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.

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

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ACPT SR-CDP</th>
<th>ACPT USR-CDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Modulus - msi (10^6 psi)</td>
<td>4.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Shear Modulus - msi (10^6 psi)</td>
<td>3.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Tensile Ultimate-lbs.</td>
<td>75,000</td>
<td>65,000</td>
</tr>
<tr>
<td>Tensile Operating-lbs.</td>
<td>25,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Compression Ultimate-lbs.</td>
<td>100,000</td>
<td>65,000</td>
</tr>
<tr>
<td>Compression Operating-lbs.</td>
<td>50,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Torque Ultimate-lb-ft</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Torque Operating-lb-ft</td>
<td>2,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Internal Pressure Ultimate-psi</td>
<td>2,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Internal Pressure Operating-psi</td>
<td>1,000</td>
<td>1,500</td>
</tr>
<tr>
<td>Collapse Ultimate-psi</td>
<td>2,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Collapse Operating-psi</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Temperature-F</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>Weight of 30 foot section-lbs</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>Weight of comparable steel pipe-lbs</td>
<td>157</td>
<td>157</td>
</tr>
<tr>
<td>Minimum ROC-ft</td>
<td>60</td>
<td>30</td>
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</tbody>
</table>
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 1925. 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.

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. After a week of drilling, the pipe showed little to no signs of wear, as seen in Figure 3 below.

**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.

**'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 Sandler 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-
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 fail 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 tailor-made to each specific application. The use of composite shafts is expanding into various areas from automotive and marine to industrial applications, where weight and corrosion resistance are always considered.

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**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 over-wrapping high-strength steel cylinders with high-strength graphite composite. Herein, one design showed a 35% 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.

**References**
