UNIVERSITI PUTRA MALAYSIA

MECHANICAL CHARATERIZATION OF S-GLASS AND E-GLASS REINFORCED EPOXY COMPOSITE ELBOW PIPE JOINTS SUBMERGED IN SEA WATER

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By

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MECHANICAL CHARACTERIZATION OF S-GLASS AND E-GLASS REINFORCED EPOXY COMPOSITE ELBOW PIPE JOINTS SUBMERGED IN SEA WATER

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August 2019

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In many engineering applications composite pipes are generally used because of their high strength and stiffness, excellent fatigue and corrosion resistance. More than 70 percent of the world’s oil and gas transport pipelines are beyond 40 years old and there is a need to change them due to their gradual degradation in their operating environment.

This research experimentally investigated the implication of sea water immersion on the impact behaviour of glass/epoxy composite elbow pipe joints. Glass-epoxy elbow pipe joints with E-glass and S-glass were fabricated using hand lay-up method. The pipe joints were immersed under sea water for 3 and 6-month periods, after which they were impacted according to ASTM D2444 at three different energy levels of 10 J, 12.5 J and 15 J at room temperature. Then they underwent monotonic burst pressure tests (ASTM D1599) and axial compression tests (ASTM D695–15). Finally the split disk tests (ASTM D2290) were performed on the untreated E-glass and S-glass pipe rings. The results showed that the contact force was higher in E-glass pipe joints with a mean value of 1.8 kN compare to 0.98 kN in S-glass pipe joints. S-glass pipe joints also showed maximum final displacement of 8 mm whereas it was only 6.5 mm for the elbow joints fabricated with E-glass. It was observed that the axial compressive strength was 957.50 MPa in the S-glass elbow pipe joints and was only 339.87 MPa in the elbow joints fabricated with E-glass fiber. Eruption and weepage failures were detected from the burst pressure tests in accordance to the applied impact energies and exposure time to sea water. At the pressure of 17.23 MPa, the E-glass elbow pipe joints damage was discovered to rupture but samples made of S-glass fiber have achieved whiteness first and then after reaching the pressure of 18.1 MPa the samples ruptured. The split disk tests concluded that the performance of tubular specimens under internal pressure

developed high hoop stresses of 17.11 MPa and 22.24 MPa respectively for the E-glass and S-glass tubular rings.

It can be concluded that after impact, internal pressure, axial compressive strength and hoop tensile strength, S-glass elbow joints showed more elastic nature, strain efficiency and strength when compared with the E-glass elbow pipe joints under both dry and submerged in the sea water.

Abstrak tesis yang disampaikan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN MEKANIKAL SENDI SIKU PAIP KOMPOSIT EPOKSI DIPERKUKUH S-KACA DAN E-KACA DIRENDAM DALAM AIR LAUT

Oleh

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Dalam kebanyakan aplikasi kejuruteraan paip komposit secara amnya digunakan kerana kekuatan dan kekukuhan tinggi, kelesuan dan rintangan kakisan yang cemerlang. Lebih daripada 70 peratus pengangkutan talian paip minyak dan gas dunia adalah melebihi 40 tahun dan terdapat keperluan untuk menukar mereka disebabkan oleh kemerosotan secara beransur-ansur dalam persekitaran operasi mereka.

Penyelidikan ini mengkaji implikasi rendaman air laut terhadap tingkah laku kesan paip/epoksi komposit sendi siku paip. Sambungan siku paip kaca-epoksi dengan E-kaca dan S-kaca dibuat dengan menggunakan kaedah "hand lay-up". Sambungan paip direndam dalam air laut selama tempoh 3 dan 6 bulan, selepas itu mereka diimpak menurut ASTM D2444 pada tiga tahap tenaga yang berbeza iaitu 10 J, 12.5 J dan 15 J pada suhu bilik. Kemudian diikuti oleh ujian tekanan letusan monotonik (ASTM D1599) dan ujian mampatan paksi (ASTM D695-15). Akhirnya ujian pecahan cakera (ASTM D2290) dilakukan pada gegelang E-kaca dan S-kaca yang tidak dirawat. Keputusan menunjukkan daya sentuahan yang lebih tinggi dalam sambungan E-kaca dengan nilai min 1.8 kN berbanding 0.98 kN dalam sendi paip S-kaca. Sendi paip S-kaca juga menunjukkan anjakan terakhir maksimum 8 mm manakala hanya 6.5 mm untuk sendi siku yang difabrikasi dengan E-kaca. Diperhatikan bahawa kekuatan mampatan paksi adalah 957.50 MPa pada sendi siku paip yang dibuat dengan S-kaca dan hanya 339.87 MPa pada sendi siku yang dibuat dengan gentian E-kaca. Kegagalan letusan dan kelelehan dikesan dari ujian tekanan letusan mengikut tenaga yang dikenakan dan masa pendedahan kepada air laut. Pada tekanan 17.23 MPa, kerosakan sendi siku paip E-kaca didapati pecah tetapi sampel yang diperbuat daripada serat S-kaca telah mencapai keputihan pertama dan kemudian selepas mencapai tekanan 18.1 MPa sampel pecah. Ujian cakera pecah menyimpulkan bahawa prestasi spesimen tiub di bawah tekanan

dalaman menghasilkan tekanan gelung tinggi 17.11 MPa dan 22.24 MPa masing-masing untuk gegelang tiub E-kaca dan S-kaca.

Kesimpulannya, selepas impak, tekanan dalaman, kekuatan mampatan paksi dan kekuatan tegangan gelung, sendi siku S-kaca menunjukkan sifat elastik, kecekapan dan kekuatan terikan yang lebih tinggi apabila dibandingkan dengan paip siku E-kaca di bawah keadaan kering dan ditenggelami air laut.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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This is to conform that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

ASTM	American standard for testing and materials
ASME	American Society of Mechanical Engineers
CNC	Computer numerical control
CFRP	Carbon fiber reinforced polymer
DAQ	Data acquisition
GF	Glass fiber
GFRP	Glass fiber reinforced polymer
SEM	Scanning Electron Microscope
MPa	Mega Pascal
MPD	Meta phenylene diamine
SDM	Successive damage model
TEM	Transmission electron microscope
HTS	Hoop tensile strength
UTM	Universal testing machine
ISO	International Organization for Standardization

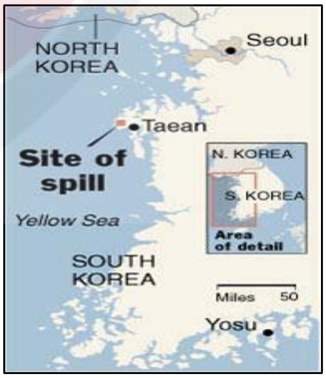
LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

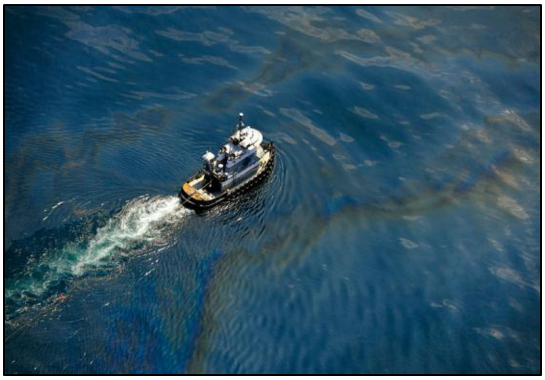
1.1 Background of the research

The most commonly used pipe systems for fluid transportation are constructed by glass fiber reinforced plastic composites, also known as fiberglass composites pipelines are commonly utilized in the oil and gas industry equally in offshore and onshore functions. After various years of function in the corrosive surroundings, present steel pipelines may experience in or out metal deficiency due to erosion and corrosion destruction methods. More than 70 percent of the world's oil and gas transport pipelines are beyond than 40 years old and in the case of the maximum part it is in need to change them in order to reproduce the actual organizing capacity. Subsea pipe line system is used to connect the offshore production platforms to onshore production platforms. Inspection of the pipe line system is done on regular basis but in few cases where the danger is not predicted the failure of the system may occur. Few instances such as, firstly the Hebei Spirit oil spill on December 7, 2007 near Mallipo Beach-Taean County was the nastiest oil spill noted in Korea, with the release of crude oil due to high pressure level in the pipe lines of approximately 10,900 tons around 376 km of seashore polluted near the west coast of Korea as shown in Figure 1.1. Secondly the explosion in the deep water horizon oil rig in the Gulf of Mexico on April 20th, 2010 as shown in the Figure 1.2 where the damage was unpredictable and took few months to recover from the damage caused and to retain to its original state, sometimes these pipelines may go to degradation process due to an impact load produced due to pressure variations in the liquid out and in of the medium in which aging might be one of the utmost factors to cause the damage as possible due to the immersion of fiber reinforced pipelines under sea water as shown in the Figure 1.3.



(a) (b)

Figure 1.1: (a) Volunteer workers collecting oil from the beach during the Hebei Spirit oil spill on December 7, 2007 near Mallipo Beach (b) Site of leakage



(a) **(b)**

Figure 1.2: (a) A tug boat moves through the oil slick (b) Oil burns after the eruption of crude oil due to pressure impacts (Justin E. Stumerg /U.S Navy via Getty images)

More or less all the fiber reinforced plastic materials in the facility are exposed to the environmental moisture at unusual temperatures and therefore this attribute of the composites has expected significant attention. In composites, water absorption is a convoluted performance, which can be subjected to various problems, such as the cured38agent and resin, void proportion, prepreg properties, fabrication. Water absorption has the momentum to rise the evolution of damages in the interior parts of the composites and causes novel damages.

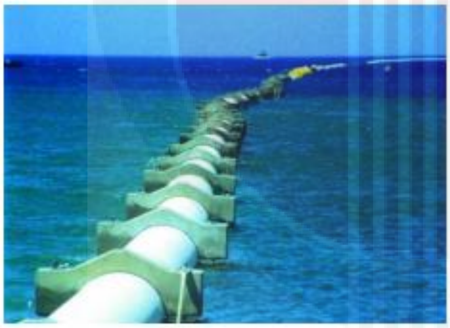


Figure 1.3: Sea water in-take pipes (www.reinforcedplastics.com)

Pipe failures are generated by concern forces which over reach the normal residual strength of the pipe medium. Pipe deterioration happens when the stresses of both operative and environmental react on pipe lines where corrosion, deterioration, in sufficient installation or manufacturing problems has influenced the pipes structural strength. The physical process of failures in pipe lines is normally a complicated function of many subscribing factors. This shows pipe line properties such as area, material, internal and external storing and environmental issue (Linkens et. al. 1998). Consequently, various other failure localities can be noticed including joint contact failure, breakable failure, crack pipe, transversal break, graphitization, pitting holes, long term and circumferential failures, circular cracking and finally blowout hole. When comparing the aspects for failure, physical characteristics such as material type, size and temperature have been analysed as the most prominent factors.

The present study focused of the analysis on the issue of the strength depletion of the E-glass composite pipe joint after the low energy impact is valuable for lot of applications. In this context, the effect of low velocity impact on the mechanical parameters such as impact reaction, internal pressure and axial compression strength of two different glass (E-glass, S-glass) fiber reinforced composite pipe joints is presented.

1.2 Problem statement

The amount of failures that occur due to rupture by external impact and eruption or leakage due to the rise in the internal pressure in the straight composite pipe lines are quiet less rather than the failures that occur in a composite pipe joints. The factors could be because of the flow which is turbulent in the pipe joints and pressure level of the fluid which is more when compared to straight line pipe joint. In some circumstances these pipe joints are unprotected to severe environmental surroundings which lead to the loss of their material parameters. These glass/epoxy composite pipe joints are sometimes are been exposed to impact loading and pressure impacts which produce different damages in the pipe joint in the form of matrix breakage, stratification, fiber deterioration, fiber–matrix breakage and fiber drag-out. These damages will cause an extensive contraction in fundamental rigidity of composite pipe joints. In this framework, many scholars have made attempts to figure out the impact state of composite fixture (Deniz et. al. 2012, Kara et. al 2014, Gemi et. al. 2017, Naik. 2005). But still so far, a less amount of investigates have been done on the environmental and impact failures of composite pipe joints.

The current study, research is performed on composite elbow pipe joints rather than considering all the joints such as T-joint, three way joints because in a pipeline structure the maximum extent of the structure is piled up with elbow pipe joints rather than other pipe joints. When it comes to the point of fibers used in the fabrication of elbow joints E-glass and S-glass fibers were used but E-glass fibers have few draw backs namely high density, low tensile strength and low thermal stability when compared to other glass fibers. This research is motivated and drawn from the above sequential problems.

In order to address the above mentioned drawbacks of E-glass composite elbow pipe joints, the E-glass fiber was replaced with S-glass fiber and proposed resin. By implementing S-glass fiber with proposed resin it will enhance the durability, strength, stiffness of the composite elbow pipe joints. The results obtained from S-glass fiber/epoxy composite elbow joints will be compared with the existing E- glass fiber/epoxy composite elbow joints based on the impact energy absorption, internal pressure, compression resistance and stiffness tests.

1.3 Objectives of the Research

The aim of this study was to replace the existing E-glass fiber reinforced epoxy composite elbow joints with the proposed S-glass fiber reinforced epoxy composite elbow joints by performing various mechanical tests. The specific objectives were:

1. To determine the mechanical properties of the existing E-glass fiber reinforced epoxy elbow pipe joints by performing mechanical tests under dry conditions.
2. To determine the mechanical properties of the proposed S-glass fiber reinforced epoxy elbow pipe joints by performing mechanical tests under dry conditions.
3. To compare the mechanical properties between the existing E-glass fiber and the proposed S-glass fiber reinforced epoxy elbow pipe joints submerged under sea water.
4. To evaluate the hoop tensile strength of different E-glass and S-glass fiber reinforced epoxy pipe rings.

1.4 Significance of the study

A good durability of the elbow pipe joints can be achieved under sea water by replacing the existing E- glass elbow joint with the proposed S-glass elbow joint due to strength, stiffness and other factors. This new S-glass elbow joint fabricated will benefit the oil and gas industry to prevent the leakage of crude oil due to high pressure to a large extent than the existing material. The cost of production of the proposed S-glass elbow joint is quite high than the existing E-glass elbow, but when it comes to the damage, the damage produced by implementing S-glass elbow pipe joint is better. The damage produced in the oil and gas industry is unpredictable, so by implementing proposed S-glass elbow pipe joint is better than the existing E-glass elbow joints.

1.5 Scope of research

The validation of good practices in the research is to determine the better glass/epoxy elbow pipe joints either E-glass or the proposed S-glass is by performing mechanical tests and microstructure investigation of the damage produced after the tests. The study also focused on the characterisation of both E-glass and S-glass elbow joints which include the moisture content, impact velocity, absorbed energy, burst pressure strength, hoop tensile strength and axial compressive strength. The glass fiber/epoxy elbow pipe joints were produced by hand layup technique. The glass fiber/epoxy elbow pipe joints were characterised as per ASTM standards. These investigations were performed to ascertain the suitability of the existing and proposed glass fiber/epoxy elbow pipe joints in oil and gas pipe line industry. The proposed S-glass elbow pipe joints were fabricated by S-glass and proposed resin suggested by Roman et. al. (1972).

1.6 Thesis Layout

The thesis has been structured into five chapters i.e. “Introduction”, “Literature review”, “Methodology”, “Results and discussion” and finally “Conclusion and recommendation”.

Chapter 1 covers the basic background and problems that necessitate the research activities. In addition, this chapter also covers the objectives, scope and significant contributions of the research. Chapter 2 deals with a comprehensive review of the major topics related to this thesis in a logical manner. This includes the previous work on glass fiber reinforced composite pipes and their characterizations and assessments of its properties as well as the potentials of the E-glass and S-glass fiber composites in the static structural and fluid flow analysis. Further work on the literature review includes previous studies on the impact, monolithic burst pressure, axial compression and hoop tensile tests of E-glass and S-glass composite materials and laminates. Mostly researchers focused on the impact, burst pressure, axial compression and hoop tensile behaviours of E-glass fiber reinforced epoxy composite pipes. Chapter 3 of the thesis covers the materials and methodology used in the thesis. Chapter 4 presents the findings and through discussion of the results as well as the implications of the findings. Finally, Chapter 5 deals with the overall summary of the findings and suggestions for further modifications and improvements

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LIST OF PUBLICATIONS

Accepted/Publication Journals

Bobba, S. Z. Leman, E.S. Zainudin, S.M. Sapuan. Hoop tensile strength behaviour between different thicknesses E-glass and S-glass FRP rings. AIMS Materials Science, 2019, 6(3): 315-327. doi: 10.3934/matersci.2019.3.315.

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Conference

Bobba, S., Leman, Z., Zainudin, E.S., Sapuan, S.M. (2017), Failures Analysis of E-Glass Fibre Reinforced Pipes in Oil and Gas Industry: A Review, IOP Conference Series: Materials Science and Engineering, 217 (1), 012004, DOI: 10.1088/1757-899X/217/1/012004.

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