Advanced Materials Research Vol. 983 (2014) pp 444-449
Online available since 2014/Jun/30 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.983.444

Flexible Thermosetting Pipe

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Keywords: Thermosetting material, Laminated composite, Dual-helical wrapping of tape stacks process, Flexible Pipe.

Abstract. The typified as flexible thermosetting pipe, is a new product, developed initially in response to the need for a non-metallic replacement for steel pipe used for oil and gas productions. This product may use for high pressure down-hole applications in which the pipe could repeatedly transported onto a drum. The proposed pipe comprise an internal thermoplastic layer play as liner and a fluid-tight cover, and one or more dual-helical wounding tape stacks applied to the internal liner for absorbing axial and bending loads. The tape stacks are wrapped helically onto the pipe structure with adjacent gaps between wrappings tape to reduce the pressure integrity of the tubular pipe structure. The composite tape stacks are formed from a plurality of thin tape strips and are bonded to each other within a stack. All the layers are manufactured from composite material consisting of highly noncorrosive epoxied matrix reinforced by long continuous fibers. Thus, the proposed flexible pipe designed to be stand alone with thermoplastic liner over-wound with one or more of an epoxy-based structural thermosetting laminate. To this aim, a straightforward simulations of thermosetting pipe is developed via using ANSYS software. Apart from possessing an accurate operational condition, on account of its simplicity the proposed simulation seems also very suitable for further developing and prototyping purposes. Finally, it has been shown that the proposed thermosetting pipe, which partially attains some classical characteristic of both offshore and onshore pipeline by a different line of reasoning, is may serve as a reference in designing flexible pipe.

Introduction

Fiber reinforced thermosetting comes into the categories of “composites” materials and have few applicable standards such as ASTM and AWWA, which is standard for fibreglass pressure pipes. The reinforcement “fibers” are responsible for the mechanical characteristics of the product, minimizing the chance of defects and so the material comes close to its theoretical strength such as glass fibers that have a tensile strength of about 18.000 Kg/cm^2, which is higher than that of the best steels [1, 2].

Furthermore, the reinforcing material can be arranged with any desired density and orientation, allowing the technical and economic characteristics of the structure to be optimized [3].

There are several technologies for manufacturing thermosetting pipes or sometimes called composite pipework such as; filament winding, continuous winding of composite tape, etc.[4]. The said tapes stacks should composed from several layers for absorbing the desired axial loads but extremely bendable.

In this paper a flexible thermosetting pipe is proposed achieved its flexibility by virtue of the fact that the tape stacks that form pipe layers are free to move relative to one another. The said flexible pipe comprise one or more thermosetting layer formed by applying a dual-helical wounding and wrapping of tape stacks to a plastic internal liner and perfectly connected one to the other. Such system will describe in next section.

Geometry Description

As mentioned earlier, the tape stacks in the pipe are design to accommodate the flexural strain by sliding on each other, during pipe coiling, without damaging either the load-bearing capability of the fibers or the fluid containment capability of the thermoplastic liner. The said flexible has minimum bending radius equal to 0.9m per each 3 foot of its length. Such flexible can have a high pressure rating, typically 350 bar, and could fabricate with large diameters (250-550)mm. The reinforcement is typically E-glass, but carbon may also be employed, according to the application and economic factors. The liner material may also be tailored to the application, but would normally be polyethylene, cross-linked polyethylene, nylon 11 or PVDF. The key components of this flexible that displayed in Fig. 1, are:

1. An inner polyethylene liner, to prevent collapse under external compressive load that applied during the hoop-wound of thermosetting layer at highly tension. As well as, to be in direct contact with the fluid, provides the highest chemical resistance and impermeability.
2. An intermediate “thermoplastic” layers, to prevent corrosive product from coming into contact with the outer components of the flexible.
3. Near-hoop, pressure resisting thermosetting tapes stacks.

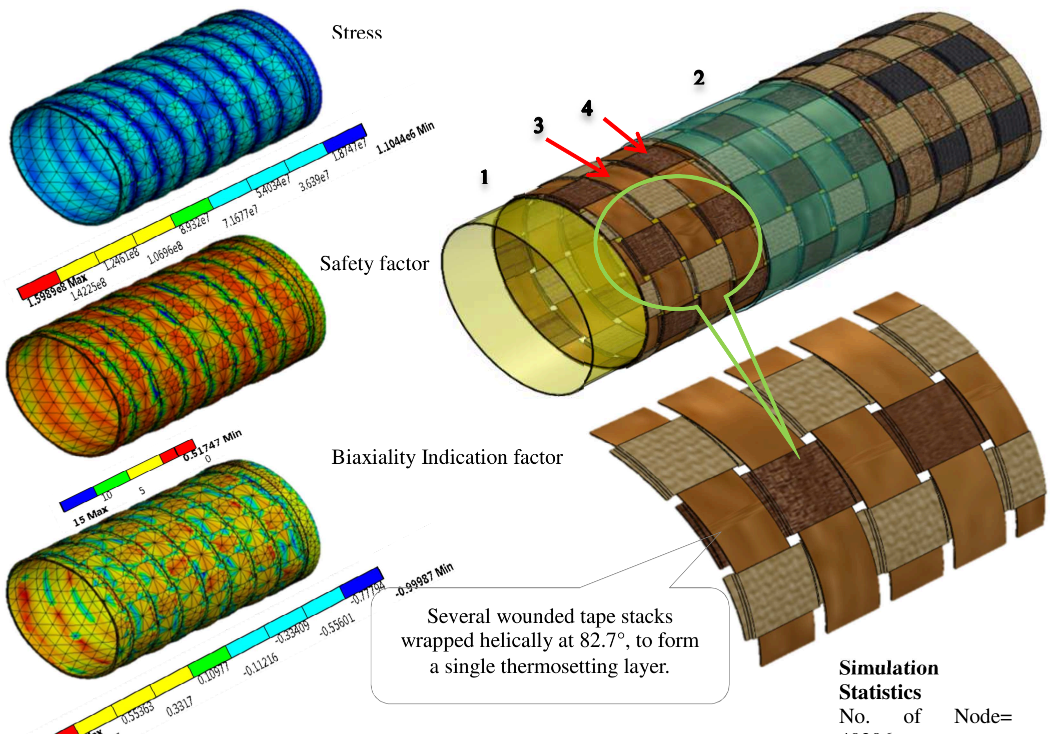


Figure 1. Flexible thermosetting pipe.

4. Near-axial thermosetting tapes stacks.

After repeating the layers construction to reach the desired characteristic, an outer polymeric casing could apply for external protection or other (gel-coat) protects the fibers externally from abrasion and atmospheric agents.

Material Selections

In order to develop flexible pipe ideal for petrochemical industry, and for transporting oil, aqueous fluids and other fluids, a composite material should select to have had a high specific strength and corrosion resistance, such as those explained in Fig. 2. The maximum temperature of the fluid being handled, of course, may limit the selections of resin system. For example, amine-cured epoxy systems could be used at temperatures up to 115ºC.

Risen can suffer rapid hydrolysis damage in steam, which must therefore be avoided. Although, epoxy and vinyl-ester systems are relatively immune to attack by CO2 and H2S, as well as the main organic components of crude oil, the care needs to be taken, however, when volatile aromatic fractions such as toluene or xylene are present. Therefore, the characteristics shown in the Table 1 are those commonly required for the proposed flexible thermosetting pipe.

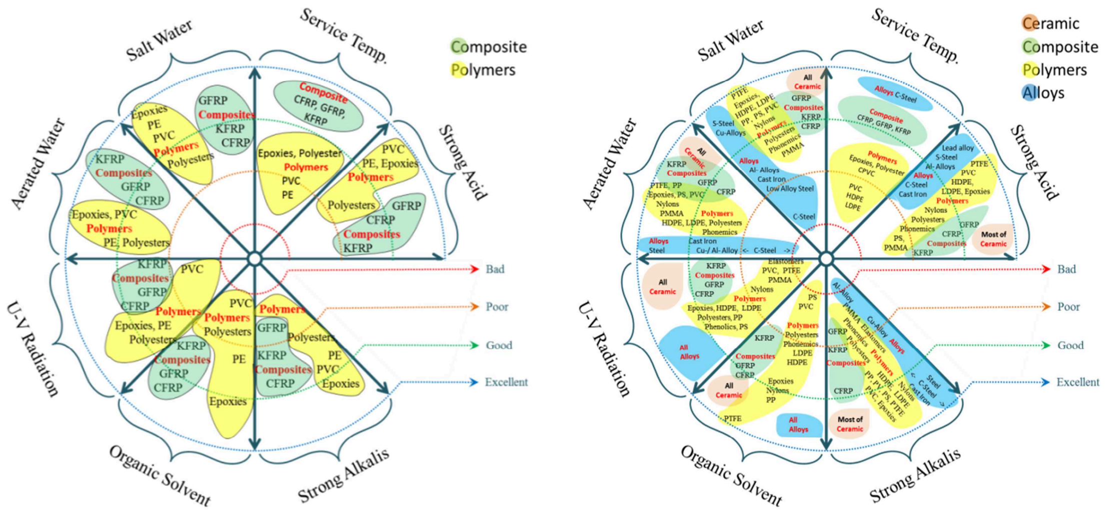


FIGURE 2. All main characteristics of all the alternative materials that could use in construction of pipeline[5, 6].

TABLE 1. The characteristics commonly required for current proposed flexible thermosetting pipe.

Properties		Flexible Thermosetting Pipe	Stainless Steel
Tensile Strength (N/mm^2)		382	340
Flexural Strength (N/mm^2)		468.3	380
Flexural Modulaus (N/mm^2)		22489	196000
Izod Impact (Kg.m/cm)		2.15	0.53
Specific Gravity		1.8	1.8
Thermal Conductivity (Kcal/hr/m^2/° C)		24.4	732.00
Coeff. of Linear Expansion (cm/cm° C) x 10-6		5.2	10
Safe Working Temp. (° C)		130	600
Flame Resistance		Good	
Corrosion Resistance	a. Acidic	Excellent	Excellent
	b. Alkaline	Good	Excellent
	c. Solvents	Fair	Excellent
	d. Coastal Environment	Excellent	Excellent
	e. Outdoor Exposure	Excellent	Excellent
	f. Effluent Water	Excellent	Excellent
	g. Steam	Good	Excellent

Parametric Analysis

An example is shown in Table 2, for a thermosetting pipe made of Gl-Ep composite material. Gl-Ep properties are found in [7-9]. Thus, the characteristics of that proposed flexible are given in Table 3. Although, Gl-Ep not cheaper than polymer according to the relative cost estimation attached in Table 3, thermosetting material still best choice for pipeline construction than steel. However, Gr-Ep material gives similar characteristics to those shown in the Table 3, which are commonly required in both onshore and offshore pipeline. As clearly seen in Table 3, the proposed flexible has a weight when full of seawater and submerged in seawater equal to 37.5624 kg/m which is less than its empty weight in air, result in small negative buoyancy force, shall minimize the pipe high self-weight when is suspended. In Table 4, 5 and 6 the proposed flexible was examined under varied external and internal pressure conditions and when subjected to wide range of applied tension. Table 4, 5 and 6 shows that flexible made of Gl-Ep could emulate the Gr-Ep and steel pipe and expect to be a good non-metallic replacement for steel pipe that would be used for conveying oil and gas. Although, Gl-Ep is slightly less flexible but shows good load bearing capability than Gr-Ep, especially when under internal pressure or when subjected to tension. In fact, this is due to large orthotropic-ratio in Gl-Ep composite result in loss in hop stiffness on account of longitudinal stiffness. Therefore, Gr-Ep could be the best choice for preventing collapse in pipeline. In other word, a hybrid composite pipe comprising both Gl-Ep and Gr-Ep expect to behave as steel pipe.

Table 2. Following give an example for flexible pipe comprising of two thermosetting mats each are form of 20 wrapped tape stacks (i.e., first mat is wrapped at (0°, −82.7°) and the second mat is wrapped at (+82.7°, 0°)), the tape layers are assumed made of Gl-Ep.

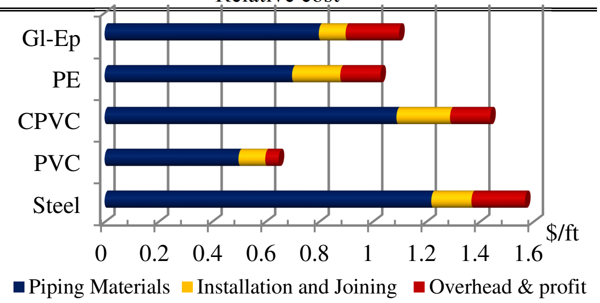
Description†	T_m (MPa)	Kg/m	D_i (mm)	H (mm)
First layer				
Carcass	250	11.047	480	5
Tape stacks made of 10 composite layer each 0.2 mm thick	420	0.030325× 16 tape stacks	485±20	2.00
The warped tape stacks made of 10 composite layer each 0.2 mm thick	420	3.7652 kg × 8 tape stacks	485	2.00
Second layer				
An intermediate Polyamide 11	250	11.047	500	5
Tape stacks made of 10 composite layer each 0.2 mm thick	420	0.030325× 16 tape stacks	505±20	2.00
The warped tape stacks made of 10 composite layer each 0.2 mm thick	420	3.7652 kg × 8 tape stacks	505	2.00

† Tm= maximum tensile strength in MPa at elasticity limit of 0.2% extension, Kg/m=weight in kg per meter of pipe, Di=internal diameter in mm, and H=thickness.

Table 3. The characteristics of the proposed Flexible pipe made of Gl-Ep.

Characteristics	Metric	Unit
Internal diameter	480	mm
Composite layer volume	0.013144	mm
Internal volume	0.18095	m³
External volume	0.21647	m³
Empty weight in air	72.3720	kg/m
Weight full of sea water in air	249.856	kg/m
Empty weight in sea water	-139.768	kg/m
Weight full of sea water in sea water	37.5624	kg/m
Floatability factor empty in sea water†	0.33412	
Bursting pressure	≈350	bars
Collapse pressure	≈150	bars

Relative cost†



†Floatability factor= Empty weight in air / (External volume×1.02×Density of sea water), and cost data are adopted by Means 2012 Mechanical Cost Data.

Table 4. Stress, Strain, Deformation at flexible thermosetting pipe its tapes stacks made of Gl-EP, Gr-Ep(AS), and Steel, under different internal pressure scenarios.

Internal Pressure (bar)	Gl-EP			Gr-Ep(AS)			Steel		
	Stress Pa×10^8	Strain m/m ×10^{-2}	Deformation m×10^{-3}	Stress Pa×10^8	Strain m/m ×10^{-2}	Deformation m×10^{-3}	Stress Pa×10^8	Strain m/m ×10^{-2}	Deformation m×10^{-3}
25	1.62	1.25	1.29	3.42	1.24	1.98	1.11	9.60	1.21
30	1.95	1.50	1.54	4.10	1.49	2.38	1.34	1.15	1.45
35	2.27	1.74	1.80	4.79	1.73	2.78	1.56	1.34	1.69
40	2.59	1.99	2.06	5.47	1.98	3.18	1.78	1.54	1.94
45	2.92	2.24	2.32	6.15	2.23	3.57	2.00	1.73	2.18
50	3.24	2.49	2.57	6.84	2.48	3.97	2.23	1.92	2.42

Table 5. Stress, Strain, Deformation at flexible thermosetting pipe its tapes stacks made of Gl-EP, Gr-Ep(AS), and Steel, under different external pressure scenarios.

External Collapse Pressure (bar)	Gl-EP			$Gr\text{-}Ep^{(AS)}$			Steel		
	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$
5	3.4043	2.5138	2.6933	7.1299	2.5434	4.1808	2.2992	1.9328	2.5337
6	4.0853	3.0166	3.2322	8.5564	3.0521	5.0173	2.7591	2.3194	3.0414
7	4.7664	3.5193	3.7711	9.9829	3.5609	5.8538	3.2190	2.7061	3.5491
8	5.4474	4.0221	4.3100	1.1409	4.0696	6.6904	3.6790	3.0927	4.0568
9	6.1284	4.5249	4.8489	1.2836	4.5783	7.5269	4.1389	3.4793	4.5645
10	6.8094	5.0276	5.3879	1.4262	5.0870	8.3634	4.5988	3.8660	5.0723

Table 6. Stress, Strain, Deformation at flexible thermosetting pipe its tapes stacks made of Gl-EP, Gr-Ep(AS), and Steel, under different tension scenarios.

Tension (ton)	Gl-EP			$Gr\text{-}Ep^{(AS)}$			Steel		
	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$	Stress $Pa\times10^8$	Strain m/m $\times10^{-2}$	Deformation $m\times10^{-3}$
0.5	4.5733	2.8693	1.6105	6.4276	5.5893	3.1663	4.4969	2.2539	1.3875
1	9.1491	5.7398	3.2266	1.2857	1.1181	6.3409	9.0038	4.5127	2.7944
2	1.8301	1.1481	6.4587	2.5716	2.2363	1.2690	1.8018	9.0304	5.6082
3	2.7452	1.7222	9.6908	3.8574	3.3545	1.9039	2.7031	1.3548	8.4221
4	3.6603	2.2963	1.2923	5.1433	4.4728	2.5389	3.6045	1.8066	1.1236
5	4.5755	2.8704	1.6155	6.4292	5.5910	3.1738	4.5059	2.2584	1.4050

Conclusions

The present invention relates to a flexible composite pipe, intended to be used for the transport of fluids and in particular hydrocarbons. The pipe may also be used as a flexible riser, adapted for transportation of fluids from/to a floating production unit to/from a subsea wellhead etc. The flexible composite line according to the present invention is expected being a high performance device developed to serve the above purposes at high temperatures (up to 135 °C) , high pressures (up to 350 bars), and for shallow water dynamic applications. Although, the proposed flexible pipe is lighter in weight than prior art pipes it expect maintaining correct performances, particularly mechanical performances.

Acknowledgments

Authors would like to acknowledge Universiti Teknologi PETRONAS, for sponsoring this research.

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Advanced Materials and Engineering
10.4028/www.scientific.net/AMR.983

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