Subsea Bolts Performance and Critical Drill-through Equipment Fastener Study

Haimei Zheng
Lawrence Berkeley National Laboratory
Outline

- Background
- LBNL bolt research goals
  - Standard review and gap analysis
  - Materials corrosion under subsea environment
- Overview of current progress
- Future work
Background

- Over the past decade, a number of fastener/bolt failures on OCS associated with
  - LMRP
  - Subsea BOP components

- It is needed for an independent assessment of critical drill through equipment fasteners in offshore oil and gas operations

- Identify fastener systems currently in use
  (offshore & onshore; domestic & global)
- Assess design, manufacture, installation, maintenance & inspection processes
- Evaluate the performance of current fastener systems
- Identify similarities & differences in industry standards & regulations globally
LBNL Project Research Goals

- Standard review and gap analysis
- Lab experiments:
  Bolting materials corrosion under subsea environment

- Review industry codes & identify existing standards or regulations underlying failure mechanisms
- Evaluate performance of existing fastener systems manufacturing, corrosion protection, installation, maintenance, inspection
- Identification of similarities & differences in industry standards & regulations
- Evaluation of alternative fastener designs used by global industries
- Recommendation -
  - Methodology for the selection for material properties & other critical parameters
  - Modification & improvement of existing industry standards
Industry Standards Review

American Petroleum Institute - 17
American Society of Mechanical Engineers (ASME) - 1
American Society for Testing Materials (ASTM) - 47
Bolt Council – 2
British Standards Institution (BSi) - 10
Desalinization Industry – 1
DNV-GL – 11
Dept. of Energy-Sandia – 1
Federal Standards – 3
Industrial Fasteners Institute – 4
International Regulators’ Forum (IRF) member country regulations on bolts (a specific requirement or a referenced standard)

Int’l Organization for Standardization (ISO) – 31
Japanese Industrial Standard (JIS) – 1
Military Standards – 10
Nat’l Association of Corrosion Engineers (NACE) – 21
NASA – 1
Navy Standards – 8
NORSOK – 1
Nuclear Regulatory Commission – 7
Society of Automotive Engineers (SAE) – 4
United States Coast Guard (USCG) – 2
Biomedical Industry Standards:
Dental Industry Standards – 3
Bone and Joint Substitute Standards - 10

Total over 200 items ...

http://www.irfoffshoresafety.com/
Industry Standards & Gap Analysis
Critical Attributes for Subsea Bolts

- **Material Specifications**
  - Hardness
  - Yield Strength (YS)
  - Ultimate Tensile Strength (UTS)
  - Elongation

- **Procurement**
  - Heat treatment
  - Coatings (thicknesses)
  - Shear stress
  - Fatigue Life
  - Threading

- **Corrosion Treatment**
  - Cathodic Protection (CP)

- **Installation**

- **Quality Analysis/Control**

- **In Service Inspection (ISI)**

- **Human Factors**
Industry Standards & Gap Analysis

Conventional way of reading & making notes is not going to work …
A Data Base
Gap Analysis Methodology

- An efficient and robust method of cataloguing industry standards
- Microsoft Access RDS and SQL programming queries

Library of Industry Standards

- Need to Identify
  - Relevant Attributes
  - Applied Environment
  - Main Ideas (Abstract)
  - Review of Relevant Attributes (Specific)
  - Notes
- Used as a resource for Gap Analysis

Example – ASTM A193/A193M – 15a
Discrepancies in hardness threshold to avoid hydrogen embrittlement (examples).

- NACE MR0175/ISO 15156 has the most strict regulations. Specific to sour service environments. The maximum allowed hardness is 22 HRC.
- vs. Industrial Fasteners Institute – “Susceptible fastener products have specified hardness above 39 HRC”
- vs. NORSOK – “In marine/subsea applications, acceptable hardness range is 32-39 HRC.”
- vs. API 17A – “Resistance against hydrogen embrittlement should be controlled by specifying that the actual hardness of the material is less than 300 HV10 [31 HRC]…”
- vs. API 17A – “Section 6.4: Bolting materials for subsea applications includes ASTM A320 L7, ASTM A320 L43, ASTM A193 B7, and ASTM A193 B8M Class 1”; none match MR0175/ISO 15156
Industry Standards & Gap Analysis
Hydrogen Embrittlement – Hardness Threshold

- Discrepancies in hardness threshold to avoid hydrogen embrittlement (cont.)
  - “For stainless steels and non-ferrous materials, resistance against hydrogen embrittlement should be controlled by specifying that the actual hardness of the material is less than 300 HV10 [31 HRC] for the base material…
    - Maximum hardness for primary load-carrying components shall not exceed 35 HRC without approval from the purchaser.
  - …..
Discrepancies in heat treatment for corrosion protection.


- ISO 21457: Hydrogen embrittlement may occur on fasteners caused by hydrogen introduced from chemical cleaning related to coating operations, e.g. electrolytic plating and HDG. Baking in accordance with ISO 9588 should be performed for chemical cleaned fasteners with an actual tensile strength greater than 1 000 MPa or hardness greater than 31 HRC.

- ASTM F1941/F1941M (ED Coating on Mechanical Fasteners) – 15: 6.4.1 Baking is not mandatory for fasteners with specified maximum hardness 39 HRC and below.
Discrepancies in heat treatment for corrosion protection (cont.)

- ASTM B633 Service Condition 4 (very severe) – “Exposure to harsh conditions, or subject to frequent exposure to moisture, cleaners, and saline solutions, plus likely damage by denting, scratching, or abrasive wear. Examples are: plumbing, pole line hardware.”


- Many do not include subsea conditions
There is only one internationally recognized standard for materials to be used in sour service environments:

- **NACE MR0175/ISO 15156** – petroleum and natural gas industries; Materials for use in H₂S-containing environments in oil and gas production
  - Defines sour water as containing at least 0.05 psi of H₂S
  - Section A.2.2.4: Bolt materials must be either sulfide corrosion resistant materials or ASTM A193 B7M and ASTM A320 L7M overlayed with below materials.
  - Nitriding to a max depth of 0.15mm is acceptable if conducted at a temperature lower than critical temperature

### Industry Standards & Gap Analysis
#### Bolting Materials for Sour Service

<table>
<thead>
<tr>
<th>Austenitic stainless steels</th>
<th>Martensitic stainless steels</th>
<th>Duplex stainless steels</th>
<th>Precipitation-hardened stainless steels</th>
<th>Cobalt-based alloys</th>
<th>Titanium alloys</th>
</tr>
</thead>
</table>
Industry Standards Gap Analysis: Report TOC

Table of Contents

Executive Summary ........................................ III

1. INTRODUCTION ........................................ 1
   1.1. Issue ........................................ 1
       1.1.1. Current Drilling Conditions .......... 1
       1.1.2. Environmental Effects ............ 1
       1.1.3. Failure Cases ......................... 1
       1.2. Objective ................................ 1

2. INDUSTRY STANDARDS APPLICABLE TO SUBSEA BOLTS .... 2
   2.1. Domestic Standards ................................ 2
       2.1.1. US Industry Standards Development Organizations (SDOs) .... 2
       2.1.2. Tabulation and Abstracts .......... 3
   2.2. International Standards .......................... 25
       2.2.1. International Standards Organizations .......... 25
       2.2.2. Tabulation and Abstracts .......... 26
   2.3. Regulations .................................. 27
       2.3.1. IRF Member Countries’ Regulatory Agencies ...... 27

3. STANDARD REVIEW .................................. 28
   3.1. Methodology .................................. 28
   3.2. Standards .................................. 28
       3.2.1. NACE MR0175/ISO 15156 .................. 28
       3.2.2. NACE SP0169 .......................... 28
       3.2.3. NACE SP0492 .......................... 28
       3.2.4. NACE TM0204 .......................... 28
       3.2.5. NACE TM0284 .......................... 29
       3.2.6. NACE TM0177 .......................... 29
       3.2.7. NACE TM0198 .......................... 29
       3.2.8. ASTM A563 ................................ 29
       3.2.9. ASTM A307 ................................ 29
       3.2.10. ASTM F3148 .......................... 30
       3.2.11. ASTM F3125 .......................... 30
       3.2.12. ASTM A325 ................................ 30

4. COMPARISON AND GAP ANALYSIS .................. 44
   4.1. Introduction .................................. 44
   4.2. Material Properties/Specification ............ 44
   4.3. Procurement .................................. 44
       4.3.1. Manufacturing .......................... 44
       4.3.2. Heat Treatment .......................... 44
       4.3.3. Corrosion Treatment .................. 44
       4.3.4. Installation .......................... 44
       4.4. Quality Analysis/Quality Control .......... 45
       4.5. In-Service Inspection .................. 45
       4.6. Installation .......................... 45
       4.7. Human Factors .......................... 45
       4.8. Best Practices .......................... 45
       4.8.1. Aerospace Industry .................. 44
       4.8.2. Aviation Industry .................. 44
       4.8.3. Automobile Industry ............ 44
       4.8.4. Military (Submarine and Shipping) ..... 44
       4.8.5. Nuclear Industry .................. 44
       4.8.6. Oil and Gas Industry ............ 44

5. RECOMMENDATIONS AND IMPACT .............. 45

Footer
Corrosion Tests

- Subsea environment:
  - High pressure
  - Media with CO_2, Cl^-, or H_2S
  - Other – T, O_2, etc.

- **Total pressure** dependence measurements
- **Oxygen partial pressure** dependence measurements
- **Temperature** dependence measurements
With increasing pressure, 316L and 430 stainless steels exhibit moderately larger corrosion current (higher corrosion rate); pressure shows no distinct effect on 304 and 310 SS.

Corrosion rate of X60 pipeline steel under different pressures.


Influence of Oxygen Concentration

**Fig. 9.** The dependency of initial corrosion rates upon O₂ concentration; circles, from initial corrosion rates; triangles, from 6 h experiments.


The corrosion rate increases with the increasing oxygen concentration.
Influence of Temperature

With increasing temperature, the pitting potential and passive current density increased.


## Corrosion Study Timeline

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>09/2016  10/2016  11/2016  12/2016  01/2017  02/2017  03/2017  04/2017</td>
</tr>
<tr>
<td>Sample production (US Bolts)</td>
<td></td>
</tr>
<tr>
<td>Experiment preparation and set up</td>
<td></td>
</tr>
<tr>
<td>Ambient total pressure test (4 °C) *</td>
<td></td>
</tr>
<tr>
<td>5000 psi total pressure test (4 °C)</td>
<td></td>
</tr>
<tr>
<td>Oxygen partial pressure ≤ 0.4ppb (25 °C) *</td>
<td></td>
</tr>
<tr>
<td>Oxygen partial pressure ~ 21% (25 °C)</td>
<td></td>
</tr>
<tr>
<td>Mechanical test &amp; SEM, XRD analysis</td>
<td></td>
</tr>
<tr>
<td>Summary and Report</td>
<td></td>
</tr>
</tbody>
</table>

* Temperature dependence results will be obtained from the data based on these tests.
Subsea Bolts Performance and Critical Drill-through Equipment Fastener Study

EXECUTIVE SUMMARY

1. INTRODUCTION
   1.1. ISSUE
   1.1.1. Current Drilling Conditions
   1.1.2. Environmental Effects
   1.1.3. Failure Cases
   1.2. OBJECTIVE

Part I
Industrial Standard Review and Gap Analysis

2. INDUSTRY STANDARDS APPLICABLE TO SUBSEA BOLTS
   2.1. DOMESTIC STANDARDS
   2.1.1. US Industry Standards Development Organizations (SDOs)
   2.1.2. Tabulation and Abstracts
   2.2. INTERNATIONAL STANDARDS
   2.2.1. International Standards Organizations
   2.2.2. Tabulation and Abstracts
   2.3. REGULATIONS
   2.3.1. IRF Member Countries’ Regulatory Agencies

3. STANDARD REVIEW
   3.1. METHODOLOGY
   3.2. STANDARDS
   3.2.1. NACE MR0175/ISO 15156
   3.2.2. NACE SP0169
   3.2.3. NACE SP0492
   3.2.4. NACE TM204
   3.2.5. NACE TM0284
   3.2.6. NACE TM0177
   3.2.7. ASTM A598
   3.2.8. ASTM A633
   3.2.9. ASTM A307
   3.2.10. ASTM F3148
   3.2.11. ASTM F3125
   3.2.12. ASTM A325

4. COMPARISON AND GAP ANALYSIS
   4.1. INTRODUCTION
   4.2. MATERIAL PROPERTIES/SPECIFICATION
   4.3. PROCUREMENT
   4.3.1. Manufacturing
   4.3.2. Heat Treatment
   4.3.3. Corrosion Treatment
   4.3.4. Coatings
   4.4. QUALITY ANALYSIS/QUALITY CONTROL
   4.5. IN-SERVICE INSPECTION
   4.6. INSTALLATION
   4.7. HUMAN FACTORS
   4.8. BEST PRACTICES
   4.8.1. Aerospace Industry
   4.8.2. Aviation Industry
   4.8.3. Automobile Industry
   4.8.4. Military (Submarine and Shipping)
   4.8.5. Nuclear Industry
   4.8.6. Oil and Gas Industry

5. RECOMMENDATIONS AND IMPACT

Part II
Materials corrosion under subsea environment

6. ---
Acknowledgements

- Roy A. Lindley (ANL)
- Joseph Lee (LBNL/UCB)
- Xiaowei Lei (LBNL/UCB)
- Kaiyang Niu (LBNL/UCB)