

AXIAL COMPRESSION OF THIN WALLED METALLIC AND COMPOSITE SHELLS

By

R. VELMURUGAN

Department of Applied Mechanics

Submitted

*in fulfilment of the requirements for the
award of the degree of*

DOCTOR OF PHILOSOPHY



to the

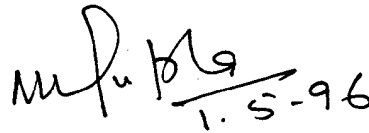
INDIAN INSTITUTE OF TECHNOLOGY, DELHI

NEW DELHI - 110016, INDIA

MAY 1996

CERTIFICATE

This is to certify that the thesis entitled " **Axial Compression of Thin Walled Metallic and Composite Shells** " by R. Velmurugan has been prepared under my supervision and has attained a standard required for a Ph.D. degree of the Institute. The thesis is a 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.

Handwritten signature of N K Gupta, dated 1.5.96.

(N K Gupta)

Professor

Department of Applied Mechanics

Indian Institute of Technology, New Delhi

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Professor N K Gupta, Department of Applied Mechanics, Indian Institute of Technology, New Delhi for his invaluable guidance, inspiration and constant encouragement through out this work.

I am extremely grateful to Dr S K Gupta and Mr K K Mittal for their advice and guidance during this period.

I am grateful to Prof SMA Kazimi, Prof C V Ramakrishnan and Prof R K Mittal, Department of Applied Mechanics and Prof U R K Rao, Department of Mechanical Engineering for their help and guidance at different stages of this research work.

I thank the Aeronautical Research and Development Board, Structural Panel, Ministry of Defence, India, for their financial assistance through the Industrial Research Project. I also thank the Industrial Research and Development Unit, Indian Institute of Technology for allowing me to register as a part time Ph.D. student.

I am thankful to Lt.Cdr. I Sivadasan for his friendly advice and encouragement and Mr Sriram Hegde for his kind help and cooperation in using the computing facility of the department.

I thank the staff of Impact Mechanics Laboratory, Strength of Materials Laboratory, Departmental Workshop, Computational Laboratory and MTS Laboratory for their assistance.

I thank Mr R Marimuthu, Mr Ravi kumar, Mr Anjan Dutta, Mr R Ansari and Mr G L Easwara Prasad for their help and encouragement.

Finally I express my heartiest thanks to my father Thiru S Ramachandran, mother Thirumathi R Selvam, father in-law Thiru M Thirumal, sister Thirumathi Subbhulakshmi Pandian, and all my family members and relatives for their encouragement, financial assistance and patience during my study.


R VELMURUGAN

AXIAL COMPRESSION OF THIN WALLED METALLIC AND COMPOSITE SHELLS

ABSTRACT

Experiments in axial compression were carried out on aluminium and steel metal tubes, and Composite tubes, cones and domes of different diameters, thicknesses and lengths to identify the various failure modes and to study the energy absorption capacity of these shells. Analysis was carried out in each case and the results obtained have been compared with experiments. A brief description of the work done on metal and composite shells is given below.

Metal tubes :

Annealed aluminium and as received steel tubes of different diameter to thickness ratios $[D/t]$, ranging from 13 to 33, with Height to diameter ratio $[H/D]$ equal to 3, were subjected to axial compression in the Instron machine. These tubes buckled in axi-symmetric concertina mode. Their load-compression curves were obtained on the machine chart recorder, and the mean compressive load was calculated from these curves. The tested tubes were sectioned vertically at their middle to study the deformation mode and to make suitable analytical models. The internal and external fold lengths were measured for all the tested specimens. Tube specimens of identical sizes cut from the same tube (of length 2 m) were tested up to different stages, and their deformation profiles were drawn in a profile projector. The hinge angles corresponding to the four hinges of a fold were measured from the traced profiles and the variation of the limit loads with the average value of the hinge angles were studied

for the tubes, and their variation with different D/t ratios is discussed.

Based on the experimental observations that the tubes fold both internally and externally with respect to the mean tube radius, an analytical model is established to study the post collapse behaviour of the round tubes under axial compression. In this analysis it is initially assumed that one third of the fold goes inside the tube radius and two third forms out side the tube radius. Expressions were obtained to find the post collapse load-compression curve, the mean collapse load and the internal and external fold lengths. The results thus obtained are compared with the experimental results as well as with some of those obtained from different models available in literature [32-34].

Experimental studies however reveal that the folding in an axi-symmetric mode of collapse takes place both internally and externally with respect to the mean radius and the amount of internal folding is a function of D/t . An empirical relation is established to show this variation. A detailed analytical study was carried out to study the effect of internal folding (ratio of internal folding to the fold length that varies between 0 to $1/2$) on the fold length, mean collapse load and the post collapse load-compression curve. The analysis is carried out firstly assuming that the hoop strain variation along the profile is piece wise linear and then by considering the variation of the hoop strain along the actual profile. An analysis is also carried out by considering the non-symmetry of folding about the middle plastic hinges by introducing that the four hinge angles corresponding to a fold are different from each other as is observed from experiments. These studies were again carried for both piece wise linear variation

and variation of hoop strain along the actual profile. The results are compared with the experimental values and good agreement is found.

Composite shells:

Tubes of different diameter to thickness (D/t) and height to diameter (H/D) ratios, made up of glass fibre woven mats with epoxy resin were subjected to axial compression in the Instron machine. The different failure modes were identified and the energy absorption capacity of the tubes were studied. The specific energy absorption capacity and the crush length (tube length crushed in a crush cycle) of the GFRP tubes were calculated from the load-compression curves. Certain empty tubes were subjected to uni-axial tension to find the tensile strength of the specimens.

Experiments in axial compression were also carried out on GFRP tubes that were filled with Polyurethane Foam. The effect of foam on the deformation mechanism and on the energy absorption capacity of the tubes was studied. Foam blocks of different length, diameter and density were subjected to axial compression and the strength of the foams were obtained from their load-compression curves. These values were compared with the theoretical results.

Based on the experimental observations an analytical model was developed to find the post crush behaviour of the composite tubes by considering the different failure modes involved in the crushing process. Expressions were obtained to find the average crush stress and the crush length. Results thus obtained are compared with the experimental results. Analysis was also carried out to find the average crush stress for tubes filled

with foam.

Conical shells, with semi cone angles 15° to 45° , and domes (the generator is a parabola of $H = C R^2$, $C = 0.4$ to 1.2 , where H is the height of the shell and R is the radius at the base) were fabricated with short-randomly oriented glass fibre mats and polyester resin. These shells were subjected to axial compression. Experiments were carried out on the shells in both empty and foam filled condition. The mechanics of deformation and the energy absorbing capacity of the shells were studied. Based on the experimental observations, an analysis is carried out to find the average crushing stress and the crush length of the conical shell. The results thus obtained have been compared with the experiments.

TABLE OF CONTENTS

	PAGE No.
CERTIFICATE	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS	vii
LIST OF FIGURES	x
LIST OF TABLES	ixx
NOTATIONS	xxi

CHAPTERS

1.	INTRODUCTION	1
1.1	Introduction	1
1.2	Literature survey	4
a)	General	4
b)	Metallic tubes under axial compression	7
c)	Composite tubes	13
d)	Conical shells	17
1.3	Present study	19
1.4	Lay out of the thesis	21
2	AXIAL COMPRESSION OF THIN WALLED TUBES - EXPERIMENTAL AND ANALYSIS	23
2.1	Introduction	23
2.2	Experiments	24
2.3	Analysis	41
2.3.1	Expression for load-deformation curve	57
2.3.2	Mean collapse load	62
2.4	Discussion of results	65
2.5	Conclusions	73

3	CONSIDERATION OF INTERNAL FOLDING AND NON-SYMMETRIC FOLD FORMATION IN AXI-SYMMETRIC AXIAL COMPRESSION OF ROUND TUBES	74
3.1	Introduction	74
3.2	Experiments	75
3.3	Analysis	79
3.3.1	Consideration of Internal folding on the fold formation	80
3.3.1.1	Piece wise linear variation of hoop strain	80
I	Folding parameter (m) varies from 0 to $1/3$	81
i)	Expression to find the fold length	87
ii)	Mean collapse load	90
iii)	Post collapse Load-compression curve	90
II	Folding parameter m varies between $1/3$ to $2/3$	92
3.3.1.2	Variation of hoop strain along the actual profile	97
I)	Folding parameter varies between 0 to $1/3$	98
i)	Expressions to find the fold length	101
ii)	Mean collapse load	102
iii)	Post collapse Load-compression curve	102
II -	Folding parameter m varies between $1/3$ to $2/3$	103
3.3.2	Analysis of axi-symmetric folding - Nonsymmetric about middle plane	106
3.3.2.1	Piece wise linear variation of hoop strain	106
I	m varies between 0 to $1/3$	106
II	m varies between $1/3$ to $2/3$	113
3.3.2.2	Variation of Hoop strain along the actual profile	116
I	m varies between 0 to $1/3$	116
II	m varies between $1/3$ to $2/3$	120
3.4	Results and discussions	122
3.4.1	Effect of internal folding	122
3.4.2	Effect of non symmetry in the axi-symmetric concertina mode	136

3.5	Concluding Remarks	140
4	AXIAL CRUSHING OF COMPOSITE TUBES	142
4.1	Introduction	142
4.2	Experimental	143
4.2.1	Empty Tubes	143
4.2.2	Foam filled tubes	155
4.3	Analysis	176
4.3.1	Empty tubes	176
a)	Expressions for crush length in a cycle	181
b)	Expression for the average crushing stress	183
4.3.2	Foam filled tubes	183
4.4	Results and Discussions	186
4.5	Conclusions	187
5	AXIAL COMPRESSION OF EMPTY AND FOAM FILLED COMPOSITE CONICAL SHELLS AND DOMES	189
5.1	Introduction	189
5.2	Fabrication of Composite shells	190
5.3	Experimental Observations	193
5.3.1	Empty Conical shells	196
5.3.2	Foam filled conical shells	206
5.4	Analysis	207
5.4.1	Expression for the crush length	226
5.4.2	Expression for the average crush stress	227
5.5	Results and discussions	229
5.6	Experiments on composite domes	236
5.7	Conclusions	245
6	CONCLUSIONS	255
	REFERENCES	267
	BIO-DATA OF THE AUTHOR	277