Statistical analysis of cross-laboratory NACE Method D test results for new 125 ksi yield strength carbon steel casing

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Introduction
The need for high yield strength OCTG (Oil Country Tubular Goods) materials has been critical to the development of high temperature high pressure (HTHP) wells worldwide. Steel casing is an integral part of well design and provides structural support to maintain operating pressures during the well life cycle, as well as prevent contamination of groundwater in the unexpected event of a production tubing leak.

Casing materials require advanced mechanical properties, as well as proven resistance to environmentally assisted cracking (primarily sulfide stress cracking [SSC]). SSC is an environmentally assisted cracking mechanism which occurs when hydrogen sulfide (H₂S) is present in production fluid. SSC embrittles casing/tubing, potentially causing failures well below the specified minimum yield strengths.

NACE TM0177 Method D (Double Cantilever Beam) test is an industry standard protocol used to qualify the SSC resistance of a new proprietary C125 grade material. The Method D test measures crack propagation in a specimen material, producing a value called KISSC, which measures how suited C125 is for an intended H₂S-containing environment. This quantified laboratory variability to analyze the fit-for-purpose qualification data for 7° casing joints of the C125 material. Statistical quality assurance analysis was conducted to improve quality control in the SSC testing process, as well as evaluate the reliability and reproducibility of results.

Materials and Methods
NACE TM0177/API 5CT regulation describes test criteria. Three independent commercial laboratories tested C125 as per Method D in NACE modified solution B.

Results
The testing was conducted on two data sets, joints of C125 7° casing utilized in two, separate ultra-deepwater gas wells. Mechanical data was provided from the manufacturer. A sample of casing joints were machined for subsequent Method D SSC resistance testing. The statistical analysis showed the steel to be consistently manufactured.

Mechanical Properties of C125 7° Casing, Well #1

Figure 5. Mechanical properties used to measure statistical distribution of 7° casing joints. All joints are of the same proprietary material chemistry and heat treatment. Red-dashed line: 80% Confidence interval; Green: 95%; Blue-dotted line: line of best fit.

Figure 6. Six randomly selected joints and their respective KISSC values, as tested by three separate commercial laboratories. Herein are observed discrepancies in SSC resistance exceeding what is mechanically/metallographically feasible as defined by Fig. 5.

Figure 7. (top) an image of C125 Method D specimen before testing. Figure 8. (bottom) are four specimens after testing. They have been opened to measure linear crack growth (brownish-black region).

Conclusions
1) Inter-lab variance is primarily an issue in assessing the reproducibility of the material properties of C125. KISSC values varied significantly (from 0.2 up to 8.4 ksi√in) for identical joints tested at multiple labs. Similarly, the proportion of joints that passed/failed Method D were systematically different. This raises an issue with commercial use of NACE TM0177 testing.

2) intra-lab variance shows the need for improved data reliability. Statistical evidence shows the distribution of SSC properties within a single laboratory to far exceed the metallurgical and mechanical properties. Furthermore, C125 requires significant evaluation of its purported SSC resistance before being considered for sour service applications.

3) Future Work and Phase II Testing are required to further examine and not only qualify C125, but to establish and implement rigorous QC protocols for future fit-for-purpose testing of any tubular. A concerted effort must be made ensure “standard” SSC testing methods are executed properly, as well as the interpretation of results. Lastly, acceptance criteria for KISSC values and Pass/Fail evaluations must be considered as they relate to structural integrity and overall well design.

Literature Cited

Acknowledgments
Blade Energy Partners Ltd. and their staff at the Houston office are greatly thankful to their contributions to this project. The materials team at Blade Houston were involved in procuring and analyzing the SSC analysis of C125.