Corrosion-Resistant Steel for COT of Crude Oil Tankers

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Japan Ship Technology Research Association
Corrosion problems in COT of tankers

Cyclic Temp. Change
Wet & dry cycle (50°C ⇔ 25°C)

Inert Gas

Upper Deck

Inner Bottom

Sludge, Drain Water

Crude Oil

H₂S

O₂

H₂O

CO₂

Upper Deck ⇒ General Corrosion

Bottom ⇒ Pitting Corrosion

SR-242
How to overcome the problem?

- Apply Protective coating (epoxy paint) on steel;
- Construct by corrosion resistant steel; or
- Other alternatives (future technologies)
What is “Corrosion Resistant Steel”?

Steel which has sufficient corrosion resistant performance to
- Protect the structure of the top of the COT and/or
- Prevent leakage of oil from the bottom of the COT.
Facts of the corrosion problem in COT

Outcome of SR242 Project (April 1999～March 2002)

Intensive field investigations have been carried out for technical understanding on corrosion in COT

Over 10 VLCCs with conventional steel were examined
Key facts found by SR242 on Upper Deck Corrosion

- **H₂S gas exists in high concentration**
- **Co-existence of O₂ and CO₂ with H₂S**
- **Cyclic temperature change ⇔ Wet and Dry cycle**
- **Upper deck corrosion is uniform corrosion**
- **Product layer is flaky and 60 wt.% of it is Elemental S**
- **Corrosion rate is not so high (Almost less than 0.1mm/y)**
Key facts found by SR242 (on Bottom Plate Corrosion)

Oil-coating exists around pit …

and pitting starts at oil-coating defect
Key facts found by SR242 (on Bottom Plate Corrosion)

Pit Growth Stops at a dock (tank cleaning)

- New Pitting starts at new location
- Pitting Stops

Diagram:
- Pit Depth
- Dock Inspection
- Ship Age

SR-242
**Change of pitting location -1**

- ★ : Pits over 4mm at 1st inspection (repaired)
- ■ : Pits less than 2mm at 1st inspection (NOT repaired)
- ● : Pits over 4mm at 2nd inspection (repaired)

Old pits(■) did not grow!
New pits(●) appear at different points.

SR-242 Result
## Change of pitting location -2

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**SR-242 Result**
**Generation of a Pitting**

(1) Under servicing condition
- Sludge & Corrosion products
- Brine: NaCl ~10wt.%

(2) Dock cleaning for inspection
- Oil coating, Sludge & Corrosion products are cleaned and dried for inspection
- Cleaned Steel Surface = No oil coat

(3) Re-Start of service
- Cleaned and dried pits are re-coated by new crude oil
- New oil coating = Resetting insulating condition

(4) Nuclear of new pit
- New defect: by COW, Brine …..
- Brine: NaCl ~10wt.%
- New defect in oil coating = Nucleation of pitting

Corrosion condition would be reset after Dock inspection → Pitting growth stops at dock cleaning

SR-242 Result
Key facts found by SR242 (on Bottom Plate Corrosion)

Strong Acid environment

Actual Vessel

pH of PIT inside: <1.5

→ Unfavorable for MIC (SRB active pH: 6~9)

SR-242 Result
Development of Corrosion-Resistant Steel

- 1998
- 2000
- 2002
- 2004
- 2006

1990~ Shift to Double Hull Tanker

1999~2002 Panel SR242 Investigation
(The Shipbuilding Research Association of Japan)

Scientific Research & understanding
of the corrosion phenomena
(Over 10 VLCC s)

Basis for Corrosion-Resistant Steel
Corrosion test method

Development of
Corrosion-Resistant Steel
and Laboratory Tests

Field Test on actual Vessels

2002~

2003~
Evaluation of Corrosion-Resistant Steel
Corrosion test for upper deck

Reproduced COT gas environment
(13%CO₂-5%O₂-0.01%SO₂-bal.N₂-H₂S 0.3%)

Temperature controlled vessel
(50°C ↔ 20°C)

Distilled water
(36°C)

Specimens
25mm × 50mm × 4mm
Surface polished: #600
An example of on board test of upper deck

Test coupons were exposed in vapor space of COTs of 2 aframax tankers for 1 year
**Corrosion environment of upper deck (Labo vs field)**

Cross sectional analysis of corrosion product formed on conventional steel after test in reproduced corrosion environment in laboratory.

<table>
<thead>
<tr>
<th>Corrosion product after laboratory test – Upp. DK -</th>
<th>α-FeOOH</th>
<th>γ-FeOOH</th>
<th>Fe$_3$O$_4$</th>
<th>Elemental S</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>COT</td>
<td>37</td>
<td>8</td>
<td>0</td>
<td>12</td>
<td>43</td>
</tr>
<tr>
<td>Simulated test</td>
<td>30</td>
<td>3</td>
<td>8</td>
<td>21</td>
<td>38</td>
</tr>
</tbody>
</table>

Laboratory corrosion test reproduces corrosion phenomena at upper deck of actual COTs.
An example of corrosion test result of upper deck

Corrosion loss after 25 years estimated from simulated test

Conventional Steel

Corrosion-resistant Steel

Average corrosion loss (mm)

Test duration (days)

Ratio of corrosion loss

Curve fit

$Y = a_1 X^{b_1}$

$Y = a_2 X^{b_2}$

Corrosion loss after 25 years, estimated from simulated test

Conventional Steel

Corrosion-resistant Steel
# Corrosion test for inner bottom plate

<table>
<thead>
<tr>
<th>Condition</th>
<th>Notice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>10 mass%</td>
</tr>
<tr>
<td>pH</td>
<td>0.85</td>
</tr>
<tr>
<td>Amount</td>
<td>20cc/cm² or more</td>
</tr>
<tr>
<td>Change</td>
<td>Every 24 to 48 hours</td>
</tr>
<tr>
<td><strong>Gas</strong></td>
<td>Air open</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>30°C</td>
</tr>
<tr>
<td><strong>Specimen</strong></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>40mm x 50mm x t</td>
</tr>
<tr>
<td>Surface</td>
<td>#600 emery paper</td>
</tr>
<tr>
<td>repeat</td>
<td>n=3 or more</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>77 hours</td>
</tr>
<tr>
<td><strong>Immersion</strong></td>
<td>Dipping specimen</td>
</tr>
</tbody>
</table>
An example of corrosion test result of bottom plate

![Graph showing ratio of corrosion rate between conventional steel and corrosion-resistant steel. The graph indicates a significantly higher corrosion rate for conventional steel compared to corrosion-resistant steel.]
An example of on board test of **bottom plate**

**VLCC**
First dock inspection was carried out at 2 years and 3 months after launching

Corrosion resistant steel without Painting

Corrosion resistant steel with Tar-Epoxy painting
An example of on board test result of **bottom plate**

Conventional steel

- Frequent deep Pits

Corrosion Resistant Steel

- No Pit observed
An example of on board test result of **bottom plate**

Conventional steel

Depth: 7.2mm

Corrosion Resistant Steel

Depth: 2.8mm
An example of on board test result of **bottom plate**

**Corrosion Resistant Steel**

No Pit around Weld

No pit has been observed also on conventional steel
Evaluation of Corrosion-Resistant Steel

Summary

- Based on the findings of SR242, steel manufactures have developed corrosion resistant steel.

- Test methods have been established.

- The performance could be evaluated by laboratory tests for upper deck and bottom plate, respectively.
Discussion at IMO

At MSC81 in Dec 2006, twenty one European countries, IACS and NGOs jointly proposed a mandatory requirement of “protective coating” to COT of tankers.

IACS/JWG has been developing Performance Standard for Protective Coating for COT of oil tankers, which will be submitted to DE51 in 2008.

Japan has proposed “corrosion-resistant steel” and its performance standard (PS) as an option for corrosion prevention.

DE and its Correspondence Group (CG) are discussing the issue with a target completion year of 2009.
3 All cargo oil tanks of crude oil tankers shall be:
  .1 coated during the construction of the ship in accordance with the Performance standard for protective coatings for cargo oil tanks of crude oil tankers, adopted by the Maritime Safety Committee by resolution MSC.(...) …, or
  .2 protected by alternative means of corrosion protection, the effectiveness of which [shall be no less than is achieved by meeting the requirements under paragraph 3.1] is approved in accordance with the appropriate Performance standard adopted by the Organization.
Main issues to be discussed at DE51:

How can a new measure like “Corrosion-Resistant Steel” be evaluated to be “no less than is achieved by meeting the requirements under paragraph 3.1(coating)”?

(i.e. Coating $\leq$ Corrosion resistant Steel)

Should “Corrosion-Resistant Steel” be specified in SOLAS or treated as one of the “alternatives”?
# Coating vs Corrosion-Resistant Steel

<table>
<thead>
<tr>
<th>Item</th>
<th>Coating</th>
<th>Corrosion-Resistant Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target</strong></td>
<td>15 years, - “GOOD” condition</td>
<td>25 years, - diminution within allowance - no leakage</td>
</tr>
<tr>
<td><strong>Inspector</strong></td>
<td>Qualified coating inspector</td>
<td>None</td>
</tr>
<tr>
<td><strong>Additional work during</strong></td>
<td>- Edge treatment</td>
<td>None</td>
</tr>
<tr>
<td><strong>construction</strong></td>
<td>- Surface treatment (blasting, cleaning, etc.)</td>
<td></td>
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<tr>
<td></td>
<td>- Multiple coating application</td>
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<tr>
<td></td>
<td>- Measurements of salts, Dry film thickness etc.</td>
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</tr>
<tr>
<td></td>
<td>- Repair of Defects</td>
<td></td>
</tr>
<tr>
<td><strong>Additional work after</strong></td>
<td>- Inspection of coating condition</td>
<td>None</td>
</tr>
<tr>
<td><strong>construction</strong></td>
<td>- Repair by recoat, weld, steel renewal</td>
<td>(Less Maintenance and Possibility of no repair)</td>
</tr>
</tbody>
</table>
Coating vs Corrosion-Resistant Steel

Depending on condition of coating

Corrosion Loss (RISK)

Conventional Steel

Conventional Steel With Coating

Corrosion-Resistant Steel

Allowance

Ship Age (Years)
A lot of benefits are expected in Corrosion-Resistant Steel

BUT

No one can define and the effectiveness of coating in COT....

No one can evaluate the effectiveness of corrosion resistant steel by comparison with coating....

No one can conduct field test for evaluation of new measure unless the equivalency is proved....
Corrosion prevention system is not only coating!
IMO should pursue more general **Goal Based Approach**, rather than a **Prescriptive Approach**
(Coating: epoxy, 200 micro, Blast Sa2.5, Salt, edge etc.)

The “**GOAL**” of the corrosion prevention should be to
- Maintain ship structure
- Prevent oil leakage

The options of **“coating”**, **“corrosion resistant steel”** or **“others”** should be left to the choice of shipowners and shipbuilders taking into account their construction and maintenance strategies.
3 All cargo oil tanks of crude oil tankers shall be protected against corrosion to ensure that net scantlings required meeting structural strength and watertight integrity are maintained throughout the specified design life in accordance with the Performance standard for corrosion prevention for cargo oil tanks of crude oil tankers,
Concluding remark

IMO should not close the door for new technologies!

- First comes, first served.
- Better comes, equally served.