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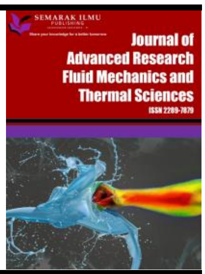

Preliminary Study on Optimization Carbon Fibre Reinforced Polymer as Wrapping Structure at 90-degree Elbows Piping System via Finite Element Analysis

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ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) considered as unique material as it is proven have the best mechanical properties which can be used as a wrapping. This composite material will be evaluated as a wrapping material using SolidWork version 2021 software. Elbow has been chosen as component to be wrapped as it is one of the most critical parts in a pipeline system. Thus, this research focuses on 90-degree butt welded elbows. The study evaluated different lamination and thickness of CFRP as a wrapping framework for elbows. Static analysis also was stimulated to analyze the stress and strain exerted on elbows at extrados location. Based on static analysis simulation from SolidWork software, lamination orientation of (0º) with 6 layers exhibit lowest stress for all the pressure tested ranging from 0.86MPa to 19.65MPa for 90-degree defected elbow at extrados location. Besides, comparing CFRP and Glass Fibre Reinforced Polymer (GFRP), CFRP showed it able to reduce stress compared to GFRP when tested on the same defected elbow. Lastly, the flow simulation in CFD showed there were no leakages especially on defected area and no sudden changes on pressure, velocity, and temperature.

1. Introduction

In the industrial world, pipelines play a major role in transportation of solid, liquid and gases. In a pipeline system consists of pipes, valves, pumps, pipe fittings, and other components to ensure the transportation of products in a pipeline can be supplied to another point without fail. Besides, pipelines are laid on ground, buried underground or submerged in liquid depending on their purpose. Despite the increasing price of raw materials, pipelines are still economical and reliable in the industrial world. Despite the effectiveness of pipelines, it still faces major issue such as deterioration

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in form of corrosion, dents, wearing, buckling, and gouging, which results in leaking and rupture [1] The pipe effectiveness depends on material selection, insulation, fluid velocity and operating pressure. Natural occurrences and exposure play a role in pipeline system failure. The most crucial parts of various pipelines and piping systems have been identified to be elbow components [2]. The failure and deformation in elbows of 60 degrees and 90 degrees mainly under cyclic loads which the elbows can withstand internal pressure [3]. In this research, carbon fibre will be use as a wrapping material on elbows.

Fibre reinforced polymer (FRP) composites have gained popularity as a corrosion-free, lightweight alternative to steel [4]. In the FRP composites, carbon fibre has been decided to be used as the wrapping material due to its characteristic which are low density, corrosion resistance and various better mechanical properties [5]. As carbon fibres have excellent properties such as high temperature stability, chemical corrosion resistance, heat impact resistance, electrical conductivity, thermal conductivity, anti-friction properties, anti-radiation properties, it been widely used in aerospace, defence, and auto industries [6]. With thin filaments structures of carbon fibres where the sizes range from 5-10 µm in diameter, been an advantage to use carbon fibre as wrapper for elbows in piping structures. Moreover, piping elbows have been identified to be frequently found to be among most strained piping components which commonly fails. The most critical part of piping system to be described components which the flow direction changes suddenly, high flow velocities caused by high volumetric flowrates and flow restriction [7]. Thus, elbows fall in critical component as it changes the direction of flow.

In an experiment conducted by Scott Senedon *et al*., using Titanium alloys with different surface roughness, concludes that cracks initiate at zones of high plastic strain at the tips of roughness valleys due to high local surface curvature [8]. Thus, surface roughness due to particle concentration or fluid movement in elbows can reduce fatigue life. Erosion-corrosion is a complicated material loss mechanism that occurs when a flowing fluid disrupts or thins the protective coating or corrosion product. If the fluid velocity is very slow, corrosion will be dominating, whereas if the fluid velocity is very high, erosion will be dominant [9]. Thus, elbow failed in above condition as flow direction or velocity are susceptible to this type of erosion

1.1 CFRP as Wrapping

All commercial continuous carbon fibres are created from carbon precursors, which are then spun into fibre form, stabilised using the necessary agents, and heated to temperatures between 1200 and 3000 °C to eliminate non-carbon components [7]. Carbon fibres can be classified as the following categories: high tenacity type (HT), ultra-high tenacity type (UHT), high modulus type (HM) and ultra-high modulus tenacity (UHM) type. The young modulus, tensile strength, and carbon content in highest in UHM followed by HM, UHT and HT.

CFRP had been proven as the best material in terms of its properties compared to other composites. In a study by Shaktivell *et al.,* CFRP been used as wrapper for straight pipe and concluded that it able to withstand pressure ranging between 0.86MPa and 19.6 MPa with layer thickness between 0.16 up to 3.76mm [10]. In addition, Jianxing Yu *et al.,* studied and investigated the performance of pipelines repaired with CFRP under external pressure [11]. Results show CFRP significantly reduces the strain in the defect region.

Lamination of CFRP plays vital role as it need to be lay up in unidirectional orientation. Same orientation would cause failure in CFRP due to its weak network. Lamination orientation of CFRP is critical as it is done in certain angles to withstand pressure from defected pipeline. Both type of lamination differs as unidirectional quasi-isotropic indicates reinforcement orientation aligned is same direction while cross-piled quasi-isotropic lamination differs across planes. CFRP. In this case, as the lamination would be on elbows, thus lamination of CFRP will be in quasi-isotropic where it will possess same strength and stiffness in all direction.

1.2 API 5L Grade X65 Carbon Steel Specifications as Elbow Material

It is crucial to select the right material and type of pipeline for the desired applications. Before carrying out the simulation, it is important to set the parameters. In piping and fittings, it is important to select correct material, thickness, and type. Nominal Pipe Size (NPS) is used to determine the pipe sizes which the diameter is normally measured in inches (in.) NPS will be determined according to its internal diameter (ID) There are several sizes of piping and fittings in market. In this research, 90 degree and 60-degree short radius elbow been used and the selection of sizes same as selection of pipe. Sizes of fittings usually will be the same as the sizes piping or fitting that are connected to it. The connection of both fittings or fittings and pipe can be threaded, socket weld or butt weld.

Besides, series of wall thickness of fittings which called schedules (SCH) is one of the important criteria. It is same in choosing any fittings or pipes where there are various schedules. Elbows schedules ranges from Sch5 to XXS depends on pressure and allowable stress of materials under design temperature. The larger the number of schedules, the thicker the surface and eventually have high pressure resistance. In this research, the selection of sizes and thickness referred to ASME B36.10. The most common schedules used for fitting and pipe are schedules 40 and 80 [10].

There is a wide variety of type of materials available and can be classified as three types which are metallic, non-metallic, and composite material. This type materials available for any piping components. Metallic material consists of cast iron, carbon steel, stainless steel, nickel, almonel and aluminum. The most common materials for non-metallic are Polyvinyl, Polypropylene (PP) and Polytetrafluoroethylene (PTFE). Each type of material has a different grade and number series depending on the composition of chemical in the material used. For instance, API 5L pipes are commonly used for oil and gas industries, therefore it has many grades in API 5L pipes. API 5L grade specification covers Gr A, B, X42, X46, X52, X56, X60, X65, X70 and X80. The grade denotes the yield strength of piping. For example, API 5L X65 has a minimum of 65,000 psi of yield strength. This due to chemical composition in steel.

Another important criterion during selection of materials is fluid services. Based on ASME B31.3, fluid services categorized into 4 which are Category D, Normal, High Pressure and Category M. This research focuses on hydrocarbons with maximum allowable working pressure (MAWP) based on yield strength which is 165 MPa and temperature around -30 till 120 degrees Celsius.

2. Methodology

The first part of research is to model whole piping system with defected elbows and CFRP wrapper with different lamination orientation. The defected elbows and CFRP wrapper on defected area need to be assembled. Piping and flanges need to be modelled to run simulation on the piping system. Materials need to be applied according to the parameter setup for the elbow, piping, flanges and CFRP wrapper as per the parameter setup. Next, defected elbow will be analyzed and evaluated through static analysis that consists of stress, strain, and displacement. Flow simulation analysis is done to validate any leakages in piping system especially in defected area and fluid flow in piping.

2.1 Formulating the CFRP New Wrapping Structure

A few parameters need to be set up before designing the elbow model in the piping system. The parameters are elbow defect, fluid boundary conditions and CFRP wrapper properties. Table 1 shows the parameters of elbow and its references. For piping and flanges attached will be the same material sizes and according to its standard. For oil and gas transmission pipelines, bigger size will be preferred for higher flowrate. Therefore, 10-inch elbow was chosen. All other parameters such as outer diameter (OD), thickness and internal diameter (ID) were referred to ASME B36.10M. For tensile strength and yield strength of elbow referred to ASME B31.3.

Design parameters for elbow defects were needed to continue with simulate and evaluate the piping system integrity. Three defects' locations were determined on elbows and defects were set 100% wall loss. For this defect location had been referred to an article from Muhammad Faiz Harun, *et al.,* research about low cycle fatigue behavior of elbows with local wall thinning [13]. In an experiment conducted by Karamanos *et al.,* [13], bending moments are applied at the end section of straight pipes. The purpose of this experiment is to analyse on deformation in elbows. The research concludes failure of the pipe bends due to high strain at the flank of the central elbow Table 2 shows the defect parameters. Figure 1 shows the defect of 90-degree elbow at extrados and wall defect is 100% loss, assuming the elbow is fully defected at extrados. The defects with 18.75mm thru wall was designed due to corrosion.

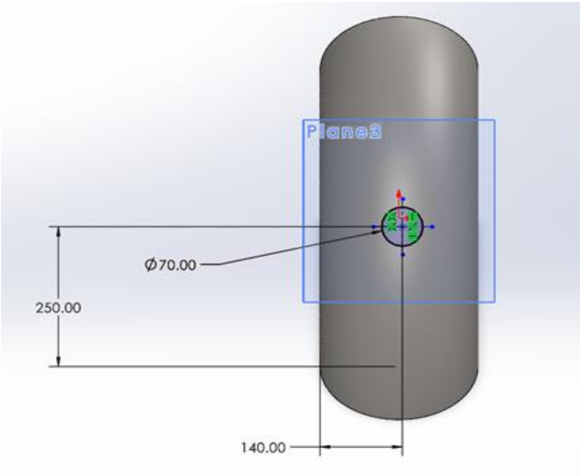
All the data in the Table 3 are based on ASME-PCC-2-2018 (mandatory Appendix Article 401-111). Maximum pressure test will be at 5.65 MPa, maximum design temperature will be set on 343.3ºC and minimum design temperature will be 37.78 ºC. When the piping system can withstand the maximum and minimum design pressure and temperature, it indicates that the CFRP wrapper on defected elbow could sustain and passed the test.

Table 1
Parameter setup for elbows

Parameters	Specimen Specification	Parameter References
Type of Pipeline	Oil and Gas Transmission	NA
Elbow types	1) 90-degree L/R elbow butt welded 2) 60-degree L/R elbow butt welded	NA
Outer Diameter (mm)	268.75	ASME B16.9 & ASTM A234 WPB.
Wall thickness (mm)	14.85	ASME B16.9 & ASTM A234 WPB.
Elbow size (mm)`	250	[13]
Elbow schedule	80	[13]
Internal Diameter	239.05	[13]
Center to End (mm)	250	[14]
Yield Strength (MPa)	450	API 5L Grade X65 Chemical and Mechanical Properties [1]
Tensile Strength (MPa)	535	API 5L Grade X65 Chemical and Mechanical Properties [1]
Material Grade	API 5L Grade X65 Carbon Steel	Table A-1 ASME B31.3

Table 2
Defect parameters of elbow

Location of defects	Wall Loss (%)	Radius of defects (r) (mm)	Area of defects ($\boldsymbol{A} = \boldsymbol{\pi r^2}$) m²
Extrados	100	70	0.015



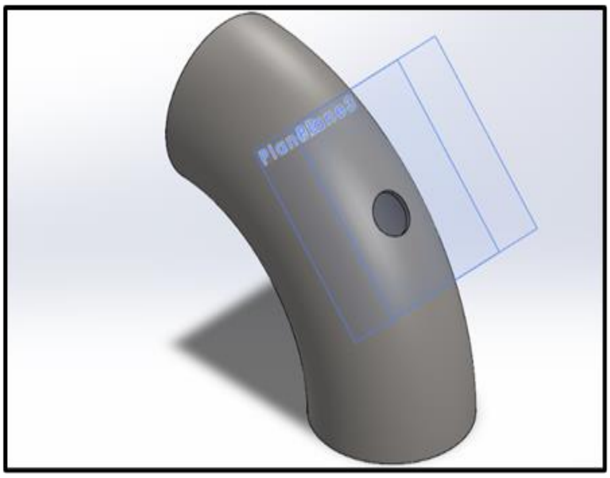


Fig. 1. Schematic diagram of defected elbow at extrados location

In the piping system consists of 90-degree elbow, flanges, pipe, sealer and CFRP wrapper. Each part will be applied material properties before analysis. The elbow, pipe, sealer, and flanges material are API 5L X65. Sealer is used to cover the defected area of elbow to improve the structural integrity of piping system. Then, the wrapper material properties been applied according to its parameters. The CFRP wrapper is considered as orthotropic material and every material properties value need to determine in material list. Besides, CFRP wrapper Elastic modulus and Thermal Expansion Coefficient were based on the general properties of Carbon Steel [13]. Table 4 below shows the CFRP wrapping structure parameters. Each of the parameters were applied on the materials properties of designed wrapper in SolidWork software.

CFRP putty or wrapper need to be designed to cover the defected elbows. Putty will be designed as a three- dimensional solid part which will simulate the physical properties of the putty. The putty will be analyzed individually and as an assembly with elbows. Figure 2 shows the putty model designed in SolidWork. This putty will be used to cover the defected area of 90-degree elbow.

Table 3
Fluid boundary conditions [15]

Piping Specification	Corrosion Allowance (0.000, 0.031, 0.063, 0.125)						
Design Pressure (MPa)	1.97	1.79	1.59	1.38	1.17	0.97	0.86
Design Temperature (℃)	37.78	93.33	148.89	204.44	260.0	315.56	343.33
Minimum Temperature (℃)	-6.67	-6.67	-6.67	-6.67	-6.67	-6.67	-6.67
Minimum Test Pressure (MPa)	2.96	2.69	2.38	2.07	1.86	1.69	1.52
Maximum Test Pressure (MPa)	5.65						

Table 4
CFRP Wrapping structure parameter [8]

Wrapper Specification	Research Parameters	ParametersReference
Wrapping Material Type	Carbon Fibre Reinforced Polymer (Standard)	ASME-PCC0-2-2018 (Article 401-1.1.3)
CFRP Density(kg/m^3)	1600	
Tensile Strength of CFRP (GPa)	3.53	[12]
Elastic Modulus of CFRP (GPa)	230	[12]

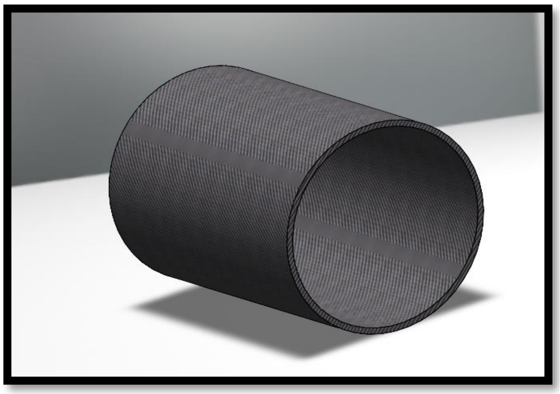
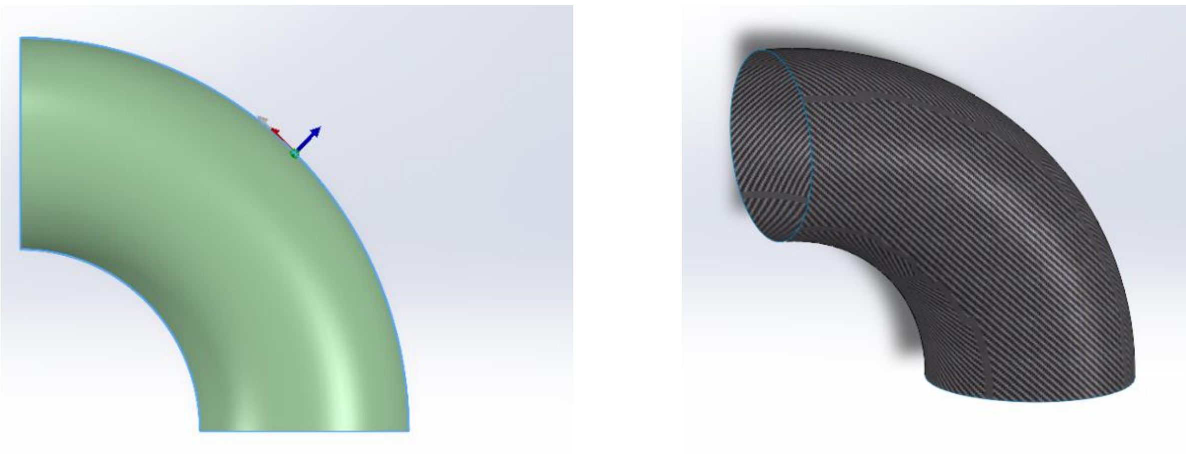


Fig. 2. Putty model

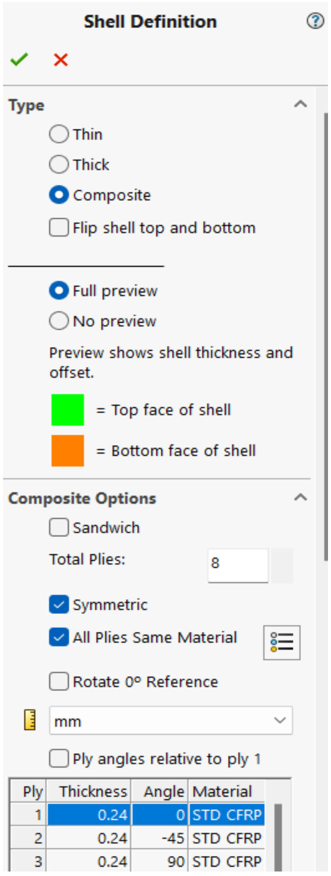
2.2 Analysis on Repaired Defected Elbow by Applying Wrapping Structure

The performance of CFRP wrapper will be evaluated through analysis once all the parts were assembled. Analysis that will be carried out are static analysis and flow simulation for the assembly in simulation. The design and parameter setup of CRRP wrapper shown in Figure 3. Firstly, the static analysis will be done to see whether wrapper could withstand internal pressure. In static analysis, stress, strain, and displacement will be analysed as all the data will be collected through simulation. Flow simulation will be done to identify any leakages in the piping system and to verify on the efficiency of the wrapper used.

Static analysis of the wrapper done by loading various internal in the pipe along with fix geometry and connection. The internal forces in the piping system constant due to assumption made which is quasi-static. Some condition during static analysis needs to be considered before running static analysis. From Figure 4, it shows fix geometry been applied to flanges hole as normally bolt nuts been used. Contact setting is one of the components to describe the interaction between part boundaries. Thus, parts like CFRP wrapper and sealer will be declared under contact interactions. After this condition been declared, internal pressure been applied according to parameter referred to standard.



(a) (b)



(c)

Fig. 3. (a) The geometry of CFRP wrapper, (b) CFRP wrapper properties applied on the geometry of the elbow, (c) CFRP Lamination Angle Optimization

Once the parameter was applied, the model designed need to go through meshing before running the simulation on static analysis. Each part of the assembly is created in such that each component can be analyzed separately. However, in SolidWork meshing property can be done by default. The illustration of mesh shown in Figure 4. As shown in Figure 4, control mesh has been applied in defected region.

As the meshing of the assembly is achieved, static analysis can be simulated. Once the assembly of the model has been simulated, several data will be covered such as stress, strain, displacement, deformed results, and Factor of Safety (FOS). The sample output of simulated results of elbow in a piping structure in normal condition is shown in Figure 5. Based on Figure 5, the average stress on elbow is 230.073 MPa. CFD analysis or Fluid simulation analysis were simulated after done with static analysis. Fluid flows were observed inside the pipeline especially in the defected region of the elbow. Then, the pressure, velocity, temperature along the pipeline was evaluated.

For CFD analysis, some assumptions have been made where the flow assumed to be steady state and laminar type flow [16]. The CFD simulation can only be done in enclosed geometry, thus the lid feature was applied in the inlet and outlet of the pipeline system. The parameters of fluid inserted in the Wizard option referring Table 5. Boundary conditions that were considered in the simulation were the inlet velocity and total pressure.

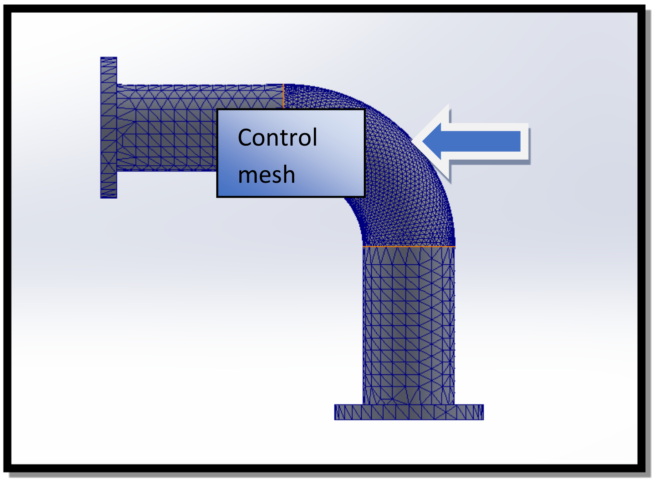


Fig. 4. The general mesh of whole structure

Table 5
Fluid parameters that were tested for simulation

Parameters	Value
Inlet velocity (m/s)	10
Pressure (kPa)	101.3 (Atm pressure)
Fluid type	Crude oil
Temperature (°C)	50

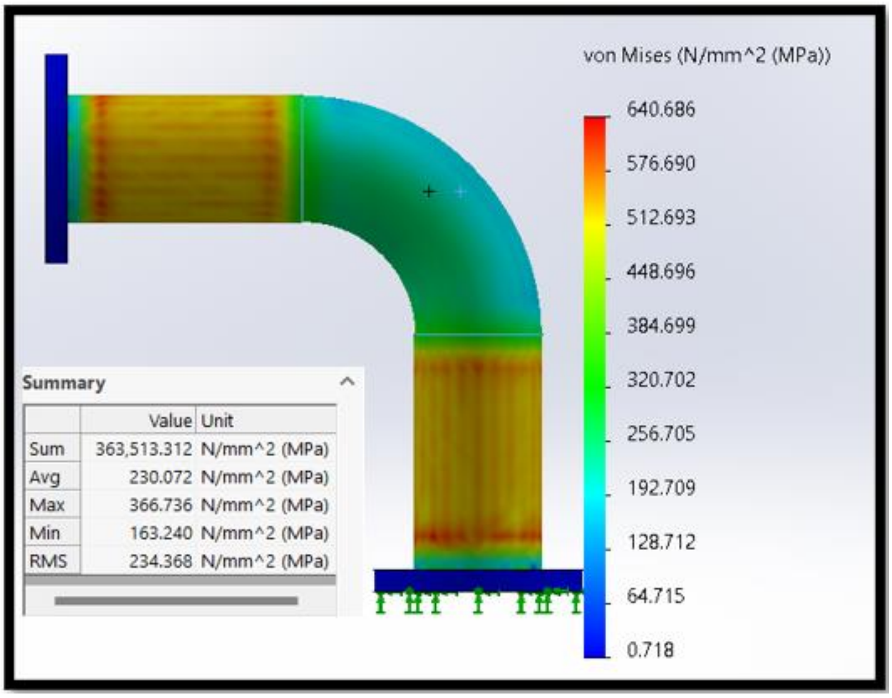


Fig. 5. Stress analysis on elbow in a piping structure

3. Results and Discussion

In this research, wrapping structure of CFRP will be analysed on defected area of 90-degree elbow in various locations. Static analysis and CFD analysis will be carried out and discussed. Figure 6 shows the parameter and lamination orientation used for CFRP wrapper. The results were collected from simulation from SolidWork software based on the parameters.

3.1 Static Analysis

SolidWorks simulation utilizes static analysis to simulate and assess the structural response of a design when subjected to constant loads and conditions. It plays a pivotal role in the design and validation phases, ensuring that a product or structure can endure the anticipated loads and forces it will experience in its intended application. By conducting static analysis, can anticipate potential failure modes like yield, buckling, or excessive deformation, thus enabling them to make informed design decisions and enhance the product's overall performance and safety. From static analysis simulation, stress, strain, displacement, and factor of safety (FOS) were evaluated. The results will be compared with GFRP (Glass fibre reinforced polymer) wrapper with the same lamination angle of wrapper. Three defects location of 90-degree angle elbow will be compared individually. Boundary conditions of for each lamination orientation of CFRP wrapper were tabulated in Table 6 [15]. CFRP behaves differently with for different orientation. Thus, range of pressure from 0.86 to 19.65 MPa were taken as test pressure to simulate the piping model. Sealer was used to cover the defect area before applying wrapper. The sealer will be the same material as the elbow which is API 5L X65. Sealer acts as a boundary to stop the leakage temporarily before applying CFRP wrapper. The structure of the elbow with sealer and without sealer been illustrated in Figure 6a and 6b where it shows the difference in the stress exerted on the piping elbow.

Table 6
Orientation and parameter of CFRP wrapper lamination [15]

Orientations	Pressure (MPa)		Temperature (℃)		Minimum Thickness (mm)
$(0^{\circ})_n$	Min. Design	0.86	Max. Design	343.33	0.02
$(45^{\circ}/-45^{\circ}/45^{\circ})_s$	Max. Design	1.97	Min. Design	37.78	0.05
$(45^{\circ}/0^{\circ}/45^{\circ})_s$	Max. Test	5.65			0.13
$(90^{\circ}/-90^{\circ}/90^{\circ})_s$	(Experiment)				
$90^{\circ}/0^{\circ}/90^{\circ})_s$	Max. Test	19.65			0.47
$(45^{\circ}/-45^{\circ}/0^{\circ}/45^{\circ})_s$	(Theory)				
$(45^{\circ}/90^{\circ}/0^{\circ}/45^{\circ})_s$					
$(0^{\circ}/90^{\circ}/45^{\circ}/-45^{\circ})_s$					
$(0^{\circ}/-45^{\circ}/90^{\circ}/45^{\circ})_s$					

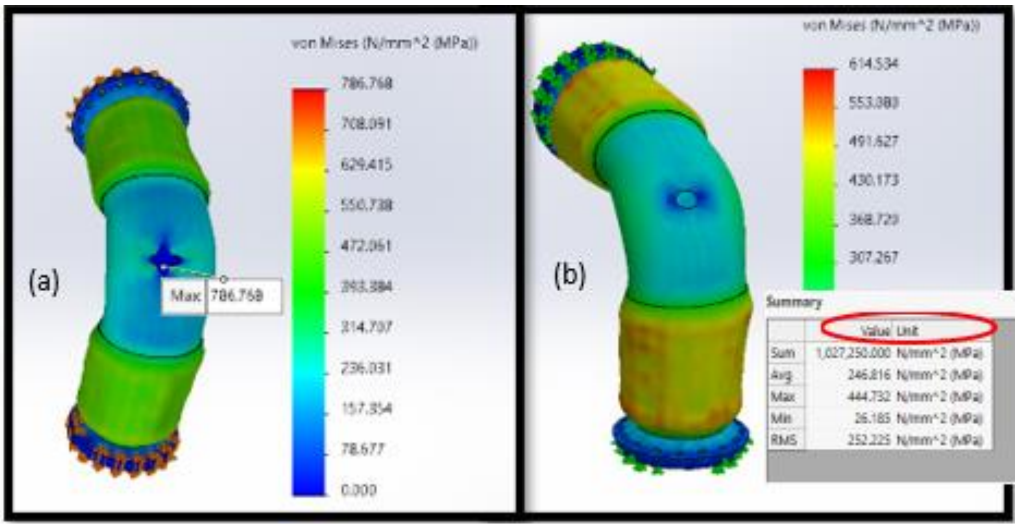
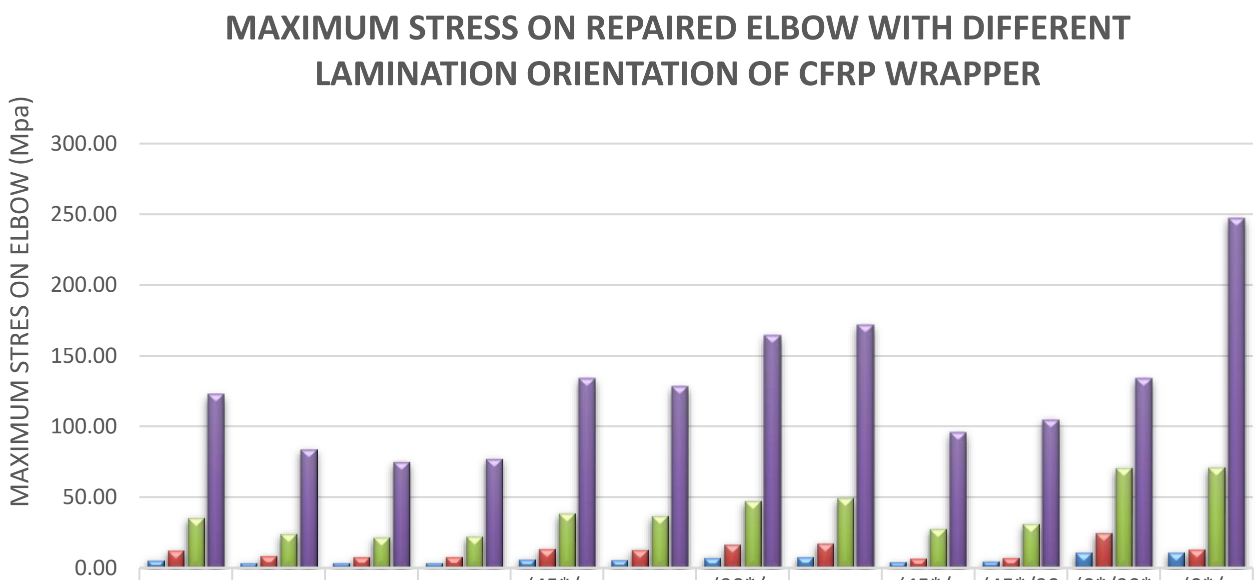


Fig. 6. (a) Maximum stress exerted on elbow structure without sealer (b) Maximum stress exerted on elbow structure with sealer

Each lamination orientation was set accordingly with its thickness and plies. The lamination orientation then was simulated with its internal pressure to evaluate the best wrapping orientation. The maximum stress data then were collected for every different lamination orientation for defected elbow at extrados location as shown in Figure 7.



Lamination orientation	(0*)2	(0*)4	(0*)6	(0*)8	(45*/-45*/45*)6	(45*/0*/45*)6	(90*/-90*/90*)6	(90*/0*/90*)6	(45*/-45*/0*/45*)8	(45*/90*/0*/45*)8	(0*/90*/45*/-45*)8	(0*/-45*/90*/45*)8
0.86 MPa	5.37	3.64	3.28	3.37	5.86	5.60	7.19	7.52	4.20	4.59	10.77	10.82
1.97 MPa	12.31	8.45	7.52	7.73	13.43	12.85	16.46	17.24	6.61	7.25	24.66	13.13
5.65 MPa	35.31	24.14	21.57	22.19	38.53	36.85	47.22	49.43	27.57	31.13	70.73	71.07
19.65 MPa	122.80	83.94	75.01	77.16	134.00	128.20	164.20	171.90	95.87	104.80	134.04	247.20

Fig. 7. The graph of maximum stress on CFRP wrapped defected elbow (extrados location) against CFRP lamination orientation

The strain was not discussed as strain exhibits low value and no huge difference for all the different type of lamination. As per the graph in Figure 7, maximum stress in elbow area with extrados defected location was determined. From the graph illustration, lamination orientation of (0º) with 6 layers exhibit lowest stress for all the pressure tested ranging from 0.86MPa to 19.65MPa.

The thickness used for 0 degree was 0.2mm for each layer, where the overall thickness for 6 layers is 1.2mm in total. Besides, 0 degree with 8 plies is the second best in terms of minimum stress exerted on pipeline system especially in elbow section. In CFRP wrapping, 0-degree lamination orientation called as hoop wrapping. Hoop wrapping have several advantages specifically in elbows and other bend fittings such as enhancing structural integrity, uniform stress distribution and improved hoop strength [17].

Hoop wrapping with a 0-degree lamination orientation offers several key advantages for reinforcing pipeline elbows. Firstly, it provides excellent hoop strength, aligning the CFRP fibres with the primary stress direction caused by internal pressure. This results in enhanced structural integrity and load-bearing capacity. Secondly, the 0-degree orientation ensures a more uniform stress distribution around the circumference of the elbow, reducing the risk of stress concentrations and potential failure points. Lastly, its compatibility with the curved geometry of elbows allows for easier application and better conformance to the elbow shape, ensuring consistent coverage and a more reliable repair. These combined benefits make hoop wrapping a proved to be effective in reinforcing pipeline elbows.

Even though 8 plies have more thickness compared to 6 plies, it has slightly more stress which is mostly likely due to wrapper weight itself adding more stress to the elbow pipeline. When multiple layers of plies are stacked on top of each other, there is a possibility of interlaminar shear stress occurring between the layers. This shear stress has the potential to affect the adhesive bonding between the plies and the substrate, which, in turn, can have an impact on the overall effectiveness of the repair [17]. The greater stress was seen in the orientation of (0º/90º/45º/-45º) of 8 plies as it was 3 times of the (0º) with 6 layers. Thus, it reduced the repairing time and cost of the CFRP wrapper as it only will be wrapped in 0 degree and with minimum thickness of 1.2mm. During the simulation, no abnormalities or defects were found when testing until 19.65 MPa which indicates CFRP wrapper withstand internal pressure.

Besides, CFRP need to be compared with glass fibre reinforced polymer (GFRP) in terms of maximum stress exerted to the piping system especially in defect area extrados. All the lamination orientation been simulated with wrapping material GFRP. From Figure 8, it shows CFRP less stress compared to GFRP when internal pressure been applied ranging from 0.86 MPa to 19.65 MPa. Even though the difference between both GFRP and CFRP not huge, but it still affects the piping system in long run. This can be said due to CFRP properties itself. CFRP typically has higher tensile strength and stiffness compared to GFRP, allowing it to withstand higher stresses without significant deformation or failure. Additionally, CFRP's higher modulus of elasticity (stiffness) enables it to resist deformation more effectively under the same applied load, resulting in lower stress levels. Moreover, CFRP's higher strength-to-weight ratio and potential to provide comparable strength with less material can reduce overall weight and stress on the piping.

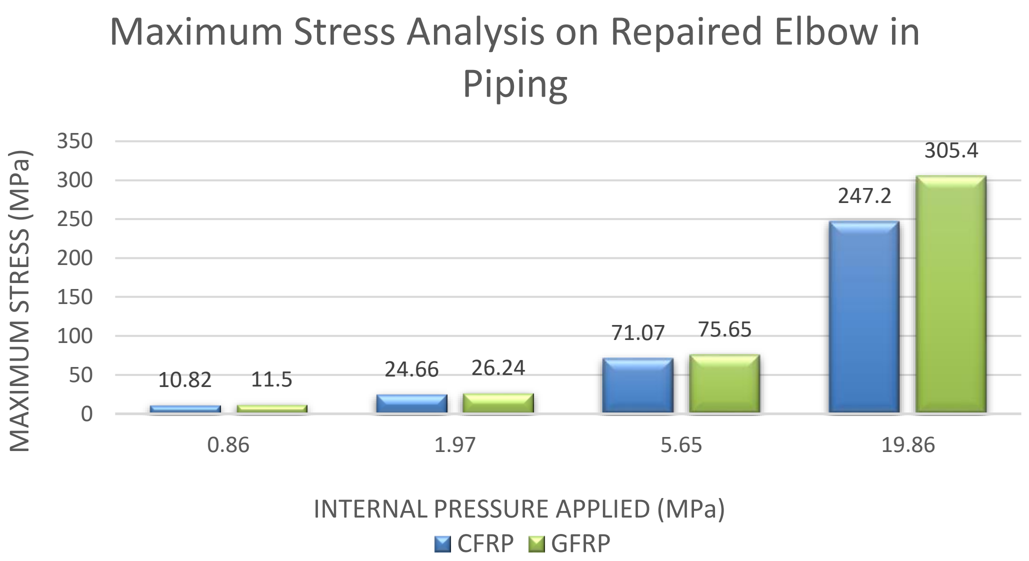


Fig. 8. Comparing CFRP and GFRP: Maximum stress on repaired elbow with CRRP and GFRP

3.2 Flow Simulation Analysis on CFRP Wrapping Structure

Flow simulation was conducted on the piping model using SolidWork simulation with the objective of ensuring uninterrupted fluid flow and avoiding significant increases in temperature and pressure [18]. Additionally, the simulation aimed to verify the watertightness of the model after wrapping it with CFRP (Carbon Fiber Reinforced Polymer). Prior to running the simulation, specific boundary conditions were set in the wizard option, including inlet velocity, temperature, and environmental pressure. The inlet velocity was set at 10 m/s, with a temperature of 50 degrees Celsius, representing crude oil, given the focus on high-pressure and high-temperature applications in this research.

In the simulation, the lamination orientation of the CFRP was set at 0º with 6 layers, and it was found to be the most effective orientation for the 90-degree elbow. Before conducting the simulation, the pipe structure needed to be closed with lids to ensure accurate results [19]. Both lids were placed on both openings of the pipe structure.

Flow trajectories for velocity and pressure were used to identify the change of velocity and pressure in the system. The area around the defect has been studied. Leak tracker been used to identify any leaks in the piping structure [20]. Figure 9 shows the piping structure is watertight and no leak found. The red colour line from flange to flange shows there is no leak found. If there is leak line will be up until leak area. Hence it shows the wrapper is seal properly.

The piping structure underwent flow simulation to observe the flow trajectory inside it, with a particular focus on the defect area (extrados). In Figure 10, the flow trajectory of the fluid is depicted, and the arrow illustrates the fluid velocity. Notably, the velocity remains relatively unchanged due to the wrapper. Typically, there is a velocity change in any bend or fitting in a piping system, but this simulation shows that no significant drop in velocity occurred, as shown in the figure below.

Additionally, pressure is a crucial factor in flow simulation. The simulation was conducted to examine the pressure behavior, ensuring that the wrapper does not cause an internal pressure buildup. Figure 11 displays the same color palette, indicating that there was no significant pressure drop observed.

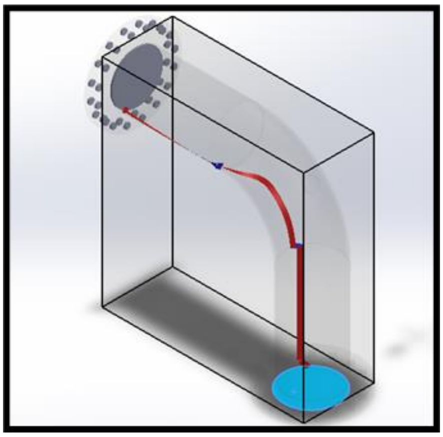


Fig. 9. Leak tracker of CFRP wrapped elbow in piping

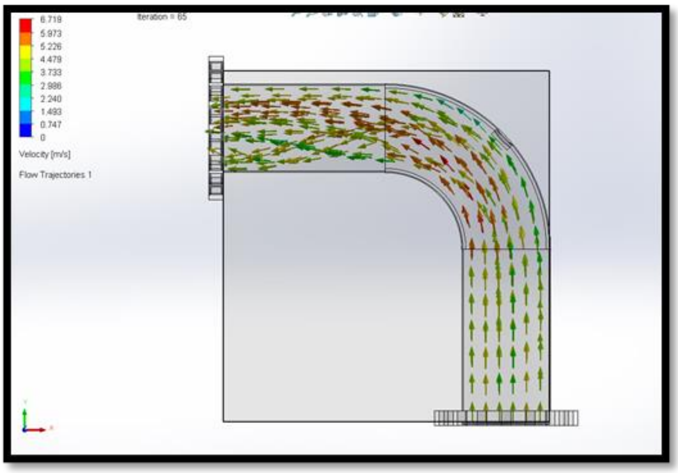


Fig. 10. Velocity flow trajectory

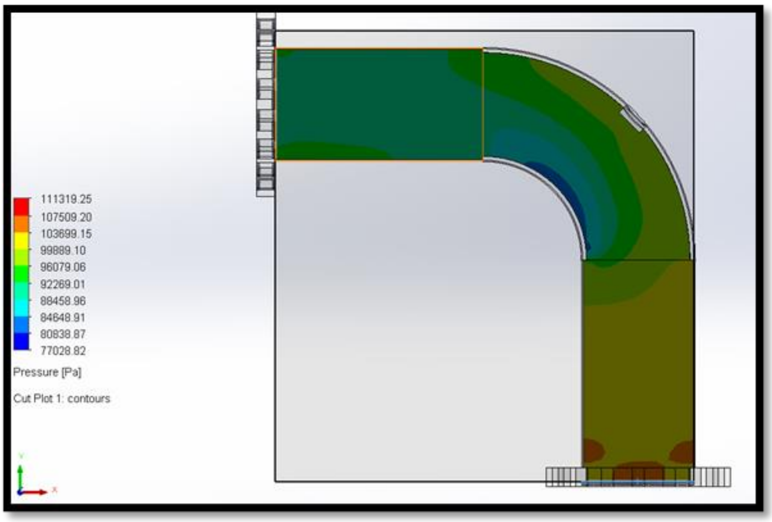


Fig. 11. Pressure cut plot

4. Conclusions

From this research, CFRP possesses better material for wrapping 90-degree elbow compared to GFRP. Firstly, the first objective of this research is achieved as this best lamination orientation was identified. Orientation up to 4 symmetric orientations were evaluated from SolidWork simulation software. From simulation, 0 degree with 6 plies shows the best orientation for 90-degree elbow at extrados defect area. Compared to other lamination orientations, 0 degree with 6 plies exhibits lower stress. Besides, compared to GFRP, CFRP shows lower stress right from 0.86MPa to 19.65MPa.

Besides, from static analysis second objective was achieved by comparing stress for CFRP and GFRP. Data shows CFRP have minimum stress compared to GFRP when tested with range pressure from 0.86MPa to 19.86MPa. Flow simulation in this research showed that fluid was not disrupted and CFRP is correctly sealed as no leak found. From cut plot of velocity, temperature and pressure, there were no any significant change or huge difference. This research is only at preliminary study to justify the wrapping material of CFRP can be used in real life application for any defects at elbow. This simulation could save cost and time due as simulation able to give lamination orientation with its thickness.

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