Titanium drill pipe a viable option for short-radius horizontal drilling

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VOLATILE OIL AND gas prices have focused the US exploration and production industry on developing more cost-effective tools and methods. Drilling engineers have become increasingly optimistic about the business growth prospects of horizontal drilling as they continue to find particular development synergisms between equipment and techniques.

One of the most promising developments has been the combination of flexible drill pipe and smaller hole diameters in so-called slimhole drilling of short-radius horizontal wells to reenter existing vertical wells, using them as the base for add-on arc and horizontal sections. But, in a typical short-radius reentry drilling program, drill pipe will have a radius of curvature of less than 60 ft, placing added stress on the pipe that significantly decreases its life and reliability due to fatigue, wear and physical damage, especially when a rotary steerable technique is used to rotate the pipe while building angle.

Engineers have tried a number of technologies, including pipe made of various steel alloys, aluminum and fiberglass/carbon fiber composite materials, to obtain the combination of high-yield strength and flexibility needed for such a severe application.

Grant Prideco, a subsidiary of **Weatherford International Inc**, and **RTI Energy Systems Inc** of Spring, Texas, a subsidiary of **RTI International Metals Inc**, have a solution: titanium drill pipe, which offers the unique combination of steel's strength and durability with composite's flexibility, lighter weight and corrosion resistance. This article provides an overview of titanium drill pipe's advantages for short-radius horizontal drilling, and looks at the development of titanium drill pipe assemblies for this application, as well as the design and testing of a high-integrity tool joint and tool joint-to-pipe connection for optimum fatigue performance. It also provides the recent results of the first commercial use of titanium drill pipe on record by **Torch Drilling Services LLC**.

OVERVIEW

In many basins and reservoirs throughout the US, horizontal-drilling technology has proven its value in a number of areas, especially in slimhole, short-radius drilling.

There are thousands of existing wells in the United States that are potential candidates for this technique, which enables the drilling of reentry short-radius horizontal wells and multiple short-radius lateral wells from the initial vertical section of a well to improve production rates and extend the life of the reservoir. However, this technology requires drill pipe that can be rotated through short-radius bends without failing prematurely due to high-cycle stresses. The ideal pipe will not cause high torque and drag while drilling through curved hole sections.

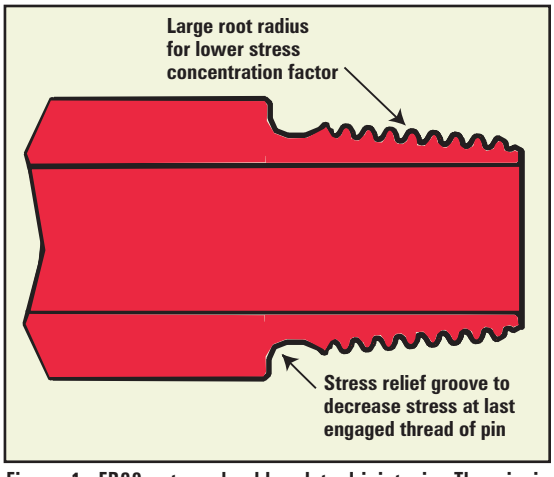

Figure 1: FR26 rotary-shouldered tool-joint pin. The pin is designed to more evenly distribute axial load from make up.

Grant Prideco and RTI began the titanium drill pipe development program for short-radius drilling in 1996, recognizing that in comparison with steel, titanium has several primary advantages for pipe used in short-radius drilling:

• Titanium does not suffer corrosion fatigue. The fatigue performance in air is sustained in the drilling environment;

• Titanium is more corrosion- and erosion-resistant than steel;

• Titanium has an elastic modulus of 17 MM psi, compared with 30 MM psi for steel, so titanium is 57% as stiff as steel;

• Titanium pipe has a yield strength of 120,000 psi, which equals a strength-to-weight ratio of 1.54 times that of S-135 steel;

• Titanium is about 56% as heavy as steel, with a density of 0.160 lb/cu in. compared with 0.283 lb/cu in. for steel.

While all of these factors contribute to titanium drill pipe's superiority over steel for short-radius horizontal drilling, the low modulus is the key advantage. When using the short-radius process to drill through curvatures of 50 ft or less, companies want to maintain a service life of more than 500,000 cycles. Lab tests show that titanium has a fatigue life greater than 10 times that of steel when cyclic stresses are between 30,000 psi and 40,000 psi. Titanium is more expensive than steel, but its greater fatigue life and enhanced capabilities make it more cost effective than steel for short-radius drilling.

Titanium also is displacing fiberglass/carbon fiber composite drill pipe due to titanium's combination of great durability, longer life and strength. Titanium pipe can handle higher torque and more abrasive geological formations that will tear up composite pipe, and it does well in high-temperature applications such as geothermal.

Titanium pipe is corrosion resistant, as well, so it is unaffected by brine, carbon dioxide or hydrogen sulfide. The uniform material characteristics of titanium make it much more reliable than composite pipe, which tends to be stronger in some directions than in others, depending on how the filaments are wound when the pipe is manufactured.

DEVELOPMENT

3 basic components make up the drill pipe assembly: the pipe body, the tool joint and the tool joint-to-pipe body

Table 1: Titanium (Ti-6A1-4V) vs steel drill pipe (2 7/8-in. x 0.362 wall)

Pipe Alloy	Minimum Material Yield Strength, ksi	Tensile Strength, lb	Torsion Yield Strength, ft-lb	Modulus of Elasticity	Adjusted String Weight, lb/ft
S-135 Steel	135	385,820	20,798	30,000,000	10.50
G-105 Steel	105	300,082	16,176	30,000,000	10.50
Ti-641-AV	120	342,951	18,487	17,000,000	6.19

interface. For the initial titanium drill pipe, the pipe body was fabricated from a Ti-6A1-4V alloy because it is a lower-cost titanium alloy with high tensile strength and fatigue strength; low elastic modulus; good corrosion resistance; and ready commercial availability. It already was proven as a material that could be easily machined, welded, or hot forged, and it is commercially produced in seamless tubular products. A hot-rolled pipe was chosen for its lower-cost, higher-yield, higher-production-rate method of producing large lots of thin-wall titanium alloy pipe in standard API sizes. The initial pipe was 2 7/8 in. OD x 0.362 in. wall x 30 ft long.

The tool joint was made of a chromium-molybdenum steel. It had a 3 5/8 in. OD x 1 3/4 in. ID with an FR26 rotary-shouldered connection. The designers chose this because they wanted to avoid the potential of galling with an all-titanium tool joint. To improve fatigue resistance of the last engaged thread of the pin, the most likely location for a fatigue failure in the tool joint, the pin was machined with a stress relief groove.

The patented thread form was machined with a very generous 0.057-in. root radius, compared with the API NC26 thread form root radius of 0.038 in. This had the effect of reducing the thread root stresses significantly, thus enhancing fatigue life considerably.

The special features of the pipe body, the tool joint and the tool joint-to-pipe body interface combine to produce a substantial improvement in the fatigue characteristics of the connection. In fact, the tool joints outlasted both the steel and titanium pipe to which they were attached, so we weren't able to determine an endurance limit for the connections.

TESTING

There were 2 key areas of focus during the titanium drill pipe testing:

- Ensuring that the connection between the pipe and tool joint was not the weak link in the assembly in terms of tension, torsion or bending;
- Showing that it had good fatigue resistance.

The connection's integrity and performance depended on the frictional torque resulting from the interference fit, the total interference between pipe and tool joint, the radial stresses in pipe and tool joint from interference fit, and the contact diameter of the pipe and tool joint.

Several types of tests were performed during development of the drill pipe to help focus the design decisions, followed by several more tests to ensure that the performance of the final product would meet customer expectations. These included fatigue testing, tensile testing, torque testing and pressure testing.

FIELD TRIALS

After all phases of the testing program were completed, with the pipe assemblies performing according to development objectives, Grant Prideco and RTI Energy Systems manufactured and supplied 18 joints of pipe for field trials.

The companies offer titanium drill pipe in sizes from 2 3/8-in. OD to 6 5/8-in. OD in combination with Fatigue Resistant (FR) eXtreme Torque (XT), HI-TORQUE (HT) or standard API tool joints. The pipe produced for the tests was 2 7/8-in. OD X 0.362-in. wall thickness, with a nominal length of 30 ft. The pipe was fitted with Grant Prideco Fatigue Resistant 3 5/8-in. OD x 1 3/4-in. ID FR26 rotary-shouldered steel tool joints specifically designed for high-stress, short-radius drilling applications.

The pipe was first run by Houston-based Torch Drilling Services on a short-radius well in Greeley County, Kansas. Torch used a hybrid drill string of steel drill pipe and titanium drill pipe with a bottom hole assembly that included 4 joints of 2 7/8-in. titanium alloy upset pipe and a patented rotary steerable horizontal drilling system.

The projected well path called for a 60-ft radius of curvature (ROC) to a target azimuth of 90°. The actual well path resulted in a 58-ft ROC to a target azimuth of 93° and a very smooth planar borehole. The titanium drill pipe was rotated at 50-80 rpm while building angle.

To date, Torch and **Horizontal Systems**, Casey, Ill, have used titanium drill pipe in drilling curved sections of horizontal wells in Kansas, Wyoming, California and Indiana. Other than some surface scratches, which were buffed out easily, there was no mechanical damage to any of the test pipe.

CURRENT AVAILABILITY

It is clear that companies want to use titanium drill pipe for the short-radius horizontal application because of its superior reliability over composite pipe, and its flexibility, weight, fatigue-life and corrosion-resistance advantages over steel pipe. We currently are developing a 2 1/2-in. OD titanium pipe that will be even more flexible for small-hole applications, such as the 4 1/2-in. hole in the field trial. We believe the 2 7/8-in. will work well in hole sizes between 5 7/8 in. and 6 3/4 in. More pipe sizes will be available soon.

CONCLUSION

Titanium is proving itself as a perfect solution for short-radius, slimhole horizontal wells and other demanding drilling projects due to its combination of high strength, flexibility, reliability and corrosion resistance. It also is proving to be a superior material to steel and composites in demanding conditions, and offers optimum string performance and cost in certain other applications when used in a hybrid string with steel pipe.