

# EMERGING TRENDS IN COMPOSITE AND ADVANCED COMPOSITE MATERIALS TECHNOLOGY FOR OIL AND GAS INDUSTRY

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## Abstract

*Composite and advanced composite materials are new age materials offering multiple benefits such as longer durability, lighter weight, high strength, tailor made properties etc. Lessons have been learnt from successful applications of composite and advanced composite materials and the results indicate that operators, designers and contractors are beginning to take a serious interest in their wide applications in Oil and Gas Industry. The most significant advances in the field of composite materials technology has been the use of glass-reinforced plastics (GRP) for pipelines and piping, structural applications for the top side secondary structures of offshore platforms and onshore installations. The introduction of carbon fibers has opened a new vista for composites applications in oil and gas industry particularly in deepwater operations such as drilling risers, production risers, umbilical, moorings etc. Numerous risers, mooring, pipeline, subsea and topside components made of polyester, titanium, glass/epoxy, and glass/carbon/epoxy materials are in the process of qualification for offshore use. These advanced composite material components have potential to extend capabilities of existing platform concept such as Semi submersibles, TLPs, FPSOs and SPARs. This paper presents the properties and advantages offered by composite and advanced composite materials, their current use and future potential applications in oil and gas industry.*

**Keywords:** *Composite Materials, Advanced Composite Materials, Fiberglass Reinforced Pipes, Carbon Fiber Reinforced Structures, Glass Reinforced Epoxy, Metal-Matrix Composite Riser System*

## Introduction

There has been a great advancement over the years in materials selection and their engineering applications in Oil and Gas Industry. Steel has up till now been the dominant material used in Petroleum Industry so far. Although ferrous metals have served the industry admirably well over many decades, they have always carried along with them the problems of corrosion. This has invariably resulted in frequent replacements of corroded material, which in turn have added to the maintenance costs of facilities and operational breakdowns.

The composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. Composite materials comprise of high strength fibers embedded in a resin matrix. These

materials have various noteworthy properties such as excellent corrosion resistance, lightweight and high strength to weight ratio [1]. Advanced composite materials are new age materials offering multiple benefits such as longer durability, lighter weight, high strength and tailor made properties [2]. The composite and advanced composite material components have longer service life of about 20-25 years as compared to the shorter service life (3-5 years) of carbon steel components in corrosive environment. All these advantages can be effectively made use of if the engineers and managers in the Oil and Gas Industry and other industries change their mindset favorably towards composite materials.

## Composite Materials

Composite materials are primarily engineered materials that combine two or more materials and could conceiv-

ably combine the unique characteristics of metals, ceramics and polymers resulting in engineering components with low onsite fabrication cost, light weight, high corrosion. Composites are able to meet diverse design requirements with significant weight savings as well as high strength-to-weight ratio as compared to conventional materials [3].

### Advantages of Composite Materials

Some advantages of composite materials over conventional ones are mentioned below:

- Tensile strength of composites is four to six times greater than that of steel or aluminum
- Improved torsional stiffness and impact properties
- Higher fatigue endurance limit (up to 60% of the ultimate tensile strength)
- 30-45% lighter than aluminum structures designed to the same functional requirements
- Lower embedded energy compared to other structural materials like steel, aluminum etc
- Composites are less noisy while in operation and provide lower vibration transmission than metals
- Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements
- Composites enjoy reduced life cycle cost compared to metals
- Composites exhibit excellent corrosion resistance and fire retardancy

### Properties of Composite Materials

Composite materials are made up of high strength fibers combined with a resin system and structural components are manufactured from these materials in a variety of forms depending on the need, using an appropriate process technology. The most commonly used fibers in composites Technology are Glass fiber (E-Glass /S-Glass /R-Glass), Carbon fiber or Kevlar fiber. The properties of these fibers along with those of Steel, Aluminium is shown in Table-1. It is obvious that it is possible to design a structure with high strength/weight and high stiffness/weight ratio using the fiber reinforced composite materials.

The resin systems in composites are either thermoset (e.g. epoxy, phenolics, polyester, vinyl ester etc) or thermoplastic (e.g. PVC, Acrylonitrile Butadiene Styrene Polysulphide etc). The thermoset resin systems are most commonly used in composite materials for application in oil and gas industry.

### Design Tools

Developments of various analytical methods, finite element analysis to deal with design of composite structures are already well developed. Standard packages such as ANSYS, NISA, ABAQUS, NASTRAN can be used to design structures with tubular, beams of different sections, plates, shells, sandwich components etc for a variety of applications. The crucial aspects to be appreciated while analyzing the results for design are Non-isotropic nature of composites, Damage / Damage tolerance and Repair technology. These are obviously different from those in steel (isotropic) structures. A complete knowledge, under-

**Table-1 : Typical Properties of Glass, Carbon and Kevlar Fibers Compared with Steel and Aluminium**

Fiber Type	Fiber dia. in um	Relative Density	Young's Modulus (GPa)	Tensile Strength (GPa)
E-Glass	10-16	2.55	72	1.5-3.0
S-Glass	12	2.5	87	3.5
Carbon HS	7	1.8	220-240	3-3.3
Carbon HM	7	2.0	330-350	2.3-2.6
Kevlar 29	12	1.44	60	2.65
Kevlar 49	12	1.46	128	2.65
Steel	-	7.8	210	0.34-2.1
Aluminum	-	2.7	70	0.14-0.62

standing and Technology are available for dealing with these aspects while designing composite material structures [4, 5, 6].

### **Fabrication Processes**

Depending on the type of structural component (for example tubular, plate, I-section beam), one can adopt appropriate manufacturing process. Some of these processes are Hand lay-up, Filament winding, Autoclave moulding, Pultrusion, Vacuum molding, Resin Transfer molding and Resin infusion molding. There are several variants of these techniques, but they are not listed. To-day there is complete understanding of these techniques for composite material component manufacturing.

### **International Certification**

Composite materials have been receiving much attention in the Oil and Gas Industry. International Standard Organization (ISO) and American Petroleum Institute (API) has developed specifications and guidelines for fiberglass reinforced plastic piping and pipelines both for low pressure and high pressure applications (ISO 14692, API 15LR, API 15HR, API 15TL4). Similarly, UK Offshore Operators Association (UKOOA) has also developed specifications and guidelines for composite material pipelines. Several test methods have been developed by ASTM for the evaluation of performance and quality control of composite and advanced composite materials (ASTM D2992, ASTM D2996, ASTM D2997, ASTM D2105, ASTM D2924 etc).

### **Application of Composite Materials in Oil and Gas Industry**

Composite materials have been used for many applications in Oil and Gas Industry for several decades now. Lessons have been learnt from successful applications of composite materials and the results indicate that operators, designers and contractors are beginning to take a serious interest in their wide applications in oil and gas industry. The most significant advances in the field of composite materials technology has been the use of glass-reinforced plastics (GRP) for pipelines and piping, structural applications for the top side secondary structures of offshore

platforms and onshore installations. These are briefly discussed below:

### **Application of Composite Materials for Secondary Structures**

The composite materials have been used for the last many years initially for the secondary structures and then for the low pressure pipelines for oilfield applications. The secondary structures include gratings, walkways, hand rails, staircase, ladders, cable trays etc and have been used both for onshore and offshore applications. The composite material secondary structure components are designed based on the application environment i.e. the resin system has to be selected keeping in view the chemical or other hazard in the application area. The photographs 1 to 2 show the various applications of composite materials for secondary structures in Oil and Gas Industry. The composite material secondary structures have been installed in many Oil and Gas Companies including ONGC in India.

### **Application of Composite Materials for Pipelines and Vessels**

The composite materials have been used for the pipelines and piping for diverse applications in Oil and Gas Industry both in offshore and onshore areas. The low pressure pipeline applications include produced water, effluent water and potable water transportation whereas the high pressure applications include injection water and hydrocarbon pipelines including the multiphase pumping and transportation. The composite material pipeline technology is well established and proven for onshore applications. However, the composite material pipeline are restricted in offshore only for produced water, effluent water and fire water applications. Photograph 3 shows the composite material piping in offshore. Glass Reinforced Epoxy (GRE) pipelines have been installed in several hundreds of kilometers in onshore for produced water, effluent water and fire water service. Apart from the flow lines and collector line, the cross country pipelines have also been installed using composite materials for the transportation of oil and gas. GRE pipes have been used on several offshore platforms including ONGC. Similarly, the composite material vessels and tanks (both over ground and underground) have been used extensively in oil and gas industry for the last many years due to high corrosion resistance and ease of handling (Photograph 4). Composite materials have also been used for the pressure vessels handling oil and gas.

### **Application of Advanced Composite Materials in Oil and Gas Industry**

There are several emerging applications of advanced composite materials in the Oil and Gas Industry. As the Oil Industry is moving into the deeper waters, the applications of advanced composite materials are becoming more and more prominent because of the weight reduction considerations. Some of the components which can be made with advanced composite materials are:

- Drilling risers and production risers
- Tethers for Tension Leg Platforms
- Sub-sea pipeline and equipment
- Spoolable tendons
- Topside components

Offshore industry has been considering two approaches for deepwater field development 1) Capability extension of existing platform concepts such as Semis, TLPs, FPSOs and Spars, and 2) New technology development for innovative concepts, such as deepwater Subsea processing and tie-backs, new floating platform designs (variations of TLP and Spar concepts). New riser systems submerged platform free standing riser towers, and buoyancy systems). Cost effective solution to weight reduction of deepwater risers, mooring tendons, and topside facilities is a critical factor for both approaches. Undoubtedly, advanced composite materials have the potential to be used in all deepwater development concepts. Some of the advanced composite materials applications are shown in Fig.1 and are discussed in the following sections.

#### **Composite Spoolable Pipe**

Spoolable composite pipe [7], describes a pressure loaded classical fiber/resin composite tubular structure designed to be capable of being bent to a relatively small ratio of bend radius to tube radius without sustaining significant damage. The pipe must be available in long lengths (thousands of feet) with the capability of being wound onto a spool. The determining property which distinguishes a composite pipe from hose is the higher Modulus of elasticity of the pipe matrix encapsulating the fiber. Composite tubing can be tailored to exhibit unique anisotropic characteristics which optimally address burst and collapse pressures and tensile and compression loads, as well as the high strains imposed by bending. Composites can be designed to be more resistant to fatigue than steel coiled tubing, especially when combined loads im-

pose strains which force the steel tubing into plastic deformation [8]. Composite tubes can weigh 1/3 as much as comparable steel tubes, which for some operations provides significant service advantages [9]. For example, composite pipes can be made neutrally buoyant if a matched density fluid or gas is placed inside the pipe. A neutrally buoyant tube provides the potential to extend the range of entry into a deviated or horizontal well or pipeline.

#### **Subsea Umbilical and Injection Lines**

Subsea umbilical and injection lines have the maximum application of composite materials technology[10]. The subsea tubing is constructed of glass fibers and epoxy resin and incorporates a cross-linked polyethylene (PEX) internal liner. The design includes axial as well as cross-ply of glass to provide axial stiffness for the Subsea application. The incorporation of axial plies increases the stiffness, but also decreases the axial strain which can be imposed on the pipe during spooling.

#### **Risers**

The composite material risers have the potential to make some deepwater field development concepts technically and economically feasible [11,12]. For a TLP platform, reduction in riser weight reduces top tension requirement, which is provided by the hydraulic tensioners. Reduction in tensioner requirement leads to reduction in the TLP displacement. Similarly, the use of composite risers and buoyancy elements also reduces the top tension requirement of spar platforms risers. For spar riser, the top tension is provided by air cans. Reduction in air can size reduces the well - bay area dimensions and the platform size. This reduction is especially significant when the well count is high and the spar is designed for deepwater. Apparently, the riser weight has nonlinear effects on the platform size for heavier risers (deepwater risers). Therefore, the composite risers have a higher impact on the size of deepwater platforms.

#### **Metal Matrix Composite Riser System**

Another astounding development in the area of advanced composite materials is use of metal matrix. At times depending on harsh environment conditions, design basis and operational requirement, a synergetic use of both metal and composite has been devised and put to operational use successfully. The basic riser pipe design consists of a stainless steel internal carcass for collapse resistance,

an extruded polymer fluid barrier, a carbon steel interlocked hoop strength layer, helically wound carbon steel tensile armor for axial strength, and an extruded watertight external sheath. For dynamic applications extruded polymer or tape polymer antiwear layers are applied between adjacent steel armor layers. For extremely highpressure applications, an additional layer of rectangular shaped helical reinforcement over the interlocked hoop strength layer, or a second set of tensile armor layers, may be applied.

### Coiled Tubing

Composite material coiled tubing [13] is being evaluated for use in several different well intervention services. The first applications were for work over services in vertical wells, but the most enabling applications promise to be for horizontal wells and pipeline services by expanding the ability to reach greater distances into the formation or pipeline. A 1.500-inch O.D. (0.985-inch I.D.) composite coiled tubing designed for 5,000 psi pressure and 250°F operating temperature was deployed in well intervention services in West Texas. These services were performed during March and April 1999 in six onshore wells located in the Permian Basin, USA. The wells selected for testing the composite tubing were CO<sub>2</sub> injection wells, which required clean-out intervention services. Based on reports

for these services, the composite coiled tube was deployed and retrieved with an estimated 38,000 running feet. During this service, it appeared that the composite coiled tube O.D. surface did not suffer from the mechanical deployment and retrieval handling equipment.

The purpose of flow line remediation services is to remove blockage within the pipeline, such as paraffin accumulation and hydrate plugs. The distance which coiled tubing can be pushed into a pipeline depends on several factors including: the length of the horizontal and deviated sections, I.D. of the flow line or pipeline, the degree and number of tight-radii bends and the stiffness of the tube. Steel coiled tubing, which is heavier than the fluid in the flow line is limited in how far it can be pushed. A point is reached at which the friction acting on the coiled tubing exceeds the pushing force and further compressive force causes the coiled tubing to helically buckle. Composite spoolable tubular have a lower density than steel, which minimizes the effects of contact drag when the tube is run along a horizontal or deviated section length. In a liquid filled flow line/pipeline, the composite tube can be neutrally buoyed and transported significantly further into the conduit than its steel counterpart. Further, the lower modulus allows for easier translation through tight-radii bends when compared to steel. Table-2 gives some examples of composite material spoolable pipe applications.

**Table-2 : Composite Material Spoolable Pipe Applications**

Product	Application	Requirement Criteria	Field Service
Line Pipe	Oil, gas flowline, water and CO <sub>2</sub> injection	Temperature, UV, Internal Pressure and Fluid Chemistry	Onshore : USA, Canada, Middle East, India
Subsea Umbilicals/injection lines	Methanol and water injection, Hydraulic fluid control lines	Temperature, Internal and External Pressure, Tension, Fluid Chemistry	Offshore : North Sea
Coiled Tubing	Well Intervention, Flowline Remediation, Pipeline Survey	Temperature, Internal and External Pressure, Tension and Compression loading (with bend cycling), Fluid Chemistry, Close Tolerances, Lateral Loads and Wear in Injector	Onshore : USA and Canada
Spoolable Drill Pipe	Drilling/Formation Evaluation	Temperature, Internal and External Pressure, Tension and Compression Loading (with bend cycling), Fluid Chemistry, Close Tolerances	Offshore : North Sea
Completion Tubulars	Production, Injection and Artificial Lift	Temperature, Internal and External Pressure, Tension and Compression Loading (with bend cycling), Fluid Chemistry	Offshore : North Sea, Canada
Large Diameter CSP	Flexible Risers, Offshore Flowlines	Temperature, Internal and External Pressure, Tension and Compression Loading (with bend cycling), Fluid Chemistry	N/A

### Conclusion

Composite and advanced composite materials technology is a new and emerging technology, but well researched in the past few years. Most of the concerns of the past are answered, and there is full confidence to use these materials for critical applications. It is well known from the experience, that even if the safety margins in design are fixed at conservative levels, composites will still provide a higher stiffness/weight and strength/weight ratios compared to steel structures with comparable life cycle costs.

Composite materials have already been adopted by Oil and Gas Industry for the secondary structures, vessels, pipelines and piping. Now the advanced composite materials are being developed for high end applications in deep waters. Numerous risers, mooring, pipeline, subsea and topside components made of polyester, titanium, glass/epoxy, and glass/carbon/epoxy materials are commercially available or in the process of qualification for offshore use. These advanced material components have potential to extend capabilities of existing platform concept such as Semi submersibles, TLPs, FPSOs and SPARs. Emerging field development concepts such as deepwater subsea processing and long tie -backs, new floating platform designs (variations of TLP and Spar concepts), new riser systems(submerged platform, free standing riser towers, and buoyancy systems) may also benefit from the advanced composite materials components.

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Photograph 3 : Composite Material Piping in an Offshore Platform



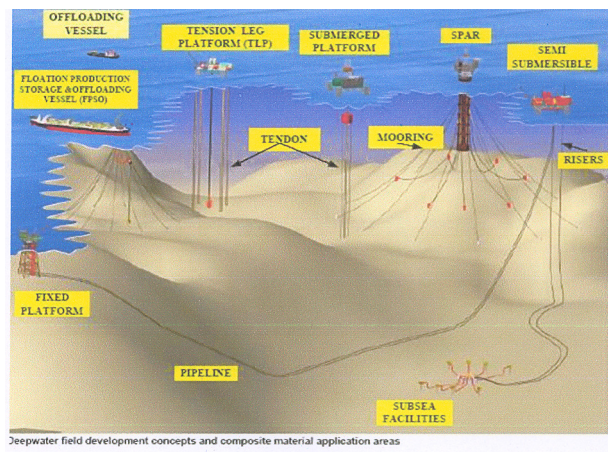
Photograph 1 : Composite Material Gratings on an Offshore Platform



Photograph 4 : Composite Material Underground Tanks Under Installation



Photograph 2 : Composite Material Grating and Handrail in Offshore Platform in Well Head Area



Deepwater field development concepts and composite material application areas

Fig.1 Most Common Floating Platform Types and Potential Application Areas for Advanced Composite Materials