Advances in composite drilling components lead to evaluation for critical E&P applications

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COMPOSITES HAVE BEEN accepted for and being used in many petroleum exploration and production applications. Use has progressed from more mundane ladders, rails, pipes and conduits through decking and sucker rods to where more critical components are now being evaluated. New technical capabilities not available with metals, reduced weight and even cost savings are potentially to be realized. The components discussed here include:

- Composite drill collars.
- Short- and ultra short-radius composite drill pipe.
- Extended reach/deepwater composite drill pipe
- Smart drill pipe.
- Power transmission shafting.
- Lightweight, composite-reinforced pressure vessels.

These components are based on technology derived from decades of research and production in the aerospace industry.

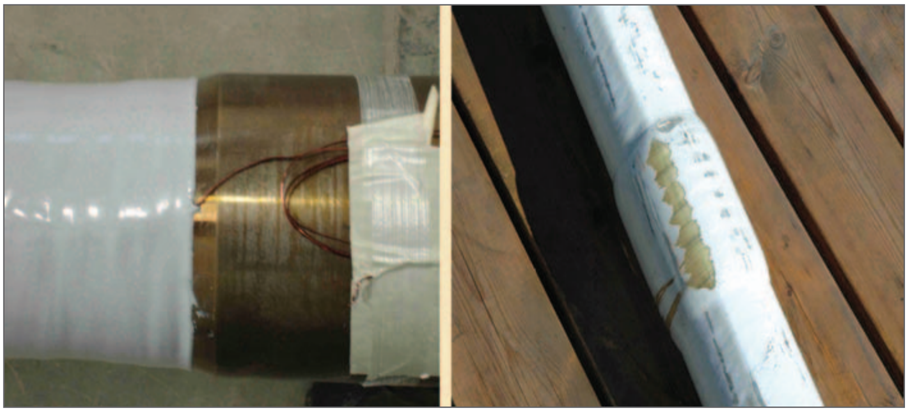


Figure 1 (above) shows pipe made from composites, with embedded wire in conduit on the left and centralizer with abrasion-resistant coating on the right. Table 1 (below) shows specifications for short-radius and ultra-short radius composite drill pipe, which take advantage of the unique fatigue properties of composites to provide drill pipe capable of short-radius of curvature direction drilling.

Table 1: Specifications for SR/CDP and USR/CDP

Characteristic	ACPT SR-CDP	ACPT USR-CDP
Bending Modulus - msi (10^6 psi)	4.9	2.4
Shear Modulus - msi (10^6 psi)	3.1	2.5
Tensile Ultimate-lbs.	75,000	65,000
Tensile Operating-lbs.	25,000	25,000
Compression Ultimate-lbs.	100,000	65,000
Compression Operating-lbs.	50,000	25,000
Torque Ultimate-lb-ft	6,000	6,000
Torque Operating-lb-ft	2,000	3,000
Internal Pressure Ultimate-psi	2,000	3,000
Internal Pressure Operating-psi	1,000	1,500
Collapse Ultimate-psi	2,000	3,000
Collapse Operating-psi	1,000	1,000
Temperature-F	325	325
Weight of 30 foot section-lbs	90	110
Weight of comparable steel pipe-lbs	157	157
Minimum ROC-ft	60	30

COMPOSITE DRILL COLLARS

Advanced Composite Products and Technology (ACPT) builds custom composite drill collars, as well as subs, isolators, casing and drill pipe, specifically designed to replace metal for various reasons. Figure 1 show examples of pipe made from composites.

Some desired properties that have been accommodated include:

- Non-magnetic.
- Non-conductive (electrical).
- Non-sparking.
- Corrosion resistant.
- Lightweight.
- Compatible threads/connections.
- Compatible tensile, compressive, torsion, pressure and stiffness ratings.
- Little to no affect on EMF up to 74 KHz.
- Copper wire embedded inside the composite pipe to join the tool joints electrically (removable). Used with electromagnetic signals inside the collar to induce and measure the same in the rock formation.
- Abrasion-resistant coating.
- Wear bands (centralizers).

Customer report/feedback: "We drilled 600-plus m with the collar in tension without any problems or excessive wear on collar. We are going to do another test this time with collar in compression this coming week. In my estimation based on field test, we can drill around 16,000 m before we need to repair the wear bands on collars. This 16,000 m is roughly equivalent to three weeks of drilling. There is no adverse effect by the embedded wire to our instruments. Therefore there is no need for the wire to be removable anymore, and we can have a permanent wire of the same diameter permanently embedded in composite collar with a reliable electrical connection." Reported by a customer using fiberglass drill collars with an embedded wire between the metal tool joints.

SR, USR DRILL PIPE

Both short-radius composite drill pipe (SR/CDP) and ultra short-radius composite drill pipe (USR/CDP) were developed as a spin-off of a program supported by the US Department of Energy (DOE) to develop extended-reach/deepwater composite drill pipe (ER/ DW CDP). SR/CDP and USR/CDP take advantage of the unique fatigue properties of composites to provide drill pipe capable of short-radius of curvature (ROC) directional drilling. The SR/CDP has been used in ROC down to 60 ft. The USR/CDP was designed for use down to a ROC of 30 ft. The specifications for SR and USR CDP are shown in Table 1.

EXPERIMENTAL FIELD EVALUATION

Field tests of SR/CDP have been completed. Initially, the CDP was employed in a short-radius drilling application where the well was being drilled from vertical to horizontal within a 50- to 70-ft radius. Additionally, only 5 to 9 joints of composite pipe were used in each test, and the pipe was always positioned in the drill string to be in the curved section of the well.

The first test used SR/CDP to re-enter an old vertical oil well that stopped producing in 1923. Just below 1,200 ft, drillers plugged the lower portion of the existing hole with cement and kicked off a new borehole that curved in a 70-ft radius until it became horizontal, then continued 1,000 feet farther horizontally.

This pipe was then used in a second well in which the pipe became stuck in the hole. During the effort to un-stick the pipe, two joints failed — one joint broke in the middle, and another broke at the metal connection/composite interface (MCI). Evaluation of the MCI break led to the interface being redesigned to create a much stronger jointure.

Figure 2 (above) shows short-radius drill pipe being added to the string in a field test, in which the pipe was run for more than 160,000 cycles at an average RPM of 70, air pressure 300 psi and torque of 1,000 lb-ft. After a week of drilling, the pipe showed little to no signs of wear, as seen in Figure 3 below.

A review of the drilling records determined that the CDP was not the reason for the pipe becoming stuck and that the mid-joint failure was a result of the extreme twisting and pulling forces applied during the effort to release the pipe.

In a third field test (Figure 2), the SR/CDP was used in a new gas well to drill a 60-ft radius turn for a horizontal lateral at a depth of 1,385 ft. A major difference in this test was that an air-hammer drilling tool was being used in the well. The air-hammer subjected the pipe to severe pounding stress, testing its fatigue life and mechanical strength. Along with the stress, the fact that the formation being drilled was very hard and abrasive provides an excellent test of the protective coatings used on the pipe.

In this test, the CDP was run for a total of more than 160,000 cycles at an average RPM of 70, air pressure 300 psi, and torque of 1,000 lb-ft. The pipe was subjected to momentary pulls of 12,000 lbs, 10,000 lbs of compression and 1,500 lb-ft of torque. Despite this rigorous testing, the pipe performed flawlessly and, after a week of drilling, showed little to no signs of wear (Figure 3).

Following the preliminary field tests, the SR/CDP was offered on a limited, continuing field-evaluation basis, to drilling companies. The first order under this testing plan was placed in January 2004 to air-drill Gulf Coast horizontal wells. The pipe performed as expected. From one location at one well in late July 2004, it was reported that steel pipe failed while drilling the lateral section and the composite pipe was used for all fishing operations, consistently pulling 20,000 to 25,000 lbs. Subsequent reviews supports the conclusion that the SR/CDP could be successfully used to re-open wells where the transition from original well to horizontal well (ROC) was equal to or greater than 50 ft.

A fourth major proof test of the SR/CDP has been run where the desired minimum ROC was 30 ft. Calculations on the SR/CDP indicated that it could be bent to 30 ft under no-load conditions. This in-ground testing provided extremely valuable design/manufacturing information: A processing flaw was found to exist in the "centralizer" (wear knot) bonding procedure. The failed centralizer caused the well to deviate from the planned 30-ft ROC to 19 ft, and the pipe body failed. As a result, the centralizer bonding process was corrected and the pipe body was totally re-designed to be more reliable drilling at a 30-ft ROC, thus creating USR/CDP.

USR/CDP TRIAL RUN

One thousand ft of USR/CDP incorporating the SMART feature is being manufactured and will be subjected to "in-ground testing" in the latter half of 2007.

ER/DW CDP

Recognizing the need to access oil and gas reservoirs that were either impossible or uneconomical to reach with metallic drill pipe, **combined with the fact that the oil industry would not fund basic technology development,** the DOE's National Energy Technology Laboratory (NETL) issued contract a to ACPT. The object was to develop "cost-effective composite drill pipe."

The basic technology supporting this effort was the fact that maximum-reach and deepest drilling is limited by the weight of the metal drill pipe, that CDP providing the equivalent mechanical properties would weigh on the order of half that of similar steel pipe, and that it could be manufactured for only 3 to 5 times the cost of steel drill pipe.

During the first six years of the NETL/DOE-supported program, specifications for both nominal 6-in.and 2½-in. composite drill pipe were finalized; materials for the composite tubing, adhesives, and abrasion coatings have been selected based on laboratory testing and a composite tube/metal tool joint interface connection has been successfully tested (the tool joints in CDP are metal).

Existing facilities have been modified to allow pilot plant production of 30-ft sections of CDP at ACPT.

Initial mechanical design goals for the ER/DW CDP have been met (Table 2 and Figure 4). An extensive test plan demonstrating that all industry requirements will be met has been compiled. The 6-in. CDP will be ready for continued evaluation and field-testing by the latter half of 2007. ACPT is soliciting support for this work.

Table 2: Extended Reach/Deep Water Product Data Sheet

Mechanical Specifications		
Bending Stiffness	EI	180 x 10^6 lb-in^2
Torsional Stiffness	GJ	115 x 10^6 lb-in^2
Axial Stiffness	EA	33.4 x 10^6 lb
Rated Tension Load	P	450,000 lbs
Rated Torsion Load	T	25,000 ft-lb
Rated Compression Load	P_c	250,000 lbs
Rated Internal Pressure	P_i	9,000 psi
Max Service Temperature	F	350°F
Design Specifications		
Tube Inside Diameter	ID	5 in
Tube Outside Diameter	OD	6 in
Length (Pin-to-Box)	FT	30
Centralizers	Optional	
Weight (30 ft sections)	LBS	358
Weight comparable steel	LBS	826
Weight of comparable steel pipe-lbs	157	157
Minimum ROC-ft	60	30
Connection Specifications		
Pin/Box Diameter	OD	7 in
Bore	ID	4 ½ in
Thread	IF	NC 56

Table 2 (above) details initial mechanical design goals for the extended-reach/deepwater composite drill pipe. The 'SMART' 6-in. CDP, seen in Figure 4 at left, will be ready for continued evaluation and field-testing in the latter half of 2007. Support is currently being sought for this work.

'SMART' DRILL PIPE

Initial testing of composite drill pipe specimens wired for a built-in data and/or energy transfer within the walls of the CDP has been demonstrated. After Sandier National Laboratory demonstrated that "wired" composite pipe walls could carry electronic signals as required for full-length drill strings, a design for transporting these electronic signals across the metal end fittings of the CDP was developed and tested. This testing included multiple making and breaking of joints and both signal and power transmission during drilling mud flow conditions.

This "SMART "capability will be further demonstrated through 2007.

POWER TRANSMISSION SHAFTING

Composite power transmission shafts (drive shafts) are being used in automotive, marine, aerospace and industrial applications, with some uses being state-of-the-art or even commonplace. When comparing specific modulus, the ratio of stiffness to density, much higher values are possible with composite materials than with metals. This allows higher critical speeds for equal-length shafts, or longer spans to be covered by a single shaft at a given speed.

In most cases where the span is long enough to warrant two shorter-length metal shafts (for higher resonant frequencies) with a support structure and carrier bearing in between, the span can be covered with a single composite shaft with resonant frequencies beyond the range of shaft rotational speeds. This eliminates the need for a center carrier bearing and supporting structure.

Another natural benefit of composite materials is their corrosion resistance. The combination of corrosion resistance and higher critical speed made compos-

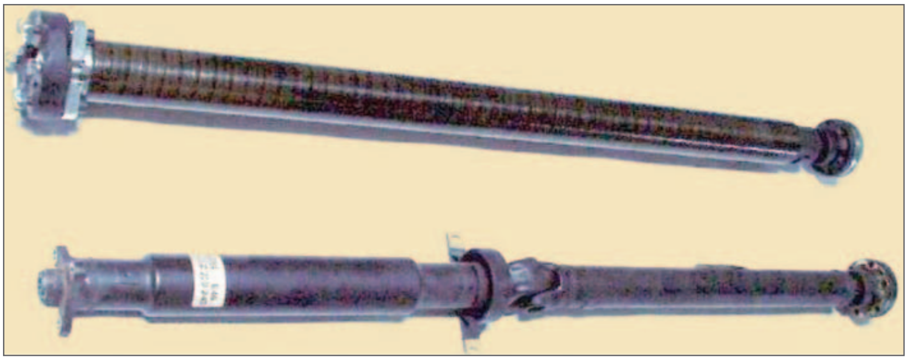
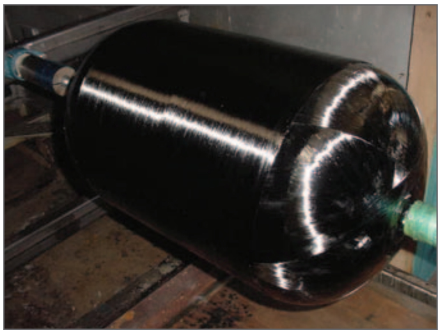


Figure 5 (above): Composite power transmission shafting, such as this single-piece composite automotive shaft and corresponding two-piece metal shaft, should find more use in oil E&P. Figure 6 (right): A graphite-overwrapped titanium pressure bottle can be a weight-saving technology applicable to pressure vessels for offshore operations.



ite shafts the preferred choice for large cooling towers with long spans from the electric motor outside the tower to the gearbox at the hub in the center of a 30-ft or larger diameter fan inside the tower. Single piece 6-in. to 8-in. diameter composite shafts that can be handled by one or two people replace 10 to 12-in. diameter, two-piece stainless steel shafts that require cranes to handle, along with the associated center bearing and support structure. Removing the metal and weight from the corrosive environment inside a cooling tower also lengthens the time between regular shaft maintenance.

In a vertical municipal pump-shaft application, use of composite shafts eliminated the need for a whole floor to be built that would have supported the center bearings for multiple two-piece metal shafts. It is easy to imagine the benefits this technology could bring to offshore drilling platforms, where weight and corrosion resistance are always considered.

Additionally, composites naturally damp vibration much faster than metals. In most composite shaft applications, utilizing internal combustion engines, such as cars, trucks and boats, the shaft acts as an isolator, reducing the vibrations transferred from the engine to the rest of the vehicle, vessel or its occupants.

There is also a rotational shock absorbing effect that provides for smoother power transfer, protecting other components like u-joints and transmissions. The automotive race industry has demonstrated these benefits in quicker 60-ft times and more consistent shifts for drag racing, and in faster cornering and better acceleration in road racing and circle track venues.

Prolonged drivetrain component life has been noted in virtually all automotive racing applications using composite drive shafts. Now composite drive shafts are also used in several OEM automotive applications for all the reasons mentioned above.

Another important factor is safety. High-speed rotating shafts are great momentum storage devices. If a component fails and a heavy metal shaft gets loose, serious damage can be caused before the angular momentum dissipates. If still being driven, the shaft can flail around ripping things apart until the motion is stopped. A much lighter-weight composite shaft does not provide as much energy for damage in a failure situation and is much more fragile in impact. In auto racing, metal drive shafts have been known to come through the floorboards and tear apart cars and, sadly, drivers' limbs. The typical damage caused by a composite driveshaft in this situation is usually just a little dirt and paint removed from the underside of the car before the shaft disintegrates.

All the attributes discussed are tailorable within a wide range, even with a fixed diameter and wall thickness. Choice of reinforcing fiber as well as fiber orientation can make a shaft stiff or flexible and change spring rates both torsionally and laterally. Composite drive shafts can actually be engineered to damp vibrations of given frequencies, absorb certain levels of rotational shock, rotate at high speed without harmonic resonance and even fail at certain torsional or axial loads.

Composite power transmission shafts are a proven and accepted technology. Trusted for use in OEM consumer automobiles and used as the standard in some industrial applications, they should find more and more use in oil exploration and production, especially offshore. Figure 5 show examples of composite power transmission shafting.

PRESSURE VESSELS

Cost-effective lightweight pressure vessels can be produced as lined composite tanks, or as over-wrapped metallic tanks or cylinders. Low-pressure tanks and buoys fabricated from inexpensive and corrosion-resistant fiberglass are fully accepted by the petroleum industry. The availability of high-strength, high-modulus graphite composite now provides a technology base for even higher-strength and lighter-weight pressure vessels, still exhibiting excellent corrosion resistance.

Fully over-wound tanks are being designed and used regularly in satellites and launch vehicles (Figure 6). This basic weight-saving technology is directly applicable to rugged, reasonable cost, lightweight, corrosion-resistant pressure vessels for offshore operations.

This same technology has been demonstrated for hydraulic cylinders. Experimental studies have demonstrated the practicality and effectiveness of overwrapping high-strength steel cylinders with high-strength graphite composite. Herein, one design showed a 33% weight savings in a 12,500 psi. burst-pressure cylinder, at a maximum cost increase of 5%. The tests performed in these studies were designed to show that composite over-wrapped cylinders could meet military specifications.

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