PERFORMANCE OF GLASS FIBRE REINFORCED EPOXY (GRE) COMPOSITE PIPES UNDER VARIOUS STRESS RATIOS, WINDING ANGLES AND AGEING CONDITIONS

by

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LIST OF ABBREVIATIONS

AMREC	Advanced Materials Research Centre
ASTM	American Standard for Testing Methods
FESEM	Field Emission Scanning Electron Microscopy
FRP	Fibre Reinforced Plastic
FTIR	Fourier Transform Infrared Spectroscopy
FWP	Filament Winding Process
GFRP	Glass Fibre Reinforced Plastic
GRE	Glass Reinforced Epoxy
HDB	Hydrostatic Design Basis
HDS	Hydrostatic Design Stress
ID	Inner Diameter
ISO	International Standards Organization
NC	Normally Closed
NI	National Instruments
NO	Normally Open
NPT	National Pipe Thread Taper
OD	Outer Diameter
PDB	Pressure Design Basis
RPMP	Reinforced Plastic Mortar Pipe
RT	Room Temperature
RTRP	Reinforced Thermo-Set Resin Plastic
SIRIM	Standards and Industrial Research Institute
UEWS	Ultimate Elastic Wall Stress
VI	Virtual Instruments

LIST OF SYMBOLS

E	Elastic modulus
G	Shear modulus
σ_{TS}	Tensile strength
ν	Poisson ratio
ρ	Density
σ_A	Axial stress
σ_H	Hoop stress
σ_{hoop}	Hoop stress
σ_{axial}	Axial stress
ε_{hoop}	Hoop strain
ε_{axial}	Axial strain
E_{axial}	Modulus of elasticity in longitudinal direction
E_{hoop}	Modulus of elasticity in transverse direction
α	Winding angle
E_1	Longitudinal modulus of the ply
E_2	Transverse modulus of the ply
V_f	Volume fraction of fibre
V_m	Volume fraction of matrices
ν_f	Poisson ratio of fibre
ν_m	Poisson ratio of matrix
E_f	Modulus of elasticity for fibre
E_m	Modulus of elasticity for matrices
G_f	Shear modulus of fibre
G_m	Shear modulus of matrices
E_{ax}	Axial modulus
E_{hp}	Hoop modulus
ν_{ah}	Poisson ratio
ν_{ha}	Poisson ratio

G_{ah}	Shear modulus
mm	Millimetre
kg/m^3	Kilogram /meter^3
g	gram
E_e	Modulus of elasticity (epoxy)
E_g	Modulus of elasticity (glass)
V_e	Volume fraction (epoxy)
V_g	Volume fraction (glass)
G_e	Shear modulus (epoxy)
G_g	Shear modulus (glass)
f	Fibre
m	Matrix
G_{12}	Shear modulus in the 1-2 plane
ν_{12}	Poisson ratio in the 1-2 plane
ν_{21}	Poisson ratio in the 2-1 plane
Q_{11}	Stiffness matrices in 1-1 plane
Q_{12}	Stiffness matrices in 1-2 plane
Q_{16}	Stiffness matrices in 1-6 plane
Q_{22}	Stiffness matrices in 2-2 plane
Q_{26}	Stiffness matrices in 2-6 plane
Q_{66}	Stiffness matrices in 6-6 plane
$\overline{Q}_{11}$	Transverse stiffness matrices in 1-1 plane
$\overline{Q}_{12}$	Transverse stiffness matrices in 1-2 plane
$\overline{Q}_{16}$	Transverse stiffness matrices in 1-6 plane
$\overline{Q}_{22}$	Transverse stiffness matrices in 2-2 plane
$\overline{Q}_{26}$	Transverse stiffness matrices in 2-6 plane
$\overline{Q}_{66}$	Transverse stiffness matrices in 6-6 plane
$G_{ax/hp}$	Shear modulus
$\nu_{ax/hp}$	Poisson ratio
$[Q]$	Stiffness matrix
$[\overline{Q}]$	Transformed stiffness matrix

θ	arbitrary angle
$\boldsymbol{P}$	Pressure applied
$\boldsymbol{ID_{sg}}$	Inner diameter of the strain gauge
$\boldsymbol{TE_{sg}}$	Reinforced wall at the location of the strain gauge
ε_{1i}	Maximum strain at the end of the first cycle of cycle group i
ε_{10i}	Maximum strain at the end of the last cycle of cycle group i

Prestasi paip komposit epoksi bertetulang gentian kaca di bawah pelbagai nisbah tegasan, sudut belitan dan kondisi penuaan

ABSTRAK

Kaca-kaca komposit yang Diperkukuh Serat Kaca (GRE) mempunyai aplikasi yang lebih luas dalam industri minyak dan gas kerana ketahanan dan kekuatan mereka. Program kelayakan yang luas diperlukan untuk menentukan prestasi paip yang berkaitan dengan tekanan, suhu, rintangan kimia, prestasi kebakaran, prestasi elektrostatik, impak, dan pemampatan. ISO 14692 memenuhi syarat paip GRE berdasarkan analisis regresi daripada ujian jangka panjang. Prosedur ujian konvensional ini memerlukan 14 bulan untuk menganggarkan harta yang tinggal pada akhir hayat yang diharapkan (20-50 tahun). Pengeluar paip komposit pasti memerlukan ujian jangka pendek yang lebih cekap dan boleh dipercayai. Rig ujian tekanan automatik mudah alih yang baru dibangunkan untuk mencapai lima nisbah tekanan multiaxial: paksi tulen 0H:1A, gelung ke paksi 1H:1A, hidrostatik tulen 2H:1A, gelung quad ke paksi 4H:1A, dan gelung tulen 1H: 0A loading. Rig ujian berfungsi sebagai alternatif kepada prosedur ujian jangka pendek yang sedia ada, yang dinyatakan dalam ASTM D2992. Kaedah ujian dibangunkan berdasarkan konsep tekanan dinding elastik muktamad (UEWS). Ujian UEWS secara dalaman menekan paip-paip, memegang dan melepaskan tekanan berdasarkan set nilai satu kitaran. Sepuluh kitaran tersebut membentuk satu kumpulan kitaran pada tahap tekanan malar. Prosedur ini diteruskan pada tahap tekanan yang meningkat sehingga paip menunjukkan weepage. Program LabVIEW dibangunkan untuk mencapai ujian UEWS dan berjalan di Komputer Panel Sentuh. NI compactRIO dan modul NI membaca nilai tekanan, mengukur bacaan tolok terikan dan mengawal pembukaan dan penutupan injap solenoid. Ukur terikan gelung dan paksi dibeli semasa ujian. Titik kegagalan pertama kali dianggarkan dari nilai terikan yang ditangkap. Sampul surat kegagalan dibina berdasarkan mata kegagalan pertama. Kesan sudut penggulungan dikaji dengan menundukkan paip dengan sudut penggulungan $[\pm45°]_4$, $[\pm55°]_4$, dan $[\pm63°]_4$. Keputusan ujian UEWS menunjukkan bahawa setiap sudut penggulungan menguasai nisbah tekanan optimum tertentu iaitu $[\pm45°]_4$ untuk beban yang dikuasai paksi (1H: 1A dan 0H: 1A); $[\pm55°]_4$ cemerlang pada muatan hidrostatik tulen (2H:1A), manakala $[\pm63°]_4$ menunjukkan dominasi sepanjang gelung quad untuk nisbah tekanan 4H:1A dan 1H:0A. Untuk mengkaji kesan penuaan, paip-paip tersebut adalah hidrothermally berusia dan tertakluk kepada ujian UEWS. Hasilnya menunjukkan paip-paip lama memperlihatkan kemerosotan kekuatan yang besar berbanding dengan hasil paip dara kerana penyerapan kelembapan. Beberapa mod kegagalan iaitu retak matriks melintang, striations putih, weepage, pecah serat, pembentukan gelang diperhatikan semasa ujian UEWS.

Performance of glass fibre reinforced epoxy (GRE) composite pipes under various stress ratios, winding angles and ageing conditions

ABSTRACT

Glass Fibre Reinforced Epoxy (GRE) composite tubes have wider application in oil and gas industry due to their durability and strength. An extensive qualification program is required to determine the performance of the pipes concerning pressure, temperature, chemical resistance, fire performance, electrostatic performance, impact, and compression. ISO 14692 qualifies GRE pipes based on regression analysis from a long-term test. This conventional test procedure requires 14 months to estimate the remaining properties at the end of expected life (20-50 years). The composite pipe manufacturers certainly require a more efficient yet reliable short-term test. A new portable automated pressure test rig is developed to achieve the five multiaxial stress ratios: pure axial 0H:1A, hoop to axial 1H:1A, pure hydrostatic 2H:1A, quad hoop to axial 4H:1A, and pure hoop 1H: 0A loading. The test rig serves as an alternative to the existing short-term test procedure, specified in ASTM D2992. A test method is developed based on the ultimate elastic wall stress (UEWS) concept. UEWS test internally pressurises the pipes, holds and releases the pressure based on the set value one cycle. Ten such cycles form one cycle group at a constant pressure level. The procedure is continued at increased pressure levels until the pipe shows weepage. A LabVIEW program is developed to accomplish the UEWS test and runs on the Touch Panel Computer. NI compactRIO and NI modules read the pressure values, measure strain gauge readings and control the opening and closing of the solenoid valves. Hoop and axial strain measurements are acquired during the test. First ply failure points are estimated from the captured strain values. The failure envelope is constructed based on the first ply failure points. The effects of winding angles are studied by subjecting pipes with winding angles $[\pm 45°]_4$, $[\pm 55°]_4$, and $[\pm 63°]_4$. The results of the UEWS tests indicate that each winding angle dominate a certain optimum stress ratio namely, $[\pm 45°]_4$ for axial dominated loadings (1H:1A and 0H:1A); $[\pm 55°]_4$ excel at pure hydrostatic loading (2H:1A), while $[\pm 63°]_4$ show domination along the quad hoop to axial 4H:1A and 1H:0A stress ratios. To study the effects of ageing, the pipes are hydrothermally aged and are subjected to UEWS tests. The results show for the aged pipes show a considerable degradation of strength compared to the results of the virgin pipes due to moisture absorption. Several failure modes namely transverse matrix cracking, white striations, weepage, fibre breakage, ring formation were observed during the UEWS tests.

CHAPTER 1

INTRODUCTION

1.1 Glass fibre reinforced epoxy composite pipes

Composite pipes are being intensively studied as replacements for metallic pipes, as the metallic piping systems are considered more susceptible to corrosion and wear under harsh environments. Glass reinforced epoxy (GRE) pipes are the commonly used composite engineering material uniquely capable of meeting a wide variety of end product requirements and applications of fluid transport needs. The GRE pipes are commonly known by various standards, as Fibre Reinforced Plastics (FRP), GRP, Glass Fibre Reinforced Plastic (GFRP), Reinforced Plastic Mortar Pipe (RPMP) or Reinforced Thermo-Set Resin Plastic (RTRP). These composite pipes are an amalgamation of resin, glass fibre, manufactured using appropriate additives and treatment methods. These pipes include exceptionally high strength to weight ratio (have low thicknesses and high mechanical properties-with stands high pressures), superior corrosion resistance (no scaling and no build up), maintenance free, higher hydraulic efficiency (smaller sizes), lightweight (lower transportation and installation costs), higher resistance to surge pressure (more safer under worst conditions due to its low modulus of elasticity), best joining systems, excellent workability and design flexibility's. Thus, allowing GRE piping to be used for high pressures and in very tough and rough conditions.

GRE piping system is often utilised in almost all applications to withstand competitive service, ambient and environmental conditions. It has been successfully used in various piping systems and applications over the entire world. Unlike metallic