AN INVESTIGATION INTO LARGE DEFORMATION BEHAVIOUR OF METALLIC TUBES

By

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Submitted in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

Indian Institute of Technology, Delhi
Hauz khas, New Delhi 110 016, India

May 2000

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to

my parents

CERTIFICATE

This is to certify that the thesis entitled **"AN INVESTIGATION INTO LARGE DEFORMATION BEHAVIOUR OF METALLIC TUBES "** by Pramod Kumar Gupta has been prepared under our supervision and has attained a standard required for a Ph.D. degree of the Institute. The thesis is record of bonafide research work carried out by him and its contents have not been submitted to any other University or Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

I express my deep sense of indebtedness to Prof. N K Gupta and Prof. G S Sekhon for their valuable guidance, keen interest, inspiration and constant encouragement throughout this work.

I am extremely grateful to Dr. S K Gupta for his valuable suggestions, discussions and guidance during this work.

I thank Mr. Umesh Kumar, Mr. S. Jafri, Mr. Mehtab Alam, Mr. M. Ahmad and Dr. Hussain Abbas for their help, guidance and encouragement.

I am thankful to Mr K K Mittal, Mr. B S Rana, Mr. Narendar Kumar and Mr. Hoshiar Singh for all their advice and help during the experimental work in this thesis.

I also wish to thank to the workshop staff of Applied Mechanics Deptt. for timely help of specimens' preparation.

I express my gratitude to my parents and other family members for their constant encouragement and supports. Finally I express my gratitude to my wife Smt. Srashti Gupta, sweet daughter Swati (micky) for their love and affection during this study.

Pramod Kumar Gupta

Abstract

Experimental and computational investigation into the energy absorbing characteristics of the metallic circular, square and rectangular cross-section hollow tubes of aluminium and mild steel is presented. Tubes were subjected to axial or lateral compression in an INSTRON universal testing machine of 50 T capacity under quasi-static loading. Following studies have been carried out

1) Axial and lateral compression of round tubes between two flat rigid platens.
2) Lateral compression of square and rectangular tubes between two flat rigid platens.
3) External inversion of round tubes over a circular profile die.

A finite element model for each case of study has been proposed and verified with the help of finite element code FORGE2. Tube material for finite element simulation has been modeled as rigid-viscoplastic. Deformation mechanism of tube during compression process in each case of study has been illustrated, analysed and discussed in detail with the help of the contours of different components of stress, strain and strain rate. The experimental and computational results, in form of deformed profiles at various stages of compression, load-compression and energy-compression curves are presented, compared and found in good agreement .

Axial compression of round tubes

Round metallic tubular specimens in as-received state of average diameter to thickness ratio (D/h) between 7.24 to 37.46 for aluminium and 11.65 to 30.67 for mild steel tubes were axially compressed between two rigid flat platens. Length of each specimen was equal to twice of its outer diameter. During the compression process axisymmetric concertina mode of collapse was observed in, aluminium specimens with D/h values between 11.3 and 37.46 and all mild steel specimens. However multiple barrelling mode of collapse was seen in aluminium specimen having D/h value of 7.24.

Development of concertina fold occurs by formation of two plastic zones as described in Art. 3.2.2.1.1 in which first plastic zone develops fully while second plastic zone develops partially till the first concertina fold gets completed. During the fold formation some portion of the tube moves radially outward while some other portion move radially inward with respect to the mean diameter. During the formation of concertina fold, tube experiences direct compression in initial stage of compression and later on hoop action and bending predominantly occur. Energy dissipation in compression thus occurs during this period only . Energy dissipation in hoop action and bending mainly occurs in the region of first and second plastic zones during their development.

With decrease of friction present between the platen and tube interface, the minima of load-compression curve is decreased and the second maxima (the second peak) is increased. So the overall effect on the energy-compression curve is negligible and the contribution of friction in energy dissipation is also negligible. Friction has the negligible effect on the fold length too.

During the formation of concertina fold the wall thickness of the tube increases at every layer of the tube throughout the compression process specially around region of second plastic zone and the tube-platen contact surface.

It is found that in the concertina fold, outer boundary profile around the first plastic zone is a segment of circle and the amount of tube length which remains straight is less than 1/6th of the half fold length.

During the development of axi-symmetric multiple barrelling mode of collapse the tube deforms due to the axial compression, hoop action and bending. Thickness of the tube thus increases over its length and load-compression curve continuously increases throughout the compression process.

Lateral compression of round tubes

Tubes of D/h ratios between 7.24 to 37.46 for aluminium and 10.43 to 36.84 for mild steel were tested after annealing under quasi-static loading. To study the influence of thickness and diameter specimens of same diameter but different thicknesses and same thickness but different diameters were taken. Generally length of specimen was 100 mm, but some experiments were also carried out by changing the length of specimen to investigate its effect. Mode of deformation and load-compression curve of all tubes were similar. The tubes deformed due to the formation of four plastic zones at the intersection of horizontal and vertical axis of symmetry with tube section, as described in Art. 4.2.2.1.

The friction between tube-platen interface and length of the specimens have negligible effect on the load-compression and energy-compression curve.

Lateral compression of rectangular and square tube

Annealed specimens of 100 mm length made up of aluminium and mild steel were compressed between two flat rigid platens under quasi-static loading. Wall thickness of all four sides of the specimens are not equal. However the wall thickness of vertical sides is treated as identical.

Tubes collapse due to the formation six plastic hinges on the vertical sides as described in Art. 5.2.3. Four in the initial stage of compression at four junctions of the two horizontal and two vertical sides and remaining two in the later stage of compression near the middle of the vertical sides. Different types of hinge mechanism were assumed by previous researchers [43,53-54]. The friction factor between the tube-platen interface has negligible effect on the energy absorbing capacity of the tube.

External inversion of round tubes

Energy dissipation, in external inversion of the as-received round aluminium tubes over the circular profile dies of three different radii is investigated. Energy dissipation, in external inversion is compared with the axisymmetric concertina fold formation.

External inversion of tube is the result of circumferential stretching of the tube due to hoop tension, meridional bending of the tube, combined stretching as well as bending and development of frictional strain between tube-die interface. The inversion process has two parts. The first is unsteady phase in which load compression curve constantly changes and the second is the steady phase during which load compression curve becomes steady. The energy absorbing capacity of a tube increases with decrease in die radius and increase in friction factor. Inversion is possible only at lower values of friction factor, at higher values of friction factor the inversion mode of compression stops and axisymmetric fold formation starts. Therefore there is a limiting value of friction factor beyond which normal tube inversion is not possible.

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