A review of state of the art in Corrosion under insulation (CUI) testing

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December 2015, Al-Jubail
The absence of test data

CUI is addressed in a number of test documents

- NACE SP0198 Control of corrosion under thermal insulation and fire proofing – A systems approach
- EFC Corrosion under insulation guideline (WP13 and WP15)
- API 583 Corrosion under insulation and fireproofing
- AGI Q151 Corrosion protection under thermal and cold insulations at industrial Installations

- Owner specifications
- Supplier documentation and recommended test practices
- Conference papers and other materials
Testing Development
- NACE and ISO

• Limited amount of work undertaken on testing
• Owner and supplier driven
• Relatively slow to deliver results
CUI Testing and the contract chain

Concept ➔ Feasibility study ➔ Design ➔ EPC phase ➔ Operations

OWNER ➔ ENGINEERING CO ➔ ENGINEERING CO ➔ EPC ➔ FABRICATORS ➔ COMMISSIONING ➔ OWNER

Long term performance
CUI performance
Performance under different conditions
Independent testing

Design limitations (min max)
Design simplification
Cost optimization (scheme thickness, no. of coats)

Cost optimization (scheme thickness)
Over-coatibility
Application sequence
Physical durability

Repairibility
Hot application data (for maintenance painting)

COATING SUPPLIER

Technical workshop – Corrosion under insulation
NACE Jubail
Testing relevant to CUI

-200 °C  -100 °C  0 °C  100 °C  200 °C  300 °C  400 °C  500 °C  600 °C  700 °C

**HEAT RESISTANCE (ASTM D2485)**

**THERMAL ANALYSIS (ASTM 2402)**

**ATMOSPHERIC EXPOSURE**

**CYCLIC TESTING**

**ASTM G189**

**CUI SIMULATION**

**IMMERSED**

**NON IMMERSED**

* Includes cryogenic testing

Design limitations (min max)

Design simplification

* Includes cryogenic testing

Technical workshop – Corrosion under insulation

NACE Jubail
Influence of coating type on test relevance

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Non Immersed Test Categories</th>
<th>Immersed Test Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>-200</td>
<td>HEAT RESISTANCE (D2485)</td>
<td>THERMAL ANALYSIS (ASTM 2402)</td>
</tr>
<tr>
<td>-100</td>
<td>ATMOSPHERIC EXPOSURE</td>
<td>CYCLIC TEST</td>
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<td>SILICON HYBRID</td>
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<td>200</td>
<td>THERMALLY SPRAYED ALUMINIUM</td>
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<tr>
<td>300</td>
<td>INORGANIC COPOLYMER / INERT MULTIPOLYMERIC MATRIX</td>
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<td>400</td>
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<td>700</td>
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</table>

NACE SP0198: 2010

Technical workshop – Corrosion under insulation
NACE Jubail
Test relevance to objective

CUI PERFORMANCE

<table>
<thead>
<tr>
<th>Temperature</th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
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Design Limits

Technical workshop – Corrosion under insulation
NACE Jubail
What tests are in common use?

<table>
<thead>
<tr>
<th></th>
<th>ASTM D2485</th>
<th>ASTM D2402 (TGA)</th>
<th>ASTM B117</th>
<th>ASTM G85 / D5894</th>
<th>ISO 2810</th>
<th>ASTM G189</th>
<th>CIPT</th>
<th>HTC</th>
<th>Cyclic</th>
<th>ISO 2812 (NACE TM0174)</th>
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</tbody>
</table>

* Denotes a modified version

Source: Review of web available test data
November 2015.
ASTM D2485

- Test panels heated T°C
- Up to $T_{\text{max}}$
- Cooling i) air ii) water
- Visual inspection / mandrel test
- Corrosion test supplement
  - Usually ASTM B117 (salt spray)

**Useful for**
- Determining coating $T_{\text{max}}$
- Ensuring film condition $< T_{\text{max}}$

**Watch out for**
- Visual inspection insufficient
- Corrosion screen also required
- Microscopic inspection
  Temperature increase rate may affect results

Microscopic examination after ASTM D2485
<table>
<thead>
<tr>
<th>CS3</th>
<th>CS6</th>
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</thead>
<tbody>
<tr>
<td><strong>Novolac Epoxy</strong> (2x 100 µm)</td>
<td><strong>High build silicone #1 (MIO)</strong> 1 x 150 µ</td>
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<td><img src="image1.png" alt="Image of Novolac Epoxy" /></td>
<td><img src="image2.png" alt="Image of High build silicone #1 (MIO)" /></td>
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<tr>
<td><strong>250°C</strong></td>
<td><strong>650°C</strong></td>
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<td><img src="image4.png" alt="Image of 650°C" /></td>
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<td><strong>High build silicone #2 (MIO)</strong> 1 x 150 µ</td>
<td><strong>High build silicone #3 (ALU)</strong> 1 x 150 µ</td>
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<td><img src="image5.png" alt="Image of High build silicone #2 (MIO)" /></td>
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<td><strong>400°C</strong></td>
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<td><img src="image7.png" alt="Image of 400°C" /></td>
<td><img src="image8.png" alt="Image of 300°C" /></td>
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</table>

Heating as per ASTM D2485 from 200°C to 650°C (250°C for Novolac epoxy, 450°C for #3 Alu) in 50°C increments every 24 hours. Visual and microscopic inspections between each interval.
ASTM D2485
- Supplementary corrosion screen

- Thin film silicone
- High build silicone #1 (MIO) 2 x 150 μ
- High build silicone #2 (MIO) 2 x 150 μ
- High build silicone #3 (ALU) 2 x 150 μ

- 650°C
- 650°C
- 650°C
- 450°C

Samples exposed to 1440 hours salt spray following heating to 650°C (450°C for #3 Alu) as per standard ASTM B117.
ASTM D2402 Thermogravimetric analysis

- Weight loss over heating period
- Sample weight is measured accurately
- Temperature increased
- Volatile = mass loss
  - Carrier solvent (low temperatures)
  - Organic binder (decomposition)

Useful for
- Determines binder resistance to heat
- Mass loss correlation with film porosity
- Candidate screening

Watch out for
- High mass loss over narrow temperature range
- Some pigment types (ALU) may contain high levels of carrier solvent
Atmospheric exposure

- Accelerated or natural corrosion
  - Hot salt spray (ASTM B117 / ISO 7253)
  - Prohesion (ASTM G85 or ISO D5894)
  - Atmospheric exposure (ISO 2812 C5M)
- Evaluation to recognised standards
  - Rusting, blistering, flaking, etc

Useful for
- Determining corrosion protection after heating
- Highlighting porosity / lack of X-linking
  - Generally gives poor results

Watch out for
- Some barrier pigments may provide very good performance
- Scheme thickness (significant effect)
- Effect of “Thermal history”
ASTM G189 (including modified variants*)

- Heated pipe (constant temp.)
- *Coating applied as coupons or pipe
- Tests specific CUI conditions can be replicated
  - Temperature / Insulation type / Presence of annular space
- More sophisticated modifications
  - Inclusion of EIS

**Useful for**
- Accurately reproducing specific CUI issues
- Detailed information about coating performance
- Analysing multiple samples

**Watch out for**
- Test program variation between operators
- Limited manufacturer information to this standard
- Limited maxim temperature
Cyclic insulated pipe test (CIPT)

- Heated pipe (temperature gradient)
- *Coating applied to pipe
- Insulated then heating cycle applied
- Salt water solution introduced regularly
  - Saturates insulation

Useful for
- Screening performance at multiple temperatures
- Identifying areas of performance concern
- Easy low cost means to produce an insulated test

Watch out for
- Effect of insulation saturation on test temperature
- Type of insulation
- Limited sample area

Cost

Ease of use

CUI relevance
Cyclic insulated pipe test (CIPT)

Mineral Wool insulation

Calcium silicate

Development of temperature over time
(Calcium Silicate)

Development of temperature over time
(Mineral Wool)
Environmental cell (HTC)

- Heated “pipe” (single temperature)
- *Coating applied to test piece
- Square samples used + scribe
- Alternates wet and dry cycles
- 5% Electrolyte heated and evaporated / condenses (250 cycles)

Useful for
- Evaluating multiple samples
- Evaluation at lower temperatures
- Indicating products performance under constant immersion
- Provides alternate views for epoxy based performance limits

Watch out for
- Different cycles can have an effect
- Absence of insulation - correlation effect with real life performance
Effect of thermal “history”

“The thermal conditions a coating has been exposed to” can have a significant effect on material performance.

- CUI is not a zero time event
- Most materials will have some thermal history before encountering CUI conditions
- Needs to be considered
- Built into test program

Consider

- Time
- Temperature
- Rate

Gradual heating to $T_{\text{max}}$  
Rapid heating to $T_{\text{max}}$
Supplementary testing

- Other factors to consider
  - Physical damage during fabrication / installation
  - Changes to film forming ability (e.g. application to hot surfaces)

Increasing substrate temperature

20° C

200° C
Current status

- Limited work to standardise CUI testing
- Industry heavily dependent upon supplier data (wide ranging)
- Different stakeholder requirements
  - Strong operator focus on CUI test itself
- CUI specific testing
- A variety of tests is required to accurately gauge material performance
So what is required?

In the authors view

- Better definition of temperature supported by evidence (i.e. min, max, range)
- Minimum suite of tests to pre-qualify a material
- Pre-qualification scheme allows consideration of
  - Insulated and uninsulated use
  - Thermal history of the products which reflects likely service
  - Application restraints. i.e hot surfaces
- Test standard development / elimination of improvised tests
- Must be driven to recognised standard status (e.g. ISO, NACE)