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1.0 INTRODUCTION

"Oil, gas and energy are an essential driving force for any modern economy. Under the astute management of PETRONAS, the domestic oil and gas industry has played a crucial role in the growth of the Malaysian economy. However, after decades of oil and gas production, our domestic resources will inevitably start to deplete.

To prepare for this, we will strengthen other value creating activities in the oil and gas value chain and ensure that we have a sustainable energy platform for the future. To this end, the Government will develop Malaysia into a leading oil and gas services hub in Asia, grow Malaysia's role in oil storage, logistics and trading and import LNG to serve latent gas demand and attract new-gas based industries. At the same time we will ensure that we develop an energy efficient, diversified and sustainable energy mix to power our future."

'YAB Dato' Seri Mohd. Najib Tun Abdul Razak'

Oil and gas production have been a mainstay of Malaysia's growth since oil was first drilled in 1910 in Sarawak. The founding of PETRONAS in 1974 provided vital impetus to the development of oil and gas resources in Malaysia. In parallel, the consumption of electricity has grown steadily to 110 gigawatts hours, putting Malaysia on par with Thailand in terms of electricity usage per capita, driven by increased levels of prosperity and the industrialization of the nation. The combined oil, gas and energy sectors represented RM127 billion or 19 percent of GDP in 2009.

The oil and gas industry is generally divided into upstream, midstream and downstream activities.

Upstream activities consist of exploration, development and production of oil and gas resources. Midstream and downstream activities range from the transportation of oil and gas, to refining and processing through to marketing and trading of end products. The energy sector comprises power generation, transmission and distribution.

In terms of size, upstream oil and gas production including petroleum and gas contributes RM87 billion, while downstream activities including refining contributes RM24 billion. Separately, the energy sector contributes an additional RM16 billion to this sector.

The availability of domestic hydrocarbon resources gave Malaysia a natural impetus to develop the oil and gas sector. PETRONAS, the national oil corporation, continues to play a major role in driving the industry's growth through its development of oil and gas resources as well as the creation of opportunities for local companies to build up their capacity and capability across the value chain.

PETRONAS' Petroleum Management Unit regulates upstream activities, while PETRONAS subsidiary Petronas Carigali participates in production sharing contracts (PSC) with other PSC contractors such as Shell, ExxonMobil, Murphy Oil, Talisman, Petrofac, Newfield and others.

The midstream segment consists of pipeline, transportation and other logistic assets that are mainly controlled by PETRONAS and other oil companies operating in Malaysia. The contribution of this segment amounts to approximately RM3.2 billion annually.

In the downstream segment, two major integrated petrochemical zones have been established in Kerteh, Terengganu and Gebeng, Pahang. These industrial zones have attracted foreign investments mainly from the USA, Germany and Japan (e.g. from Dow Chemical, BASF and Idemitsu), complementing investments from PETRONAS. These investments involve the production of petrochemical materials such as polypropylene, acetyls, and other such materials. There are also refineries operated by PETRONAS (in Kerteh, Terengganu and Sungai Udang, Melaka), Shell and ExxonMobil (both in Port Dickson, Negeri Sembilan).

The oil field services and equipment (OFSE) industry supports primarily upstream activities and currently contributes RM1 to RM2 billion in GDP. Included in this sector are lands drilling services, offshore drilling services, geophysical services, engineering and contracting (E&C), equipment assembly and manufacturing, offshore structure fabrication and installation and operations and maintenance (O&M). While most of the major international players in OFSE such as Schlumberger, Baker Hughes and Technip are already present in Malaysia, PETRONAS has supported the development of local companies such as Scomi, SapuraCrest, Kencana, Petra Perdana and Wasco.

2.0 OPPORTURNITY AVAILABILITY

Global oil and gas production has grown by approximately 1.5 percent per year in the last decade, driven by robust demand in OECD countries and rapidly rising demand from developing economies, notably China and India. According to the International Energy Agency the global growth outlook for 2010 to 2020 for both oil and gas demand will shift further to developing economies in this decade. While "green" policies
and de-carbonization are taking place, especially in developed economies, any impact on oil and gas demand is not expected to be marked until the end of the decade. Demand for gas, especially, may actually benefit in the near term, as natural gas is both plentiful and green vis-à-vis other fossil fuels.

Global oil and gas supply capacity jumped ahead of demand during the financial crisis of 2008 and 2009. This created a temporary but significant price dip in oil prices and enduring turmoil in global gas markets. The ongoing volatility in gas markets has been exacerbated by significant supply additions in the USA from domestic production of shale gas. A tighter balance of supply and demand is expected in both oil and gas by the middle of the decade, as demand growth catches up with supply infrastructure.

In the last decade, growth in the upstream sector in Malaysia has been driven more by rising prices in oil and gas than by increases in production. PETRONAS' international expansion has also contributed to Malaysia's GNI.

Oil Field Services

The Asian market for oil field services has grown by approximately 20 percent per year over the last decade, primarily driven by the shift towards more technically challenging fields, e.g. deepwater, and increases in the price of oil, which has boosted industry margins. The sector outlook continues to be bright, driven by the upbeat outlook for offshore exploration activity in Southeast Asia, tight gas developments across Asia and the liquefied natural gas (LNG) boom in Australia.
The market for OFSE in the region is quite fragmented, with most of the players setting up operations in Malaysia, Indonesia, Singapore and Thailand. This is unlike Europe

and America, where OFSE activities are centered on hubs such as Aberdeen, Stavanger and Houston. This presents an opportunity for Malaysia, as most of Malaysia's offshore producing fields are more mature than those of our Southeast Asian neighbours (i.e., Indonesia, Thailand and Vietnam). This means that there will be significant opportunities for maintenance and replacement of assets, in addition to development of new fields, which will continue to drive growth in this subsector.

Mid- and Downstream Oil

The regional midstream logistics market (oil and oil product storage) also offers a positive growth outlook, as crude oil consumption in the Asian region is expected to grow by 420 thousand barrels per day in each year from 2010 to 2015. The increased flow of hydrocarbons in the region will require additional storage capacity (for transshipment, sales and marketing and trading purposes). At the same time, the region's existing trading hub, Singapore, is nearing full utilization.
Downstream processing (petrochemicals and refining) and marketing industries are likely to also show at least modest growth levels. The opportunity to expand the large installed petrochemical complexes in Malaysia will depend on regional supply and demand balances as well as on the opportunity to introduce process and product innovations. Likewise, the pace of potential refinery expansion will be driven by regional supply-demand balances.

Mid- and Downstream Natural Gas

There exists a positive growth outlook for the Malaysian domestic gas market: economic growth will increase the volumes needed by existing gas consumers, and the lower gas prices compared with fuels like diesel and liquefied petroleum gas (LPG) will make switching to natural gas attractive. The depletion of gas resources in Peninsular Malaysia and the technical and economic challenge of sending gas from Sabah and Sarawak to Peninsular Malaysia by pipeline limit the availability of gas to feed this demand-growth. The import of liquefied natural gas (LNG) from international markets into Peninsular Malaysia could help to meet the growing demand for gas, provided that such gas is sold in Peninsular Malaysia at liberalized and unregulated market prices.

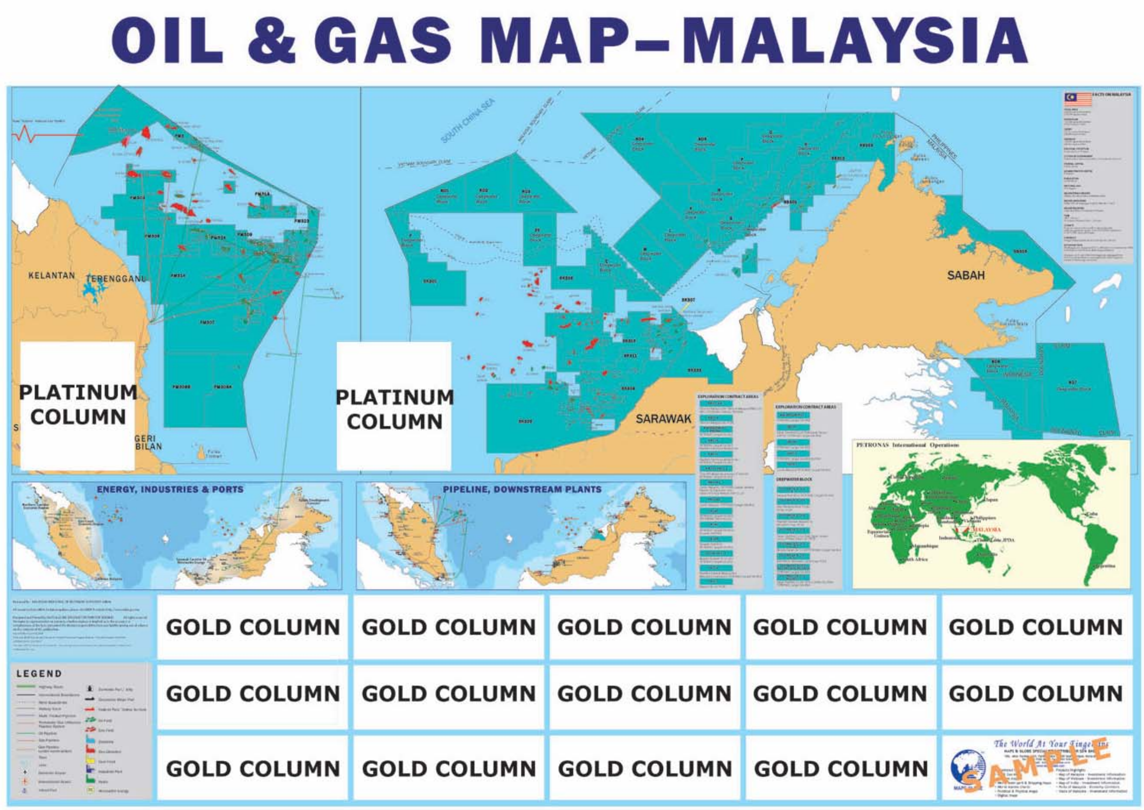
Energy

Malaysia is going to need more energy as our economy continues grow: 6 gigawatts of new generation capacity is expected to be needed by 2020 to provide energy for businesses and the growing population, representing an increase of about 25 percent over installed capacity in 2009.

The power sector faces a major challenge as declining gas production will have an impact on the power generation industry. Currently, 58 percent of power generation in Peninsular Malaysia is based on natural gas, with the remainder coming from coal (37 percent) and hydro (5 percent)

3.0 MARKET SURVEY – THE BUSINESS STRUCTURE IN BRIEF

Access to Market in the Oil and Gas (O&G) Industry



Petroleum exploration in Malaysia started at the beginning of the 20th century in Sarawak, where oil was first discovered in 1909 and first production in 1910. Prior to 1975, petroleum concessions were granted by state governments, where oil companies have exclusive rights to explore and produce resources. The Petroleum Development Act 1974 governs the upstream and the downstream sectors which PETRONAS (Petroleam Nasional Berhad) is party of. The Oil and Gas (OG) industry can be split into upstream and downstream sectors. The upstream sector includes the exploration and the extraction of crude oil and or gas. Among the PSC Contractors operating in Malaysia are Petronas Carigali, BHP Billiton, ExxonMobil, Kebabangan Petroleum, Shell, Lundin, Murphy Oil, Nippon Oil, Newfield Exploration, Talisman Energy, and Carigali Hess. These companies are involved in upstream operations activities taking place prior to processing and refining of hydrocarbons i.e.

- Exploration
- Conceptual Development
- Development
- Production

The Oil and Gas (O&G) industry is involved downstream activities as well. The downstream process involvement in processes taking place after oil has been transported from the reservoir and into crude oil terminals. Downstream have few players in the O&G i.e. Petronas Penapisan (plants in Kerteh, Terengganu and Melaka), Shell, Esso Malaysia and ConocoPhillips. PETRONAS Gas and MLNG are involved in gas processing and transmission.

All work which is contracted out in the upstream sector is through licensed contractors. One of the objectives of the Act was to make sure local players were involved. One of the requirements to obtain a license is being local company.

To access PETRONAS business it is imperative that the company is registered in Malaysia and have the relevant licenses for its business, services and/or products.
To obtain licenses:-

The company must be a Bumiputera company with the following criteria:

i. Registered with "Suruhanjaya Syarikat Malaysia (SSM)"

ii. Paid capital of at least RM100,000

iii. Shareholders are 51% Bumiputera

iv. Board of Directors are at least 51% Bumiputera

v. Supporting staff are at least 30% Bumiputera

4.0 COMPOSITES – THE DEVELOPMENT AND FEASIBILITIES

Deepwater E&P technology has become increasingly critical for effective, economical development of offshore fields. At present, offshore E&P facilities, including both topside platform structures and underwater subsea systems, have been designed and constructed with conventional materials, i.e., steel and concrete.

In deeper fields, conventional materials become less practical, **because of weight and fabrication considerations**. Alternatives, such as advanced composites, offer significant enabling capabilities and economies that could facilitate and accelerate deepwater technology development for future offshore petroleum drilling and production.

However, it also is clear that — owing to complex material, design and regulatory issues unique to offshore systems — **significant development work** must be done before the full potential of offshore composites can be realized.

Composite materials already are used in a number of secondary structures (not primary load-bearing components), including fire water main and deluge pipe, high- and low-pressure tubing, processing vessels and tanks, fire blast panels, accommodation modules, **gratings and handrail**.

Composite structures have been developed and constructed for subsea processing (e.g., separators) and for protecting wellheads and satellites, manifolds, templates and pipelines. There also have been advances in fiber composites and syntactic foams for fire protection, thermal insulation and deepwater buoyancy.

And newer developments, such as steel-strip laminate (SSL) pipe, have been shown to be cost-effective for large-diameter; high-pressure subsea flowlines with excellent flow assurance.

The fire performance issues of topside composites are well understood, and good results on electrostatic discharge of FRP have been obtained — although **acceptance of the results by regulatory and certification agencies** will require further discussion and cooperation among the various agencies.

Important advances include the application of filament-wound carbon fiber/epoxy composite accumulation bottles in tensioning devices for the production risers used on the Shell's Mars production platform in the Gulf of Mexico.

These high-pressure vessels have demonstrated that fiber-reinforced composites can be applied cost-effectively and safely in large, primary load-bearing offshore structures. And a number of new commercial composite products have emerged for other high-load applications, such as flexible piping, carbon-fiber rods for TLP (tension leg platform) tendons, reinforcing elements for deepwater umbilicals and mooring elements for MODUs.

Since the 1980s, major national and international initiatives have spurred R&D of advanced composites for primary structures in deepwater E&P. These projects have the joint support of the oil and gas industry, composites manufacturers, government agencies and some academic institutions.

In the main, the foci of the research initiatives have been development of manufacturing technology and performance evaluation of large, primary structures, such as composite drilling and production risers, extended-reach composite drill pipe and spoolable composite pipe. After many years, most of these technologies are ready for deepwater deployment.

For example, significant field experience has been accumulated on the composite drilling riser joint deployed on Statoil's Heidrun TLP. Also, the successful test of Shell's thermoplastic hoop-wound, high-pressure choke and kill lines marked an important milestone. A decade of R&D has established advanced analytical and modeling capabilities for composite risers that yield better designs and greater understanding of deepwater performance (e.g., vortex-induced vibration and long-term reliability).

In addition, certification agencies have started to issue guidelines and standards (e.g., Det Norsk Veritas' *Recommended Practice on Composite Risers, and Offshore Standards on Composite Components)*, which certainly will accelerate acceptance of major offshore composites in the near future.

Challenges remain: The Malaysian composites industry must take the lead by providing reliable, large-scale composites manufacturing capabilities (for example, for long-length composite riser production), but needs proper opportunities within field development projects to implement the composite structures they make.

A key factor will be the willingness of offshore companies to design composite products and the regulators' willingness to *accept* them — which will require that all groups work together to overcome the remaining industry cultural barriers.

Source: Transocean Sedco ForexHandrails, ladders and gratings made with pultruded or molded composite materials require less maintenance and mean significantly less topside weight.

5.0 COMPOSITES – FOR OFFSHORE APPLICATIONS

Composites are fast taking over as superior alternative to other traditional materials even in high pressure and aggressive environmental situations. Applications of composite are increasing tremendously along with the concurrent need for knowledge generation in the area.

With technology innovations and developments in processes and products, composites have become attractive candidates for applications in oil gas, piping system, topside applications, down-hole tubing in sub-sea, and others.

Composites meet diverse design requirements with significant weight savings and exhibit high strength-to-weight ratio compared to conventional materials. Composites have proved to be a worthy alternative to other traditional materials even in the high-pressure & aggressive environmental situations.

Besides superior corrosion resistance, composite materials exhibit excellent fatigue performance, good resistance to temperature extremes and wear, especially in industrial sectors.

The tailorability of composites to suit specific applications has been one of its greater advantages such as imparting low thermal conductivity & low coefficient of thermal expansion, high axial strength & stiffness etc.

Composites have found extensive applications in the oil & gas industry since 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 longevity 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 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 & also leads to lower life cycle costs.

These are the results in reduced problems with corrosion and blockage of fire lines, reduction in structural support sizes & material handling during construction.

Applications of composite piping are increasing tremendously along with the concurrent need for knowledge generation in the area.

Researches have been widely done including prediction of **life expectancy, joining technology, inspection methods, standardization of materials, and database development**.

With technology innovations and developments in processing/products, composites have become an attractive candidate for topside applications, down-hole tubing in sub-sea & others.

The selection of suitable resin plays an important role for imparting durability of the composites when exposed to aqueous fluids.

The important issues relating to materials selection are smoke & toxicity in fires, mechanical properties including resistance to impact and adverse environments.

5.1 Composite Piping System

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 is 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 reduce heavy and expensive construction cost. Established Oil fields use GRE pipes for high pressure & steam injection lines for the recovery of oil preserves. GRE piping system can withstand the detrimental effect of brackish water when expelled under pressure from fire mains.

The effect of rupture free GRE pipes under such shocks makes the system more reliable. The chemical resistance & service temperature of such composites in a particular fluid depends on resin formulations, additives used etc.

GRE pipe is commonly manufactured by filament winding technique. A typical GRE pipe is fabricated with an optimum wind angle of ± 54.75° to the longitudinal (0°) axis. The filament winding helps in providing better strength & stability for internal & external loadings in both the circumferential and longitudinal directions for the pipes and pressure vessels.

Such wound pattern attains resistance to high internal pressures, thermal variations and the impact loads induced by thrust due to water pressure. The appropriate joining procedures for composite piping, supporting systems etc. assume importance for better system performance.

In order to ensure high degree of stability and safety, generally filament wound fittings such as elbows, T-joints, laterals, reducers, crosses and Y-joints are made of same materials used for fabricating the composite pipe itself. The proven corrosion resistance, strength and light weight of composite piping coupled with increased confidence level has been instrumental in reducing load and cost on off-shore platforms. Standards for the use of composite piping and qualification procedures are being facilitated by various certifying agencies.

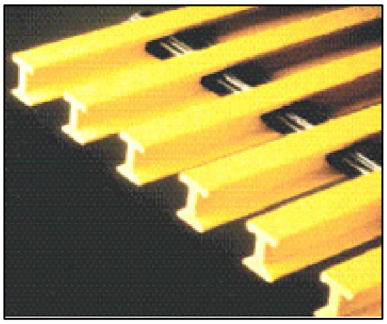
In general, three types of joining techniques are adopted for composite piping viz. adhesive bonding, laminating type (butt & wrap joints) and mechanical means of jointing (rubber seal joint or the threaded joint). For higher pressure applications, socket and spigot joints with moulded threads are successfully used, sometimes in conjunction with a thread sealant and adhesive. The thread design is often similar to the API tapered threads used with steel tubing. For evaluating the structural integrity of piping system, hydraulic test is carried out at 1.5 times the operating pressure.

5.2 Top Side Applications

Composite grids/gratings, hand rails, cable trays, ladders, decking, flooring have been used on fixed and floating off-shore platforms world over for more than two decades.

In topside applications, the inherent corrosion resistance of composite materials reduces life cycle costs by minimizing its maintenance. BP-Amoco had totally replaced metallic grids/gratings by the composite ones in two small-scale off-shore platforms in shallow water for technology demonstration. Low cost, minimum topside weight and ease of transport were important features in their monopod design construction.

5.3 Composite Grids/Gratings



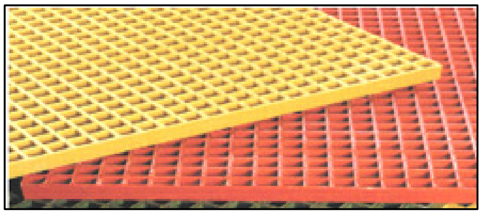
Conventionally, grids/gratings are made of mild steel/cast iron. Due to the limitations on corrosion resistance, weight, durability, lifecycle costs etc. for the metallic gratings, composite grids/gratings perform much better due to their superior properties under aggressive environments as in chemical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

Worldwide many industries are manufacturing pultruded or compression moulded composite grids/gratings for their applications as *industrial walkways, hand rails, ladders, cable trays*, etc. in chemical/pharmaceutical, transportation & infrastructural sectors.

The performance of the composite product 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 products due to high fibre-to-resin ratio (70:30), helps in achieving higher load bearing capacity. Pultruded gratings have longer span with less deflection as compared to moulded gratings.

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



On the other hand, compression moulded gratings have high resin content (fibre to resin ratio of about 60:40) – this contributes to greater corrosion resistance properties compared to pultruded gratings.

Bi-directional reinforcement in moulded gratings leads to higher impact strength. The grating limits the use of mechanical fasteners for fixation at any desired location. These types of gratings are used mainly at splash zones in offshore platforms.

The fiberline gratings and profiles in glass fibre reinforced plastics are lightweight and strong, and cannot be corroded by salt, water or chemicals. This makes them ideal for use in offshore industries.

The aggressive environment on offshore installations requires materials that are resistant to water, salt and chemicals.
Fiberline gratings and profiles are made of glass fibre reinforced plastics (GRP) – also known as fiberglass. The company is Europe's leading manufacturer of advanced GRP profiles which among other things are used for ladders, stairs, railings and connecting bridges in the offshore industries.

Long life - minimal maintenance

GRPs are resistant to weather and chemicals, which results in very long service life and minimum requirements to maintenance. Gratings and profiles can be machined and adjusted on site with ordinary tools, and, due to their low weight, can be assembled and mounted without using lifting equipment. Replacing worn or corroded steel structures with similar structures in GRPs also results in significant weight reductions.

Fiberline also manufactures gratings and profiles in phenols for uses involving stringent demands to fire safety and smoke retardation.

Mounted from above

Fiberline has developed special offshore fittings for mounting gratings on existing structures. The fittings make it easy to assemble the new gratings and mount them from above.

5.4 Composite Ladder & Handrail Components

Composites enjoy a significant market share of industrial ladders in replacing aluminium and wood in residential ladders. The ladders were originally developed for electrical utilities but have increasingly gained acceptance for general industry & residential uses. Composite ladders are stronger than wood or aluminium and do not absorb water, rot or corrode.

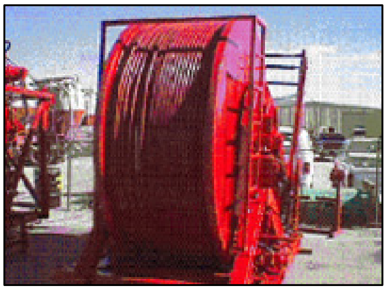
The products could be pigmented with a suitable colour along with the resin during the pultrusion process. With the colour throughout the part, there is no chipping or peeling.
Unlike aluminium, fiberglass has excellent insulation properties which substantially reduce the hazard of electrocution by contacting high voltage power lines. For rough jobs where a ladder

takes a beating, composite provides the ultimate ruggedness and long-term durability.

Strongwell, a composite ladder manufacturer from North America has designed & developed ladder rails for a variety of uses and requirements including stepladders ranging from 3 to 12 feet, extension ladders that stretch up to 40 feet, articulating ladder, step-stands and mobile maintenance platforms.

5.5 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 and can easily be transported to the desired location of the wells.



The tube comprises of thermoplastic liner at inner surface over-wound with a structural thermosetting laminate. Flexible tubing can be classified into two categories viz. bonded & unbonded type. In case of bonded coil tube, the thermoplastic liner and structural laminates are bonded together as one unit. On the other hand, unbonded tubing has flexibility to have a relative movement between each other. 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.

5.6 Composite Pressure Risers

Composite riser is the pipeline 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 riser can drastically come down with the use of composite material as alternative to heavy metallic risers.

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 improved.

5.7 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.

5.8 Composite Caissons & Pull tubes

Caissons are attractive applications for composites as an offshoot of GRE piping technology. 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 are designed to withstand flexural fatigue loads created by waving loads and corrosion to aqueous fluids in the sea.

In Summary Composite Applications for Off-Shore

A few current applications of composites for off-shore are listed in Table 1.0
Sl.No Application

1. Composite Grids/ Gratings
2. Hand rails & Ladder Components
3. Aqueous Piping System
4. Water & fuel storage tanks, Vessels
5. Low pressure composite valves
6. Spoolable type thermosetting tubes
7. Sump Caissons and pull tubes
8. Cable support systems
9. Modular paneling for partition walls
10. High pressure accumulator bottles
11. Flexible & Floating Risers, Drill pipe
12. Sub – sea structural components
13. Boxes, housings and shelters
14. Fire water pump casing & sea water lift pump casing
15. Tendons
16. Offshore bride connecting between platforms
17. Blast & Fire Protection

6.0 COMPOSITES – FOR WELL APPLICATIONS

For the near future, at least, oil and natural gas will continue to be critically important sources of energy worldwide. As easily tapped land and shallow coastal water reserves continue to decline, deepwater exploration and production is growing and with it, demand for strong yet lightweight materials able to stand up to incredibly harsh subsea environments.

At the recent Fourth International Conference on Composite Materials and Structures for Offshore Operations (CMOO-4), sponsored by the University of Houston's Composites Engineering and Applications Center (CEAC), offshore experts were cautiously upbeat about the future of offshore composites and cited a number of new applications — in progress and planned. During introductory remarks, University of Houston vice chancellor R. Arthur Vailas pointed out that new materials, including composites, are almost a necessity in the deepwater environment, one of the most challenging next to space. Dr. Howard Hwang of Shell Exploration and Production described a few of those challenges, which include high hydrostatic pressure, low temperatures, vortex-induced vibration (VIV), platform designs that are maxed out with regard to payload capacity and scattered fields containing low volumes of oil or gas, which make drilling and gathering of oil increasingly difficult: "Composites can reduce the weight and size of platform structures and therefore reduce infrastructure costs," he explains.

Composites have established some real footholds in offshore apps where their properties enable specific performance attributes, especially when combined with other materials — umbilicals, tethers, spoolable pipe, topside platform pipe, grating, "smart" monitoring systems and new concepts for natural gas transport are just some success stories. Composite material proponents at major oil companies say that, though it may take some time, a few recent setbacks in the areas of risers and gathering pipe can be readily overcome.

Umbilicals and tethers

Although the partnership of ConocoPhillips (Houston, Texas) and Aker Kvaerner (Oslo, Norway) — the group that developed the CompRiser and the CompTether during the 1990s — has been dissolved, Aker Kvaerner Subsea AS has continued work on composites applications. The company now is commer-cializing a new umbilical concept, a direct outgrowth of CompTether: the carbon rod dynamic umbilical, the winner of one of 14 "Spotlight on New Technology" awards given by the Offshore Technology Conference in 2005. Turid Storhaug, department manager with Deepwater Composites, a department within Aker Kvaerner Subsea, reports that umbilicals certified by Det Norsk Veritas (DMV, Oslo, Norway) are currently being assembled at Aker's facility in Mobile, Ala. and will be installed this summer in 3,000m/9,842 ft of water on Kerr-McGee's Merganser and Independence Hub MC-920 platforms in the Gulf of Mexico.

Offshore umbilicals are critical to 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 depths, Aker Kvaerner Subsea turned to a design that places the hoses and cables within free-floating stainless steel tubing cradled within plastic profiles, all covered with an extruded thermoplastic overwrap. This arrangement better resists 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 large tensile loads produced in this type of dynamic service required further axial reinforcement," says Storhaug. "We found that the Merganser/MC-920 environment had surpassed the limits of our patented steel tube product."

Increasing the thickness of internal steel tubes within the umbilical cluster, or adding even more steel, would have increased umbilical weight to an unacceptable level. The company instead has enhanced axial stiffness with carbon fiber rods, nearly as stiff as steel but 80 percent lighter.

Thin carbon rods are pultruded by Vello Nordic AS (Skodje, Norway) using Zoltek Corp.'s (St. Louis, Mo.) Panex 35 commercial 48K tow (produced at Zoltek's Hungarian facility) and vinyl ester resin from Reichhold (Research Triangle Park, N.C.). The 6.5-mm/0.25-inch rods, with a tensile modulus of 150 GPa and tensile strength of 1,730 MPa, are made in 3,050m/10,000-ft continuous lengths. For the Merganser/MC-920 platform project, a total of 384 rods (about 60 tons of fiber) were required for the four-umbilical set. The rods are spooled at the Vello facility onto 1.8m/6-ft diameter reels, a size that permits easy incorporation into the manufacturing line without exceeding the material's strain capacity.

As shown in the figure on p. 36, rods are placed along the outer circumference of and within the umbilical structure, held in place by designed indentations in the extruded internal plastic profiles that cradle the multiple stainless steel tube conduits. The rods are incorporated into the umbilical during manufacturing just like the other elements, at the same helical "lay angle," explains Storhaug. "This is an elegant, cost-effective design that has the benefit of eliminating bulky added buoyancy elements, which greatly complicate installation and add considerable project cost."

Storhaug reports that there is a lot of enthusiasm about offshore composite materials, not only among customers but even within her own company. "We get a lot of phone calls from internal groups who want to learn more. This umbilical project has been very important for carbon fiber in deepwater structural elements — we think that this is the start of something quite big," she concludes.

Another application for thin, pultruded carbon rods is reported by offshore project integrator Deepsea Engineering & Management (Epsom, Surrey, U.K.). Dan Jackson, Deepsea's commercial director, says that his company is investigating carbon fiber tethers as an alternative to polyester mooring ropes for anchoring mobile offshore drilling units (MODUs), essentially ships or moveable semisubmersible structures that drill offshore wells. Multiple tethers are needed to keep the MODU "on station," or centered exactly above the hole being drilled, typically thousands of feet below.

Jackson says that the carbon tethers will perform much better than polyester because they're far stiffer at one-half the diameter. Their stiffness reduces the "watch circle" or the distance tethers allow the MODU to drift from center. The tethers are essentially carbon fiber ropes made from pultruded rods. They are manufactured by Oceaneering Multiflex & Marine Production System (Houston, Texas), an umbilical supplier. 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.

The 500m/1,640-ft long tethers, produced for Petrobras, are scheduled for a full-scale offshore field trial at the end of 2006, Jackson reports, adding, "Petrobras is very happy so far, with the preliminary test results."

"Smart" composites part of systems monitoring

One area where composites have found a niche is in monitoring systems where they are combined with other materials and sensors. An example is a composite "shape sensing mat" developed by U.K.-based Insensys Ltd. (Hamble, Southampton, U.K.) for use with a metallic riser system. The flexible mat, which incorporates fiber optics, wraps around a steel riser and enables operators to monitor excessive bending and fatigue life during riser deployment.

"The idea is to incorporate the fiber optics into a structure that can be mounted anywhere on any type of pipe. It's a carrier mat designed to transmit strain data," says Damon Roberts, Insensys' founder and VP. An Insensys mat was installed on the lowest point of a completion-and-work-over riser string on the Enterprise Endeavor, a dynamic positioned drill ship (DPDS) moored in the Gulf of Mexico's Thunder Horse field, during July 2004. The 5.5m/18-ft long mat, affixed to the riser joint by means of straps, extended about 180°, or about half way around the circumference of the pipe. Roberts says the mat successfully reported data to the surface during multiple trips to the sea floor and back during riser deployment (i.e., as the riser was lowered through the water column, joint by joint, then pulled up again), in more than 1,830m/6,000 ft of water.

Reported data consisted of direct strain measurements, obtained with Bragg grating strain gages. The tiny gages, about 5 mm/0.2 inch long, are placed at various points along fiber-optic cables, themselves only 0.25mm/0.01 inch in diameter. When light pulses are passed through the cables and thus through the gratings, any bending of the pipe changes the wavelength of the light transmitted or reflected by the fiber, in a linearly proportional relationship. By placing the sensors around the circumference of the riser pipe, at different "clock" positions, Roberts explains, it becomes possible to monitor actual pipe strain: "The strain differential shows the magnitude of the bending and hence the strain in the riser string." Real-time light wavelength monitoring is accomplished with an opto-electronic "interrogation unit," also part of the sensing mat.

The benefit of composites for this application is that the fiber optics and sensors can easily be embedded within the layup, to form a flexible yet strong sensing "mesh" in the desired configuration. For the Enterprise Endeavor project, the mat was fabricated with multiple plies of woven biaxial E-glass fabric in an epoxy matrix, using a vacuum-assisted resin transfer molding (VARTM) process in an open, curved composite mold. Fiber-optic cables with Bragg grating sensors were located at three stations along the length of the mat, in the middle of the layup thickness. The biaxial fiber architecture makes the mat flexible longitudinally, enabling it to conform to the pipe shape, while maintaining enough stiffness in the hoop direction to hold the cables and sensors in place and keep them separated properly, says Roberts. At the upper edge of the mat, cables were gathered together in a customized "exit structure," that was potted for water and pressure resistance.

Roberts says the concept has tremendous flexibility for many different types of structures: "We could do multiple units on a single long riser string, or a very long mat covering several riser joints." The mats don't need to be directly in contact with the pipe, but can be installed over deepwater insulation units, he continues, as long as such units mimic the general shape of the pipe. They can even be placed onto pipelines remotely, by an underwater ROV (remotely operated vehicle).

While the composite will likely absorb approximately 1 to 2 percent water (by weight), says Roberts, the structural performance knockdown (if any) isn't an issue: "The application isn't structural, it must simply maintain enough strength to hold the sensors in place."

Roberts' company isn't the only one that envisions "smart" composites for offshore applications. SMARTEC SA (Manno, Switzerland) uses the phenomenon of Brillouin scattering — when refracted light changes its path slightly due to variations in density, which can be caused by temperature gradients — in its SMARTape and SMARTProfile sensors. The sensors can be incorporated into the walls of coiled tubing or pipelines. The company is a partner with Smart Pipe Co. LP (Houston, Texas). The latter is developing self-monitoring pipelines that use the temperature gradient changes to detect leaks. One of its applications is a pull-through system that acts as a liner to remediate existing oilfield pipelines — special machinery literally folds the flexible pipe liner into a C-shape for easy installation, says Smart Pipe's Steve Catha. Another partner is Airborne Composites (Leidschendam, The Netherlands), which sells PDT-Coil, a smart downhole coiled tubing complete with power and data transmission capabilities for drilling or workover applications.

Spoolable pipe

The concept of spoolable composite piping has been around since the 1960s. Conoco was the first oil company to push for a commercially viable product in the mid-1980s. Although they were envisioned for high-pressure downhole and offshore uses, composite spoolable, for the present, find greater use in *onshore* gathering systems, says Mike Feechan, VP of operations at Fiberspar LinePipe LLC (Houston, Texas), owing to their corrosion resistance and the fact that they can be produced in long, continuous lengths that reduce connections.

Spoolable composite pipe consists of a thermoplastic liner overwrapped 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 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.

Fiberspar manufactures its bonded pipe by first extruding the thermoplastic (usually high-density polyethylene or cross linked polyethylene) in the appropriate size, typically 62 mm to 112 mm (2.5 inch to 4.5 inch) in diameter. The liner acts as a moving production mandrel, pulled through a system of orbital filament winding devices that wind the wet-out glass or carbon fibers around it in a helical fashion. The production rate is typically 3m/10 ft or more per minute. The proprietary fiber architecture, winding angles and wall thickness of the structural laminate have been optimized in order to accommodate high spooling strains and pressure loads, says Feechan.

More than 1.8 million m (6 million ft) of spoolable pipe have been installed *onshore* in North America in the last five years, in applications such as wellhead production gathering lines, flow lines and injection lines. The composite product is displacing steel primarily because of speed and ease of installation — more than a mile of pipe can be spooled onto a single reel. "Experimental trials are one way to show feasibility and gain acceptance," he says, pointing out that Fiberspar both manufactures and installs its products, using appropriate equipment compatible with the composite. He expects that more than 1.2 million m (4 million ft) of additional spoolable line pipe will be installed this year and reports that the company has tripled its capacity to accommodate high demand. One growing use involves pulling the spoolable pipe through leaking steel pipelines, as a remediation measure, creating an impermeable and corrosion-resistant liner.

Opportunities for *offshore* spoolable applications are growing slowly. Statoil (Stavanger, Norway) tried a composite spoolable pipeline project several years ago with mixed results. Bjorn Melve, Statoil's composite champion, says the company qualified an offshore spoolable pipeline for 380 bar/550 psi glycol service at a water depth of 300m/980 ft, in the North Sea's Åsgard field. The now-defunct NAT Compipe AS (Tau, Norway) manufactured the 6.5 km/4 mile-long continuous pipe in the late 1990s. Pipe laying was complicated because of its buoyancy and the use of installation equipment and methods designed for steel, says Melve. But the biggest issue was the pipe's extreme elongation under pressure loading. "The internal pressure caused a 0.41 percent strain," he reports. "The resultant buckling made the pipe jump completely out of the sea floor trench in some areas." Unfortunately, the pipeline was abandoned because of uncertainty regarding its performance. But, says Melve, an appropriate design with the correct winding angle and wall thickness can result in an elongation matching that of a steel pipe of similar size for any type of pressure application.

Dozens of potential apps will consume composites

Pipelines are not the only means of petroleum product transport under consideration. Trans Ocean Gas Inc. (St. Johns, Newfoundland, Canada) has a new concept — transporting compressed natural gas (CNG) by ship in large composite pressure bottles or tanks. A $1.5 million joint industry project (JIP) involving Trans Ocean Gas, Composites Atlantic Ltd. (Lunenberg, Nova Scotia, Canada), certification society Det Norske Veritas and several other parties are currently verifying the technology for certification. "About half of the world's discovered natural gas is considered 'stranded,' or beyond the economical limit of a pipeline, and most is located offshore," says Trans Ocean Gas president Steven Campbell. "CNG transport by ship will allow stranded gas to be economically gathered and delivered to market."

While the company is mum on specific fabrication and material details, the concept involves filament winding large, cylindrical, fiberglass-reinforced pressure tanks as long as 12m/40 ft, with thermoplastic liners and stainless steel fittings on both ends. They will be placed upright in modular "cassettes" holding from 16 to 25 tanks, and connected to upper and lower piping manifolds for ease of filling and draining. Cassettes will be permanently installed and transported in container ship hull forms, says Campbell. Pressure will range between 10 Mpa and 25 MPa (1,450 psi and 3,600 psi) and temperature will be kept as low as possible, to maximize the amount of gas that can be transported. Says Campbell, "The density of our CNG is about 85 percent that of LNG without processing." Prototype bottles are being fabricated by Composites Atlantic and will be tested as part of the JIP.

"Composites are the preferred material over steel," notes Campbell, "because of lighter weight, corrosion resistance (thanks to the thermoplastic liner), cryogenic temperature resistance and crack and rupture resistance. Cost is also competitive with steel, given the proposed bottle size and relatively high steel prices."

Det Norske Veritas' Andreas Echtermeyer reports that his organization has developed acceptance criteria for the large composite tanks, as well as the necessary test requirements. Testing of tanks is scheduled to start in April of this year, and full certification is anticipated in October. "Our 40-ft refrigerated modal container will hold just over 500,000 ft3 at -5°C/20°F," concludes Campbell, adding, "The 40-ft composite 'reefer' containers will be available for lease by the end of the year."

While several presenters at CMOO-4 discussed composite riser projects in the works, their optimism was somewhat overshadowed by the industry's inability to get a number of composite riser joints installed on the ConocoPhillips' Magnolia tension leg platform (TLP) in the Gulf of Mexico. The CompRiser project, which was originated and championed by Conoco and Kvaerner in 1997, saw titanium-lined composite risers successfully tested on Statoil's Heidrun platform in the North Sea (see *HPC* July 2002, p. 40). The next-generation design has steel replacing the titanium as the liner material. A steel-lined riser design was successfully qualified for Magnolia, but field joints failed the factory acceptance pressure tests in late 2004. The cause of the failure appears to be a problem with welds in the steel liner, which allowed leakage, says Marc Leveque, principal engineer with ConocoPhillips. "For the Magnolia project, it's too late to get any risers in place now," states Leveque. "The problem was found at the very last moment and there wasn't time to continue — it's very painful, given the amount of money spent." ConocoPhillips terminated the CompRiser project and is no longer part of a riser JIP, but Leveque says that other JIP entities are likely to carry on. Shell Oil is pursuing a steel-lined riser project, working with Lincoln Composites (Lincoln, Neb.). Several European groups, including the Institut Francais du Petrole (Rueil-Malmaison Cedex, France), Vetco Gray (Stavanger, Norway) and Umoe Mandal (Mandal, Norway), also are developing riser concepts.

Other projects to watch for include a new flexible fiberglass pipe produced by Deepflex (Houston, Texas), which is similar to a steel-armored unbonded spoolable pipe but of all-composite construction. It's made with precured unidirectional laminate strips for pressure containment. Deepsea also is investigating a subsea buoyancy element. The hollow, thick-walled, cylindrical vessel is made with carbon fiber/epoxy sandwich construction to take the high compression loading of the deepwater environment. The element could be used for subsea separation, to house electronics or equipment on the seabed or for riser buoyancy.

"Deepwater development can be profitable and sustainable," sums up Shell's Hwang. "By working together with industry groups and contractors we can develop the best system solutions." Those solutions without a doubt will continue to include high-performance composite materials.

Composite Riser Design project conceived by Lincoln Composites Inc. (Lincoln, Neb.) in collaboration with Stress Engineering Services Inc. (Houston, Texas) is one of nine proposals recently selected for negotiations that could lead to funding awards under the Research Partnership to Secure Energy for America's (RP
News Item From: High-Performance Composites September2008

A composite riser design project conceived by Lincoln Composites Inc. (Lincoln, Neb.) in collaboration with Stress Engineering Services Inc. (Houston, Texas) is one of nine proposals recently selected for negotiations that could lead to funding awards under the Research Partnership to Secure Energy for America's (RPSEA) Ultra-Deepwater Program (UDW). RPSEA, a Sugar Land, Texas-based nonprofit corporation established to help meet the growing need for hydrocarbon resources produced from U.S. reservoirs, made the announcement on July 28.

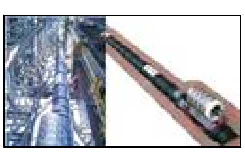
The riser project, in common with the other eight proposals, addresses specific technologies and architectural needs required in seawater depths greater than 1,500m/4,875 ft. According to RPSEA, tapping the substantial oil and gas resources at such depths is challenging and requires a complex and integrated systems approach, where the time from first discovery to first production can range from six to nine years and individual well costs can exceed $100 million (USD). RPSEA President C. Michael Ming says that, toward that end, "the 2007 Ultra-Deepwater Program is designed to bring the resources of America's leading universities, research institutions and technology innovators to bear on reducing costs, increasing efficiency, improving safety and minimizing environmental impacts of domestic production."

The projects are funded through the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program authorized by the Energy Policy Act of 2005 with funding from lease bonuses and royalties paid by industry to produce oil and gas on federal lands. More information on RPSEA and the UDW

Source: Aker Kvaerner Subsea An umbilical incorporating carbon fiber rods is being manufactured in Mobile, Ala. for a deepwater Gulf of Mexico platform.

Source: Aker Kvaerner Subsea The cross-section of the Aker Kvaerner Subsea umbilical shows the plastic profiles and stiffening rods that increase tensile strength.

Source: Conoco Offshore opportunities for high-performance composites abound, especially as oil prices stay high and deepwater reserves become more important.



Source: Insensys A composite carrier mat with embedded sensors is used to monitor bending strains in a metallic riser system.

Source: Fiber Spar Manufacture of bonded composite spoolable pipe includes orbital filament winding.

7.0 COMPOSITES – THE GROWTH

The composites industry seems to be waiting for "the big one" — the killer application requiring vast quantities of materials that will propel composites into the material mainstream. Offshore oil has been recognized as one arena with that kind of potential. For some time, composites have slowly and steadily replaced topside (above water-level) metal on a growing number of offshore facilities, in both new installations and retrofits of existing structures. But today, large-scale applications, such as carbon composite riser pipe for deepwater drilling, are on the brink of commercial success, bringing the market, for the first time, very near to "big one" status.

Factors fueling market growth include the dramatically lower weight and far greater corrosion resistance of composites, compared to conventional offshore materials, and the increasing acceptance of composites by regulatory and materials-certification agencies. Weight reduction is a major driver — less weight means the structure costs less to build and allows for more drill pipe and production equipment for oil production.

Jerry Williams of Petroleum Composites (Houston, Texas, U.S.A.) points out that when comparing composites with steel, "The cost differential narrows when installed costs are compared, and shifts in favor of composites when life-cycle costs are considered. We've seen life-cycle savings of up to 70 percent for fiber-reinforced plastic pipe."

In contrast to steel, which seawater quickly corrodes, composites are virtually corrosion-free when made with chemical-resistant resins. For platform components such as column pipe (pipe that extends from the platform down below the water surface to supply seawater) and firewater systems (strategically placed pipes for fighting potential fires), this corrosion resistance translates to years of maintenance-free service. One Gulf Coast fabrication facility reports that steel pipe installations are often severely corroded after just two or three years of service, while thousands of composite column pipes are still in service, several more than 25 years old.

Key regulatory developments over the last five years also have encouraged the use of composites. In late 1998, the U.S. Coast Guard approved the use of fiber-reinforced plastic (FRP) piping and glass/Phenolic gratings on offshore platforms and drill ships (USCG Policy File Memoranda [PFM] 1-98 and 2-98).

The International Maritime Organization (IMO) has approved composite piping for use in platform fire-fighting systems carrying water, as specified by its Level 3 Fire Endurance standards (A.753 [18]), which include jet fire endurance standards. ("Jet fire" refers to the release of burning hydrocarbons under high pressure.) However, IMO regulations do not allow the use of composite pipe for flammable liquids like hydrocarbons or diesel fuel (Level 1 Fire Endurance), and such certification is probably unlikely to occur.

ISO (International Organization for Standardization) regulation ISO 14692 recommends a performance-based risk assessment for composite piping applications. Det Norsk Veritas, a Norwegian-based organization that certifies seagoing vessels and structures, recently released two standards related to composites: Draft Offshore Standard OS-C501 provides requirements and recommendations for composite component structural design and structural analysis procedures.

Recommended Practice DNV-RP-F202 describes performance-based guidelines for composite riser certification. Both signal a growing acceptance of composites in offshore oil platform design and construction.

COMPOSITE PIPING SAVES TOPSIDE WEIGHT AND COST

Composites are considered standard equipment for some types of topside facility piping. Since its first installation in 1974 on the Trinmar Ltd. Platform 9 near Trinidad, fiberglass pipe has been specified in hundreds of offshore platform projects (e.g., the topside fire pipe installation on the Shell Mars platform, covered in "Inside Manufacturing," *CT* July/August 1998, p. 16).

Today, with phenolic resins, fire-retardant additives and intumescent coatings, composite pipe can be designed to survive even the most extreme jet fire conditions. While standard fiberglass composite pipe is non-conductive, there is some disagreement within the industry as to whether conductivity is required on an open deck of a platform. For applications where operators request or require electrical conductivity, most manufacturers offer electrically conductive versions of their piping products.

Fred Landry of J. Ray McDermott, a well-known offshore platform fabricator in Morgan City, La., U.S.A., says that composites are less expensive than the copper/nickel alloy often used for fire pipe and can be fabricated in fewer pieces to fit into unusually shaped or tight quarters. Its lower modulus gives composite piping some elasticity and flexibility in configurations that might not be possible with more rigid metal. Plus, bonded joints eliminate the need for hot welding, which can be a potential fire source on a platform filled with flammable hydrocarbons.

Composites must be handled differently than metal during installation because they can be damaged if dropped or struck by a heavy object, says Landry. He typically installs composite pipe at the end of a job, to minimize the risk. The thermal and pressure behavior of composites is different than metal, and is accounted for in pipe hanger design, which allows for pipe movement and includes protective wear pads to protect the pipe from abrasion.

EDO Specialty Plastics (Baton Rouge, La., U.S.A.) has manufactured its FIBERBOND composite pipe for hundreds of offshore installations. **The company's licensee in Malaysia, Dialog Systems SDN BHD, recently completed a project for the Tapis B and Irong Barat A platforms, operated by EMEPMI (ExxonMobil E&P Malaysia), replacing metal piping for firewater headers and deluge systems. Because the piping carries only seawater, no special corrosion liner was necessary, but specified design pressure was 290 psi/20 bars.**

"The Malaysian platforms have traditionally used a lot of copper/nickel piping, so we were successful in finally convincing them to use composite materials for this high-pressure application," says EDO Specialty Plastics' engineering manager Kevin Schmit. Pipe ranging from 2-inch to 12-inch diameter was constructed as follows.

Two plies of fiberglass surfacing veil, supplied by the Nicofibers division of Hollinee Corp. (Shawnee, Ohio, U.S.A), were layed up on a mandrel to form a 0.5-mm/0.02-inch thick liner, over which E-glass roving was filament wound at an angle of ±54.75° relative to the longitudinal (0°) axis.

For most applications, this fiber architecture satisfies stress loads in both hoop and axial directions. Winding angles are often modified for installations requiring greater strength, such as long unsupported spans, in which ±20° and ±70° winding angles are used. The liner and roving was wet out with Dow Chemical Co.'s (Midland, Mich., U.S.A.), Derakane corrosion-resistant epoxy vinyl ester resin, optimized by EDO with proprietary additives for fire endurance. Final wall thickness was 6 mm/0.25 inch to 14.5 mm/0.58 inch. Piping was produced in 12.2m/40 ft lengths and cured at room temperature.

On the platform, pipe was joined by the patented FIBERBOND composite butt-welding technique. Similar to steel butt welding, the plain ends of the composite pipes are simply butted together. The "weld" is accomplished by wrapping the seam with resin-wet layers of chopped-strand mat and woven E-glass roving, using the same epoxy vinyl ester resin used in the pipe bodies. The joint cures without heat, so no hot work permits are required.

McDermott's Morgan City facility is currently fabricating a SPAR platform for BP's Holstein field, destined for installation in 1,311m/4,300 ft of water in the Gulf of Mexico before 2004.

Designer’s specified conductive composite piping supplied by Ameron International, Fiberglass Pipe Division (Houston, Texas, U.S.A.) for the fire system, says Ameron's director of product marketing services Joie Folkers.

"Because the spar platform will sit high above the water surface, more pressure is needed to lift the seawater up to the facilities area," says Folkers. "So the piping has a fairly high-pressure rating of 250 psi/17 bars and it is all conductive to meet the requirements for use in a hazardous area." The fire system features Ameron's B

Bondstrand Series 7000M and PSX-L3C piping for the ring main piping, together with PSX-JFC for the dry deluge piping downstream from the ring main. Dry pipe contains seawater only when the system is activated, which reduces topside weight and helps prevent corrosion of the system's metallic valves and nozzles. The JFC product name stands for jet fire conductive, which means the pipe is approved for jet fire conditions.

Fabrication of the 7000M piping begins by filament winding glass roving, typically supplied by Johns Manville (Denver, Colo., U.S.A.) and 3K carbon tow, wet out with an amine-cured epoxy resin from Dow Chemical. The carbon fiber makes up about 10 percent of the hybrid laminate, spaced such that it forms a grid. "The carbon fibers contact each other and provide through-the-wall conductivity as well as end-to-end conductivity," Folkers explains, noting that the stiffer, stronger carbon fiber also increases the pipe's structural performance.

Ameron's PSX (polysiloxane-modified phenolic) resin matrix tackles the traditional processing challenges posed by phenolics. Phenolic gives off water and formaldehyde during cure and has a tendency to be brittle. Ameron modifies the base Cellobond phenolic resin supplied by Borden Chemical Inc. (Louisville, Ky., U.S.A.) by adding siloxane in a proprietary manner, which improves processibility, bond strength and impact resistance of the finished piping.

Fire resistance also is enhanced with the PSX piping's heat barrier design. The pipe incorporates 10 to 12 plies of polypropylene veil tape and glass roving in the outer laminate. The veil vaporizes under extreme jet fire conditions, leaving an air gap in the laminate. This gap works in combination with the phenolic (which chars when it burns) and the glass rovings to create a heat barrier that helps keep the pipe intact. After heat curing, Ameron's piping is adhesively bonded by fitting the slightly tapered end of the pipe joint into the mating end of the adjacent joint and bonding with PSX-

60 two-part polysiloxane-modified epoxy adhesive. For composite-to-metal pipe attachments, Ameron bonds filament-wound flanges onto the pipe that can be bolted to corresponding flanges on the metal pipe.

MORE TOPSIDE INSTALLATIONS

Offshore use of composite gratings, handrails, ladders and other topside hardware has expanded significantly since Petrobras' wide-scale use of gratings in 1994 and the breakthrough installation in 1995 of 215 tons of glass/phenolic grating on Shell's Mars tension leg platform in the Gulf of Mexico. U.S. Coast Guard acceptance of phenolic grating as a Level 2 fire-retardant has opened the door for numerous platform installations that previously weren't possible. (Level 2 areas include those where groups of people would assemble for safe refuge and/or lifeboat embarkation.)

Pultruded products have the highest fiber-to-resin ratio (typically about 70:30) and, therefore, the highest load-bearing capacity with the least deflection. A 38-mm/1.5-inch deep pultruded grating, at one third of the weight of steel, supports more than 4,882 kg/m2 (1,000 lb/ft2), of uniform load over a 1.2m/4 ft clear span. Because pultruded grating has a high fiber content, its surface resin layer is relatively thin, which impacts its corrosion resistance. Molded gratings and parts, on the other hand, have a fiber-to-resin ratio of about 35:65, which provides less strength, but gives greater corrosion resistance than pultruded products. Molded gratings, stairs and railings are especially well-suited to the splash zone, where resistance to seawater corrosion is more critical.

Fiberline Composites A/S (Kolding, Denmark) makes composite topside products, including pultruded gratings, handrails, ladders and stairs, as well as customized products. The company recently completed an installation consisting of over 1,000m2/10,600 ft2 of glass/phenolic gratings that meet USCG Level 2 fire performance (with a minimum glass content of 60 percent) on an Amoco platform in the British sector of the North Sea.

The customer specified composites to replace stainless steel, which had corroded in the marine environment. The composite products weighed less than one-third of the steel installation, saving significant topside weight and improving the overall platform balance.

Fiberline also recently installed a 21.8m/71-ft long of connection bridges between two platforms in the Danish sector of the North Sea, operated by Maersk Oil and Gas. The 2.3m/7.5-ft high by 1.2m/4-ft wide bridge was assembled from pultruded flat and tubular profiles that were machined and bolted together with stainless steel fasteners at Fiberline's Kolding facility. The 2,000 kg/4,400 lb assembled bridge was barged to the North Sea site and lifted into place with the larger platform's crane — possible only because of the bridge's low weight.

WHAT IS THE "BIG ONE?"

"Topside composite technology is maturing fast," says one oil industry insider. "We're now moving on to higher-risk components like risers which have to withstand subsea conditions." Composites have been envisioned as a breakthrough material for deepwater subsea tubulars ever since initial development of 15,000-psi, 102-mm/4-inch diameter composite choke and kill lines by the Institut Franç1ais du Pétrole (IFP) two decades ago. (Choke and kill lines are auxiliary pipes that are attached to the exterior of the drilling riser pipe, used to control shear rams at the wellhead in the event of a catastrophic blowout.) Yet because of the enormous risk involved, full-scale use of an all-composite riser string or choke and kill lines has never materialized. "Deepwater developments are physically, technically and economically unforgiving as there is no room for failure in any area," notes Turid Storhaug of Deepwater Composites AS, a joint venture of ConocoPhillips, Houston, Texas, U.S.A. and Kvaerner Oilfield Products, KOP, Oslo, Norway.

The hesitancy to use composite tubulars may be changing, based on the success of the CompRiser project, spearheaded by Deepwater Composites. After initial design and development efforts by General Dynamics Advanced Technical Products, Lincoln Operations (formerly Lincoln Composites, Lincoln, Neb., U.S.A.), Spencer Composites Corp. (Sacramento, Calif., U.S.A.) has fabricated several full-scale, high-pressure drilling riser joints that have been successfully field tested in the North Sea.

The CompRiser's layup consists of about 40 alternating, low-angle helical and hoop plies of 12K carbon fiber tow supplied by Grafil Inc. (Sacramento, Calif., U.S.A.), wet out with epoxy resin from Resolution Performance Products (Houston, Texas, U.S.A.) and wound over a thin titanium liner protected with a hydrogenated nitrile rubber coating. (A liner is critical for a drilling riser to avoid damage from tools and other pipes that are placed inside during drilling operations.) The riser's end fittings are massive 24-bolt titanium flanges from Oil States (Aberdeen, Scotland) with traplock (i.e., grooved) flange extensions. Special attention was given to winding over the traplocks to ensure the carbon fibers were locked into the grooves, thus forming a solid composite-to-metal bond, without adhesives. The outer surface of the joint was protected with a layer of rubber as well as fiberglass wet out with epoxy and carbon black filler. Winding of each joint took about five days and consumed approximately 682 kg/1,500 lb of fiber.

The bending stiffness of the composite joint — 195 MNm2/6.79 x 1010 lb-in2 — had to be the equivalent of the titanium drilling joints normally used on the Heidrun Platform, where the field test took place. Minimum design burst pressure was 12,000 psi/827 bar and axial load capacity had to be 1.361 million kg/3 million lb. Risers were inspected ultrasonically, then subjected to impact and bending fatigue loads that simulated a 150-year loading spectrum. Several joints were tested to failure in a burst pressure test. All tests confirmed that the CompRiser performs above its design specifications. The Heidrun operator is so comfortable with the composite joint that it has incorporated the riser into several riser strings used to drill additional wells from the platform.

Since the 2001 Heidrun tests, Spencer have continued to develop other composite tubulars, including choke and kill lines with steel liners. The 165-mm/6.5-inch OD (114-mm/4.5-inch ID), 15,000-psi tubulars are made with the same materials as the larger risers, with traplock composite-to-metal joints and "pin-and-box" end connectors. The company has tentative plans to field test the choke and kill lines on a Petrobras platform off the coast of Brazil.

Spencer is gearing up for commercial production of both risers and choke and kill lines through its spin-off company C4PO (Composites for Producing Oil) and has tentative plans for a manufacturing facility in the Gulf of Mexico coastal region. President Brian Spencer says talks are underway with several oil companies. "We're very close to signing deals on several applications."

IFP has taken an approach similar to Spencer's, and has produced its version of a hybrid choke and kill tubular designed to reduce overall riser weight for deepwater projects. Prototype tubes have been fabricated by Composites Aquitaine (Salaunes, France) with a steel liner, overwrapped with carbon fiber/polyamide (nylon) thermoplastic ribbon and cured on the fly. IFP's Emmanuel Laval says that the thermoplastic overwrap design can accommodate 15,000 psi with a smaller 12-mm /0.5-inch steel liner, rather than a 24-mm/1-inch thick steel liner, which reduces the tubular's weight by 50 percent. The prototypes have been extensively tested in the laboratory and are undergoing field tests initiated in April 2002, on a drill ship in the Gulf of Guinea off the Nigerian coast.

"If you consider a 7,500-ft long, 21-inch diameter drilling riser, outfitted with two 15,000-psi choke and kill lines and a third 5,000-psi booster line, the mass of that riser is approximately 4,800 kips/4.8 million lb-force," says Laval, "Substituting composite choke and kill and booster lines for steel lines reduces the riser mass by 1,000 kips." Another advantage is existing riser strings can be upgraded with higher-pressure composite choke and kill lines without increasing overall weight or top tension. Other composite riser projects are close to fruition, including ABB Vetco Gray's (Houston, Texas, U.S.A.) drilling riser and a spoolable catenary riser under development in Norway by ABB Offshore Systems (Billingstad, Norway). Another tubular product that's already commercially available is small-diameter bonded spoolable pipe made with carbon fiber, produced by Fiberspar Corp. of West Wareham, Mass., U.S.A. (Risers, spoolable pipe and other products mentioned in the article are examined in detail in Composites in *Offshore Oil: A Design and Application Guide*.)

Performance Composites' Jerry Williams points out that while composites might be making inroads into the retrofitting of existing platforms, simple material substitution to gain immediate weight savings or corrosion resistance doesn't exploit the full advantages of composites. "If you retrofit, you're not taking advantage of all of the benefits of composites," he explains. "Composites will really come into play in reducing overall platform system costs at the design stage." Given the range of proven composite products now available, platform engineers have significant motivation to design with composites in mind.

Source of – International Composite Conference 2003

8.0 DESIRED MECHANICAL PROPERTIES OF COMPOSITES – REFERRENCE CASE STUDY

Composite Pultruded Profiles

The profiles like gratings, solid rods for electrical insulation, cable trays, ladders etc. were developed successfully by M/s. Sucro Filters Pvt. Ltd., Pune with technology support from National Chemical Laboratory (NCL), Pune with excellent surface finish and flame retardancy as per international standards.

NCL had worked & established various critical parameters such as using 3-cataylst system for improved curing, high pultrusion speed (1.0 – 1.5 m/min) and flame retardancy characteristics for the products. The comparison chart of the properties of FRP pultruded sections and other structural materials are listed in table 2.0 & 3.0.

Table 1.0: Mechanical Properties of Pultruded Profiles Vs. Other Structural Materials

Properties	Pultruded FRP	Rigid PVC	Mild Steel	Stainless Steel	Wood
Tensile Strength (N/mm2)	382	44	340	340	80
Flexural Strength (N/mm2)	468.3	70	380	380	12
Flexural Modulus (N/mm2)	22489	2400	196000	196000	700
Izod Impact (Kg.m/cm)	2.15	0.09	1.5	0.53	-

Table 2.0: Physical & Chemical Properties of Pultruded Profiles Vs. Other Structural Materials

Properties	Pultruded FRP	Rigid PVC	Mild Steel	Stainless Steel	Wood
Specific Gravity	1.8	1.38	7.8	7.92	0.52
Thermal Conductivity (Kcal/hr/m2/° C)	24.4	6.4	1220	732.00	0.4
Coeff. of Linear Expansion (cm/cm° C) x 10-6	5.2	37	8	10	1.7
Safe Working Temp. (° C)	130	55	600	600	160
Flame Resistance	Good*	Poor	Excellent	Excellent	Poor
Corrosion Resistance					
a. Acidic	Excellent	Good	Poor	Excellent	Poor
b. Alkaline	Good	Fair	Good	Excellent	Poor
c. Solvents	Fair	Poor	Good	Excellent	Fair
d. Coastal Environment	Excellent	Good	Poor	Excellent	Fair
e. Outdoor Exposure	Excellent	Poor	Fair	Excellent	Fair
f. Effluent Water	Excellent	Good	Poor	Excellent	Fair
g. Steam	Good	Poor	Fair	Excellent	Fair

*** Excellent with special additives**

(Source: Product Information Brochure; DK Fibre Forms, Pune, India)

Towards market seeding of the pultruded products, the Company targeted three major segments viz. new projects, replacement market in industrial & non-industrial applications. The products such as cable trays, fittings and other accessories are being inducted by various industries in India and abroad.

Compression Moulded Grids/Gratings

The project was launched in partnership with M/s. Technocrat, Chennai with technology support from IIT-Madras. The project aims at designing & developing GRP grids/gratings by compression moulding technique to replace the existing grids/grating made of heavy steel/cast iron.
The product proposed under the project would have potential applications in oil platforms, chemical plants etc. such as walkways, foot-bridges, roofing systems partition paneling etc. in chemical /pharmaceutical, transportation & civil/infrastructural sectors.

While a pultruded grating has load carrying capacity only in one direction, the GRP grating has three dimensionally curved shapes with equal load carrying capacity in both the directions. As an integral part of the project, a computer controlled automatic glass fibre laying machine was designed & fabricated for manufacturing of grids & gratings of different sizes with beams at various sections.
Moulding of the grating (3m x 1m) would commence by end July 2004. Technocrat's plans to offer the process technology complete with the equipment for computer controlled fibre laying & compression moulding of composite grating to other manufacturers.

Composite Pressure Vessels

- The project was launched in partnership with *M/s. Kineco Pvt. Ltd., Panaji* and with technology support from IIT-Bombay. The project aimed at developing filament wound pressure vessels for the following applications:
- Undercarriage FRP tanks (450 mm dia. with 2.00 bar operating pressure to be fitted to the railway passenger coaches for water supply to the toilets Two sizes of pressure vessels (500 mm & 600 mm dia.) for water treatment application; operating pressure : 3.50 bar
- The above vessels were designed as per BS 4994:1987. For fabricating composite pressure vessels with dished/hemispherical ends, a multiple axes CNC filament winding facility was designed & developed indigenously for the first time in the country by *CNC Technics Pvt. Ltd., Hyderabad*. The system has the following unique features:
- The filament-winding machine is powered & controlled by SIEMENS 840 D control system. Pressure vessels/pipes with diameter ranging from 50 mm – 4.00 m can be wound on the system.
- Length of the job being wound can vary from 1.00 – 9.50 m.
- While the first spindle can wind diameters ranging from 50 – 1500 mm at high rotational speed, the second spindle can rotate diameters up to 4.00 m at relatively slower speeds. The second spindle can hold component and mandrel weight up to 6.00 tonnes.
- The unique design of the cross axis allows the winding pattern to be unaltered from 50 mm – 4.00 m dia.
- The main filament winding carriage feeding the impregnated glass fibre moves at a very high speed of 60 m/minute

- The creel stand for fiberglass rovings accommodates 24 spools and has adjustable mechanical tensioning device at its spool. The tension can be accurately controlled for each roving.
- The drum type resin bath with micrometric adjusting doctor's blade can control resin pick-up accurately. Top wetting rollers assure proper wetting of rovings and squeeze blades remove excess resin. A temperature controller and a hot water pump controls the resin bath temperature within ± 20 C enhancing the pot life of epoxy resins
- The CNC control system is enclosed in a fully sealed panel, which has a piggyback air conditioner and can work in any environment.
- The multi-axis filament winding system is equipped with CADWIND software to facilitate various design configurations of composite parts.

Composite Pipes & Pipe Fittings

On assessing greater application potential for composite piping system, a new project has recently been envisaged under the Advanced Composite Programme in partnership with the industry. The project aims at design & development of glass-reinforced epoxy (GRE) pipes & pipe fittings as per API standards by using CNC filament winding system.
It is proposed to develop a 2-axes CNC filament winding system along with CADWIND software for fabricating long pipes and 6-Axes filament winding system for fabricating pipe fittings. The GRE piping system could be effectively used in oil refineries, offshore platforms, desalination, chemical/ pharmaceutical industry, sewerage etc.

Wrapping it up

Efficient and economical adaptation of composite materials to offshore applications is becoming an attractive research area. The important issues such as the aging effects in a marine environment and the load transfer between different fibers have to be dealt with in designing & fabricating composite products for offshore applications. These issues are studied with an integrated experimental/ analytical approach.

With the growth in petroleum sector, the demand for fiberglass products have increased manifold. Also the amount of energy required for fabricating FRP composite materials for structural applications with respect to conventional materials such as steel & aluminium is lower and it thus works for its economic advantage.

Until recently, the use of high performance GRE piping was demonstrated for onshore fluid transport (i.e. oil, fresh water, injection water, seawater and other fluids). Efforts were being directed by the composite industry to extend usability of GRE piping for aqueous fluids (fire water, aqueous waste, ballast water, seawater cooling etc.) in transport on offshore platforms.
The weight of the topside assembly could drastically come down by using composite products such as pultruded glass/phenolic gratings for floors, walkways and handrails, along with enclosures and heat protection walls etc. Composites have been successfully demonstrated for applications such as accumulator bottles for riser tensioning systems, blast relief systems, fire walls, enclosures, modular housing panels etc.

9.0 COMPOSITE INDUSTRIAL STANDARD

ASTM's composite standards are instrumental in the evaluation and determination of the physical, shear, tensile, flexural, and compressive properties of various forms of composite materials used in structural applications. These composites can be in the form of sandwich core materials, honeycomb core materials, polymer matrix composite materials and their laminates, fiber-reinforced polymer-matrix composite plates and bars, fiber reinforced metal matrix composites, carbon fiber-epoxy prepregs, continuous filament carbon and graphite fiber tows, hoop wound polymer matrix composite cylinders, sandwich beams, flat composite panels, simply supported sandwich composite plates, and fabric-reinforced textile composite materials. These composite standards are also helpful in guiding manufacturers and users of such materials in their proper fabrication and testing for the assurance of their quality.

List of composite standards developed by ASTM:

Constituent/Precursor Properties

Designation	Title
C613 / C613M - 97(2008)	Standard Test Method for Constituent Content of Composite Prepreg by Soxhlet Extraction
D3529M - 10	Standard Test Method for Matrix Solids Content and Matrix Content of Composite Prepreg
D3530 / D3530M - 97(2008)	Standard Test Method for Volatiles Content of Composite Material Prepreg
D3531 / D3531M - 11	Standard Test Method for Resin Flow of Carbon Fiber-Epoxy Prepreg
D3532 - 99(2009)	Standard Test Method for Gel Time of Carbon Fiber-Epoxy Prepreg
D3800M - 11	Standard Test Method for Density of High-Modulus Fibers
D4018 - 11	Standard Test Methods for Properties of Continuous Filament Carbon and Graphite Fiber Tows
D4102 - 82(2008)	Standard Test Method for Thermal Oxidative Resistance of Carbon Fibers

Editorial and Resource Standards

Designation	Title
D3878 - 07	Standard Terminology for Composite Materials
D4762 - 11a	Standard Guide for Testing Polymer Matrix Composite Materials
D6507 - 11	Standard Practice for Fiber Reinforcement Orientation Codes for Composite Materials
E1309 - 00(2005)	Standard Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
E1434 - 00(2006)	Standard Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
E1471 - 92(2008)	Standard Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases

Interlaminar Properties

Designation	Title
D5528 - 01(2007)e3	Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites
D6115 - 97(2004)	Standard Test Method for Mode I Fatigue Delamination Growth Onset of Unidirectional Fiber-Reinforced Polymer Matrix Composites
D6415 / D6415M - 06ae1	Standard Test Method for Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer-Matrix Composite
D6671 / D6671M - 06	Standard Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites
D7291 / D7291M - 07	Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material

Lamina and Laminate Test Methods

Designation	Title
D2344 / D2344M - 00(2006)	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
D3039 / D3039M - 08	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
D3171 - 11	Standard Test Methods for Constituent Content of Composite Materials
D3410 / D3410M - 03(2008)	Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading
D3479 / D3479M - 96(2007)	Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials
D3518 / D3518M - 94(2007)	Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate
D3552 - 96(2007)	Standard Test Method for Tensile Properties of Fiber Reinforced Metal Matrix Composites
D4255 / D4255M - 01(2007)	Standard Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method
D5229 / D5229M - 92(2010)	Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5379 / D5379M - 05	Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method
D5448 / D5448M - 93(2006)	Standard Test Method for Inplane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders
D5449 / D5449M - 93(2006)	Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite

	Cylinders
D5450 / D5450M - 93(2006)	Standard Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders
D5467 / D5467M - 97(2010)	Standard Test Method for Compressive Properties of Unidirectional Polymer Matrix Composites Using a Sandwich Beam
D5687 / D5687M - 95(2007)	Standard Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D6641 / D6641M - 09	Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
D6856 / D6856M - 03(2008)e1	Standard Guide for Testing Fabric-Reinforced "Textile" Composite Materials
D7028 - 07e1	Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)
D7078 / D7078M - 05	Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method
D7264 / D7264M - 07	Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials

Sandwich Construction

Designation	Title
C271 / C271M - 11	Standard Test Method for Density of Sandwich Core Materials
C272 - 01(2007)	Standard Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions
C273 / C273M - 07a	Standard Test Method for Shear Properties of Sandwich Core Materials
C274 - 07	Standard Terminology of Structural Sandwich Constructions
C297 / C297M - 04(2010)	Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions
C363 / C363M - 09	Standard Test Method for Node Tensile Strength of Honeycomb Core Materials
C364 / C364M - 07	Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions
C365 / C365M - 11a	Standard Test Method for Flatwise Compressive Properties of Sandwich Cores
C366 / C366M - 11	Standard Test Methods for Measurement of Thickness of Sandwich Cores
C393 / C393M - 11	Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure
C394 - 00(2008)	Standard Test Method for Shear Fatigue of Sandwich Core Materials
C480 / C480M - 08	Standard Test Method for Flexure Creep of Sandwich Constructions
C481 - 99(2005)	Standard Test Method for Laboratory Aging of Sandwich Constructions

D6416 / D6416M - 01(2007)	Standard Test Method for Two-Dimensional Flexural Properties of Simply Supported Sandwich Composite Plates Subjected to a Distributed Load
D6772 - 02(2007)	Standard Test Method for Dimensional Stability of Sandwich Core Materials
D6790 - 02(2007)	Standard Test Method for Determining Poisson's Ratio of Honeycomb Cores
D7249 / D7249M - 06	Standard Test Method for Facing Properties of Sandwich Constructions by Long Beam Flexure
D7250 / D7250M - 06	Standard Practice for Determining Sandwich Beam Flexural and Shear Stiffness
D7336 / D7336M - 07	Standard Test Method for Static Energy Absorption Properties of Honeycomb Sandwich Core Materials
F1645 / F1645M - 07	Standard Test Method for Water Migration in Honeycomb Core Materials

Structural Test Methods

Designation	Title
D5766 / D5766M - 11	Standard Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates
D5961 / D5961M - 10	Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates
D6264 / D6264M - 07	Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force
D6484 / D6484M - 09	Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
D6742 / D6742M - 07	Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates
D6873 / D6873M - 08	Standard Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates
D7136 / D7136M - 07	Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event
D7137 / D7137M - 07	Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
D7205 / D7205M - 06	Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
D7248 / D7248M - 08	Standard Test Method for Bearing/Bypass Interaction Response of Polymer Matrix Composite Laminates Using 2-Fastener Specimens
D7290 - 06	Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications
D7332 / D7332M - 09	Standard Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite
D7337 / D7337M - 07	Standard Test Method for Tensile Creep Rupture of Fiber Reinforced Polymer Matrix Composite Bars
D7522 / D7522M - 09	Standard Test Method for Pull-Off Strength for FRP Bonded to Concrete Substrate
D7565 / D7565M - 10	Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures
D7615 / D7615M - 11	Standard Practice for Open-Hole Fatigue Response of Polymer Matrix Composite Laminates
D7616 / D7616M - 11	Standard Test Method for Determining Apparent Overlap Splice Shear Strength Properties of Wet Lay-Up Fiber-Reinforced Polymer Matrix Composites Used for Strengthening Civil Structures
D7617 / D7617M - 11	Standard Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars