Burst Strength and Impact Performance on Glass Fibre Reinforced Epoxy (GRE) Composite Pipes

by

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A thesis submitted in fulfilment of the requirements for the degree of
Master of Science in Mechanical Engineering

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2016

ACKNOWLEDGEMENT

First of all, I would like to express my sincere thanks and deep gratitude to my supervisor Dr. Mohd Shukry bin Abdul Majid for his guidance, insight, and patience throughout the research. I greatly appreciate dedication, attention and patience provided by him throughout the course of this study.

Thanks are due to my co-supervisor, Dr. Mohd Afendi bin Rojan and technician, Mr. Muhamad Aliff bin Mad Yusof for their constructive guidance, technical support and also for giving permissions to work in the Solid Mechanics and Acoustics Laboratory at School of Mechatronic.

The technical support and help provided by my senior colleague, Pranesh Krishnan in conducting experimental work is highly appreciated. The sincere and untiring efforts by him in preparing the experimental program and set-ups utilized in this study are also highly acknowledged.

Special thanks also goes to Advanced Material Research Centre (AMREC), SIRIM Berhad, for manufacturing of the filament wound composite pipes and all the research fellows involved in this project, especially from the School of Mechatronics Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia.

Last but not least, I specially wish to thank with deep gratitude and appreciation to my family for their never-ending patience, motivation and moral support during the period of my study at UniMAP.

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SYMBOLS

θ	Winding angle (°)
τ	Shear stress (MPa)
γ	Shear strain
σ	Stress (MPa)
ε	Strain
ρ	Density (g/cm^3)
σ_1, σ_2	Ply stresses in longitudinal and transverse direction (MPa)
ε_1, ε_2	Ply strains in longitudinal and transverse direction
ν_{12}, ν_{21}	Ply Poisson‟s ratio in longitudinal and transverse direction
σ_a, σ_h	Pipe stresses in the axial and hoop direction (MPa)
ε_a, ε_h	Pipe strains in the axial and hoop direction
ν_f, ν_m	Fibre and matrix Poisson’s ratio
A	Area (mm^2)
A_d	Damage area (mm^2)
C_m	Moisture content (%)
D	Diffusion coefficient (mm^2/s)
D_o	Outer diameter (mm)
d	Internal diameter (mm)
E	Impact energy (J)
E_1, E_2	Ply Young’s Modulus in longitudinal and transverse direction (GPa)
E_a, E_h	Axial and hoop Young’s Modulus (GPa)
E_{abs}	Absorbed energy (J)

E_f, E_m	Fibre and matrix Young's Modulus (GPa)
F	Force (kN)
G	Shear modulus (GPa)
G_f, G_m	Fibre and matrix shear modulus (GPa)
L	Length of specimen (mm)
n	Number of layer(s)
P_b	Burst pressure (MPa)
RH	Relative humidity (%)
S	Displacement (mm)
t	Wall thickness (mm)
t	Time (ms)
t_a	Ageing time (h)
V_f, V_m	Fibre and matrix volume fraction (%)

ABBREVIATIONS

ASTM	American Society for Testing and Materials
GRE	Glass fibre reinforced epoxy
GRP	Glass fibre reinforced plastic
SEM	Scanning electron microscopy
UEWS	Ultimate Elastic Wall Stress

Kekuatan Letusan dan Perlaksanaan Hentaman pada Paip Komposit Gentian Kaca Bertetulang Epoksi

ABSTRAK

Perubahan pada mekanisme paip komposit GRE boleh berlaku di dalam matriks, gentian kaca, dan lapisan antara gentian kaca-matriks disebabkan oleh kerana penyerapan air yang terjadi semasa digunakan, Paip komposit tersebut juga mungkin boleh terkena beban hentaman ketika proses pembuatan, pemasangan atau semasa dalam tempoh perkhidmatan. Kajian ini melibatkan penyelidikan eksperimental mengenai perubahan bentuk dan kegagalan pada paip komposit GRE yang tidak direndam dan direndam apabila dikenakan beban hentaman dan ujian letusan monotonik. Paip komposit direndam di dalam air paip pada suhu 80°C bagi masa 500, 1000 dan 1500 jam untuk mensimulasikan dengan persekitaran perkhidmatan, dan pada masa yang sama untuk mendapatkan keputusan yang boleh dipercayai hasil daripada ujian makmal. Pada akhir tempoh pemeraman, paip dikenakan beban hentaman pada suhu bilik dengan tiga tahap tenaga yang berbeza, iaitu 5 J, 7.5 J dan 10 J sebelum menjalani ujian letusan monotonik. Model hiperbolik tangen memperlihatkan ramalan yang lebih baik untuk kadar resapan kelembapan apabila dibandingkan dengan keputusan eksperimen. Daripada keputusan eksperimen dan analisis matematik, ia adalah jelas bahawa modulus paip komposit GRE mengalami kemorosotan (27% di arah aksial dan 15% di arah gegelang) yang disebabkan oleh resapan air. Keputusan eksperimental menunjukkan bahawa apabila tenaga hentaman meningkat, daya kemuncak, sesaran, dan tenaga terserap juga meningkat. Peningkatan pada tenaga terserap menandakan bahawa lebih banyak tenaga digunakan dalam perkembangan kerosakan pada paip. Paip yang dikenakan beban hentaman dan mengandungi kadar penyerapan melebihi 1% meghasilkan kekuatan letusan yang rendah dan kadar baki kekuatan letusan juga menurun lebih kurang 50%. Kerosakan seperti rembesan dan letusan diperhatikan berlaku berdasarkan kepada tenaga impak digunakan.

Burst Strength and Impact Performance on Glass Fibre Reinforced Epoxy (GRE) Composite Pipes

ABSTRACT

While in service environment, the changes in the degradation mechanisms of the GRE composite pipes may occur in the matrix, fibre, and the fibre-matrix interfacial regions due to water diffusion. These composite pipes may also be subjected to impact loads, during manufacturing, installation or while in service. This research involves an experimental investigation of the deformation and failure on unaged and aged GRE composite pipes through the impact loadings and monotonic burst tests. Pipes were aged in tap water temperature at 80°C for periods of 500, 1000 and 1500 h in order to simulate in service environments, while trying to obtain reliable results from accelerated laboratory tests. At the end of ageing condition period, the pipes were impacted at room temperature for three different energy levels, which are 5 J, 7.5 J and 10 J before subjected to monotonic burst tests. The hyperbolic tangent model produced better predictions of moisture diffusion rate to the experimental results. From the experimental results and mathematical analysis, it was evident that the modulus of GRE pipes were significantly degraded (27% in axial and 15% in hoop direction) due to water diffusion. The results indicated that as the impact energy increase the peak force, displacement and absorbed energy also increased. The increased absorbed energy signifies that more energy was consumed in damage growth of the pipes. The impacted pipes have been subjected to moisture absorption content above 1% yielded lower burst strength and the ratio of the residual burst strength also reduced rapidly by about 50%. Weepage and eruption failures were observed depending on the applied impact energies.

CHAPTER 1

INTRODUCTION

1.1 Background

A composite material can be defined as a combination of two or more materials that results in better properties compared to those of the individual components used alone or conventional materials. The general constituent in composite material is a reinforcement and matrix. The main advantages of composite materials are their high strength properties, good corrosion resistance, lightweight and it can offer considerable price savings through the use of their beneficial material properties (Agarwal and Broutman, 1980; Hull and Clyne, 2010). Composites have ended up being a commendable option compared to other conventional materials, even in the high-pressure and extreme environmental conditions, basically within the research and manufacturing fields.

Other than excellent in corrosion resistance, composite materials also feature an excellent fatigue performance, and good resistance to high temperature, especially in industrial sectors. The ability of composites to suit particular applications has been one of its most desirable benefits, for example granting the low thermal conductivity and low coefficient of thermal expansion.

Composites are rapidly adopting as a perfect solution to other conventional materials, even in high pressure and excessive environmental circumstances. Uses of composite are expanding drastically together with the simultaneous demand for knowledge generation in the field. With technological innovations and developments in processes and products, composites have become ideal selection for applications in oil and gas, piping system, topside applications, undersea piping, and others.

Presently, composite materials have gained wide demands in the aerospace, transportation, infrastructure and oil and gas industries since the last two decades. Critical improvements have been made in the areas of composite pipe function and fluid handling. The expensive cost to repair steel piping in underground or undersea applications and increased lifespan in latest development are generating the utilization of composites, which endure extreme conditions as experienced in the offshore environment.

In the aerospace industry, low weight is a major point for performance and freight reasons, and composite often approaches 20-40 percent of the airframe weight. For quite a long time, helicopters have incorporated glass fibre reinforced rotor blade for improved fatigue resistance. Both small and large commercial aircraft depend on composite to decrease weight as well as increase fuel performance, for example the Boeing and Airbus aircraft use large amounts of composite for the airframe.

Uses of composite materials to improve the infrastructure of roads, bridges, light poles and electric towers are a brilliant idea. Most of the roads and bridges are seriously corroded and in need of persistent maintenance. Composite offers much longevity with less maintenance because of their corrosion resistance. Maintenance costs are therefore less than for comparable structures in conventional materials such as concrete, steel and wood.

In the oil and gas industry, composite pipes was utilized for sea water cooling lines, air vent systems, drilling fluids, fire fighting, ballasts and drinking water lines because their simplicity of taking care and repair. Their resistance to corrosion helps in enhancing dependability and safety and additionally prompts lower life cycle costs. These results in diminished issues with corrosion and blockage of fire lines, reduction in structural support sizes and material handling during development. The composite piping system is also being used on underground transportation such as petrochemical, oil refineries, waste water, oil transportation where resistance to crude oil, paraffin build-up as well as ability to withstand relatively low and high pressures is required.

1.2 Problem Statements

Glass fibre reinforced epoxy (GRE) composite pipes are generally designed for undersea and underground transportation of fluid materials, for example all natural gas, oil, thermal water, waste water, as well as drinking water. The burst failure pressure of GRE composite pipes is a critical parameter that needs to be focused on, considering the fact that they may subjected to impact loads during their service life period. Impact loads could potentially damage the inner layer of the composite pipes, which commonly goes unnoticed by visual inspection. All of these problems raise significant concerns regarding the long-term strength of the GRE pipes and constitute issues that require solutions before the GRE pipes are widely use in applications such as undersea and underground transportation of fluid materials.

1.3 Objectives

This study embarks on the following objectives:

- To investigate the effects of hydrothermal ageing on glass fibre reinforced epoxy (GRE) composite pipes due to impact loading.
- To establish the relationship between immersion time and impact behaviour on burst strength of glass fibre reinforced epoxy (GRE) composite pipes.
- To analyse the damage mechanisms after monotonic burst test through a scanning electron microscope (SEM) analysis.

1.4 Scope

The GRE composite pipes are commonly produced by the filament winding technique. After the composite specimens were cut into required size, it was immersed in 80°C water for periods of 500, 1000, and 1500 h to simulate the ageing effects. An instrumented impact testing machine with the drop weight system was used to carry out the impact tests. Then the impacted specimens proceed with internal hydrostatic monotonic burst tests to determine the deformation behaviour of the composite pipes. Scanning electron microscopy (SEM) was used to analyse and characterize the inner and outer surface of the damage pipe wall.

1.5 Thesis Organization

This research report is divided into five chapters which consist of introduction, literature review, methodology, results and discussions, and conclusion of the investigation. Each of the chapters will have the sub-chapter in it.

The introduction of an investigation on the effects of hydrothermal ageing on impact behaviour and burst pressure strength of glass fibre reinforced epoxy (GRE) composite pipes will be stated in Chapter 1. In this chapter, there will wrap of general description of composite materials, problem statement, objectives, scope of work, and the last one was the thesis organization of this study.

The previous works and researches that related to this investigation are thoroughly reviewed in Chapter 2. Firstly, the information regarding glass fibre reinforced epoxy (GRE) was collected from previous works obtained from journal articles, theses and research reports, books, and information from internet were discussed. This chapter continues with discussion of environmental effects on composite pipes, the performance impact behaviour of composite pipes and will conclude with the monotonic burst tests. From this chapter, the result of this investigation can be predicted. All the knowledge gained for this chapter will be used as references to carry out the experimental tests.

Next, the implemented to achieve the objectives of this investigation was covered in Chapter 3. The dimension of specimens used for the tests is included. This chapter will cover on the method and facilities that have been used to carry out the tests. Controlled parameter of experiments are also included to ensure the system performing smoothly and satisfactorily. The micromechanics of GRE pipes are also covered at the end of this chapter, where including the mathematical validation of the moisture diffusion rate, and laminate theory to determine elastic reduction.

Chapter 4 will present the result of experimental tests. The discussions of the results obtained from tests will also be included. The obtained results will be comparable with theoretical and previous works of other researchers.

This study will be concluded in Chapter 5 which is the last chapter in this thesis. The conclusion is made based from the starting until the end of this research which also included the summary of experimental results. The future improvements and also latest studies that are relevant to this research were stated as the recommendation for future works.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The purpose of this literature review chapter is technically to gather knowledge from previous work about the project title such as reference books, magazines, journals, technical papers and websites. In this chapter, the information gathered from the variety of sources will be discussed in more detail. First, the background of GRE composite pipes, how does it produce and its constituents are elaborated. Then, the literature review regarding the effect of environmental conditions on the mechanical properties of composite materials are presented. At the end of this chapter, the impact behaviour and hydrostatic monotonic burst test of composite pipes had also been presented.

2.2. Glass fibre reinforced epoxy (GRE) composite pipes

Currently, the most common used composite pipes is a filament-wound glass fibre reinforced epoxy (GRE) composite pipes (EMCO, 2015). GRE composite pipe consist of fibres of high strength and modulus embedded bonded to a matrix with distinct interfaces between them. In this form, both fibres and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannnot be achieved with either of the contituents acting alone.

The most common form in which GRE composite pipes are used in structural application is called a laminate, which is made by stacking number of thin layers of fibres and matrix and consolidating them into the desired thickness. Fibre orientation in each layer as well as the stacking sequences of various layers in composite laminate can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

A typical GRE pipe subjected to pure hydrostatic pressure is fabricated with an optimum wind angle of ± 55° to the longitudinal (0°) axis (Gemi, Tarakçioğlu, Akdemir, and Şahin, 2009; Onder, Sayman, Dogan, and Tarakcioglu, 2009). The filament winding helps in providing better strength and stability for internal and external loading in both the circumferential and longitudinal directions for the pipes and pressure vessels. Such wound pattern attains resistance to high internal pressures, thermal variations and the impact loads induced by thrust due to water pressure. The appropriate joining procedures for composite piping and supporting systems was assumed importance for better system performance.

Being made up of various layers of glass fibres and resin, GRE composite is not a homogenous material. For this reason, it exhibits different elastic moduli in the axial, hoop and radial directions. Due to the particular orientation of the reinforcing fibres, the permissible strains and proportional elastic limits also differ according to direction.

GRE composite piping system can withstand the detrimental effect of brackish water when expelled under pressure from fire mains (Fig. 2.1). The effect of rupture free GRE composite pipes under such shocks makes the system more reliable. Its offers complete solution for offshore environment against highly corrosive fluids at various pressures, temperatures, adverse soil and weather conditions.

Figure 2.1. Use of GRE composite pipes in the oil and gas industries (EMCO, 2015).

2.3. Manufacturing process of GRE composite pipes

Filament winding is the method most commonly used to produce GRE composite pipes. It is traditionally used to produce cylindrical and spherical products such as chemical and fuel storage tanks and pipe, pressure vessels and rocket motor cases. Furthermore, the winding angle can be adjusted to give the required balance of hoop and axial properties.

To begin with, a large number of fibre roving is pulled from series of creels into bath containing liquid resin, catalyst and other ingredients such as pigments and UV retardants. Fibre tension is controlled by the guides or separator combs located between each creel and resin bath. Just before entering the resin bath, the rovings are usually gathered into a band by passing them through a textile thread board or stainless steel separator comb.

At the end of the resin tank, the resin-impregnated rovings are pulled through a wiping device that removes the excess resin from the rovings and controls the resin coating thickness around each roving.

The most commonly used wiping device is a set of squeeze rollers in which the position of the top roller is adjusted to control the resin content as well as the tension in fibre rovings. Another technique for wiping the resin-impregnated rovings is to pull each roving separately through an orifice.

The latter method results in better control of resin content. Once the rovings have been thoroughly impregnated and wiped, they are gathered together in a flat band and positioned on the mandrel.

Band formation can be achieved by passing through a nip roller and later through the guide eye (Fig. 2.2). The transverse speed of the carriage and the winding speed of the mandrel are controlled to create the desired winding angle patterns.

After winding, the filament wound mandrel is subjected to curing and post curing operations during which the mandrel is continuously rotated to maintain uniformity of resin content around the circumference. After curing, product is removed from the mandrel, either by hydraulic or mechanical extractor.