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Stress concentrations around an axisymmetrically attached nozzle on a glass reinforced plastic hemispherical dome

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CSM - 32% glass content (by weight)
WR - 50% glass content (by weight)

This yielded the following table of normalised results which were used in processing the test data using lamination theory. The more detailed analysis of the normalisation is contained in Appendix B.

Table 2. Normalised Material Properties

Type	Mechanical Properties		Poisson's Ratio	% Glass Content (by weight)
	Ei(MPa)	σf(MPa)	v	
Type 1	10 300	113,8	0,339	32%
Type 2	18 176	214,9	0,0947	50%
Type 3	9 072	86,3	-	50%

2.3 PREPARATION OF THE TEST RIG AND EQUIPMENT

Plate 1 indicates the various items of equipment used. The following is a brief description of the equipment with suggestions for future reference.

Switch Box. Portable MK Manual Compensator.
Al sixty strain gauges and five dummy gauges were simultaneously connected to the compensator. It was calibrated accordingly and using a 9V potential difference provided consistent output readings which were corrected using Fig 4 of the operating manual.

Strain Gauges:

Specifications for the gauges are given in Appendix B.

The gauges were attached to their respective sites on the inside and outside of the hemisphere wall as indicated in Plate 2 and Plate 3. Compensation was achieved using 2 dummy gauges inside the vessel and 3 dummy gauges outside. They were used consecutively to prevent overheating and consequent irregularities in output voltages.

The inside gauges were successfully waterproofed up to 1,6 bars using a plastic - none lead based lacquer 'Plastik 70, produced by Kontakt Chemie Germany'. Six coats were applied on the gauge and the bare wire surface taking due account of the bare wire/wire coating interface where good layering was necessary.

Mercury Manometer:
Once calibrated this enabled all pressure readings to be measured taking due account of the height correction factor on the readings. The one arm of the manometer had water from the hemisphere bearing down on the mercury surface. This permitted pressure readings being taken up to 1.6 bars.

Pump

This was a single action water pump capable of attaining pressures of 14 bars.

Backing Plate of Nozzle:

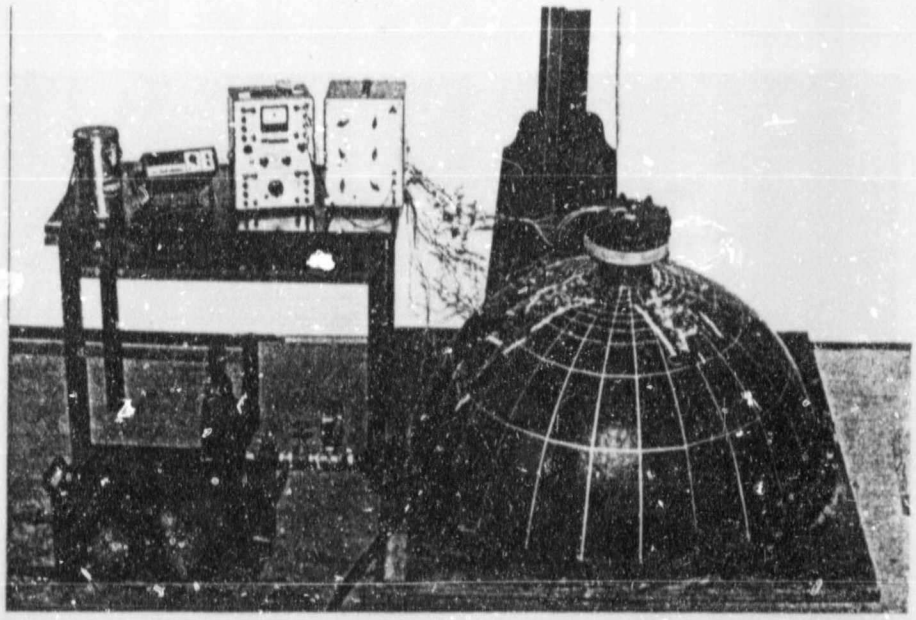
Plate 4 indicates the instrument cable pathway through the backing plate. Successful installation was achieved by fitting the cables through a 5mm hole and filling with a flexible adhesive, 'Pratleys Wonda Fix'.

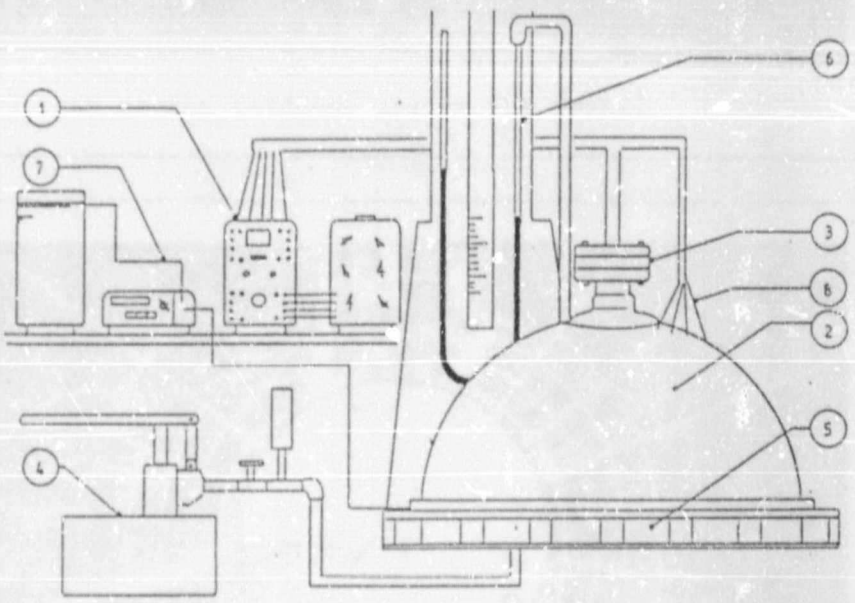
Hemisphere Flange/Base Gasket

A foamed rubber tubing commonly used in the motor industry was used as the gasket material. No leakage occurred.

Base

This consisted of a sandwich of 2/30mm plywood skins stiffened with a core of 80/40mm pine beams. The top surface of the base was coated with 2 layers of chopped strand mat.





1: Portable MK Manual Compensator
2: Hemisphere
3: Nozzle SMC Backing Ring, Flange and Backing Plate
4: Hand Pump
5: Sandwich Base
6: Mercury Manometer
7: Cold Sink Thermocouple
8: Strain Gauge Cables

Plate 1. Components of the test rig.

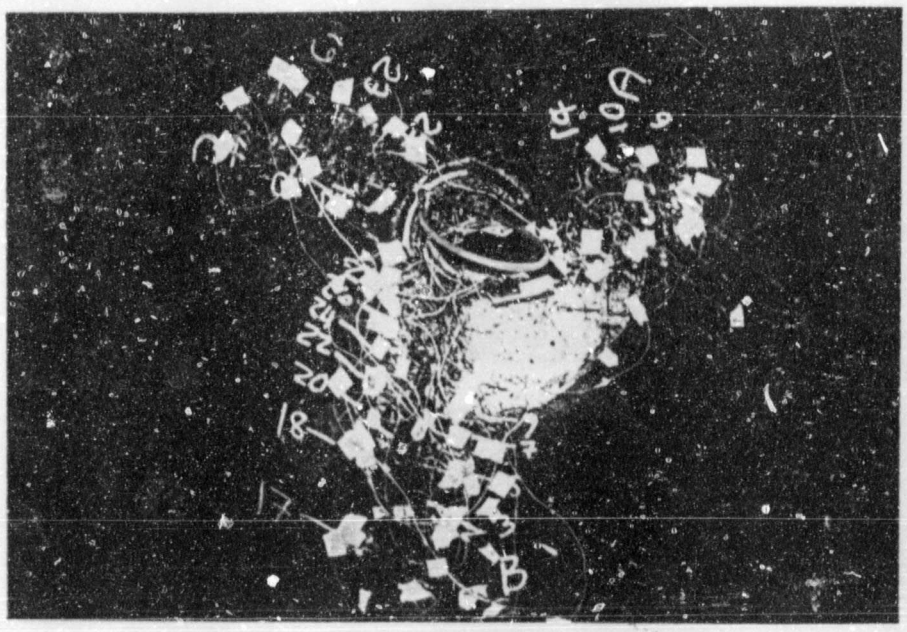


Plate 2. Strain gauges attached inside the vessel.

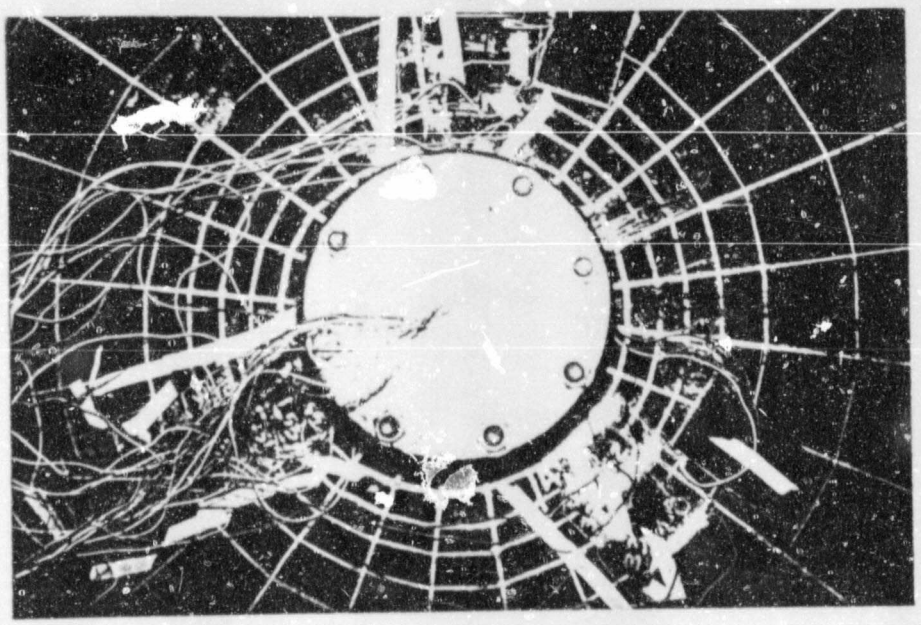


Plate 3. Strain gauges attached outside the vessel

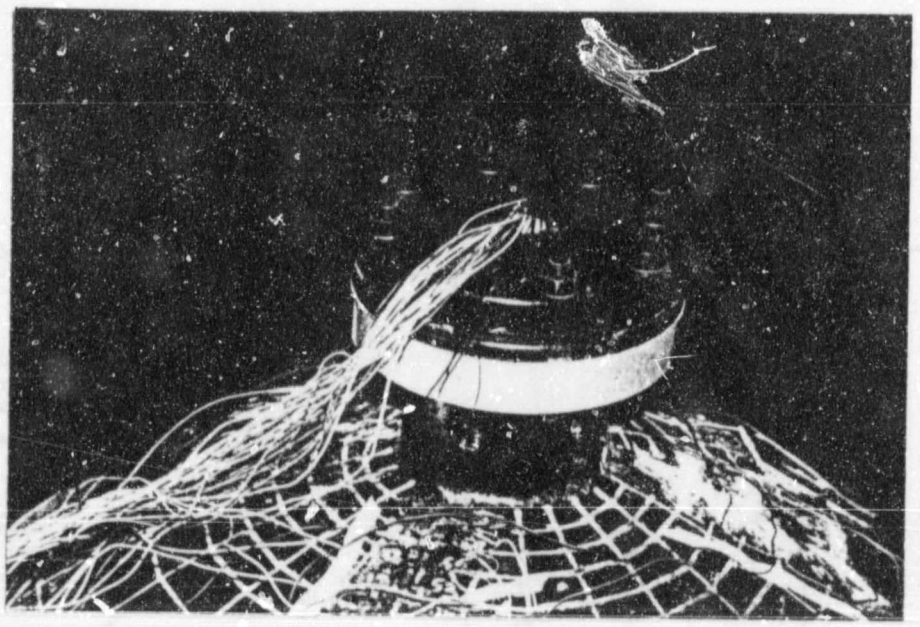


Plate 4. Detail of nozzle backing flange.

Positioning of the Strain Gauges

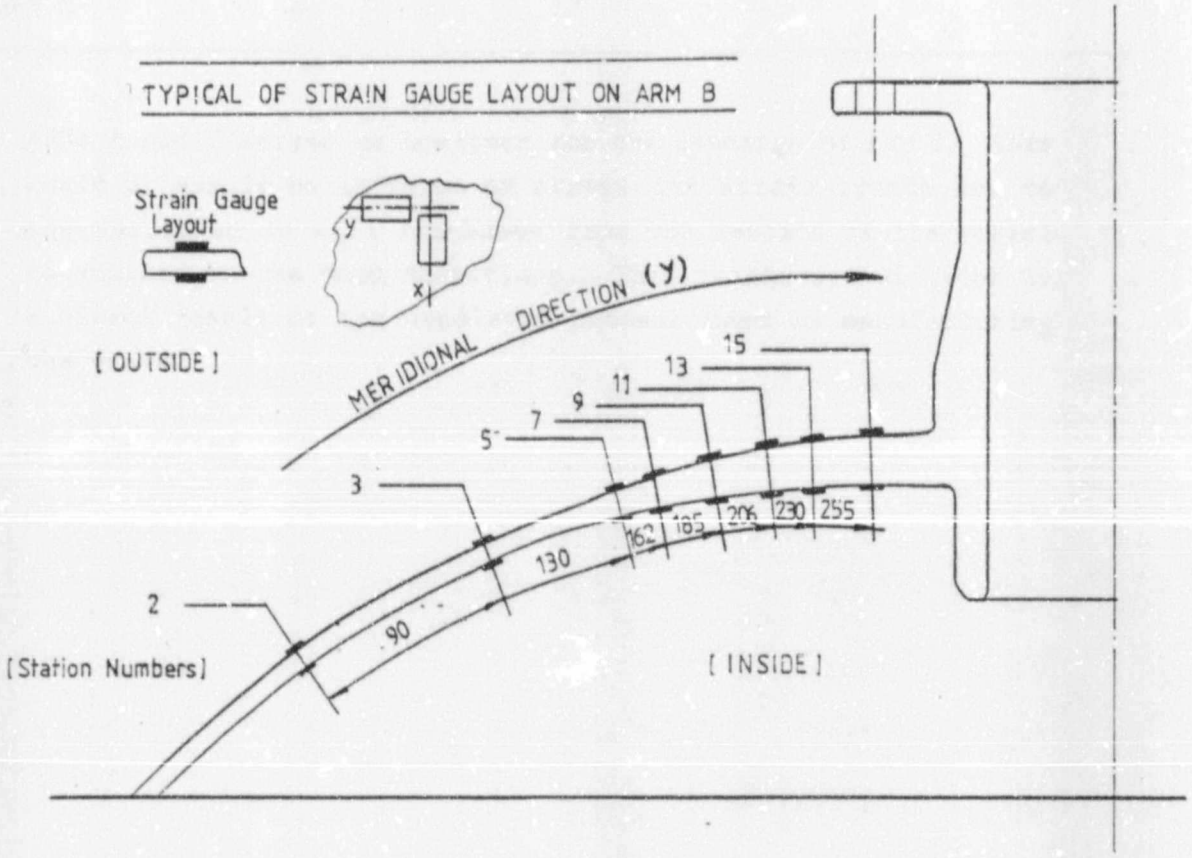


Figure 3. Detail of strain gauge arms.

Three arms of gauges were specifed as indicated in Fig 3. Arm B consisted of 9 stations with four gauges per station. This permitted the determination of strains in the hoop and meridional directions on the inside and outside of the vessel wall. Arms A and C both contained three stations each of which correspond to consecutive stations on arm B, as indicated below

Station Numbers

ARM A:				6		10		14	
ARM B:	1	2	3	5	7	9	11	13	15
ARM C:			4		8		12		

ARMs A and C served as monitors for the readings of ARM B. This would primarily be in terms of stress and strain trends due to the variation in wall thickness from one section of the vessel to another in the hoop directions. This thickness variation is a direct result of the handlayup process used in manufacturing the vessel.

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2.4 TEST PROCEDURE

The following test procedure was adopted at the experimental stage.

Operating Temperature
The operating temperature would be the ambient temperature of 20 Degrees Celsius.

Preliminary Preparation
(Performed before testing at a specific pressure)

a. Measurement of the temperature inside the hemisphere, (thermocouple) and outside the hemisphere, (thermometer)

b. Zero the manual compensator at 26000 as required in the operating manual.

c. Zero the hemisphere pressure to 0 bars. gauge.

d. Obtain the strain gauge readings at 0 bars. These serve for obtaining the strain in the gauge at a particular pressure level.

e. Hemisphere Testing procedure

Hemisphere Testing Procedure

The factor which largely contributed to the method used was the relaxation property of the glass reinforced plastic due to its low modulus of elasticity. It was found on initial test runs that the pressure would drop by 10% after 15 minutes. To overcome this the test runs proved the following

method to be suitable for reducing the pressure drop during data acquisition which occurred over a time of 15 minutes.

First Pressure Reading

a. Pressurise the hemisphere to 3% above the desired test pressure and allow relaxation for 45 minutes.

b. Restore the pressure to 3% above the desired test pressure and allow relaxation for 15 minutes.

c. Restore pressure to 1% above the desired test pressure and commence data acquisition from the strain gauges.

Second and Subsequent Pressure Readings

a. Drop the pressure to 30% below the test pressure level and permit relaxation for 30 minutes.

b. Restore the pressure to 3% above the desired test pressure and permit relaxation for 15 minutes.

c. Restore the pressure to 1% above the desired test pressure and commence with the data acquisition.

At each pressure level obtain 4 sets of strain readings as described. Once completed, reduce the pressure to 0 bars, and allow for stress relaxation for an hour, before-beginning with the preliminary preparations.

Using the above procedure, four sets of strain readings were taken at each strain gauge site for the following pressures :-

0.4 , 0.8 , 1.0 , 1.2 , 1.4 and 1.6 bars.

Due to stress relaxation of the hemisphere, test pressure drops of 2% were recorded at 1.6 bars. These did not adversely effect the data acquisition of the other readings taken at lower pressure levels.
The four sets of readings obtained at all pressure levels were processed as described in the following section.

2.5 PROCESSING OF DATA

2.5.1 CORRECTION OF THE EXPERIMENTAL STRAINS

Four sets of strain readings were found for each pressure level. A statistical approach was used in processing this data and then the group means found and corrected using a gauge correction factor.

Gauge Correction Factor

The instruction manual for the MK Compensator provided the following means for obtaining the gauge correction factor.

Strain

Final strain gauge reading (Test Pressure)
\- Initial strain gauge reading (0 bars)

Strain at measuring point (not corrected)

Factor:

The gauge factor of the compensator was set to 2 for the duration of all data acquisition. For this reason the following equation was used as the gauge factor of the gauge was 1.9.

$$\epsilon^{1} = \frac{\epsilon}{\beta} \cdot \frac{2}{k}$$

Where ϵ = strain at measuring point
ϵ^{1} = actual strain
β = Correction factor for gauge resistance
k = gauge factor of strain gauge ($k = 1.9$)

$$\epsilon^1 = \epsilon \cdot 2/(0,99933.1,9)$$
$$= 1,05334.\epsilon$$

Statistical Mean:

The t - distribution for small samples was used with a 95% confidence limit placed on the mean. The t-distribution is commonly used for sample sizes less than 30. It was believed that as four sets of readings were taken at each station for each pressure level that the use of this distribution would be satisfactory for determining the mean. This would result in a smooth curve being drawn through the data points, lower mean values. Hence the use of a Spline Curve in the Graphical outputs.

Example

The four strain readings from strain gauge 1 at 1,1 bars were 244.5, 249.5, 248.5 and 247. The t - distribution mean provided the following corrected strain.

Mean $x = 247,375$

SDEV $s = 2,175$

Correction factor = 1,05334.

Therefore 95% confidence limit of the population mean.

$$(247,375 - (2,175.2,35/\sqrt{3})) \cdot 1,05334$$

$$= 257,47$$

All lower means for each gauge at each pressue level were processed in this manner and the corrected strains used in the data processing with lamination theory.

2.5.2 LAMINATION THEORY

It was necessary that certain assumptions be taken in utilising this theory for processing the actual strains. These were:

Assumptions

1. The thickness of each laminate element was determined to investigate purely the structural components of the hemisphere laminate. For this reason resin rich areas were sanded away prior to gauge installation.

2. For the theory it was taken that both sides of the laminate were parallel. This essentially is true for the hemisphere wall but on the overlay region slight displacement of 1-3 degreees on opposite faces was found. This may give rise to discrepencies in the stress value approximations.

3. The curvatures and the strains in the xy direction were taken to be zero as this is an axisymmetrical pressure case with no applied torque.

4. The calculation of the curvature was approximated to be equivalent to the ratio of the difference between the inside and the outside strain divided by the total laminate thickness. This was considered necessary as a result of the difficulties involved in the experimental measurement of this value.

5. Chopped strand mat has been considered as an isotropic material.

6. Woven roving was considered balanced in strength in both principal directions and was assumed to be orthotropic.

2.5.3 ELEMENT LAMINATE STRUCTURE

As previously described in section 2.2 on specimen data, burnoffs were taken of each element. This permitted the determination of the type of glass used, and its direction of layup within the laminate. These are more clearly displayed in Table 3.

A computer program was developed to determine the mechanical loadings particular to each element at the various pressure levels. These properties were:

- curvature
- midplane strains
- unit forces
- unit moments
- stresses

The above results were for both the hoop and the meridional directions on the inside and the outside of the hemisphere wall.

The use of lamination theory equations permits the determination of the stresses at specific points along the thickness of the laminate. In this case the stresses in each lamina were also determined. The values were, however, not used for analysis but rather provided an indication of the possible stresses within the laminate.

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Name of thesis Stress Concentrations Around An Axisymmetrically Attached Nozzle On A Glass Reinforced Plastic Hemispherical Dome. 1987

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