

Development of Improved High-Strength Coiled Tubing

Today, there is a need for higher-strength coiled-tubing (CT) grades with better resistance to severe environments and better fatigue performance in both the tube body and the bias weld. A complete redesign of CT technology and its manufacturing process has recently been carried out. Testing has shown that the fatigue life of the new CT grades exceeds that of currently available high-strength grades. Additionally, the bias-weld fatigue life has improved significantly. Sulfide-stress-cracking (SSC) resistance of the new CT grades is considerably better than that of conventional CT grades with the same strength.

Introduction

Significant changes in CT operating conditions have been driven by the adoption of multistage fracturing in long horizontal wells for shale oil and gas completions. In these, CT is used in well-completion operations, typically perforating the toe of the well, then milling zonal-isolation plugs used in fracturing, and then cleaning debris from the wellbore.

Stress and strain levels in the CT used for well-completion operations are typically much greater than those experienced in traditional intervention operations. These operating conditions have identified performance limitations of the CT as it is currently manufactured. One limitation is the yield strength of currently available CT grades. Another limitation is the reduced fatigue life of the bias welds relative to the adjacent base

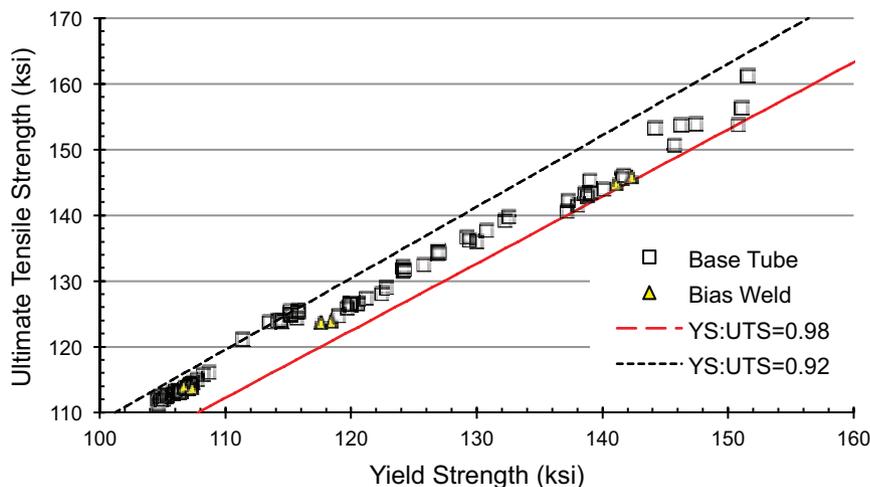


Fig. 1—Ultimate tensile strength (UTS) vs. yield strength (YS) for base-tube and bias-weld tensile tests.

tube, particularly in high-strength-grade tubes. A third limitation is the resistance to SSC, which generally deteriorates as the strength of the tube increases. The objective of this new CT-technology development was to provide a higher-strength tube with better bias-weld performance and improved SSC resistance. This required a full metallurgical understanding of current CT materials and of the manufacturing process, in order to identify improvements. For a discussion of past and current CT technology, manufacturing, and validation methodology, please see the complete paper.

Testing Results and Discussion

Mechanical Performance. Fig. 1 shows a plot of tensile strength vs. yield strength for base-tube and bias-weld results from a number of manufactur-

ing trials covering a wide range of tube strengths. The upper curve is a plot that marks where the yield-strength/tensile-strength ratio equals 0.92, and the lower curve marks where the ratio is 0.98. Fig. 1 shows that the bias-weld results fall on the same trend as those of the base tube, indicating a consistency in yield/tensile ratio between base tube and bias welds. Also, all results fall within the upper and lower yield/tensile-ratio curves. The results all fall within the upper and lower curves—closer to 0.92 at the lowest yield-strength values and closer to 0.98 at the highest yield-strength values. While tube-grade specifications have not all been finalized, on the basis of analysis of Fig. 1 for the 110-ksi-grade tube, the expected range of ultimate tensile strength (UTS) would be from 116 to 136 ksi, and the maximum yield/tensile ratio would be 0.96. For the 125-ksi-grade tube, the expected range of UTS would be 129 to 149 ksi, and the maximum yield/tensile ratio would be 0.98. For the 140-ksi-grade tube, the expected range of UTS would be 144 to 163 ksi, and the maximum yield/tensile ratio would be 0.98.

This article, written by JPT Technology Editor Chris Carpenter, contains highlights of paper SPE 173639, "The Development of High-Strength Coiled Tubing With Improved Fatigue Performance and H₂S Resistance," by M. Valdez, C. Morales, R. Rolovic, SPE, and B. Reichert, SPE, Tenaris, prepared for the 2015 SPE Coiled Tubing and Well Intervention Conference and Exhibition, The Woodlands, Texas, USA, 24–25 March. The paper has not been peer reviewed.

For a limited time, the complete paper is free to SPE members at www.spe.org/jpt.

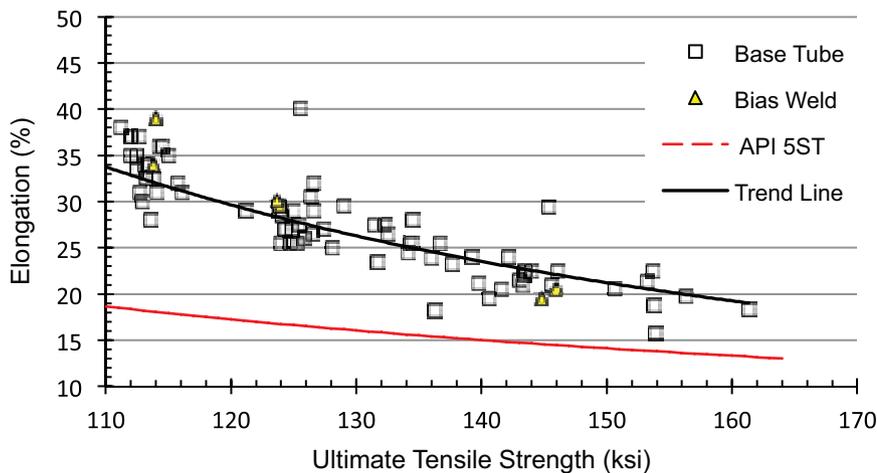


Fig. 2—Elongation vs. UTS for base-tube and bias-weld tensile tests.

CT Grade		Test Environment		
Type	Material	Mild	Intermediate	Severe
Conventional	HS-80	Passed (5/5)	4/4 with crack-like features	Failed (6/6)
	HS-90	Failed (2/2)	N/T	Failed (2/2)
	HS-110	Failed (2/2)	N/T	Failed (2/2)
Heat Treated	HT-80	N/T	N/T	Passed (3/3)
	HT-100	N/T	N/T	Passed (6/6)
	HT-110	Passed (4/4)	Failed (2/2)	Failed (2/2)
	HT-125	Failed (2/3)	N/T	N/T

N/T=not tested

Table 1—Summary of C-ring-test results.

The relationship between elongation and tensile strength is shown in Fig. 2. The same data population was used in Figs. 1 and 2. The results show that there is no difficulty in satisfying American Petroleum Institute (API) elongation requirements, in both the base tube and the bias welds.

API 5ST requirements for CT-110 were used to determine the amount of flattening and expansion achieved in the flattening and flare tests, regardless of the actual yield strength of the sample (from 110 ksi to more than 140 ksi). All flattening and flare tests meet these requirements. The relationship between surface hardness and tensile strength was also explored on the basis of a set of data in which a surface hardness measurement had been taken adjacent to a tensile test. Results indicated that the expected maximum surface hardness for the new tube grades is consistent and on trend with API 5ST.

Environmental Performance. Summarized next are results from SSC C-ring tests and hydrogen-induced-cracking (HIC) tests that show CT performance in sour (wet H₂S) environments under static-load (C-ring) and no-load (HIC) conditions.

C-Ring-Test Results and SSC Performance. A summary of C-ring-test results for conventional and new CT grades is shown in Table 1. In the table, N/T indicates material/test conditions that were not tested because the other tests on that grade failed at less-severe conditions or passed at more-severe conditions. A test is considered passed when no cracks or crack-like features are observed and this is verified following the 30-day exposure. The first number in parentheses indicates the number of individual samples passed or failed, and the second number is the total number of specimens tested at that condition. The test results show the improved SSC performance of new CT grades in C-ring tests.

These results imply that the improved SSC performance of the new CT grades could allow the use of 20- to 30-ksi higher-strength grades in SSC environments compared with the conventional CT grades. This observation applies only to static-loading conditions because the fatigue-damage mechanism and CT-fatigue performance after CT exposure to sour environments are different. However, the improved SSC performance of the new CT grades is beneficial in reducing the risk of catastrophic failures related to that phenomenon, and in providing robustness to the product by diminishing the possibility of formation of small SSC-induced cracks.

HIC-Test Results. No cracks were observed in the base metal, electric-resistance weld, or bias weld of any CT grade after sectioning the specimens and following the analysis protocol.

Fatigue Performance. Extensive fatigue testing of new CT grades has been performed in the fatigue machine. On average, the observed HT-110 fatigue life is approximately 30% longer than the HS-110 fatigue life across the entire pressure range. This shows a clear fatigue-performance advantage of the new-CT material microstructure for the same tensile-strength level as the conventional CT. The HT-125 tests showed approximately 90% longer average fatigue life than HS-110 across the entire pressure range.

Fatigue-test results show that the bias-weld fatigue performance of the new CT grades is similar to their base-tube fatigue performance. The observed similarity of the bias-weld fatigue performance and the base-tube fatigue performance is expected. This is a welcome departure from the conventional-CT bias-weld performance, which progressively decreases as the CT yield strength is increased, limiting the life of the entire CT string. The new CT grades allow full use of the entire CT string, in addition to overall longer fatigue life.

CT undergoes plastic deformation every time it is bent and straightened during normal operations, resulting in fatigue-damage accumulation inside the CT material. When there is pressure inside CT during these bending and straightening events, in addition to the

fatigue-damage accumulation, the CT diameter tends to increase gradually, a phenomenon called CT ballooning. To determine the ballooning performance of the new CT grades, the final maximum CT outside diameter (OD) was measured at two axes 90° from each other at the end of each fatigue test. The maximum and minimum ODs were averaged, and the average OD increase was divided by the number of cycles to failure to determine the average OD growth per CT bend/straighten cycle. HT-125 clearly showed much lower OD growth rates than the other two CT grades for midrange and high CT pressures. HT-110 showed somewhat lower OD-growth rates than HS-110, but the difference was not as pronounced as in the case of HT-125.

In all current tests presented here, the sour-fatigue results suggest nonoccurrence of HIC, which is in agreement with what was observed in the HIC-specific tests presented previously under the same sour conditions.

Test results show that, for the conventional-CT grades, the absolute sour-fatigue life decreases as the CT yield strength increases from 90 to 110 ksi, even for the higher pressure where the higher yield strength is normally beneficial for better handling of the hoop stress. The opposite trend is observed for the new-CT grades, which show an increase in the absolute sour-fatigue life as the CT yield strength increases from 110 to 125 ksi. The improved microstructure of the new-CT materials makes possible this favorable reversal in the sour-fatigue trend related to the yield strength of the CT material.

Another beneficial aspect of the new-CT material technology and manufacturing process is that the bias-weld performance in sour fatigue is very similar to the improved base-tube performance in sour fatigue for the same conditions. This is not a surprise, considering that, for the new-CT grades, the bias-weld microstructure is virtually identical to the base-tube microstructure.

Conclusions

Metallurgical analysis of CT made with the new technology shows a much-more-uniform and -homogeneous microstructure throughout the tube, and particularly in the bias weld, in which conventional-CT technology and manufacturing are not able to restore the microstructure after bias welding. Mechanical testing has established consistency between base tube and bias welds in all tested properties, and, in general, the new CT falls within current API and industry standards when available (HT-110), or it is on trend with extensions of current standards to the new higher-strength grades.

CT manufactured with the new technology showed significant performance improvements in sour environments under static-load conditions. The results imply that the improved SSC performance of the new-CT grades could allow the use of 20- to 30-ksi higher-yield-strength grades in SSC environments compared with the conventional-CT grades. HIC tests showed that all CT grades have good HIC resistance for the sour conditions covered by the tests. **JPT**



TEXAS TECH UNIVERSITY

Bob L. Herd Department
of Petroleum Engineering

Faculty Positions

The Bob L. Herd Department of Petroleum Engineering at Texas Tech University has three (3) immediate openings.

- The successful candidate in Position #3536BR will be expected to teach graduate and undergraduate courses and manage related laboratories in Drilling (casing design, drilling fluids, directional/horizontal, well control and borehole stability). The candidate should have earned a doctorate in petroleum engineering or closely related field by September 1, 2015. This position is for tenure track or tenured positions at the level of assistant, associate and full professor.
- The successful candidate in Position #3537BR will be expected to teach graduate and undergraduate courses in Production and manage related laboratories (artificial lift, completions, stimulation and workovers.) The candidate should have earned a doctorate in petroleum engineering or closely related field by September 1, 2015. This position is for tenure track or tenured positions at the level of assistant, associate and full professor.
- The successful candidate in Position #3720BR will be expected to teach graduate and undergraduate courses Production and manage related laboratories (artificial lift, completions, stimulation and workovers.) The candidate should have a minimum of bachelor's degree in petroleum engineering or closely related field. This position is for the level of assistant, associate and full professor of practice and is not a tenure track or tenured position.

Candidates may apply to one, two, or all three positions. Duties include teaching undergraduate and graduate courses, advising and mentoring students, supervising graduate student research, developing sponsored research projects, and actively participating in departmental, university and professional service activities. Prior academic experience is considered an asset and a mandatory minimum of 4 years of industry, including field experience, is required. The ideal candidates will have teaching and research interests in either Drilling or Production Operations. New faculty are expected to be engaged in scholarship or creative activity that attracts outside funding in the form of fellowships, grants, exhibits, etc. Candidates who have very strong records of scholarship supported by extramural funding and who have the proven capacity or clear potential to bring externally sponsored research to Texas Tech University are encouraged to apply. Service duties include program-building, as well as commitment to extra-curricular activities. Service to the department, college, university, and community is expected.

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Qualified applicants are requested to submit an application letter with their resume and three references at www.WorkAtTexasTech.com. Click Faculty, then search for requisition 3536BR, 3537BR, and 3720BR.

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