STRESS CONCENTRATIONS AROUND AN AXISYMMETRICALLY ATTACHED NOZZLE ON A GLASS REINFORCED PLASTIC HEMISPHERICAL DOME.

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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(Signature of candidate)

7 day of DECEMBER 1987.

ABSTRACT

The need for intensive research on an aspect of hand-laid-up vessels was considered relevent for validating the theory provided in a locally used vessel design Standard. This resulted in the stress concentration around an axisymmetrically placed nozzle on a hemispherical dome being analysed.

The 1054 mm diameter dome and the 100 mm diameter nozzle attachment were designed according to BS 4994 (1985) for a test pressure of 2 bars. The construction was of chopped strand mat and woven roving cloth laminated with Derakane 470-36 vinyl ester resin using the handlayup manufacturing technique.

The hemisphere was hydraulically tested up to a pressure of 1.6 bars at 0.1 bar intervals. Strain readings were obtained in both the hoop and the meridional directions, inside and outside the vessel wall. The data obtained permitted the determination of the the midplane strains , curvatures, forces, moments and stresses using the principles of Classical Lamination Theory.

An analysis was made of the bending and plane stress components together with a comparison of the experimental results with those obtained using two isotropic computer models.

The findings have provided information regarding the use of symmetrical laminates on the vessel wall and the asymmetrical laminate requirement of the nozzle overlay region. The validity of using simple FEM models to predict the stress distribution around the attachment is shown with proof that the BS 4994 vessel design code provides theory adequate for the design of nozzle overlays on internally pressurised hemispherical domes.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF FIGURES

LIST OF GRAPHS

LIST OF PLATES

LIST OF TABLES

1.0 INTRODUCTION

South African industry over the past decade has experienced substantial growth in the use of Glass Reinforced Plastics (GRP) in the chemical process industry. To a large extent this can be attributed to the chemical resistant properties of the resin systems used and the versatility of the material, which permits a vast range of applications in this sector of industry. The question which remains however is, " What is the design basis for the introduction of GRP to the chemical industry, particularly in the vessel and tank market ? "

Considerable progress has been made in the development of mathematical models for analysing the fibre/matrix systems in aerospace technology. These theories may involve invariant stiffness matrix theory or the theories enclosed in classical lamination theory for examining the behaviour of orthotropic and anisotropic materials under load. The theories form a sound foundation for the designer of GRP products but their complexity provides little grounds for use in the general industry.

It was with this in mind that various countries in the late 1960's and early 70's formulated GRP pressure vessel design standards. The most widely known being the German Merkblatt (1969), the American ASME X (1973) and ASTM D3299 (1975) and the British BS 4994 (1973). It became possible for more consistency to be maintained in designing with GRP for a particular application.

To a large extent, the standards are applicable mainly to their country of origin. i.e. ASME X deals with the vacumm bag and filament winding processes whereas BS4994 is primarily orientated towards the handlay up process. Local industry is thus in the position where the necessity arises to gravitate toward a standard which is geared to the capabilities of its manufacturers.

A survey of internationally recognised design standards reveals that BS4994 is the most suitable standard for use in the South African GRP industry. This primarily results from the extensive design method described which is orientated around the handlayup process and the use of raw materials such as resin and glass mats which are locally available.

The standard whilst being comprehensive in the procedures stipulated has largely been adapted from theory on steel vessels. The necessity for continued research must thus be undertaken to validate the applicability of the models stipulated for designing wall structures, seams and the nozzle compensation laminates in GRP.

Stress concentration is a prime concern in designing vessels built for high pressure applications. Areas such as support atttachments, seams and nozzle attachment areas are some of the more obvious high stress concentration areas found on a vessel. Although general views are to increase wall thicknesses to reduce local stresses, the obvious may have the opposite affect.

It was with this that the author embarked on a project in which the stress concentrations around an axisymmetrically positioned nozzle on an internally pressurised GRP hemispherical dome were analysed. The aim was to validate the theory used in BS 4994 (1985) and to compare the results with those found from simple isotropic FEM models.

It is hoped that a meaningful contribution has been made to furthering our understanding of the behaviour of glass reinforced plastic materials with applications in the industrial sector.

1.1 LITERATURE SURVEY

The survey provides an overview of international vessel and tank design procedures applicable to glass reinforced plastic (GRP) materials. This is followed by literature which pertains more directly to the stress concentrations found around nozzle attachments on pressure vessels and tanks. The difficulty in obtaining literature which deals specifically with this aspect of GRP vessel design has led to the use of information on research undertaken on steel vessels.

The details on stress concentrations on steel vessels has been compared to the relevant GRP vessel analyses where applicable.

1.1.1 PRESSURE VESSEL DESIGN PROCEDURES.

The anisotropic nature of GRP has caused the development of various theoretical approaches for its analysis. These particularly in GRP vessel design, have varied from the isotropic thin shell theory approach to macromechanical theories. The study of GRP laminates in chemical environmants however, has further necessitated the addition of safety factor considerations for pressure vessel design. These account for the material strength losses due to chemical stress corrosion and material defects.

Safety Factors:

BS 4994, has approached the design safety factor aspect as follows. It considers vessel lining, manufacturing technique, temperature, cyclic loading and cure applicable. A factor of 3 is included to account for material strength losses due to long term loading. The German Merkblatt (1969) however, suggests a safety factor together with a material factor. The effect of cyclic loading, inhomogeneities and temperature are contained in the material factor together with an additional anisotropy contribution. The American ASME X (1971), using data accumulated over 15 years, suggests that a laminate stressed at 25% to its tensile strength will have a fatigue life of 250 000 cycles. It also includes that the maximum design temperature is limited to 65 Celsius. BS 4994 however, permits temperatures up to 120 Celsius with a respective temperature factor consideration which is dependent on the heat distortion temperature of the resin.

Anisotropy is not dealt with in BS 4994 and Owen.M.J. (1982) considers this a shortcoming of the Standard. However, as conservative material Unit Strengths and Extensibilities are advised, the transverse and longitudinal material strengths are similar when using balanced woven rovings as glass reinforcement. Owen states that the Standard is solely applicable to the use of balanced woven roving mats and chopped strand mats as vessel reinforcement materials.

The standard further remains unique in that it utilises a unit loading method for determining the laminate thicknesses required. This is as a result of theory derived from BS 2782 (1982). ASME X provides minimum design tensile strength values which correspond to the particular type of vessel manufacture to be used ie. Bag moulding, Centrifugal Casting and Filament Winding. The ASTM D3299 similarly provides a minimum design tensile strength for contact moulding. These are related, in Table 1 of the Standard, to the expected thickness of the laminate. These figures also show an increase in the tensile value with thickness. Whilst these expected strengths may be valid in the short term, none of the standards provide safety criteria for vessels in aggressive chemical enviroments over long term periods. This would largely be dependent on the type of liner used and its material and method of construction.