Lightweight, ultra-high-strength drill pipe may meet demands of ERD, critical deep drilling

By Michael Jellison, NOV GrantPrideco

CURRENT AND FUTURE extended-reach drilling (ERD) and other critical projects exceed the capabilities of conventional steel S-135 drillstring assemblies. Drilling teams are evaluating alternative materials and advanced technologies to expand the ERD envelope. One solution under development incorporates a new ultra-high-strength steel with minimum 165 ksi yield strength combined with thinner wall, lighter-weight tubes compared with conventional steel drillstrings.

Z-140 and V-150 drill pipe has been used successfully for more than seven years, and over 1.4 million ft have been produced and deployed throughout the world. By designing advanced steel alloys and with carefully controlled processing, ultra-high-strength 165 ksi steel drill pipe can be consistently manufactured. Early attempts at producing 165 ksi drill pipe resulted in material with low toughness that was subject to brittle cracking type failures in even relatively benign environments. Emphasis with the current UD-165 material grade was on maintaining excellent toughness properties to make it suitable for use in most, if not all, applications where API S-135 drill pipe is acceptable.

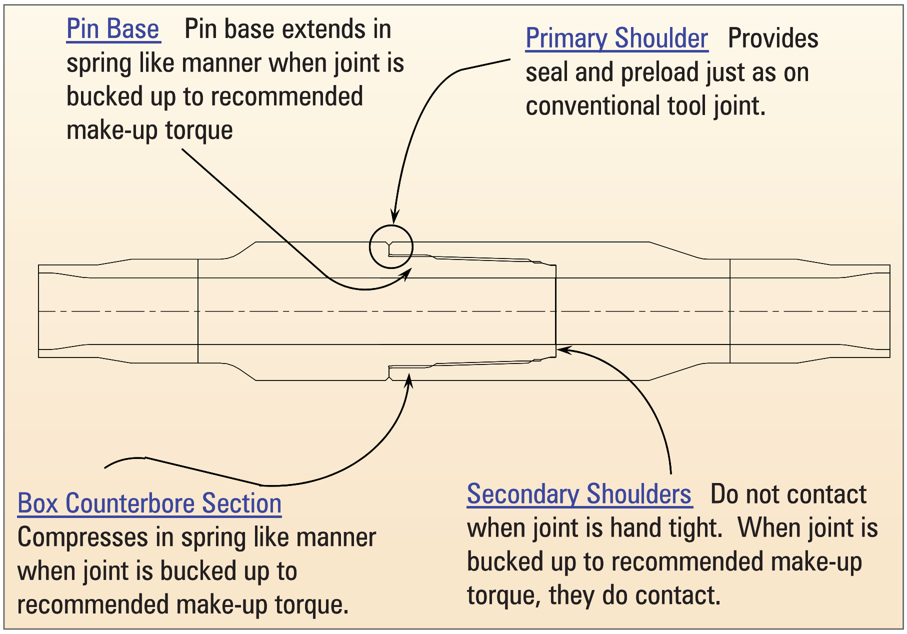

Figure 1: Mechanics of double-shoulder connections (DSC). External shoulder acts as seal and primary shoulder. Internal shoulder is not considered a seal and acts as secondary torque stop to increase connection torsional strength compared with single-shoulder connections.

Table 1 provides a summary of advanced material comparisons alongside S-135, Z-140, V-150 and UD-165 steel drill pipe products. When considering strength-to-weight ratio, many publications have neglected to factor in the steel tool joints attached to the non-steel alternative material tubes. Rather, they have focused on the strength-to-weight ratio improvement of the material density only. This is somewhat misleading and errs on the side of promoting non-steel alternative materials.

Drill Pipe Type	Grade	Yield Strength (psi)	Tube OD (in.)	Tube ID (in.)	Tube C.S.A. (in^2)	Tube Tensile Strength (lbf)	Joint Length (ft)	Joint Air Weight (lbf) [3]	Joint Strength to Joint Weight (lbf/lbf)	% Improvement to S-135	Cost Compared to S-135
Titanium	Ti 6Al-4V	120,000	5.875	5.153	6.254	750,421	46.24	741	1,013	37%	≈7 - 10X
Steel	UD-165™	165,000	5.875	5.153	6.254	1,031,829	46.24	1,145	901	22%	NA
Aluminum[1]	Al-Zn-Mg II[2]	69,618	5.787	4.764	8.477	590,175	46.24	717	823	12%	≈1.5 - 2.5X
Steel	V-150	150,000	5.875	5.153	6.254	938,026	46.24	1,145	819	11%	NA
Steel	Z-140	140,000	5.875	5.153	6.254	875,491	46.24	1,145	765	4%	NA
Steel	S-135	135,000	5.875	5.153	6.254	844,224	46.24	1,145	737	0%	1X
Aluminum[1]	Al-Zn-Mg IV[2]	50,763	5.787	4.764	8.477	430,335	46.24	717	600	-19%	≈1.5 - 2.5X
Aluminum[1]	Al-Cu-Mg-Si-Fe III[2]	49,312	5.787	4.764	8.477	418,034	46.24	717	583	-21%	≈1.5 - 2.5X
Aluminum[1]	Al-Zn-Mg I[2]	47,137	5.787	4.764	8.477	399,596	46.24	717	557	-24%	≈1.5 - 2.5X

Notes:
1 = Aluminum drill pipe design (drill pipe with protector thickening) from ISO 15546 Petroleum and natural gas industries — Aluminum alloy drill pipe
2 = Aluminum drill pipe grades from ISO 15546 Petroleum and natural gas industries — Aluminum alloy drill pipe
3 = includes weight of steel tool joints

Table 1: Strength-to-weight ratio comparisons of steel grades to non-steel alternative materials, including steel tool joints attached.

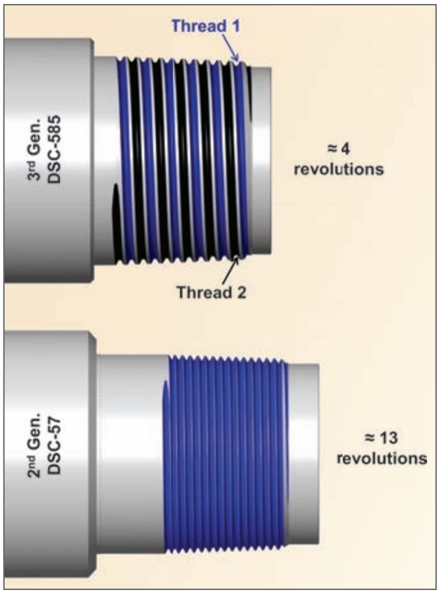

Figure 2 compares scale figures of a third-generation DSC to a second-generation DSC. All other things equal, the double-start thread form reduces revolutions from stab to makeup by 50%. Changes in thread taper and thread pitch further reduce revolutions in total from 13 to 4.

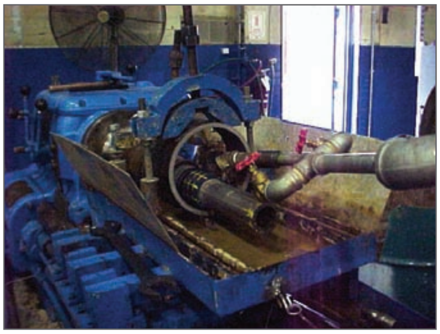

Figure 3: First-generation hardband test machine according to DEA-42.

Table 1, however, factors in the presence of steel tool joints and uses a conservative approach (optimistic) by analyzing range 3 drill pipe products. It should be noted that range 3 product lengths can offer handling efficiency advantages but may present wear issues and elevated torque versus range 2 designs.

The development of UD-165 grade with 165 ksi yield strength tube provides a 22% improvement in strength-to-weight ratio compared with S-135 drill pipe. This represents an alternative second only to titanium drill pipe (Ti DP) by 15% in the strength-to-weight ratio criterion. It is likely that the cost of UD-165 is substantially less than Ti DP.

By combining ultra-high-strength steel with thin wall, lightweight tubes, steel drillstrings can offer strength-to-weight ratios that exceed aluminum (Al) drill pipe, are comparable to titanium drillstrings, and hydraulic performance that surpasses both materials. Compared with standard-weight 5 7/8-in. drill pipe (a size often used for critical ERD applications), the lightweight UD-165 design can potentially reduce the weight per joint by over 30%. This significantly reduces torque and drag forces on long ERD and highly directional well applications.

In addition, since the lightweight pipe features a larger ID, hydraulic performance is greatly improved. Good hydraulic performance is crucial to maintaining high penetration rates, good hole-cleaning and optimum drilling efficiency on ERD and deep-drilling projects.

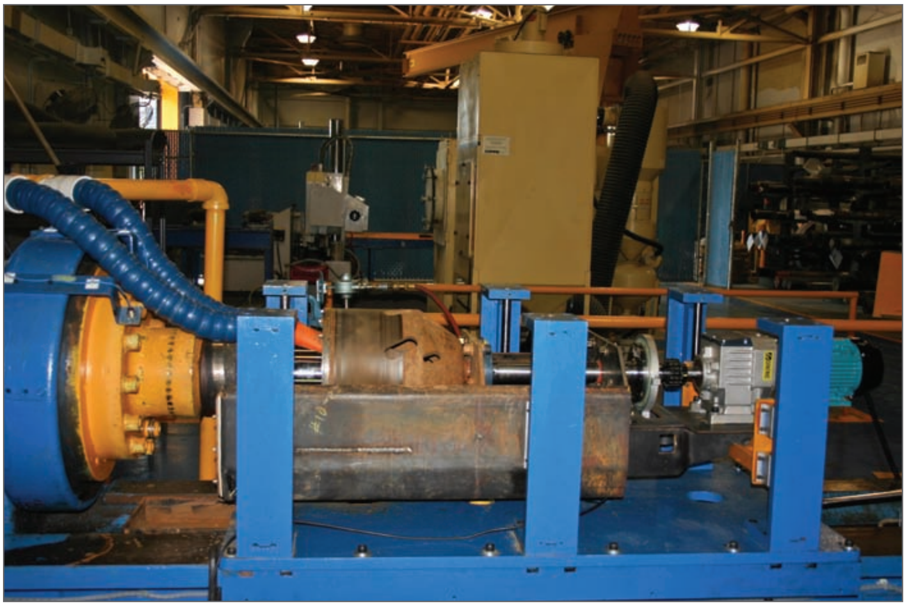

Figure 4: Third-generation hardband test machine with multiple improvements.

After development of the UD-165 material grade for drill pipe applications, extensive metallurgical laboratory tests were conducted to verify that the material met expectations for ultra-high-strength combined with good toughness properties and resistance to cracking. These laboratory tests included tensile testing, hardness measurements and review of the material microstructure. Other important tests conducted that directly or indirectly relate the material toughness and cracking resistance included Charpy impact testing, fatigue testing and fracture toughness testing.

After laboratory testing confirmed desirable and consistent material properties, the decision was made to build approximately 50 joints of 5-in., 0.500-in. wall thickness UD-165 drill pipe. Thirty of these joints were deployed to a land rig application in South Texas to be run in combination with 5-in. 19.50-lb S-135 NC50 drill pipe. The wells in this area typically range in depth from 8,000 ft to 12,000 ft.

The UD-165 pipe was successfully run in two wells. The drill pipe performed as expected, with no unusual running or handling issues experienced. Since then, 5 7/8-in., 0.500-in. wall thickness UD-165 pipe has been manufactured. This pipe is awaiting field trials.

The first lot of lightweight 5 7/8-in., 0.300-in. wall thickness UD-165 drill pipe is being processed for evaluation and field trials. In addition, there are plans to build two ultra-high-capacity 6 5/8-in. UD-165 landing strings this year.

As water depths in deepwater drilling increase and casing strings lengths and weights rise, landing strings with ever-higher axial load carrying capacities are required. The new UD-165 material grade will enable the construction of 2.5-million lb rated landing strings for these critical applications.

A paper that details the development, evaluation and qualification of the lightweight, ultra-high-strength drill pipe system will be presented at the IADC World Drilling 2009 Conference, 17-18 June in Dublin. The paper will also provide detailed comparisons with conventional S-135, Al and Ti drill pipe, outline the advantages and considerations of UD-165 lightweight drillstrings, provides design examples of the new system for world-class ERD applications and provide field trials summaries.

3RD-GENERATION DSC

A third-generation double-shoulder connection (DSC) for drill pipe and drill stem components has been developed and deployed in several critical drilling applications. A key objective for the third-generation DSC was to significantly improve connection make-up/break-out speeds relative to second-generation DSCs. Mechanical and hydraulic gains were also dictated based on the industry's trend toward deeper and further well programs. A closer review of the connection performance needs required for each drill pipe size was also desired.

Third-generation DSCs differ from first- and second-generations in several ways:

• Double-start thread – One of the primary differences is the addition of a dual-start, twin lead or double-start thread. Double-start threads incorporate two threads spaced 180° apart, reducing the number of turns to assemble the connection by 50%, all other things equal. Third-generation DSCs incorporate double-start threads in all design groups for all drill pipe sizes to effectively improve make-up/breakout running and tripping speeds. Figure 2 presents a comparison of a double-start third-generation DSC to a common single-start second-generation DSC.

• Dual-radius thread form – A dual-radius thread form is utilized that reduces peak connection stresses and enhances connection fatigue life.

• Optimized taper – Tapers were reviewed for each connection size and optimized to best balance the needs of the specific drill pipe size. Sizes prioritizing speed of makeup resulted in increased tapers, and sizes prioritizing increased torsional capacity resulted in equivalent tapers.

• Material strength – The new connection is machined on high-strength tool joint forgings with specified minimum yield strength (SMYS) of 130,000 psi compared with standard API tool joints with SMYS of 120,000 psi to increase torsional strength and/or more streamlined dimensions for hydraulic efficiency.

The third-generation DSC is designed to increase target depths for deepwater and ultra-deep drilling and reach on critical ERD wells while improving efficiency and lowering well cost by significantly reducing handling, makeup, running and tripping speeds.

The combination of lightweight, ultra-high strength drill pipe and the new third-generation DSC represents a powerful enabling technology for the next generation of ERD, deepwater and ultra-deep drilling applications.

HARDBAND TRENDS

Proper hardband selection, application and maintenance are essential to successfully and safely drilling world-class UDD, ERD and deepwater projects. The correct hardband solution can maximize drillstring life by protecting the tool joints from excessive wear, minimize wear of the intermediate casing strings in the well (essential to maintain pressure integrity of the well and ensure a safe operating environment) and reduce the friction coefficient between the drill pipe and the wellbore, which in turn reduces the torque and drag forces acting on the drillstring.

The hardband system for critical applications should incorporate the following features:

• The hardband must be casing friendly with no tungsten carbide in its formulation.

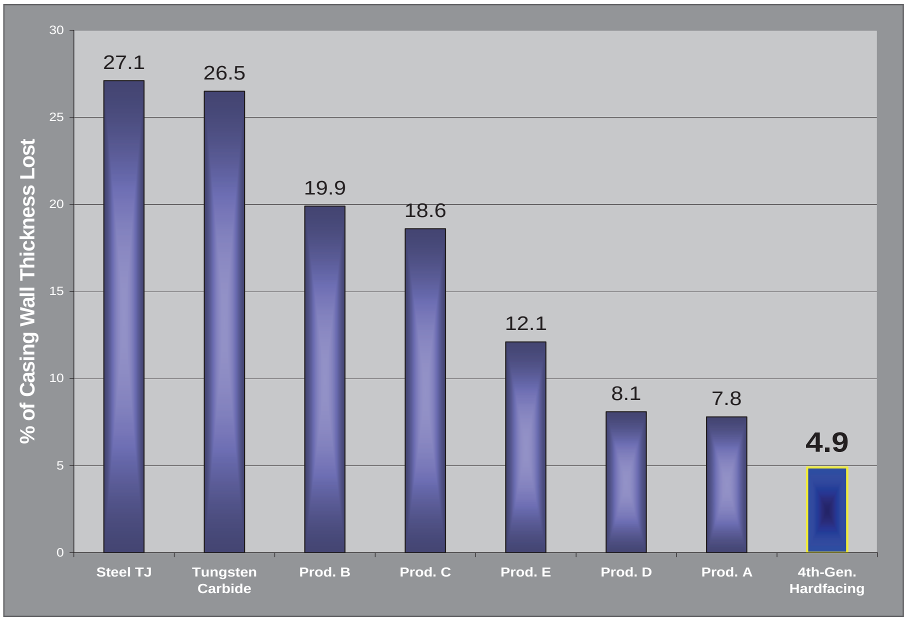

Figure 5: Hardband test results comparing casing wear.

- The hardband should be applied in a raised configuration to maximize tool joint protection and limit contact between the bare steel tool joint OD and the wellbore.

- Both the pin and box members should include hardband to provide tool joint protection and minimize contact between the tool joint OD and well bore.

The industry generally considers hardband applications that are free of tungsten carbide to be casing friendly. These hardbands are designed to prevent aggressive wear of the casing. There are dramatic differences in terms of casing wear among the many tungsten carbide-free hardbands available.

When tungsten carbide-free hardbands were introduced, drilling engineers wanted hardbands that caused the absolute lowest level of casing wear measured through laboratory testing. These hardbands tended to provide the lowest ability to protect the tool joints, wore down quickly and required frequent re-application to protect the drill pipe investment over time.

Since that time, experience has shown that if the hardband is free of tungsten carbide and properly engineered and applied, casing wear is generally not a problem. Consequently, over the last few years, hardband materials with higher hardness properties that offer better tool joint protection have been developed to reduce the frequency of reapplication.

One issue with higher-hardness materials is cracking of the hardband during cool-down after the welding application. Although cracking is not desirable, it can be tolerated provided the cracks in the hardband do not extend into the tool joint base material and that the cracks do not result in hardband spalling.

The hardband designer must balance the often-conflicting traits of high hardness to protect the tool joint, low casing wear properties and cracking tendencies. In addition, the optimum hardband should offer low friction coefficients to minimize torque and drag forces. Significant advances have taken place over the last few years, and there are several hardband systems that offer a good balance of performance characteristics for aggressive applications. Research and development in this area is ongoing.

HARDBAND CASING WEAR, TOOL JOINT PROTECTION

First attempts to evaluate wear performance in accordance with DEA-42 exposed many limitations on testing equipment. Machine deficiencies were:

- The test fixture utilized a hinged table to support the tested specimen fixtures. This meant that the applied force was delivered angularly rather than perpendicularly. The actual applied force reading had to be determined by applying trigonometric functions, which would vary continuously during the test. This was an obvious source for error.

- The side load for this setup was measured with a pressure transducer, which, due to the hinged table, did not provide accurate readings.

- The machine was limited to circulation of water. Use of other drilling fluids was not possible.

- Only the tool joint rotated while the casing remained stationary.

- The table was allowed to reciprocate while the tool joint rotated introducing load variations.

- The load fluctuated 30%-35% of the actual values.

- The setup only allowed for testing of hardfacing material to casing. Alternative conditions such as open hole could not be tested.

- The specified casing grade was API N-80, an uncontrolled grade. Utilizing an L-80 grade is more appropriate to eliminate variation in mechanical and metallurgical properties.

A new hardband test machine was designed and built to improve testing capabilities and repeatability of results. This next-generation machine included the following enhancements:

- A free floating table was incorporated that allowed for the force to be applied perpendicularly to the test specimen, eliminating all variances of the first machine design. A load cell replaced the pressure transducer as the means to measure the applied load. A more robust and accurate measurement was possible.

- Modifications to circulate drilling fluid were added. Variable frequency drives were incorporated into the machine in order to control rotational speed (RPM) and drilling mud pump speed. With these improvements, the load fluctuation was reduced to 10%-15%.

- "Open-hole" test capability was also added. Modifications to the testing machine provided rotation of the formation sample in the opposite direction of the tool joint. With this new setup, the casing material could be rotated instead of reciprocated.

Casing wear results for various commercially available hardband materials are depicted in Figure 5. Tool joint protection results for the same materials are available in the online version of this article, available at www.drillingcontractor.org.

UD-165 is a trademarked term.

This article is a preview to an NOV GrantPrideco presentation, "Light Weight – Ultra-High Strength Drill Pipe for Extended Reach and Critical Deep Drilling," to be made at the IADC World Drilling 2009 Conference & Exhibition, 17-18 June, Dublin.