DESIGN AND DEVELOPMENT OF THIN WALLED CYLINDRICAL SHELLS FOR OFFSHORE APPLICATION

M T Kishore[1], K Mithunn[2], U Mohammed Akram[3], G Nikilash[4]

[1] *BE, Mechanical Engineering, K Ramakrishnan college of engineering, Tamil nadu, India*
[2] *BE, Mechanical Engineering, K Ramakrishnan college of engineering, Tamil nadu, India*
[3] *BE, Mechanical Engineering, K Ramakrishnan college of engineering, Tamil nadu, India*
[4] *BE, Mechanical Engineering, K Ramakrishnan college of engineering, Tamil nadu, India*

ABSTRACT

The most commonly used stainless steel in offshore application is SAE 304 stainless steel. And here pipe is reinforced with Glass Fiber Reinforced Polymers (GFRP). The use of Glass Fiber Reinforced Polymers (GFRP) is gradually increasing in the oil sectors for the transportation of petroleum and natural gases. And these transportation of petroleum and natural gases is little tougher in offshore structures when comparing to normal transportation, because in offshore structures the extraction and transportation of petroleum and natural gases are done under the sea level. Therefore, the traditional stainless steel pipes are replaced by the composite pipes. By replacing the stainless steel pipes with the composite pipes, the time period between the successive maintenance of the pipelines can be extended and increases the service life of the pipelines. The pipes which are reinforced with GFRP are expected to remain in operation for fifty years as a long term design constraint regulated by international rules and regulations.

KEYWORD:- *304 stainless steel, GFRP .*

INTRODUCTION

The use of Glass Fiber Reinforced Polymers (GFRP) is gradually increasing in the oil sectors for the transportation of petroleum and natural gases. And these transportation of petroleum and natural gases is little tougher in offshore structures when comparing to normal transportation, because in offshore structures the extraction and transportation of petroleum and natural gases are done under the sea level. Therefore, the traditional stainless steel pipes are replaced by the composite pipes. Composite pipes are a low cost best alternative for the replacement of steel pipes. This is done for reducing the corrosion problems when normal steel pipes are used especially in the regions where large quantities of petroleum is extracted from the wells. Though the stainless steels do not suffer corrosion, they do start to degrade due to aging when they come in contact with chemicals and water for a long period of time and also lose its mechanical characteristics. These also cause failure and leakage in pipelines.

By replacing the stainless steel pipes with the composite pipes, the time period between the successive maintenance of the pipelines can be extended and increases the service life of the pipelines. The pipes which are reinforced with GFRP are expected to remain in operation for fifty years as a long term design constraint regulated by international rules and regulations. Here, the woven fabric type of GFRP is used to reinforce the stainless-steel pipes with the help of resins and hardeners to bond steel and GFRP firmly. And the mechanical tests for the composite pipes are done and compared based on the number of GFRP wraps made on the pipes.

1. SAE 304 STAINLESS STEEL

Material: **Stainless Steel - Grade 304 (UNS S30400)**

Composition: **Fe/<.08C/17.5-20Cr/8-11Ni/<2Mn/<1Si/<.045P/<.03S**

SAE 304 stainless steel also known as A2 stainless steel or commercially as 18/10 or 18/8 stSAE 304 stainless steel also known as A2 stainless steel or commercially as 18/10 or 18/8 stainless steel, European norm 1.4301, is the most common stainless steel. The steel contains both chromium (between 18–20%) and nickel (between 8–10.5%) metals as the main non-iron constituents. It is an austenitic stainless steel. It is less electrically and thermally conductive than carbon steel and is essentially non-magnetic. It has a higher corrosion resistance than regular steel and is widely used because of the ease in which it is formed into various shapes.

304 stainless steel has excellent resistance to a wide range of atmospheric environments and many corrosive media. It is subject to pitting and crevice corrosion in warm chloride environments and to stress corrosion cracking above about 60 °C. It is considered resistant to potable water with up to about 200 mg/L chlorides at ambient temperatures, reducing to about 150 mg/L at 60 °C. Stainless steel, European norm 1.4301, is the most common stainless steel. The steel contains both chromium (between 18–20%) and nickel (between 8–10.5%) metals as the main non-iron constituents. It is an austenitic stainless steel. It is less electrically and thermally conductive than carbon steel and is essentially non-magnetic. It has a higher corrosion resistance than regular steel and is widely used because of the ease in which it is formed into various shapes.

304 stainless steel has excellent resistance to a wide range of atmospheric environments and many corrosive media. It is subject to pitting and crevice corrosion in warm chloride environments and to stress corrosion cracking above about 60 °C. It is considered resistant to potable water with up to about 200 mg/L chlorides at ambient temperatures, reducing to about 150 mg/L at 60 °C.

1.2 Mechanical Properties:

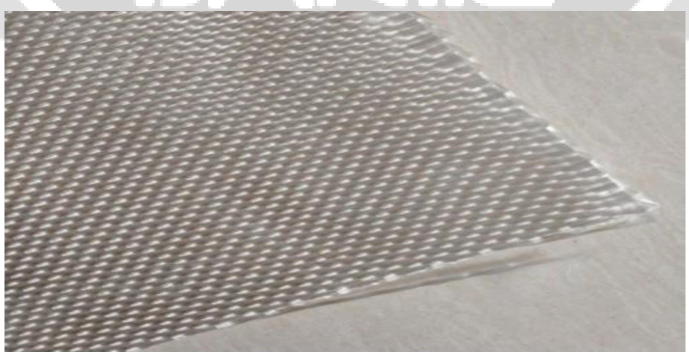
Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)	Minimum Value (Imp.)	Maximum Value (Imp.)	Units (Imp.)
Density	7.85	8.06	Mg/m^3	490.06	503.17	lb/ft^3
Ductility	0.3	0.57		0.3	0.57	NULL
Elastic Limit	205	310	MPa	29.7327	44.9617	ksi
Endurance Limit	175	260	MPa	25.3816	37.7098	ksi
Fracture Toughness	119	228	$MPa.m^{1/2}$	108.296	207.491	$ksi.in^{1/2}$
Hardness	1700	2100	MPa	246.564	304.579	ksi
Poisson's Ratio	0.265	0.275		0.265	0.275	NULL

Shear Modulus	74	81	GPa	10.7328	11.7481	10^6 psi
Tensile Strength	510	620	MPa	73.9692	89.9234	ksi
Young's Modulus	190	203	GPa	27.5572	29.4426	10^6 psi
Melting Point	1673	1723	K	2551.73	2641.73	°F
Specific Heat	490	530	J/kg.K	0.379191	0.410145	BTU/lb .F
Thermal Conductivity	14	17	W/m.K	26.2085	31.8246	BTU.ft /h.ft^2.F
Thermal Expansion	16	18	10^{-6}/K	28.8	32.4	10^{-6}/°F

2. GLASS- FIBER REINFORCED POLYMER

It was first developed in the mid 1930's; Glass-Fiber Reinforced Plastic (GFRP) has become a staple in the building industry. Fiberglass is a common type of fiber-reinforced plastic using glass fiber. The fibers may be randomly arranged, flattened into a sheet called as chopped strand mat, or woven into a fabric.

The plastic material may be a thermoset polymer material, most often it is based on thermosetting polymers such as epoxy, polyester resin, or vinyl ester, or a thermoplastic. It is cheaper and more flexible than carbon fiber, it is stronger than many metals by weight, and can be molded into complex shapes. The process of manufacturing fiberglass is called pultrusion**.**



GFRP E-class Woven type

E-glass: Alkali free, highly electrically resistive glass made with alumina-calcium borosilicate. E-glass is known in the industry as a general-purpose fiber for its strength and electrical resistance. It is the most commonly used fiber in the fiber reinforced polymer composite industry.

2.1 Properties:

Fiber type	**Density (g/cm3)**	**Tensile Strength MPa**	**Modulus GPa**	**Percent Elongation**
A-glass	2.44	3300	72	4.8
AR-glass	2.7	1700	72	2.3
C-glass	2.56	3300	69	4.8
D-glass	2.11	2500	55	4.5
E-glass	**2.54**	**3400**	**72**	**4.7**
ECR-glass	2.72	3400	80	4.3
R-glass	2.52	4400	86	5.1
S-glass (also S-2 glass)	2.53	4600	89	5.2

2.2 Advantages

- High Strength- GFRP has a very high strength to weight ratio.
- Lightweight- Low weights of 2 to 4 lbs. per square foot mean faster installation, less structural framing, and lower shipping costs.
- Resistance- Resists salt water, chemicals, and the environment - unaffected by acid rain, salts, and most chemicals.
- Seamless Construction- Domes and cupolas are resigned together to form a one-piece, watertight structure.
- Able to mold complex shapes- Virtually any shape or form can be molded.
- Low Maintenance- Research shows no loss of laminate properties after 30 years.
- Durability- Stromberg GFRP stood up to category 5 hurricane Floyd with no damage, while nearby structures were destroyed.

3. INTERNAL PRESSURE TEST

- For internal pressure testing, the average fluid pressure is given while testing for the leakage in joints.
- In pipes, the internal pressure is based on the circumferential and longitudinal stresses.
- For 304ss pipe,

Internal pressure, p = 10MPa

$\sigma_1 = pd/2t$

$\sigma_2 = pt/4t$

σ_1 = circumferential stress

σ_2 = longitudinal stress

p = internal pressure

d = inner diameter of the pipe

t = wall thickness
4.1 Calculations:
d = 0.037m
t = 0.003m

$\sigma_1 = pd/2t$
= 61MPa (circumferential stress)
$\sigma_2 = pd/4t$
= 30.8MPa (longitudinal stress)

The above two results are the maximum yield stresses.

For 304ss pipe reinforced with GFRP

Internal pressure, p = 10MPa

$\sigma_1 = pd/2t$
$\sigma_2 = pt/4t$
σ_1 = circumferential stress
σ_2 = longitudinal stress

p = internal pressure
d = inner diameter of the pipe
t = wall thickness
d = 0.037m
t = 0.0045m

$\sigma_1 = pd/2t$
= 41.1MPa (circumferential stress)
$\sigma_2 = pd/4t$
= 20.55MPa (longitudinal stress)

The above two results are working stresses.

3.2 Factor of safety:

- Factors of safety (FoS), is also known as safety factor (SF), is a term describing the load carrying capacity of a system beyond the expected or actual loads. Essentially, the factor of safety is how much stronger the system is usually that needs to be for an intended load.
- Factors of safety, FoS = Maximum yield stress/ working stress

For circumferential stress:
FoS = 61/41.1
FoS = 1.48
For longitudinal stress:
FoS = 30.83/20.55
FoS = 1.5

Hence, the Factor of safety is greater than 1 for both circumferential and longitudinal stresses, therefore it is safe to use the pipe under high internal pressure caused by the petroleum and natural gas which are transported below the sea level.

1.Salt Spray Test:

Chamber Temperature: 34.5 – 35.5^{0}C
PH Value: 6.65 – 6.85
Volume of Salt Solution Collected: 1.0 – 1.50 ml/hr
Concentration of Solution: 4.80-5.30% of Nacl
Air pressure: 14-18 Psi
Components Loading in the Chamber Position: 30 Degree Angle.

Observation: No red rust formation noticed upto 24 Hrs

2.Tensile Test:

Test Parameters	Observed Values
Yield Strength (N/mm2 or Mpa)	341

3.Crushing Test

Test Parameters	Observed Values
Ultimate Tensile Load (kN)	289.20
Ultimate Tensile Strength (N/mm^2 or Mpa)	511

Remarks: No Cracks Observed

4. CONCLUSIONS

Hence the design and development of thin walled cylindrical pipes made of 304 stainless steel which has been reinforced with Glass Fiber Reinforced Polymer (GFRP) and the composite pipe has more service life than the 304 stainless steel pipe which has been proved by the above discussed mechanical tests through practically and theoretically.
Therefore the 304 stainless steel pipe can be replaced with the composite pipe which has been reinforced with Glass Fiber Reinforced Polymer.

6. REFERENCES

1.“Composite Materials in the Offshore Industry”. AG Gibson, University of Newcastle, Newcastle upon Tyne, UK. S Arun, NIT Meghalaya, Shillong, India, 2016.
2.“Optimal maintenance strategy for corroded subsea pipelines”. Xinhong Li, Hongwei Zhu Guoming Chen, Renren Zhang, India, 2017.
3.“Design and Installation of Subsea Cable, Pipeline and Umbilical Crossing Interfaces”. Ahmed Reda Khalil, Ian M. Howard, Gareth L. Forbes, Ibrahim, A. Sultan, Kristoffer K. McKee. Australia, 2017.
4.“Elastic collapse of thin long cylindrical shells under external pressure”. Soheil Salahshour, Famida Fallah, Iran, 2018.
5.“The scaling mechanism of glass fiber reinforced plastics pipeline”. Wei Tang, Yuanhua Lin, Shangyu Ma, Kun Huang, Tuanjun Yao, Fu Li, Songsong Chen. China, 2017.
6.“On the mechanical performance of glass-fiber-reinforced thermosetting-resin pipes”. Roham Rafiee, Iran, 2016.
7.“Evaluating long-term performance of Glass Fiber Reinforced Plastic pipes subjected to internal pressure”. Roham Rafiee, Behzad Mazhari, Iran, 2016.
8.“Simulation of the long-term hydrostatic tests on Glass Fiber Reinforced Plastic pipes”. Roham Rafiee, Behzad Mazhari, Iran, 2015.
9.“Failure analysis of a GFRP pipe for oil transport. E.S. Rodríguez, V.A. Alvarez, P.E. Montemartini”. Argentina, 2012.
10. “Durability and service life prediction of GFRP for concrete reinforcement”. M. Sc. Valter Dejke, Sweden, 2016.