SIMULATION OF LAMINATION ORIENTATION FOR CARBON FIBER REINFORCED POLYMER AS A WRAPPING STRUCTURE ON PIPING SYSTEM

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This thesis is submitted in partial fulfilment
of requirements for the award of the
Degree of Master of Mechanical Engineering

Faculty of Mechanical Engineering and Manufacturing
Universiti Tun Hussein Onn Malaysia

July 2021

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For my beloved father **Mr. M.Letchumanan** and my mother **Mrs. R. Tamilselvi**

"Sire greatest boon on son confers, who makes him meet,
In councils of the wise to fill

the highest seat"- Kural: 67

The benefit which a father should confer on his son is to give him precedence in the assembly of the learned

"When mother hears him named 'fulfill'd of wisdom's lore,'
Far greater joy she feels,than when

her son she bore"- Kural: 69

The mother who hears her son called "a wise man" will rejoice more than she did at his birth

"To sire, what best requital can by grateful child be done?
To make men say, 'What merit gained the

father such a son?'"- Kural: 70

(So to act) that it may be said "by what great penance did his father beget him," is the benefit which a son should render to his father.

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ACKNOWLEDGEMENT

"In the name of God, the most gracious, the most compassable"

It has been God's blessing that the completion of my Master's Research that has been achieved and completed after facing lots of hurdles during this COVID-19 crisis. I wish to express my sincere gratitude to all the parties, as this thesis would not has been the same as presented here. I am also indebted to Universiti Tun Hussein Onn Malaysia (UTHM) for providing the facilities for my thesis completion. Staff at the Faculty of Mechanical and Manufacturing Engineering and Centre of Graduate Studies (CGS) also deserves special thanks for their assistance during my project.

I sincerely would like to thank my supervisor Ts. Dr. Ahmad Mubarak Bin Tajul Arifin for his guidance, flexibility and unconditional support throughout this journey. Without his outmost dedication I may not complete this project successfully in this particular time frame. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and advices are useful indeed. I also specially would like to thank Encik Mohamad Rashid Bin Kasmari (Solidwork Modelling Lab Assistant Engineer-FKMP) for providing a good support during my lab work. Last but not least, I would like to appreciate my parent's effort, guidance and economical support on being a part of this successful journey. Unfortunately, it is not possible to list all of them in this limited space and I appreciate to those whom had supported me directly and indirectly to complete the research.

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ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) was designed, simulated and evaluated as a wrapping material on defected pipe using computational approach. This composite material was considered as a unique wrapping material as it may have the combined characteristics of the constituents or have substantially different properties than the individual constituents. Specifically, this research evaluates the capability of CFRP as a wrapper through SolidWorks Simulation using the static analysis and computational fluid dynamics (CFD) analysis. This approach gives a preliminary consideration and justification on choosing the optimized lamination orientation of CFRP in real cases based on the simulated data. Various orientations were simulated and analysed throughout this research. Based on all the simulation analysis, the CFRP wrapper with quasi -isotropic lamination with the 8 plies $(45°/90°/0°/45°)_s$ orientation was seen most effective in reducing the stress and possess highest minimum safety factor at the fully defected region (100mm x 100mm x 7.11mm thru) after the repair. Eventually, this optimized CFRP lamination orientation, proved that it was able to withstand pressures ranging between 0.86MPa to 19.6MPa with a layer thickness in between 0.16mm up to 3.76mm. Based on the static analysis, this optimized laminated orientation of CFRP indeed showed that it was able to reduce the stress on an average of 94.10% after the repair was done. Relatively, CFRP was 0.2% higher in reducing the maximum stress at the defected region at the pipe, than the Glass Fiber Reinforced Polymer (GFRP) with the same orientation. Additionally, the flow simulation analysis in SolidWorks showed that fluid flow was undisrupted after the repair was done and the wrapped region was resistant to any fluid leakages.

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ABSTRAK

Polimer Bertetulang Gentian Karbon (CFRP) telah direka bentuk, disimulasikan dan dinilai sebagai bahan pembalut pada paip yang rosak menggunakan pendekatan pengkomputeran. Bahan komposit ini dianggap sebagai bahan pembalut yang unik kerana ia mungkin mempunyai gabungan ciri-ciri komponen atau mempunyai sifat yang jauh berbeza daripada individu. Secara khususnya, kajian ini menilai keupayaan CFRP sebagai pembalut bagi struktur paip melalui simulasi SolidWorks menggunakan analisa statik dan Pengkomputeran Pengaliran Bendalir (CFD). Pendekatan ini memberikan pertimbangan dan justifikasi awal untuk memilih orientasi laminasi CFRP yang paling sesuai pada keadaan sebenar berdasarkan data simulasi. Berdasarkan semua data analisa simulasi, pembalut CFRP dengan laminasi kuasi-isotropik dengan orientasi 8 lapisan (45°/90°/0°/45°) dilihat paling berkesan dalam mengurangkan tekanan dan mempunyai faktor keselamatan minima tertinggi di kawasan yang bocor sepenuhnya selepas dibaiki (100mm x 100mm x 7.11mm). Akhirnya, orientasi laminasi CFRP ini, membuktikan bahawa ia dapat menahan tekanan antara 0.86MPa hingga 19.6MPa dengan ketebalan lapisan antara 0.16 mm hingga 3.76 mm. Berdasarkan analisa statik, orientasi CFRP berlamina ini memang menunjukkan bahawa ia dapat mengurangkan tekanan pada kadar 94.10% setelah dibalut. Secara relatifnya, CFRP lebih effisien dalam mengurangkan tekanan maksimum di bahagian paip berbanding dengan Polimer Bertetulang Gentian Kaca (GFRP) dengan orientasi yang sama pada kadar 0.2%. Selain itu, analisa simulasi aliran dalam SolidWorks pula menunjukkan bahawa aliran bendalir tidak terganggu setelah pembalutan dilakukan dan kawasan yang dibalut mampu bertahan terhadap tekaan air di bahagian yang mengalami kebocoran bendalir.

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LIST OF ABBREVIATIONS

API	-	American Petroleum Institute
ASME	-	American Society of Mechanical Engineers
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
CFD	-	Computational Fluid Dynamics
CFRP	-	Carbon Fiber Reinforced Polymer
CI	-	Critical Structure
DM	-	Diametre Nominal
Exp.	-	Experimental
exp. coeff	-	Exponential Coefficient
FEA	-	Finite Element Analysis
FKMP	-	Faculty of Mechanical Engineering and Manufacturing
FOS	-	Factor of Safety
GFRP	-	Glass Fiber Reinforced Polymer
MAWP	-	Maximum Allowable Working Pressure

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NACE	-	National Association of Corrosion Engineers
NPS	-	Nominal Pipe Size
OD	-	Outer Diameter
SCH	-	Schedule
SEM	-	Scanning Electron Microscope
SI	-	Strategic Infrastructure
STD	-	Standard
Theo.	-	Theorical
UD	-	Unidirectional
USA	-	United States of America
UV	-	Ultraviolet
XS	-	Extra Strong
XXS	-	Double Extra Strong

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CHAPTER 1

INTRODUCTION

1.1 Background of study

In this modern working culture, sustainable technologies that focusses on ensuring modern competitive production that are supported by systems consisting of software, communications, machines instruments, tools and structures, which in combination form infrastructure systems, distributed across a certain territory are given the priority. The most important infrastructural facilities are called as Critical Infrastructure (CI) and the most critical of them are the strategic infrastructures (SIs) [1]. One of the most common CI elements is the pipeline system. These includes, the infield and main oil product, as well as gas distribution lines, pipelines of nuclear and cogeneration power plants, pipeline systems of ships and aircraft control systems. Pipelines are also useful for the transport of drinking water or irrigation over long distances when it is required to travel over hills or when the canals which are low for reasons of evaporation, contamination or environmental effects. In spite of the costs of constructing pipelines, they are relatively economical means of transport.

In this pipeline system it consists of pipes, pump stations, compressor stations, and other facilities to support the safety environment and to make sure a continuous movement of liquids and gases. Pipes are most often buried in three ground, but they also laid under water and sometimes erected above the ground. In order to ensure constant fluid flow through the pipe, the reliability of the pipe system is accomplished by pipe insulation,

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offering high hydraulic efficiency and stability in a range of uses, including oil and gas pipelines, city water pipes and manufacturing tanks. As mentioned earlier these critical sectors safety is given the highest priority since the risk exposure is very high. The combination of design, material and operating practices always lowers the chances of pipe failure. Natural occurrence and exposure to critical elements also contributes to the failure of pipeline system. To eliminate such failures, pipeline structure is given the highest level of priority and maintenance to maintain the continuous product flow in the pipe. Durability of the pipe structure is achieved through the pipe insulation where it provides a high mechanical strength and flexibility in a variety of applications. Mechanical insulation systems have a substantially positive effect on thermal, acoustical and personnel safety and on the annual operating budget. Thermal insulation and acoustic insulation are constructed on pipe and hydraulic structures to accomplish several of the following: energy efficiency, staff safety, process management, condensation management, noise reduction and greenhouse gas emission reduction. This insulation method is discussed earlier as this research focusses on usage of carbon fibre as the wrapping material on pipe [1].

For decades composite material had started to play a key role over the metal pipeline in the oil and gas sectors. This option is now been considered for funnel protection as an alternative for conventional pipeline fix practices. As "ASME PCC-2: Repair of Pressure Equipment and Piping standard and ISO/TS 24817" gives clear guidelines on fixing and evaluating the composite material as pipe repairing material, this research was decided to study on the Carbon Fibre Reinforced Polymer (CFRP) as wrapping material. Since carbon fibre falls under the composite category in general, at first the composite material needs to be defined where it is means, as it is made up of different parts or various materials where they are referred as constituents. This composite material has a very unique characteristic were depending on the manner in which the constituents are put together, resulting composite material may have the combined characteristics of the constituents or have substantially different properties than the individual constituents [2,3]. That's the reason behind its high consumption in various industry sectors as it possibly could possess low density, corrosion resistance and various better mechanical properties.

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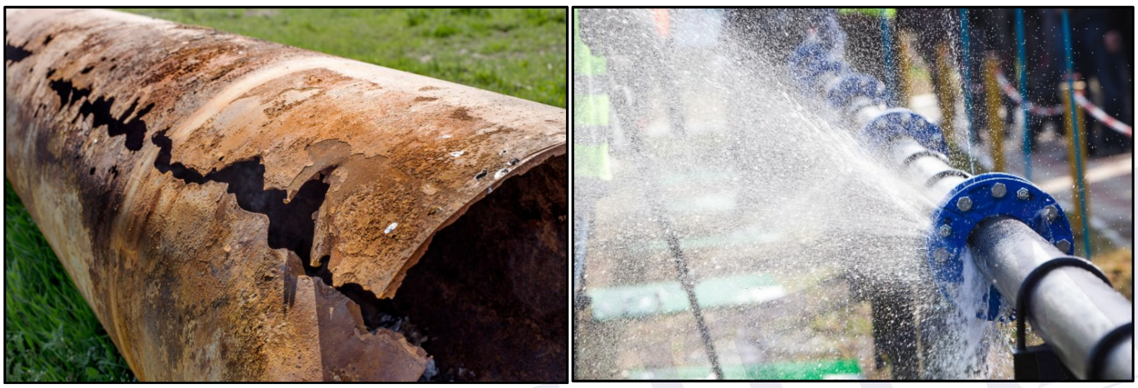
Furthermore, the carbon fibre was decided to be used as the main material among the other type of composite material, due to its specific characteristics which will be discussed further in this research. In present, the above-mentioned approach on piping system is applied as defect, leakage and imperfection in pipe have been the critical problem that being faced in various industry as what has been illustrated in Figure 1.1.



(a) **(b)**

Figure 1.1: Sample pipeline problems **(a)** Corrosion on pipe; (b) Pipe burst

Replacing the damaged steel pipes with the new one will not only consume high cost but also will create complication during product flow. Moreover, replacing the damaged pipe with new one due to gouges, pits, and splits was never been the right choice as it is costly, time consuming, labour intensive and create complication during product flow [4,5]. Due to long moulding cycle times, these materials, which may also be reinforced with glass or other fibres, have a high price tag and are better suited for lower volume manufacture. In recent years, new technology for lowering fibre costs and panel processing has been in the news, and growing implementation is a good indicator that progress is being made. Over the next few years, expect more announcements of upgrades and applications. Composite wrap repair can be used to repair non-leaking pipeline flaws permanently, as well as to treat interior corrosion-related problems temporarily. It will save money since it will avoid the need to shut down a damaged pipeline. Composite wrapping takes two days on an average, whereas pipeline replacement takes five to seven days [104]. When repairing non-leaking faults that must be finished fast, composite wrap

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