Titanium Tubular Technology

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More Details found in: SPE Paper # 115708

Krystian Maskos - Chevron
Bob Hargrave – Chevron
Manuel Gonzalez - Chevron
Jim Grauman - TIMET
John Kuberry - Hunting Energy Services, Inc.
Doyle Reeves - Hunting Energy Services, Inc.
Jim Skogsberg - Chevron Retired
Syed Ali - Schlumberger
Seamless Titanium Alloy 6246 for HPHT OCTG Applications

TIMET alloy
Common names, Ti-6246, TIMETAL ® 6246, UNS R56260

*Included in NACE MR0175/ISO 15156 without restrictions on maximum temperature, \( H_2S, \) or Chlorides to prevent environmental cracking*
Titanium Alloy Advantages

- High Strength – 135 mys, 150 uts
- Reduced Weight - half the weight of nickel, generating half the axial loads
- Corrosion Resistant - comparable to Ni-base CRA’s such as Alloy C-276
- Half of Young’s Modulus compared to Ni-base CRA’s
- Two-thirds of Thermal Expansion Coefficient compared to Ni-base CRA’s
- Seamless pipe can be produced in large sizes - (9 5/8 inch OD and larger) with 40 foot lengths
- Isotropic. Uniform mechanical properties in longitudinal and transverse directions
- Erosion. And Erosion-Corrosion Resistant
- Corrosion Resistant. 6% Mo gives exceptional resistance to Cl and H₂S
Ti-6246 Mechanical Properties

Isotropic

RT Tensile Properties of Extruded TIMETAL 6246 Pipe

Strength (ksi) or Ductility (%)
Tubing Design Safety Factors

**Duplex production**

Using 9-5/8”, 0.545 Wall, 110 GD, 25 Duplex
Min Axial SF is 1.4

**Titanium production**

Using 9-5/8”, 0.395 Wall, 145 GD, Ti-6246
Min Axial SF is 5.5
Titanium Tubular Technology

Metallurgy Testing Program
Ti-6246 Qualification Program

- Corrosion Resistance
- Environmental Cracking (SCC, SSC)
- Simulated Production Fluids
- Packer Fluids
- Methanol
- Mineral Acids
- Repassivation
- Fracture Toughness
- Sand Erosion and Erosion-Corrosion
- Collapse
- Connection Tests
Simulated Production Environment

- 400 F *
- 1500 psia H$_2$S
- 425 psia CO$_2$
- 25% NaCl (150,000 ppm Cl)
- With and without 1 g/L elemental Sulfur

* original target temperature of 500 F was reduced to 400 F because of recurring C276 autoclave leaks
Qualification Test Methods

- C-rings stressed at 90% or 100% AYS for 90 days, galvanically coupled to steel per NACE TM0177-2005
- Corrosion Coupons
- Slow Strain Rate (SSR), per NACE TM0198-2004
- Fracture Toughness (FT) using Arc(T) or SEN(B) geometry per ASTM E399
- Sand Erosion and Erosion-Corrosion test loops
- Electrochemical passivation test
- Collapse tests per API 5C3
Qualification Test Results

Corrosion and Environmental Cracking
- No Pitting, Crevice Corrosion or Hydrogen Absorption after 90-day exposure to simulated production environment
- No significant galvanic corrosion when coupled to Ni-base alloys or duplex SS. Carbon steel corrodes when coupled to titanium
- No cracking from SCC or SSC in 90-day C-ring tests

Slow Strain Rate (SSR) Tests
- Passed environmental SSR tests with no cracking from scc

Packer Fluids - C-rings and coupons passed with no cracks or corrosion for 15 ppg CaBr₂ and 19 ppg ZnBr₂ brine

Methanol - Cracked in MeOH with 1% H₂O. No cracks in MeOH with 5% H₂O

Mineral Acid
- Tests included 10% and 15% HCl with 12% H₂S
- Acid solutions inhibited with Sodium Molybdate
- Acceptable wall loss for 6 hr and 9 hr exposures

Repassivation
- Modified electrochemical test with scratch on Ti-6246 electrode in 15% NaCl brine purged with CO₂
- Ti-6246 reacts with H₂O to repassivate almost instantaneously in oxygen-free environment
Qualification Test Results

Fracture Toughness
- Using Arc-tension and Single Edge Notched Bend geometries per ASTM E399
- $K_q/K_1c$ values for Ti-6246 are 38 to 49 ksi $\sqrt{\text{in}}$ for seamless pipe and 70 ksi $\sqrt{\text{in}}$ for coupling stock

Collapse
- Tests correlated actual results with predicted results based on API 5C3 formula for theoretical elastic collapse
- Ti-6246 seamless pipe exhibits predictable collapse values based on API 5C3 Sec. 2.2.4
- Ti-6246 seamless pipe can be specified with a minimum collapse value rating based on 90% of its theoretical predicted value

Sand Erosion and Erosion-Corrosion Testing (The University of Tulsa)
- Tests involving direct impact of sand in air show erosion resistance is generally better than 1018 CS, and similar to Stellite #12 and 316 SS
- Tests with Ti-6246 ER probe in a 2 inch elbow using air and air-water multiphase (annular) flow show erosion resistance similar to Alloy 625
- The erosion-corrosion resistance in a CO$_2$, sand and brine mixture is nearly identical to pure erosion performance in air

Pipe Roughness. For finished Titanium 6246 pipe based on test results, the average surface readings from 3 different pipe sections were.
- ID Surface Roughness - 70-160 RMS
- OD Surface Roughness - 200-380 RMS
WARNING: the collapse values from industry publications (red book values) cannot be used for titanium tubing, since they are calculated using a Young’s Modulus for steel. The Young’s Modulus for titanium must be used in the API formula.
Titanium Tubular Technology

Connection Testing Program
Hunting SL APEX XP Connection
Titanium Connection Testing

We had performed an initial FEA analysis on the Apex connection with positive results. The analysis consist of titanium to titanium connections. The stress levels are very low compared to the minimum yield strength

Delta P of 7800 psi  
395 Kips Tension
API CAL III Test

Series A Test
• Conducted at ambient temperature, consists of combined load testing in all four VME quadrants which include
  – Tension with internal pressure
  – Compression with internal pressure
  – Compression with external pressure
  – Tension with external pressure

Series B Test
• Consists of combined load testing in the upper two VME quadrants which include loads with and without bending of:
  – Tension with internal pressure
  – Compression with internal pressure

Series C Test
• Consists of ten temperature cycles between 125 F. and 275 F while each sample is subjected to tension and internal pressure.
• Each sample is also subjected to five tension and pressure cycles three separate times throughout the test.

Failure Test
• One sample is subjected to high internal pressure with increasing tension to failure.
• Another undergoes compression loading with increasing external pressure to failure.
• The third sample is subjected to pure tension until failure
• The fourth sample undergoes external pressure with increasing compression to failure.
Testing Ellipse

Sample 5 - VME Tri-Axial Equivalent Yield Ellipse at ID of Pipe
4 1/2" x .254" Min. Wall Ti-6246 Gr. 144.2 KSI SL APEX XP
Series "A" Load Pts Based on 80% Pipe Body VME & 100% Collapse
Make & Break Test

Make and Break Test.

- Three of the four samples were subjected to at least four make and breaks at 5,000 ft-lb followed by a final assembly.

- The fourth sample underwent a final assembly only as specified by the test procedure.
Connection Tests

Internal Pressure and Tension to Failure 4-1/2”
Connection Testing Conclusion

- The connection remains structurally sound when subjected to tension and compression loads up to 200 kips and 180 kips respectively.
- The connection remains leak tight and structurally sound when subjected to combined loads of internal pressure with tension or compression producing pipe body VME stresses up to 80% of the actual material yield strength.
- The connection remains leak tight and structurally sound when subjected to combined loads of 120 kips tension and 8,100 psi external pressure.
- The connection remains leak tight and structurally sound when subjected to combined loads of 180 kips compression and 8,100 psi external pressure.
- A maximum interference connection can withstand up to five make and breaks without galling or permanent damage to the connection.
Titanium Pipe Produced

7-5/8” Ti-6246 Pipe

7-5/8” & 9-5/8” Ti-6246 Pipe
Conclusions

• Ti-6246 pipe is competitive to Ni-base alloys for production tubing in corrosive and highly sour wells

• Chevron has developed and approved a material specification for Ti-6246 tubulars

• Chevron has also qualified the Hunting Apex connection for 4-1/2” service in sour environments as per API 13679 modified test protocol

• Ti-6246 has excellent resistance to environmental cracking and corrosion in HPHT production environments

• Any limitations associated with Ti-6246 can be resolved with appropriate project planning, tubing design, and field operations practices

• Project-specific testing should always be considered to define material performance with respect to the environments and stresses assumed for the completion