A New Sucker Rod Coupling Material: An Economical Solution for Downhole Wear in Deviated Unconventional Wells

Seth Silverman and Logan Stoner
Hess Corporation, Houston, TX

William Nielsen and Diane Nielsen
Materion Corporation, Mayfield Heights, OH
INTRODUCTION
Bakken ToughMet Pilot Project

- Develop a new base material for sucker-rod couplings
- Produce prototypes using production scale process
- Investigate torque/turn behavior relative to existing technology
- Make modifications to coupling surfaces interfacing with rod
- Select candidate wells
- Install ToughMet couplings during workovers
- Evaluate performance
58% of failures are rod/tubing. (~$39,000,000 OPEX in 2015)

~30% of all failures are rod/tubing failures in the bottom 1,000 feet (~$20,000,000 OPEX in 2015)
ToughMet 3

- UNS C72900 Copper-Nickel-Tin
- Heat-treatable alloy
- Very successful high strength, non-galling oilfield material over nearly 20 yrs and use is still growing
- Widely used for key components in directional drilling tools.
- Materion made selective property upgrades to ToughMet 3 that provide an ideal material for coupling
  - Increased fatigue strength
  - Increased fracture toughness
ToughMet 3 TS 95 Material

- **UNS C72900 Cu-Ni-Sn alloy**
  - > 95 ksi minimum yield strength
  - > 40 ksi fatigue limit
  - > 30 ft-lb Charpy impact energy

- Resistant to chloride SCC, pitting and crevice corrosion

- Resistant to erosion, HE, SSC and general corrosion (including in mildly sour wells)

- Anti-galling to typical steel production tubing and sucker rods.
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2% Offset YS, ksi</td>
<td>102ksi</td>
</tr>
<tr>
<td>UTS, ksi</td>
<td>112ksi</td>
</tr>
<tr>
<td>Elongation in 2in., %</td>
<td>24%</td>
</tr>
<tr>
<td>RA %</td>
<td>57%</td>
</tr>
<tr>
<td>CVN, Ft-lbs</td>
<td>55,55,70</td>
</tr>
<tr>
<td>Hardness</td>
<td>98HRB (20.5HRC)</td>
</tr>
</tbody>
</table>
Improved Fracture Toughness in ToughMet 3 TS 95 temper material

ToughMet® 3 TS

Impact Toughness (CVN), ft-lb

0.2% Offset Yield Strength, ksi

High Performance for Oil and Gas Applications
Comparison of T-Coupling, Spraymetal and ToughMet 3TS-95

<table>
<thead>
<tr>
<th></th>
<th>T-coupling</th>
<th>Spray Metal</th>
<th>ToughMet 3TS-95</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface Finish</strong></td>
<td>125RMS in µ-in.</td>
<td>63 RMS in µ-in.</td>
<td>125RMS in µ-in.</td>
</tr>
<tr>
<td><strong>End Finish</strong></td>
<td>125RMS in µ-in.</td>
<td>125RMS in µ-in.</td>
<td>250 RMS in µ-in.</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>16-23 HRC</td>
<td>55-60 HRC</td>
<td>20 HRC</td>
</tr>
</tbody>
</table>
Transmission electron micrograph showing the spinodal structure in aged ToughMet 3, 160,000X (alternating waves of chemically different but structurally coherent atomic clusters of copper, nickel and tin present after spinodal decomposition.)
Typical Sliding Friction Coefficients

Selected Materials in Contact with Carbon Steel

μ
sliding

Ni Alloy Carbon Steel Aluminum Bronze ToughMet

0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
Clearance Increase Due to Wear (inches)

- Oscillating axial motion with side loading.
- Average bearing stress @ 2,000 psi.
- Carburized steel shaft.
Fatigue Strength – ToughMet® 3 TS95

4-point bending; Rotating beam; $R=\text{minus 1}$; Room temperature
Corrosion fatigue strength – ToughMet® 3 TS95

- 4-point bending; Rotating beam; R=minus 1
- Tests conducted for drilling mud environments
- Ending pH approximately 8
Controlled Makeup/Breakout Tests at Key Energy Services

Sept. 29 - 30, 2016

2016 Sucker Rod Pumping Workshop
Field Trials

- Thirteen deviated wells running in Bakken shale locations
- Typically 10,000 ft vertical / 10,000 ft horizontal
- Sweet: range of water cut, sand, brine
- Typically six pump strokes per minute
- L80 production tubing
- Wells have history of elevated, frequent failure rates for target cause
  - > 1 failure per year
- Installed 1 inch slim hole Couplings in deviated sections both near-surface and deep
- No failures in 19 to > 31 months of continuous running
- 100% of inspected couplings suitable for placement back into service
- Wells continuing to run
### Status of Initial Ten Pilot Wells

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Days</th>
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<tbody>
<tr>
<td>GO Biwer 157-98-2635 H1</td>
<td>937</td>
</tr>
<tr>
<td>GO Braaten 156-07-3329 H1</td>
<td>853</td>
</tr>
<tr>
<td>GO Strahan 15-22 H</td>
<td>783</td>
</tr>
<tr>
<td>GO Elvin Garfield 156-97-1819 H1</td>
<td>945</td>
</tr>
<tr>
<td>SC Tom 153-98-1514 H4</td>
<td>622</td>
</tr>
<tr>
<td>SC Tom 153-98-1514 H1</td>
<td>595</td>
</tr>
<tr>
<td>SC Tom LS153-98-1514 H1</td>
<td>615</td>
</tr>
<tr>
<td>GN Alice 158-97-1324 H3</td>
<td>584</td>
</tr>
<tr>
<td>GN EJ 158-97-0706 H1</td>
<td>576</td>
</tr>
<tr>
<td>GN-Ring-158-98-1522 H1</td>
<td>605</td>
</tr>
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</table>

Run time as of September 20, 2016
Case History 1
GO ELVIN GARFIELD
Pilot Testing – Phase 1 Run-Time Enhancement
Improvement in Run Time with 24 ToughMet Couplings

This well is still running. Runtime increased five-fold

Fig. 4 GO Elvin Garfield well shows significant run time improvement with ToughMet couplings in the lower 600 ft of the 1 inch bottom rods
Appearance of Coupling after 6 months in the well
no evidence of wear or metal transfer
New and Used Coupling (Strahan)
Case History 2
GO STRAHAN 15-22 H WELL
Pilot Testing – Phase 1 Run-Time Enhancement
### Strahan 15-22 H Well

<table>
<thead>
<tr>
<th>New Coupling</th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>1.998</td>
<td>1.998</td>
<td>1.999</td>
<td>1.997</td>
<td>1.997</td>
</tr>
<tr>
<td></td>
<td>2.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Reading</td>
<td>= 1.998</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Used Coupling</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>1.968</td>
<td>1.959</td>
<td>1.959</td>
<td>1.985</td>
<td>1.989</td>
</tr>
<tr>
<td></td>
<td>1.989</td>
<td>1.995</td>
<td>1.990</td>
<td>1.956</td>
<td>1.987</td>
</tr>
<tr>
<td></td>
<td>1.987</td>
<td>1.965</td>
<td>1.993</td>
<td>1.987</td>
<td></td>
</tr>
<tr>
<td>Average Reading</td>
<td>= 1.978</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Apparent diametric loss = 0.020 inches after 20 months running
Apparent surface loss = 0.020/2 = 0.010 inches
Tubing Inspection

- 1 inch slim ToughMet Couplings; guided rods
- 3/4 inch full Steel SM Couplings; guided rods
Fewer Damaged Tubes

<table>
<thead>
<tr>
<th>Coupling Material</th>
<th>SM</th>
<th>ToughMet</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of tubes having ≥ 30% wall loss after 551 days</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>% of tubes having ≥ 30% surface pitting after 551 days</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>
Reduced Tubing Damage

**ToughMet couplings increase MTTF of tubing by at least 3X**
(highest, lowest and mean values are shown)
Case History 3
GO BRAATEN WELL
Pilot Testing – Phase 1 Run-Time Enhancement
GO Braaten Well History

• March 2013
  – 15 month runtime
  – Deep tubing leak required WO

• May 2014
  – 14 month runtime
  – Deep tubing leaks due to wear
  – Ran ToughMet couplings

• Feb. 2016
  – Deep tubing leak, 2 joints above seating nipple
ToughMet® 3 Sucker Rod Couplings after 20 Months in a Well

- Evidence of contact between coupling and tubing.
- Insignificant wear: no flat spots and no evidence of metal transfer.

Serial number still visible on the coupling

0.010 inches lost from outer surface
Coupling after 20 Months in the GO Braaten Well
Coupling after 20 Months in the GO Braaten Well
Coupling after 20 Months in the GO Braaten Well
Coupling after 20 Months in the GO Braaten Well
ToughMet Coupling and SM Coupling

After 20 months in same section of well
Case History 4

EN – L – CVANCARA WELL

Pilot Testing – Phase 2 Productivity Enhancement
### 1st New Operating Trial – 55 ToughMet Couplings

- ToughMet couplings installed in bottom 1,400 ft section
- 24 each ¾” Full; 31 each 1” Slim on bottom; one crossover
- Guided

<table>
<thead>
<tr>
<th>Tube/coupling friction coefficient</th>
<th>Prior Standard Practice 0.2</th>
<th>ToughMet hypothesis 0.1</th>
<th>ToughMet hypothesis 0.05</th>
<th>ToughMet Actual 0.035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump stroke (in.)</td>
<td>141</td>
<td>146</td>
<td>148</td>
<td>151</td>
</tr>
<tr>
<td>Liquid production (bpd)</td>
<td>233</td>
<td>240</td>
<td>243</td>
<td>248</td>
</tr>
<tr>
<td>Polished rod load (lbs)</td>
<td>33,000</td>
<td>32,500</td>
<td>32,200</td>
<td>31,570</td>
</tr>
<tr>
<td>Gear box max design load exceedance (%)</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>minus 2</td>
</tr>
</tbody>
</table>
EN-L-Cvancara Well Pump Card
Before Installation of ToughMet

Figure 8 – Pump card of the Cvancara well before installation of the ToughMet couplings in the ¼ in. and 1 in. bottom section of the well. Note the erratic movement of the top load curve, indicating possible sticking of rods.
EN-L-Cvancara Pump Card After Installation of ToughMet

Figure 9 - After installing 24 of the 3/4 in. full size ToughMet couplings and 31 of the 1 in. slimhole couplings, the pump curve is much smoother. This indicates a potentially lower friction force.

Fluid Output Up 6%
EN-L – Cvancara Well

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oil production rates - pre and post workover rates

interval plot of sample
95% CI for the mean

individual standard deviations were used to calculate the intervals.

I chart of sample by period

before

after

UCL = 108.55
X̄ = 87.52
LCL = 66.49

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EN Leo Well
2nd New Operating Trial – 176 ToughMet Couplings

Prior performance

Pump Stroke Up 24%

ToughMet performance
Summary

• Costs of working over shale wells operating on artificial lift run into the hundreds of millions of dollars per year across our industry.

• Almost half of the failures in such wells are related to either tubing or sucker rod coupling failures, primarily caused by wear damage when couplings contact the inner tube wall.

• Materion and Hess Corporation collaborated to develop and field test a new coupling manufactured from ToughMet 3 TS-95, Materion’s spinodal copper-nickel-tin alloy.

• Well run-times have improved significantly

• Well production has increased significantly

• 40 wells are now running; the program will be expanded.
• Results indicate the ToughMet Couplings can mitigate the most common causes of well failure, reducing work over costs by $100,000 per well per year. The return on investment is high and the payback is quick.

• Results indicate the ToughMet Couplings may reduce overall system friction and increase production.

• There have been NO failures of the ToughMet couplings and run times have improved up to five times over what they were previously.

• Material recovered from two wells after 6 months and 20 months show the couplings to be in almost new condition.

• The Hess pilot will be expanded to include up to 75 wells this year.
QUESTIONS?
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