Titanium Alloys for High Pressure, High Temperature Wells:

A Joint Industry Program

Presentation by:
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New horizons for oil and gas development are rapidly expanding to include deeper, HPHT wells:
- Well depths >30,000 ft,
- Temperatures up to 525 F
- Pressures >25,000 psi

The quest for deep hydrocarbons started in the 1970’s deep, sour and highly pressured Smackover formation around Jackson, Mississippi.

This effort helped pioneer the initial use of CRA tubulars and equipment downhole with the development of high strength, highly alloyed nickel-base alloys such as 42Ni (825), 50Ni (G-3) and higher alloys (C276).
Impact of HPHT Conditions on Well Design

Wells drilled with 15,000 ft TVD

- Actual
- Forecast

SMYS 110 ksi
SMYS 125 ksi
25,000 ft
Background – Need for Ti-alloy JIP

- Potential HPHT well design limitations for present corrosion resistant alloys (CRAs) exist due to depth, temperature and high pressure.

- Combination of high strength, low density and corrosion resistance make Ti-alloys attractive for HPHT wells. But, only limited experience and corrosion data impede their use.

- To address these issues Honeywell has organized a Joint Industry Program (JIP).

- The JIP group includes:
  - Oil companies, service companies and suppliers of titanium alloys.

- The JIP work scope includes studies on corrosion of Ti-alloys for down-hole oil country tubular goods (OCTG), and components in HPHT wells.

- This presentation will provide background, industry needs and experience, and an overview of the JIP.
But, What is a JIP?

- A JIP is a jointly funded (usually industrial) program which has pre-set terms for funding, IP development and sharing, and confidentiality.

- A JIP is directed at solving a recognized, industry-wide problem.

- A JIP involves companies related to the problem area: End-users, Manufactures, Services.

- A JIP is a good mechanism to obtain an industry-wide initiative, build consensus and fast-track solution.

**JIP Business Model can be Applied to Many Other Industry Problems & Developments**
The current sponsorship group includes the following companies:

**Blue Circle:**
- BHP Billiton
- BP America
- ExxonMobil
- Petrobras
- ConocoPhillips
- Chevron

**Yellow Circle:**
- RTI
- TIMET
- ATI Allvac
- Titanium Engineers

**Green Circle:**
- Tetra Technologies

Each sponsor benefits:
- Pays only a portion of the total $’s
- Shares equally in IP
- Credit given to in-kind contributions
- Users & Producers work together in development

Titanium Alloy JIP
Titanium alloys have been considered as potential alternative materials to Ni-based alloys;
- High yield strength exceeding 110 ksi (760 MPa)
- Much lower density than conventional steel or nickel alloy tubulars (reduced hanging weight)
- Potentially high corrosion resistance
- Potentially competitive price between Ti-alloys and Ni-based alloys

However, there is limited experience and data on high strength Ti-alloys over the range of conditions for HPHT wells.
Ti-alloy JIP Scope of Work

- **Task 1** – Review of Literature and Relevant Experience with Ti-Alloys for HPHT Wells
  - Subtask 1.1 – Metallurgy and Corrosion Behavior of Ti-alloys
  - Subtask 1.2 – Other Issues (fracture resistance, elastic modulus, galling tendencies, etc.)
  - Subtask 1.3 – Processing and Microstructural Issues with Ti-alloys

- **Task 2** – Engineering Data Development on Ti-alloys
  - Subtask – Mini-Matrix
  - Subtask 2.1 – Sour Production Environments
  - Subtask 2.2 – Packer Fluids
  - Subtask 2.3 – Acidizing Fluids
  - Subtask 2.4 – Galvanic Effects with other materials.

- **Task 3** – Development of Socrates® Corrosion Prediction/Alloy Selection Module for Ti-alloys
Both $\alpha/\beta$ and $\beta$ alloys offer potential for use in HPHT well applications.

Need to evaluate high production capacity Ti-alloys in addition to high performance alloys for these applications.

Evaluation needs to take into account influence of TiO$_2$ layer and potential for changes and damage in-service.

Some testing has been performed in production & related environments on Ti-alloys but it is very limited.

In addition to corrosion, other issues may present challenges for Ti-alloys, including collapse resistance, fracture toughness, anisotropy, low temperature creep, different modulus, loss of strength with temperature (outside the scope of this program).
Ti-alloy Concerns

- Galvanic interactions with other materials and iron embedded in Ti-alloys.
- Industry ability to supply large scale orders of Ti-alloy tubulars for multi-well programs.
- Expansion in production capacity needs to be defined based on end-user needs. But, alloy service limits have not yet been clearly identified for a range of alloys.
- An extensive Task 1 report is available to sponsor companies.

The results of this program should:
- Help to define major corrosion issues and build a consensus on general service limits.
- Help guide additional more focused studies on Ti-alloys by end-users, alloy producers and equipment manufacturers.
Task 2 Mini-Matrix Testing

- **Task 2 Objective:** To determine the serviceability limits of commercially available Ti-alloys in HPHT environments and guide subsequent JIP testing
- Utilize three commonly available alloys – Ti-6Al-4V, Ti-6Al-2Sn-4Zr6Mo, and Ti-3Al-8V-6Cr-4Zr-4Mo (Ti-Beta C)
- Data from Task 1 Survey established specific environment test conditions of high interest:
  - **2 Production Environments** — 25% NaCl / 500 psi H₂S / 1000 psi CO₂ / with and without 1 g/L elemental sulfur
  - **Packer Fluid Environment** — 12 ppg CaBr₂ Solution with no oxygen scavenger / aerated at room temperature / filled ¾ of gage section
  - **Acidizing Environment** — 5% HCl + 10% Acetic Acid with inhibitors. The inhibitors are based on quaternary nitrogen heterocyclic compounds along with organic condensation products. They are blended with an appropriate solvent and the final blend was intended for titanium high temperature use.
- All tests involve SSR testing at 500 F at 4 x 10⁻⁶ in/in/sec and limited examination at 1 x 10⁻⁶ in/in/sec.
Task 2 - Mini-Matrix Alloys

Ti-6Al4V

Ti-6246

Ti-Beta C
### Mechanical Properties of the Mini-Matrix alloys

<table>
<thead>
<tr>
<th>HON ID #</th>
<th>Material</th>
<th>Product Form</th>
<th>0.2% Offset YS, Ksi</th>
<th>UTS, Ksi</th>
<th>%E</th>
<th>%RA</th>
<th>Hardness HRC</th>
<th>Heat Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10389</td>
<td>Ti64</td>
<td>Pipe</td>
<td>128</td>
<td>145</td>
<td>12</td>
<td>27</td>
<td>-</td>
<td>Mill Annealed</td>
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<tr>
<td>10390</td>
<td>Ti6246</td>
<td>Pipe</td>
<td>140</td>
<td>151</td>
<td>12</td>
<td>25</td>
<td>33</td>
<td>Duplex Annealed</td>
</tr>
<tr>
<td>10391</td>
<td>Ti Beta C</td>
<td>Pipe</td>
<td>140</td>
<td>155</td>
<td>18</td>
<td>27</td>
<td>36</td>
<td>Cold Worked and Aged</td>
</tr>
</tbody>
</table>

Titanium Alloy JIP

Honeywell
Experimental Approach

- Slow strain rate (SSR) testing per NACE TM0198
- Variable solutions and $\text{H}_2\text{S}/\text{CO}_2$ partial pressures
- Environmental testing is compared to an average of duplicate baseline air tests
- Straining breaks passive film.
- Results give ranking of environmental or metallurgical effects for different materials
- Accelerated short duration test for screening.
- Long term autoclave tests are also planned based on SSR data.
Task 2 – Proposed Test Matrices

<table>
<thead>
<tr>
<th>Type of Environments</th>
<th>Conditions</th>
<th>Number of Tests</th>
<th>Num of Env. Tested per Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Sour Production</td>
<td>6 Alloys, 3 H₂Spp, 2 Cl contents, 3 temperatures, with and without elemental S</td>
<td>240 SSR 90 DCB specimens 60 corrosion coupons</td>
<td>15 Env. – Task 2 4 Env. – Wild Card</td>
</tr>
<tr>
<td>2.2 Packer Fluid</td>
<td>4 Alloys, 4 solutions, 3 temperatures, air and H₂S</td>
<td>176 SSR</td>
<td>19 Env. – Task 2 2 Env. – Wild Card</td>
</tr>
<tr>
<td>2.3 Acidizing</td>
<td>4 Alloys, 4 solutions, 3 temperatures, N₂ and H₂S</td>
<td>176 SSR</td>
<td>19 Env. – Task 2 2 Env. – Wild Card</td>
</tr>
<tr>
<td>2.4 Galvanic</td>
<td>4 Alloys, 5 solutions, 5 temperatures</td>
<td>40 SSR</td>
<td>4 Env. – Task 2 1 Env. – Wild Card</td>
</tr>
</tbody>
</table>

- Extensive data base development over a wide range of simulated service environments.
- A set of tests in each environment has also been reserved for the end (Wild Card Tests). Will investigate:
  - Replication of data
  - Sensitivity of environmental conditions
  - Influence of compositional, metallurgical processing and microstructural variables.
## Ti-Alloys Selected for Task 2 JIP Study

<table>
<thead>
<tr>
<th>Material</th>
<th>Designation</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-6Al-4V *</td>
<td>Grade 5</td>
<td>α/β high production capacity alloy</td>
</tr>
<tr>
<td>Ti-6Al-4V ELI + Pd*</td>
<td>Grade 24</td>
<td>High corrosion performance α/β alloys</td>
</tr>
<tr>
<td>Ti-6Al-4V ELI + Ru</td>
<td>Grade 29</td>
<td></td>
</tr>
<tr>
<td>Ti-6Al-2Sn-4Zr-6Mo*</td>
<td>NA</td>
<td>α/β alloy for downhole O&amp;G service</td>
</tr>
<tr>
<td>Ti-3Al-8V-6Cr-4Zr-4Mo* - CW</td>
<td>Cold Worked Gr 19 Beta C</td>
<td>High-strength β alloy; CW versus HT</td>
</tr>
<tr>
<td>TMZF Ti-12Mo-6Zr-2Fe</td>
<td>TMZF</td>
<td>High-strength, corrosion resistant β alloy</td>
</tr>
</tbody>
</table>

*Materials utilized for the Packer Fluid, Acidizing and Galvanic test environments
Task 3 – Implementation of Data

- The results from the Ti-alloy JIP will be integrated into the Socrates software model for selection of CRAs for oil and gas service.
- Socrates currently performs rigorous evaluation of over 160 CRAs for resistance to corrosion (general, pitting) as well as cracking (SCC, SSC), and includes some data from public domain on commonly used Ti-alloys.
- Sponsors will be provided with a single user, perpetual license for the enhanced Socrates-Ti program stemming from the JIP data and model development.
Summary

- New demands are being placed on metallurgical approaches to HPHT wells in the oil and gas industry.

- Ti-alloys appear to offer attractive attributes versus more conventionally used Ni-based CRA materials.
  - Corrosion resistance
  - High strength
  - Low density

- Honeywell’s Ti-alloy JIP is bringing together a range of companies to fund the establishment of better guidelines and a consensus for use of Ti-alloys in HPHT wells.

- JIP approaches can be used to create new industry-wide initiatives to solve important problems.
For More Information

- For more information on participation in Honeywell’s Ti-Alloy JIP or for development of other focused joint industry initiatives contact:

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