Utilization of composite materials in offshore structures

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With technology innovations and developments in processes and products, composites have become attractive candidates for many applications in marine industry. Applications of composite are increasing tremendously along with the concurrent need for knowledge generation in the area. In the current paper, the utility of composite materials in the field of offshore applications is investigated to emphasize the advantages of using these materials and to show their capability to be utilized as a superior alternative to other traditional materials, even in high pressure and aggressive environmental situations. Many applications are presented such as oil gas piping system, topside applications, pressure riser tubing in sub-sea, and others. The cost reduction in operation, installation due to the use composite materials can be considered as the most benefits of using such materials.

إن التطور المذهل والهائل في صناعه المواد ومنتجاتها جعل من المواد المركبه هدفا جذابا لاستخدامها في تطبيقات عديده في المجال البحري. هذه التطبيقات تزداد انتشارا مع إزدياد المعرفه في مجال المواد المركبه. هذا البحث يتناول مميزات استخدام المواد المركبه في بعض التطبيقات الهامه في إنشاء المنشأت البحريه البعيده عن الشاطئ لإظهار مدى إمكانيه إستخدام المواد المركبه كمواد بديله وفعاله للمواد التقليديه. لذلك تم عرض بعض التطبيقات مثل أنابيب نقل الغاز، بعض الاجزاء من السطح العلوي للمنشأ البحري البعيد عن الشاطئ، كذلك الأجزاء السفليه مثل أنبوبه الرفع وبعض التطبيقات الاخرى. وكان من أبرز الاستنتاجات ان التكلفه الاقتصاديه المنخفضه سواء في تشغيل أو تركيب المواد المركبه مع وجود مميزاتها الاخرى يجعلها مستقبلا مزهرا في هذه الصناعه.

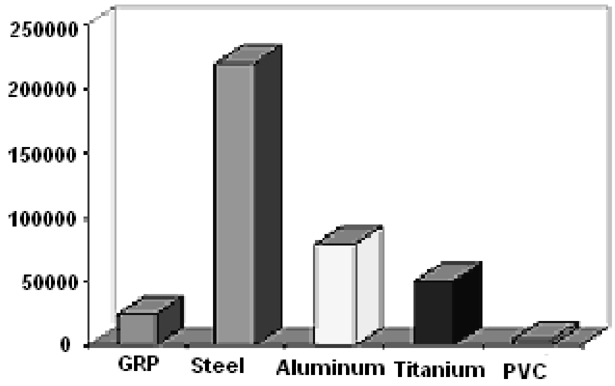
Keywords: Offshore structures, Composite Materials, Fibre reinforced plastic

1. Introduction

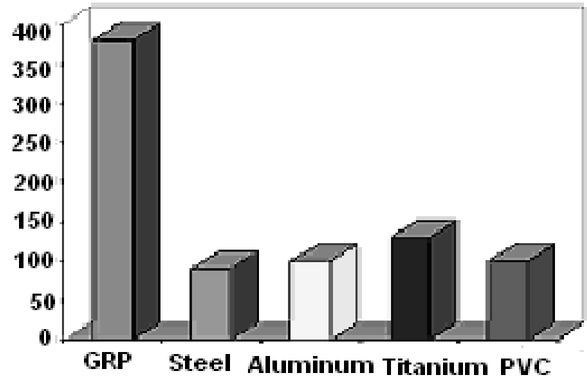
Composite materials of various types and forms have become important engineering solutions for the construction of a wide range of mechanical, aerospace and marine structures. The use of composite materials in fabricating these structures has resulted in a significant increase in payload, weight reduction, speed, manoeuvrability and durability. Composite materials inherently possess a high variability in their properties and geometric values because of their heterogeneous nature in structure as well as their manufacturing processes. The word ‘composite’ in the term ‘composite material’ signifies that two or more dissimilar materials are physically combined on a macroscopic scale in order to form a useful third material that has complex anisotropic properties. An advantage of composite materials is that they exhibit the best qualities of their components, or constituents, and often have some additional qualities that neither constituent possesses. The main factors that drive the use of composites are weight reduction and environment resistance. Other advantages that motivate some applications include electromagnetic transparency, wear resistance, enhanced operating life, thermal and acoustical insulation, and low thermal expansion.

Weight reduction provides one of the most important motivations for the use of composites in transportation in general and aerospace in particular. Composites are lightweight because both the fibres and the polymers are as matrices that have low density. For composites have one of the highest strength to weight ratio when compared with the other materials as shown in fig. 1.

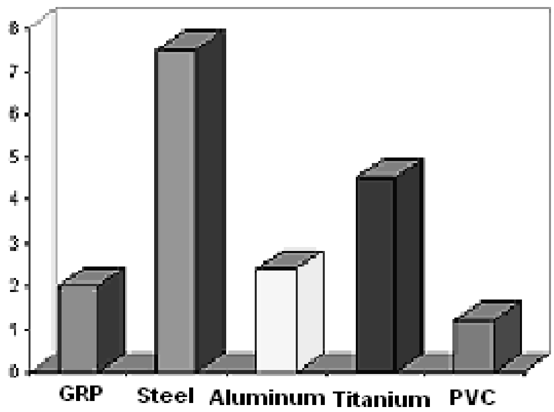
This research is concerned with presenting more additional applications of composites in offshore engineering fields. The paper describes the barriers of using composites



Young Modulus



Material Densities

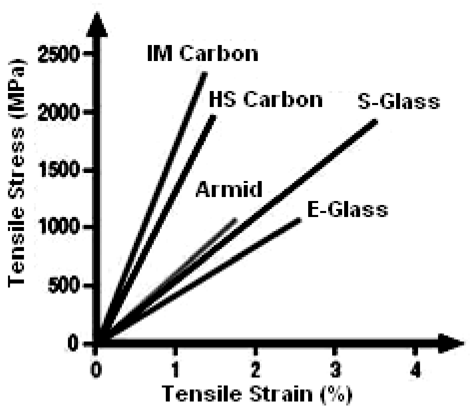


Specific Tensile Strength

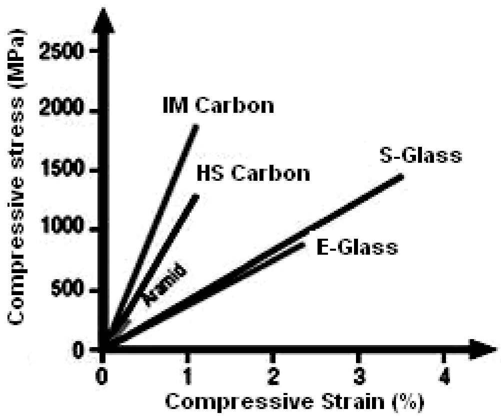
GRP: Glass Reinforced Plastic

PVC: Polyvinyl Chloride

Fig. 1. Comparison between properties of composite and other materials.



Tensile properties of U/D laminates



Compressive properties of U/D laminates

Fig. 2. Main fibre types.

in offshore fields. It also, presents the topside applications of such materials in offshore inshore, and provides the subsea applications.

2. Applications of composite materials to marine structures

Fibre Reinforced Plastic composites (FRP) or Glass Reinforced Plastic (GRP) and their fabrication methods are under continuous development in a wide variety of marine structural applications. The benefits of using such composites include ease of moulding to complex shape, light weight, durability, fire resistance, and low maintenance cost. The benefits of using FRP materials for a wide range of primary and secondary structures and lightweight fittings have been particularly exploited in the building of small vessels up to 70 m Such vessels include pleasure craft, fishing boats, work boats, fast ferries, patrol boats, and, among the largest ships worldwide, corvettes and mine counter measure vessels, in which the further advantages of non-metallic structure and high shock resistance are of particular benefit.

They also provide additional benefit in ship structures of otherwise metallic structure as they allow for potentially significant weight savings by reducing the fixed mass or lightship of the vessel. This is of particular benefit for weight sensitive designs such as fast ferries and warships. There is an ever increasing demand for the ability to carry more fuel oil for increased endurance or to carry more payload. Reducing weight in components higher up the ship, such as in superstructure and masts, has the further benefit of aiding the vertical centre of gravity of the ship thus so allowing acceptable transverse stability to be maintained, [1, 2]. Fig. 2 shows a basic comparison of the main fibre types when used in typical high-performance unidirectional applications.

In addition, sandwich construction combining FRP faces with a light core material offers a substitute to stiffened single-skin construction for shell, deck, and bulkheads structures of ships and boats, for the pressure hulls of submersibles and for superstructures of ships and offshore platforms. Some of the candidate core materials are foam cores, balsa and other wooden cores, honeycomb cores and cellular cores [3].

The cost and maintainability are to be considered as important features of composites, a comparative price of a 300g woven fabric is presented in fig. 3.

3. Barriers to utilization

Composite materials are increasingly being considered for use in offshore engineering fields particularly for deepwater offshore platforms and drill technologies. Composites materials are characterised by substantial weight reduction, superior fatigue and corrosion resistance, outstanding acoustic, vibration damping and energy absorption and provide the desired stiffness and strength of the structure. Success in obtaining these great potential requires understanding the existing composite technology base and its future development, structural requirements of deepwater offshore operation, economic and reliability constraints in the use of composites.

Composites, as secondary structures have been used as staircases, gratings, fire water pipes, flowlines, and downhole injection strings [4].On the other hand, as primary structures, the application of composites remains in its early stages. The basic barriers that are holding composites back are [5]:

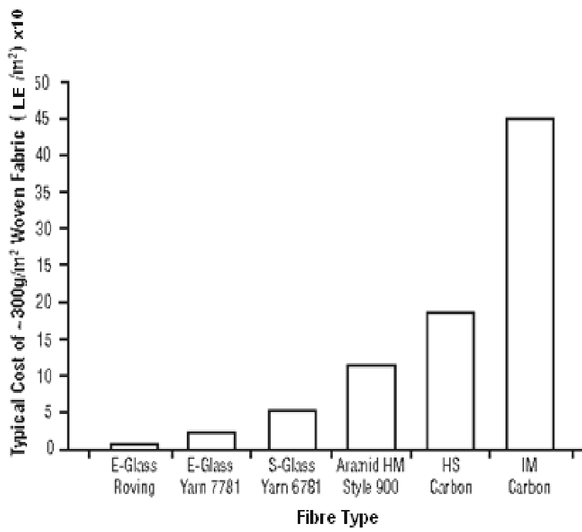


Fig. 3. Typical cost of 300g woven fabric.

- Structural reliability which is the most important barrier because of the higher failure consequence of the complicated offshore operation systems. So, the design of critical components must be based on statistical materials data bases and probabilistic design methodology must be developed to satisfy risk assessment analysis.

- The absence of manufacturing technology needed to produce cost effective offshore structures.
- Design methodology and design software for composite structures user friendly.
- The lack of construction techniques, equipment and experience with the use composites in offshore operations.
- Reliability of composite offshore system during service.

Even though composite materials can be applied to a range of oil industry applications onshore, offshore, both on topsides facilities and subsea, and down hole. The principal benefits of FRP or GRP composites are:

- corrosion resistance
- lightweight
- ease of handling
- Fire resistance
- Static Electricity
- Qualification procedures for GRP piping
- Layout considerations
- Chemical resistance
- Impact and damage tolerance

When applied correctly these enable the operator to achieve:

- Reduced installed costs
- Reduced operating costs

Below are listed established and emerging polymer composite applications for offshore industry.

4. Topside applications

In topside applications, the inherent corrosion resistance of composite materials reduces life cycle costs by minimizing its maintenance. Composite materials can offer significant applications with important features such as low cost, minimum topside weight and ease of transport at ion. These applications are as follow.

4.1. Composite piping system

Composites have found extensive applications in the oil and gas industry for last two decades. Significant advances have been made in the areas of composite pipe work and fluid handling. The high cost to replace steel piping in retrofit applications and increased durability in new construction are driving the use of composites, which withstand severe conditions as experienced in offshore environment.

In the offshore oil and gas industry, the cost of manufacturing and erecting oil rigs could be reduced significantly if heavy metal pipelines could be replaced with lighter ones made of composites. Composite pipes, as shown in fig. 4, also could be used for fire water piping, sea water cooling, draining systems and sewerage. The cost advantages of composite products are much greater when they replace expensive corrosion-resistant metals such as copper-nickel alloys, duplex / super duplex stainless steel, titanium etc. used in offshore platforms for various applications. Their resistance to corrosion helps in improving reliability and safety and also leads to lower life cycle costs. These results reduced problems with corrosion and blockage of fire lines, large in structural supports size and material handling during construction.

Glass Reinforced Epoxy (GRE) piping system offers complete solution for offshore environment against highly corrosive fluids at various pressures, temperatures, adverse soil and weather conditions (especially in oil exploration, desalination, chemical plants, fire mains, dredging, portable water etc.)

GRE pipes are commonly used in oil transportation where resistance to crude oil, paraffin build-up as well as ability to withstand relatively high pressures are required. GRE piping system is also being used on offshore rigs for sea water cooling lines, air vent systems, drilling fluids, fire fighting, ballasts and drinking water lines in offshore application. The lightweight helps in reducing heavy and expensive construction cost. Established oil fields use GRE pipes for high pressure and steam injection lines for the recovery of oil preserves. GRE piping system

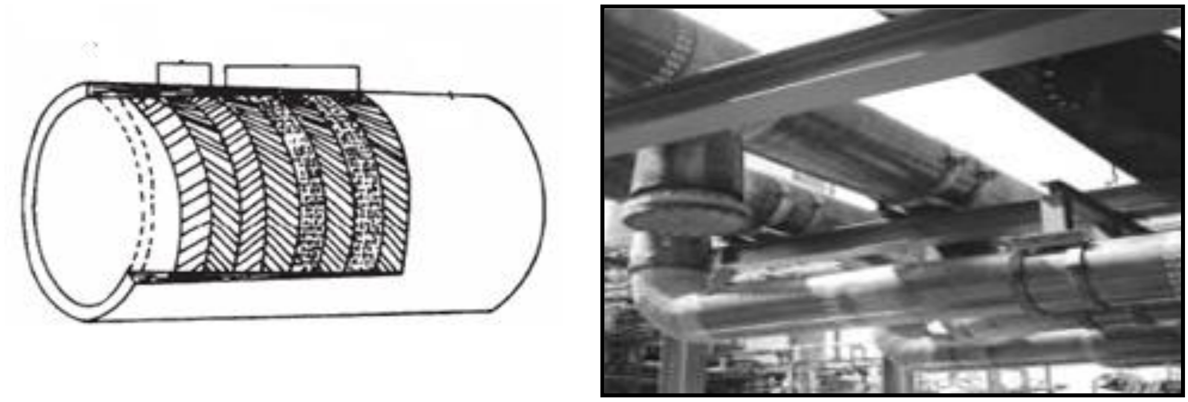


Fig. 4. Composite piping system.

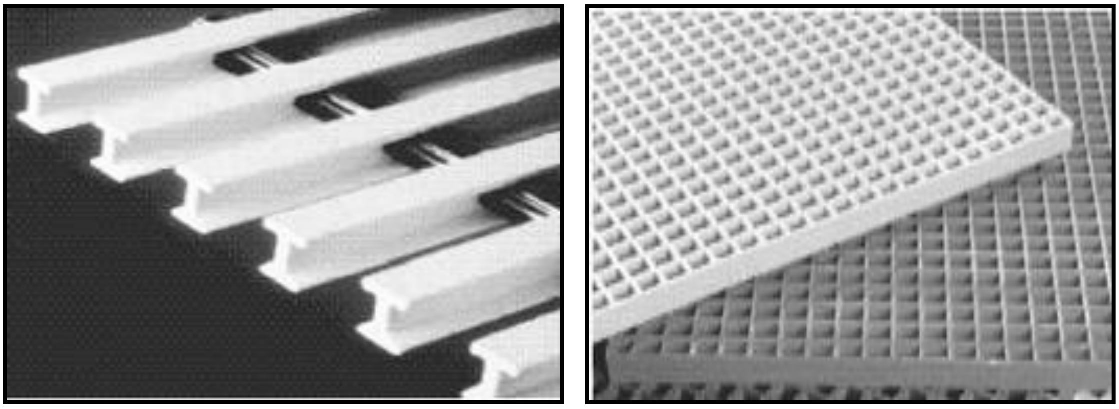


Fig. 5. Pultruded compression moulded grids/gratings.

can withstand the detrimental effect of brackish water when expelled under pressure from fire mains. The effect of rupture free GRE pipes under shocks makes the system more reliable. The chemical resistance and service temperature of such composites in a particular fluid depends on resin formulations, additives used etc.

4.2. Composite grids/gratings

Conventionally, grids/gratings are made of mild steel/cast iron. Due to the limitations on corrosion resistance, weight, durability, lifecycle costs etc. for the metallic gratings, composite grids/gratings perform much better due to their superior properties under aggressive environments as in chemical process industry.

Pultruded or compression moulded composite grids/gratings, fig. 5, have been manufactured for many applications as industrial walkways, hand rails, ladders such cable trays. The performance of the composite materials mainly depends on the process of fabrication. The pultruded FRP grating is an assembly of pre-shaped FRP pultruded sections joined together by various mechanical means. Pultruded structural profiles provide extremely useful options to offshore designers. Pultruded gratings have longer span with less deflection compared with moulded gratings.

The pultruded grating panels can easily be cut and modified to fit almost evry plant requirement. Resents gratings have achieved significant offshore usage particularly for situations where fire integrity is important. The main advantage of gratings lies not only in their performance during fire but also in their ability to retain significant level of functionality after fire exposure including low smoke emission.

4.3. Composite ladder and handrail components

Composite ladders, shown in fig. 6, are stronger than wood and aluminium one and do not absorb water, rot or corrode.

Unlike aluminium, fibreglass has excellent insulation properties which substantially reduce the hazard of electrocution by contacting high voltage power lines. For rough jobs where a ladder takes a beating, composite provides the ultimate ruggedness and long-term durability.

4.4. Flexible thermosetting tube

Composite coil tube replaces the existing steel coil tubing for high pressure down-hole applications in offshore platforms. The tube can be coiled or uncoiled on a drum as shown in fig. 7 and can easily be transported to the desired location of the wells.

Unlike steel coil tubes, composite tubes are effective for their insertion in horizontal wells. Flexible thermoset coil tubing can withstand high pressure rating up to 500 bars. In general, E-glass is used as the reinforcement but for specific applications carbon fibres could be used.

The liner material can also be tailored to suit the application requirement. At present a few composite components are being used by various industries for flexible riser construction. Until now the use of flexible coil tube has been restricted to below 100 mm diameter. However, future developments are underway for exploring the usage of composite tube for down-hole applications.

Fig. 6. Fibreglass ladder system and hand rails.

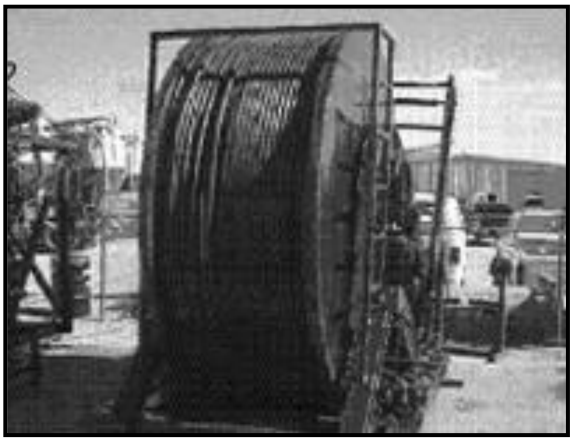


Fig. 7. Composite coil tube.

4.5. High pressure accumulator bottles

To accommodate the relative motions between the platform and the riser, in case of tension leg platforms, a telescopic joint is used at the upper extremity of each riser. These joints require a tensioning system capable of storing and releasing large amounts of energy as movement takes place. Tension is applied through gas-pressurized tensioners with accumulator bottles. In older designs steel accumulator bottles were used but recently considerable success has been achieved with composite bottles. The composite bottles offer significant weight and cost saving being less than 1/3 of the weight of equivalent steel bottles. These bottles can withstand very high internal pressures.

4.6. Composite caissons and pull tubes

Caissons are attractive applications for composites as a result of glass reinforced epoxy GRE piping technology [6]. In general, caissons are used to provide the service fluids to enter or leave the sea. These are located at splash zones in the sea water. Caissons, shown in fig. 8, are designed to withstand flexural fatigue loads created by waving loads and corrosion to aqueous fluids in the sea.

Fig. 8. Caissons at offshore platforms.

5. Subsea, flowlines, pipelines and risers

Subsea protection, Mud mats, GRP tubing, FRP lined steel tubing, HDPE lined steel pipe, Spoolable umbilicals and flowlines, flexible risers, production risers, drilling risers, composite tethers, composite buoyancy modules.

5.1. Offshore umbilicals and tethers

Offshore umbilicals are critical for operation of subsea systems in which a host production platform connects to wells scattered over long distances on the sea floor. Typically more than a mile in length and 140 mm to 175 mm (5 inches to 8 inches) in diameter, umbilicals are essentially large hoses or pipelines containing a cluster of smaller, high-pressure hydraulic hoses as well as electrical and optical cables that connect to subsea wellheads for remote operation of valves. Early models were simple thermoplastic tubes bound together, but with increasing water depth all covered with an extruded thermoplastic over wrap. This arrangement has a better resist once to the tensile loads induced by long, free-hanging catenary configurations. But at depths greater than about 2,150m/7,000 ft, the steel elongates under the extreme tensile loading, exceeding the tensile strength of the contained electrical cables, which can short out wellhead connections.

The cross-section of the subsea umbilical, fig. 9, shows the plastic profiles and stiffening rods that increase tensile strength.

The carbon tethers will perform much better than polyester because they're much stiffer at one-half the diameter. Their stiffness reduces the "watch circle" or the distance tethers allowing the MODU to drift from centre. The tethers are essentially carbon fibre ropes made from pultruded rods. The 6mm (almost 0.25 inch) rods are bundled, then multiple bundles are pulled together to form a helical rope. The rope is encased in an outer armor layer made of steel. The overall reeling diameter is a manageable 3m/10 ft.

5.2. Spoolable pipe

The concept of spoolable composite piping has been around since the 1960s. Spoolable composite pipe consists of a thermoplastic liner over wrapped with a structural laminate of glass or carbon fibers in an epoxy matrix, which is then covered with an outer sacrificial wear layer of either unreinforced or glass-reinforced thermoplastic. In "bonded" spoolables, the thermoplastic liner is directly

Fig. 9. Subsea umbilical cross-section.

bonded to the structural laminate, while "unbonded" pipe has multiple discrete and unattached structural layers (composite and/or metallic) over the liner that can slip in relation to each other, allowing higher spooling strain and generally higher pressure capacity.

5.3. Composite pressure risers

Composite risers are the pipelines that connects the rig of the water surface to the well bore at the seabed. They must separate the oil, gas and drilling fluids from seawater. The weight of a riser can drastically come down with the use of composite material as alternative to a heavy metallic riser. The composite risers could be designed to withstand highly corrosive chemicals, salts and fluids under different environmental conditions. The durability and life cycle costs in offshore platforms can be reduced. A cross-section in two proposed composite riser is shown in fig. 10.

5.4. Piling forms and jackets

A line of forms and jackets has been created in order to use in the building and restoration of bridge columns. The "tidal zone" of maritime structures is known to endure the most severe erosion effects and traditionally is the initial area requiring restoration [7]. Common practice involves the use of a pourable epoxy to encapsulate this portion of decaying piles. Repairs using the jacketing system can also be accomplished underwater. The forms shown in fig. 11 are lightweight permanent forms with specially treated inner surfaces to enhance bonding characteristics. The basic jacket material is E-glass mat and woven roving in a polyester resin matrix.

6. Conclusions

The use of composite materials in the offshore industry has flourished over time for a number of different reasons. Initially, long-term durability and favourable fabrication economics were the impetus for using FRP. Since the early 1960s, a key factor that makes FRP materials attractive is the reduction of labour costs. Various applications of the use of composite materials in the offshore field are presented. It can be concluded that the composite materials can play a significant role

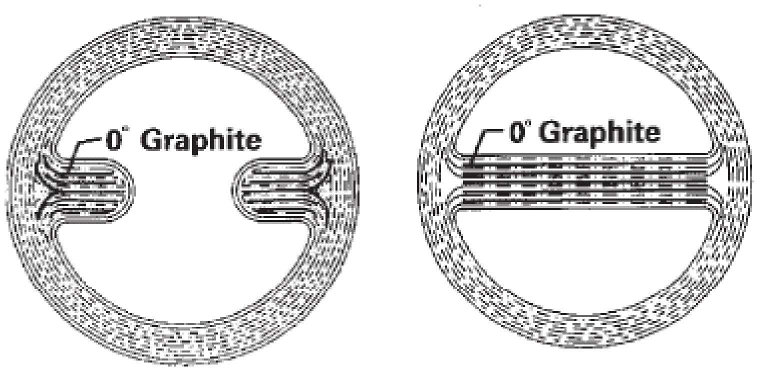


Fig. 10. Two proposed composite riser geometries utilizing E-glass for the bodies of the tubes [Jerry Williams. Conoco, SSC/NAS Sep 1990 conference].

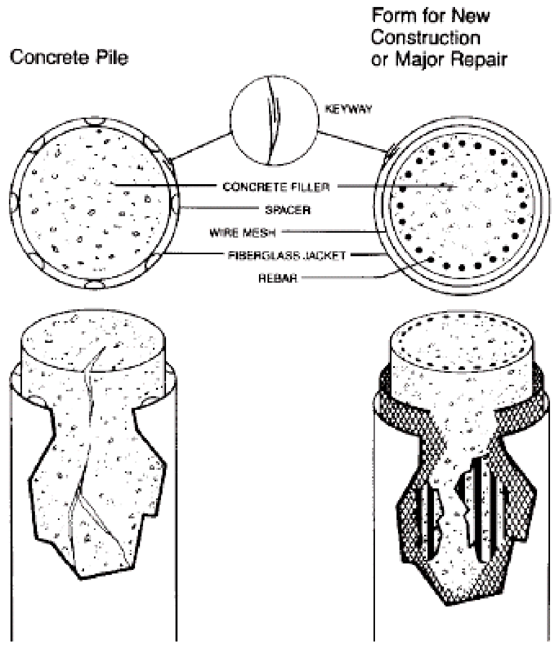


Fig. 11. Fibreglass forms and Jackets for pylon erosion restoration.

in increasing the growth of oil and gas industry. Using such materials returns with considerable reduction in operation, installation and fabrication cost. Composite materials need more research and investigations in order to broad en the utilization of composites in offshore field.

References

[1] P.N.H. Wright and Y. Wu, and A.G. Gibson, "Fibre Reinforced Composite-Steel Connections for Transverse Ship Bulkheads", Plastics, Rubber and Composites: Processing and Applications, PRC, the Institute of Materials, Vol. 29 (10), pp. 549-557 (2000).

[2] P.N.H. Wright, Y. Wu, and A.G., Gibson, "Factors Affecting Mechanical Strength of Steel to Composite Connections for Warship Structures", FRC 2002, 9th International Conference on Fibre Reinforced Composites, 26-28 March 2002, University of Newcastle Upon Tyne (2002).

[3] P.N.H. Wright, A.G. Gibson and Y. Wu, "Fire Safe Composite to Metal Joints for Warships", SAMPE Conference, Society for the Advancement of Materials and Process Engineering, Long Beach CA, USA, 16-19th May (2004).

[4] "Composite Materials for Offshore Operations", Proceedings of the First International Workshop Houston, Texas, USA October 26-28 (1993).

[5] O.O. Ozden, and M.M. Salama, "Offshore Composites: Transition Barriers to an Enabling Technology", Composites Science and Technology Vol. 65, pp 2588–2596 (2005).

[6] P.J. Boothby, C.D. Johnstone, "Fibre-Reinforced Caissons for Offshore Applications", Composite Structures Vol. 38, (l-4), pp. 141-149 (1997),

[7] Summer Scales, John. Royal Naval Engineering College, "Marine Applications", in Engineered Materials Handbook, Vol. 1, Composites, ASM International (1987).

[8] G.G. Huntoon and J.D. Alkire, "Design and Performance Properties of Oilfield Fibreglass Tubulars", 64th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, October, SPE 19728 (1989).

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