two sides of crack plane, therefore unsymmetric six noded line spring elements are used for modelling the crack. Out of these six nodes, three nodes lie on one side of crack plane and rest three nodes lie on other side of crack plane. The local increase in pipe wall thickness near corner intersection line of piping tee is considered by supplying the increased thickness to line spring elements. The stress intensity factors are evaluated for various crack depth to wall thickness ratios (0.125, 0.25, 0.5 and 0.75) but keeping the crack aspect ratio constant. Figure 11 and 12 show the distribution of SIF along the crack front for various circumferential surface crack dimensions. Figure 13 and 14 show the comparison of SIF distribution for axial and circumferential surface cracks for shallow and deep cracks respectively. The comparison of maximum SIF variation with crack depth is shown in figure 15 for surface crack oriented in axial and circumferential direction.

6 INTEGRITY ASSESSMENT

The threshold value SIF for crack initiation is 825.7 Kg√mm/sqmm [6] for reactor header material. From the analysis it is seen that computed SIFs for axial and circumferential surface cracks at tee corner are much lower than SIF required for crack initiation. So there is no likelihood of surface crack extension up to a crack depth of 56.25mm (crack depth/wall thickness = 0.75) at tee corner due to operating internal pressure. The SIFs are higher for axial surface cracks with maximum SIF at centre of crack. For 56.25mm deep axial surface crack at inner surface of tee corner the SIF computed is one third of the fracture toughness of the material. The crack extension may occur at tee corner for deep inner axially oriented surface cracks at large internal pressure.

7 DISCUSSION AND CONCLUSION

Axial and circumferential surface crack at tee corner in pressurized piping are analysed using line spring elements. Line spring elements are economical in computer time and space. However, it is less accurate but results are conservative. It is shown that axial
surface crack at piping tee corner running along the branch and run pipe is more severe axial crack.

Variation of SIF with crack depth for axial and circumferential surface crack located at tee corner is presented. The stress intensity factors for axial surface crack at tee corner are more than those for circumferential surface crack at tee corner. But the surface crack up to a depth of 56.25mm is not likely to grow due to normal operating internal pressure. The deep axial inner surface crack at tee corner may grow at very high internal pressure. However, the reactor trips at 1.07 Kg/sqmm header pressure and therefore, crack growth will not occur.

REFERENCES

1. ASME Boiler and pressure vessel code, Section XI, Division 1, Rules for Inservice Inspection of Nuclear power plant components.
5. ABAQUS version 5.3, Hibbit, Karlson and Sorenson Associates.

Table 1 Comparison of computed result with published result for piping tee.

<table>
<thead>
<tr>
<th>Computed Normalized Jmax</th>
<th>Normalized Jmax Ref.[4]</th>
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<tr>
<td>10.493</td>
<td>8.996</td>
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Note:
1. Normalized $J = J / [(Pd/2t)^2 (\pi a/E)]$
2. Above result is for the axial inner surface crack simulated at run pipe.
Fig. 1 GEOMETRY OF PIPING TEE

Fig. 2 ORIENTATION OF SURFACE CRACKS AT TEE CORNER
(a) AXIAL  (b) CIRCUMFERENTIAL
FIG. 3 FINITE ELEMENT MODEL OF PIPING TEE

CRACK ORIENTATION

FIG. 4 MODEL OF PIPING TEE WITH AXIAL SURFACE CRACK AT CORNER

CRACK ORIENTATION

FIG. 5 MODEL OF PIPING TEE WITH CIRCUMFERENTIAL SURFACE CRACK AT CORNER
FIG. 6 VARIOUS LOCATIONS OF AXIAL INNER SURFACE CRACK AT TEE CORNER

(a) BRANCH PIPE
(b) Run Pipe
(c) Branch and Run Pipe

FIG. 7 COMPARISON OF SIF FOR DIFFERENT POSITIONS OF AXIAL CRACKS AT TEE CORNER (a/l=0.25).

FIG. 8 EFFECT OF TAPER MODELLING ON SIF FOR AXIAL CRACK (a/l=0.25, 2c/a=6).

FIG. 9 SIF FOR AXIAL SURFACE CRACKS AT TEE CORNER (2c/a=6).

FIG. 10 SIF FOR AXIAL SURFACE CRACKS AT TEE CORNER (2c/a=6).

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