

# ON NON-AXISYMMETRIC COLLAPSE OF THIN TUBES

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Summary Occurrence of non-axisymmetric collapse modes in axial compression of thin tubes has been studied both experimentally and with the help of FE simulation. Variables considered are tube diameter to thickness ratio, annealing, variation in tube wall thickness, eccentricity, and boundary conditions. It is seen that amongst other factors, a certain combination of thickness eccentricity and unsymmetrical in plane end conditions favours formation of diamond mode.

## INTRODUCTION

Progressively collapsing tubes in axisymmetric concertina, non-axisymmetric diamond or mixed mode are efficient kinetic energy absorbing structure elements and therefore mechanics of their collapse under axial loading conditions has received considerable attention in the past. Several experimental, analytical and numerical studies have appeared in recent years, which help in understanding of the plasto-mechanics of the collapse phenomenon. Experimental studies [1-3] have shown that tubes with D/t (diameter to thickness) ratio less than about 70-90 deform in axisymmetric mode while those with larger D/t values deform non-axisymmetrically. Analytical and numerical studies, however, have mostly been confined to axisymmetric collapse mode, and not much is available in literature which deals with the analysis of the diamond mode of collapse or conditions under which this mode of collapse takes place. The present experiments were conducted on tubes of aluminium and mild steel in both as received and annealed conditions. Their D/t was varied from 10 to 40, and in this range these tubes were expected to collapse in axisymmetric concertina mode. Experiments however showed that many of these tubes collapsed in non-axisymmetric diamond or mixed mode. Detailed experimental and numerical studies were therefore undertaken to analyse the conditions under which the non-axisymmetric deformation would occur in a tube under axial compression. It is seen that the factors on which occurrence of non-axisymmetric collapse depends include tube diameter to thickness ratio, annealing, variation in tube wall thickness, eccentricity, and boundary conditions.

## Experimental and Numerical Simulation

Transition of deformation mode shapes from axisymmetric concertina mode to non-axisymmetric diamond pattern have been studied with different configurations of tube wall thickness eccentricity, increasing levels of eccentricity in single lobe configuration, boundary conditions and tube shape deviations for round tubes of Aluminum with D/t ratio 27 and L/D = 2. The deformation process is modeled and simulated in the FE code ANSYS using a nonlinear implicit quasistatic analysis.

The wall thickness eccentricity was introduced around the circumference of a machined 50.8 mm diameter tube in a single lobe configuration through off center machining for the quasi static axial compression tests. The global geometric imperfection has been parameterized as a function of the specified eccentricity 'e' in the Finite Element model of the tube. The required reduction in the thickness around circumference is incorporated into the discretised domain by unchecking the FE mesh from the solid model. The nodal coordinates are updated as a half sine wave around half the tube circumference with amplitude 'e' as maximum reduction in thickness for the single lobe eccentricity. The collapse mode dependence on increasing level of wall thickness eccentricity (e/t ratio) in single lobe configuration has been studied with axisymmetric as well as non-axisymmetric radial displacement tube end constraints (Fig. 1)

Different configurations investigated in addition to the single lobe eccentricity are 2, 3 and 4 lobe wall thickness eccentricity around the tube circumference; the wall thickness reduction around the tube circumference has been modeled as a full, one & half and double sine wave respectively around the tube circumference with an amplitude 'e'. The sensitivity of collapse mode to varying wall thickness eccentricity configurations in 1, 2, 3 and 4 lobes has been studied numerically with axisymmetric as well as non-axisymmetric radial displacement tube end constraints (Fig. 2). Validation and comparison of non-linear FE solution with experimental results based on quasi-static axial compression of Aluminum tubes of D/t = 29.19 and L/D = 1.4 in the single lobe eccentricity configuration has been carried out.

Collapse mode variations with tube shape deviations from circular cross section but with a uniform wall thickness have also been studied with variations in tube end conditions (inplane radial displacements). The tube radial coordinates at any point around the circumference is modeled by modifying the coordinates as a function of its polar coordinate ' $\theta$ ' in 1,2,3 and 4 lobe configuration.

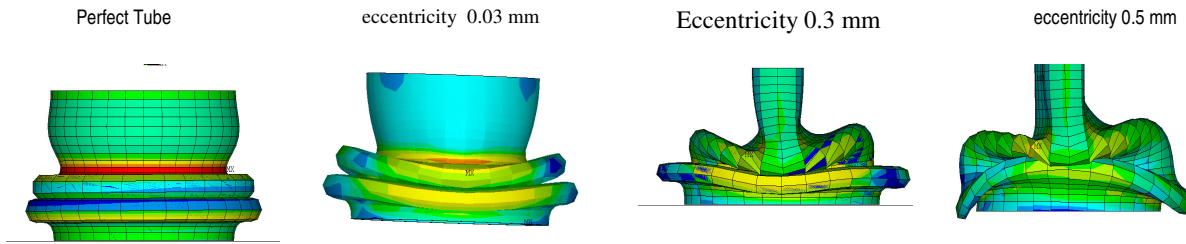


Fig 1 : FE simulation of collapse modes and deformation profiles with Perfect Tube, 0.03 mm , 0.3 mm, and 0.5 mm wall thickness eccentricity around circumference at 40 mm axial compression of the 50.8 mm diameter ( $D/t = 29.19$ ) eccentric Al tube. The tube end conditions are perfect axisymmetric.

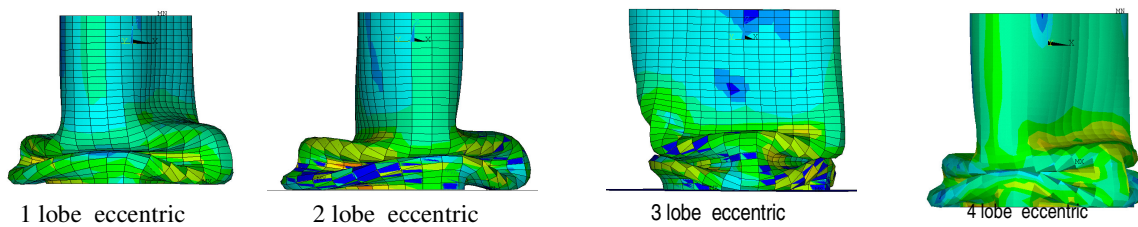


Fig 2 : FE simulation of collapse modes 1, 2, 3 and 4 lobe wall thickness eccentricity around circumference at 40 mm axial compression of the 50 mm diameter ( $D/t = 27$ ) eccentric Al tube. The tube end conditions for inplane radial displacements are non axisymmetric (constrained over 180 degree sector only).

## Results and Conclusions

Good correlation has been obtained between the experimental results and the numerical model for the load deformation response; energy absorbed and collapse mode shape. It has been established that there is a strong dependence of the collapse mode to the eccentricities in the tube end conditions. Deviations from axisymmetry in the inplane radial displacement constraints causes even a geometrically perfect tube to collapse in the diamond mode. It has also been demonstrated through numerical studies that diamond mode collapse tendency of Al tubes under quasi static axial compression increases with increasing tube wall thickness eccentricity around the circumference with axisymmetric tube end conditions. There is a linear decrease in  $P_i$  (First peak load) and  $P_m$  (Mean Load) with increasing level of tube wall thickness eccentricity in single lobe configuration.

For axisymmetric tube end conditions, it is seen that while the Al tubes with 1 and 2 lobe wall thickness eccentricity collapse in a mixed concertina and diamond mode, the models with 3 and 4 lobe eccentricity interestingly collapse in a concertina mode. In the latter case however, a non axisymmetric stress profile away from the plastic zone is observed. Collapse mode is found to be insensitive to minor tube shape deviations from circular cross section under axisymmetric tube end conditions. However, under non-axisymmetric inplane tube end conditions, the collapse mode is diamond for all the studied configurations of tube shape eccentricity.

It is seen that the diamond mode of collapse is more likely to occur when there is a combined effect of thickness eccentricity and unsymmetrical in plane end conditions.

## References

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