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AXISYMMETRIC BUCKLING AND STRAIN DISRIBUTION OF SHALLOW SPHERICAL CAPS WITH FREE EDGES

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ABSTRACT

This work investigates the strain distribution during buckling of thin shell axisymmetric spherical caps with free edges. The mechanical tests performed resulted in the identification of unique, novel strain distribution data of aluminium and steel shallow spherical caps.

Keywords: spherical cap, buckling, free edges, strain.

INTRODUCTION

Research on thin shell axisymmetric spherical caps has been primarily focused on spherical caps as structural members in the area of Aerospace and Mechanical engineering (Dumir, Gandhi, and Nath 1984). The non-linear buckling of clamped spherical caps under uniform step loading was investigated by (Lee, Lin, and Liou 1993); this research focused on buckling clamped spherical caps using uniformly distributed loads. Furthermore (Vaziri 2009) performed numerical simulations and qualitative experiments to study the mechanics of elastic spherical caps under point indentation. The spherical caps that were studied were plastic and clamped along the radial edge. Many papers have investigated vibration, static and dynamic buckling, strength and post-buckling analysis of spherical caps, but so far to the authors' knowledge, there has been limited information on the collection of strain data during the process of buckling spherical caps with free edges to flattening.

Spherical caps are parameterised by: radius of curvature, $\boldsymbol{R}$; height, $\boldsymbol{h}$; thickness, $\boldsymbol{t}$; and across flats radius, $\boldsymbol{a}$ as shown in Fig. 1. These parameters are related by the shallowness parameter, $\boldsymbol{\lambda}$.

$$\boldsymbol{\lambda \equiv 2[3(1-\nu^2)]^{\frac{1}{4}}(h/t)^{\frac{1}{2}}}$$

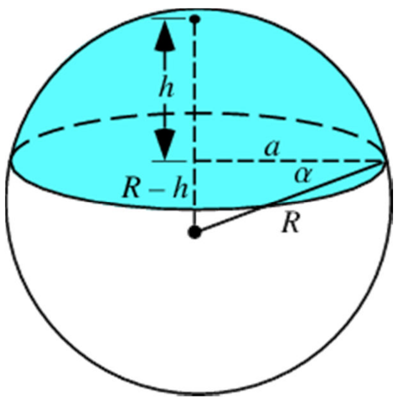

Fig. 1 - Spherical Cap Parameters

METHODOLOGY

A total of 8 individual tests were performed on various caps of ranging λ and two varying materials, mild steel and aluminium (4 samples per material). The caps were manufactured from circular blanks and formed using a CNC die and rubber pad forming process. In order to minimise ‘spring-back’ of the caps after forming, the circular blanks were annealed beforehand.

Tee-Rosette strain gauges were attached to the samples at various points as shown in Fig.2 and were oriented in the longitudinal φ and latitudinal θ directions according to general spherical coordinates. Position A is the gauge at the innermost part of the cap, while position C is at the outermost end, leaving position B at the centre.

The caps were placed in a tensile testing machine such that the open face rests on a fixed horizontal plate while another horizontal plate compresses the cap in the vertical direction only as seen in Figure 3. Compression/Buckling was conducted in a quasi-static manner, meaning the upper buckling plate was displaced by 0.5mm at a time in the “y-direction’ and the system was allowed to reach steady-state before taking the respective strain data. This was repeated until the cap was fully buckled into a flat plate. The tests were conducted at a slow displacement rate (10 mm/s) and at room temperature (≈25º C) while strain data was recorded.

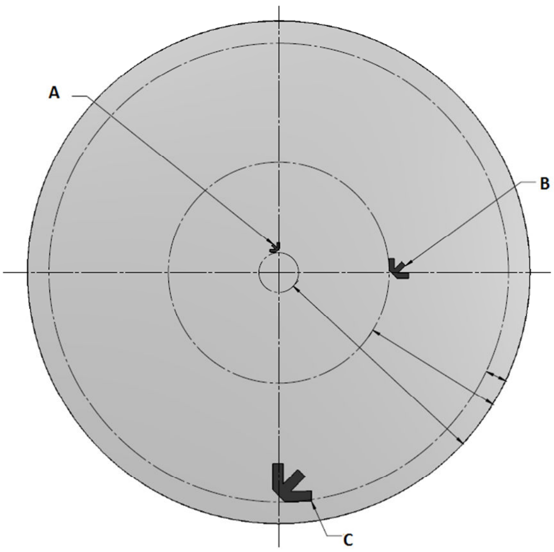

Fig. 2 - Strain Gauge Positions

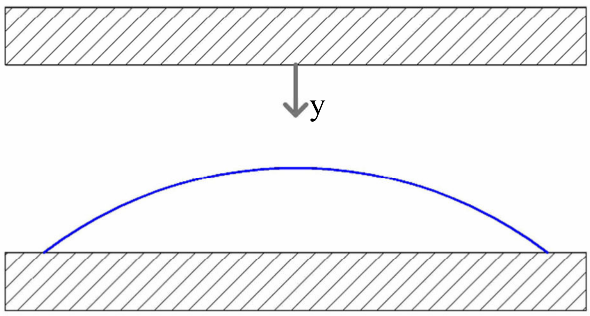

Fig. 3 - Buckling Schematic

EXPERIMENTAL PARAMETERS

Mild Steel

Sample	Radius/mm	t/mm	h/mm	a/mm	λ	ν	φA	φB	φC
1	350	1.1	2.766	43.913	4.076	0.3	0.059	0.090	0.121
2	350	1.1	3.291	47.887	4.447	0.3	0.057	0.088	0.136
3	350	1.1	3.863	51.856	4.818	0.3	0.057	0.108	0.158
4	350	1.1	5.143	59.779	5.559	0.3	0.062	0.108	0.170

Aluminium

Sample	Radius/mm	t/mm	h/mm	a/mm	λ	ν	φA	φB	φC
1	350	1.5	3.716	50.864	4.025	0.33	0.046	0.089	0.131
2	350	1.5	4.641	56.811	4.499	0.33	0.049	0.106	0.149
3	350	1.5	5.316	60.768	4.814	0.33	0.046	0.089	0.160
4	350	1.5	7.000	69.649	5.525	0.33	0.043	0.100	0.186

RESULTS AND CONCLUSIONS

Fig. 4 and 5 shows the results from the buckling test from aluminium sample 4 and mild steel sample 4 respectively. The load-displacement curves for gauges in the φ-direction at the three different locations are illustrated as well.

The most significant observation is that at position A, recorded strains were initially positive (tensile). As the deformation continued, the strains passed through zero and attained a negative value (compression) in both samples. The samples were continuous and homogeneous, hence the data suggests an axis of neutral strain.

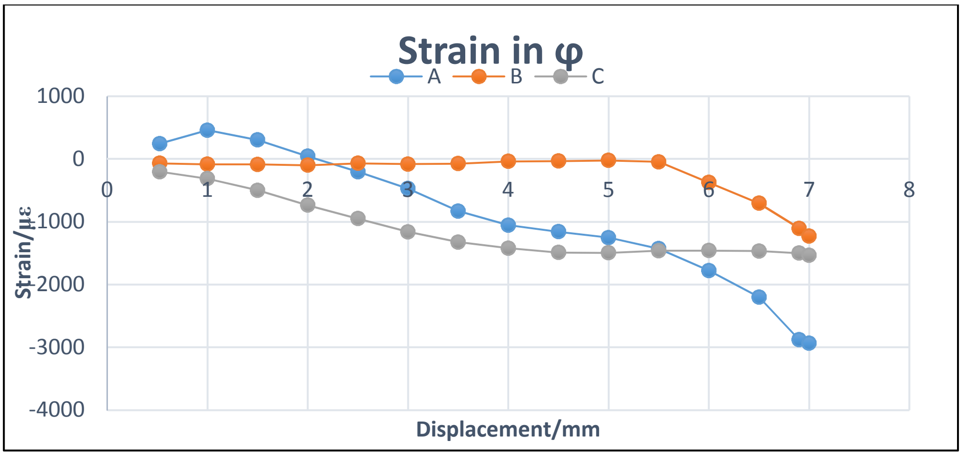

Fig. 4 - AL4 Buckling Results

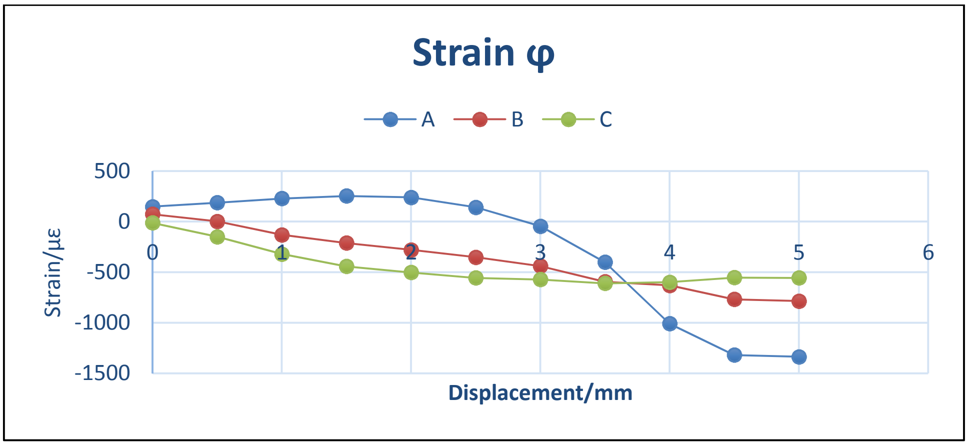

Fig. 5 - MS4 Buckling Results

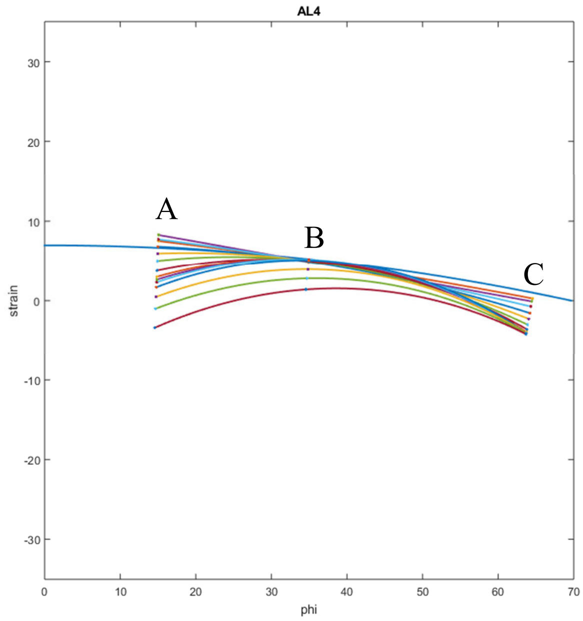

Fig. 6 - AL4 Strain-Phi

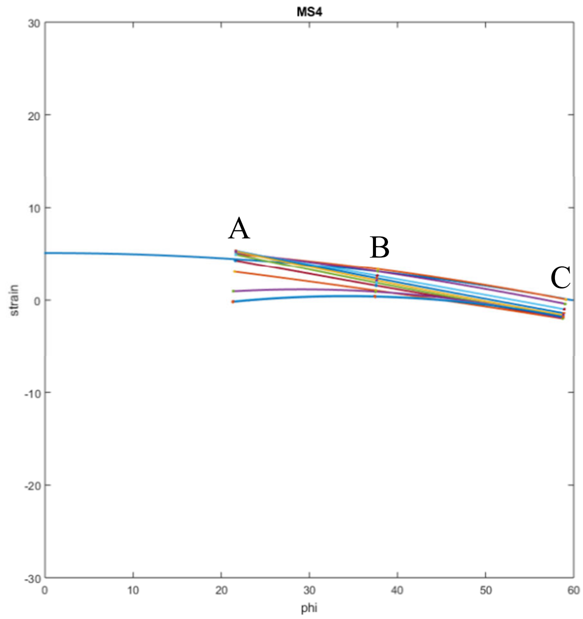

Fig. 7 - MS4 Strain-Phi

Figures 6 and 7 illustrate the strain distribution with respect to φ, with each line representing a strain line across the three points for each “step” in quasi-static experiment.

This study shows substantial data on the existence of a neutral axis of strain within spherical caps that are being buckled. Further research is warranted in order to fully develop strain distribution equations.

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