Qualification of Deepwater Power Umbilical

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Why Qualify Aluminium for Subsea?

- **Increasing demand for deep water electrical power:**

  - Water depth capability of copper limited by poor material properties
    - R&D study
      - Exceed the water depth limits of conventional copper cables by innovating with lightweight, high strength, electrical conductors.

- **Subsea Pumping Requirements**
  - Ref: Offshore Magazine March ’12

  - Subsea Gas Compression
  - Subsea Boosting
  - Subsea Water Injection
  - Subsea Separation

  - Chinook
Conductor Investigation

- Initial Conductor Investigation

<table>
<thead>
<tr>
<th>Conductor Material</th>
<th>Conductivity (% of Copper)</th>
<th>UTS (Mpa)</th>
<th>Density (g/cm³)</th>
<th>Ratio Score Conductivity × UTS Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (Standard Plain Annealed)</td>
<td>100</td>
<td>220</td>
<td>8.89</td>
<td>2.47</td>
</tr>
<tr>
<td>Copper Iron Alloy</td>
<td>70</td>
<td>700</td>
<td>8.89</td>
<td>5.51</td>
</tr>
<tr>
<td>Aluminium (6000 series)</td>
<td>52</td>
<td>295</td>
<td>2.69</td>
<td>5.70</td>
</tr>
<tr>
<td>Composite (Aluminium plus carbon strength member)</td>
<td>54</td>
<td>314</td>
<td>2.85</td>
<td>5.95</td>
</tr>
<tr>
<td>Aluminium (Standard grade 1350)</td>
<td>61</td>
<td>152</td>
<td>2.71</td>
<td>3.42</td>
</tr>
</tbody>
</table>

- Selected for further investigation

Aluminium Composite

Aluminium 6000 series

Cu Iron Alloy
Aluminium Cable Water Capability

**Water Depth Capability**

- \[ WD = \frac{\mu \varepsilon_{\text{limit}} (E_c A_c + E_s A_s)}{[A_c (\rho_c - \rho_s) + A_s (\rho_s - \rho_c)] g \times DAF \times CF} \]

- Dependant upon ratio of conductor material and strength member.
- \( \mu = \) Stress utilisation (ISO13628)
- Catenary Factor = 1.1
- DAF
  - 1.1 (Static)
  - 1.3 (Quasi-dynamic) – TLP / Spar
  - 1.5 (Highly dynamic) – FPSO
- Assume only strength member is load bearing
  - Available tensile strain of steel tube reduces with increased pressure.
Aluminium Cable Qualification Program

- **Manufacture**
  - 300mm² 18/30kV triplex extruded and dry cured design.

- **Electrical**
  - Qualified by type testing to ISO 13628-5 and IEC 60502-2.

- **Mechanical**
  - Initial conductor fatigue testing performed gave a fatigue life 15x better than copper.
Aluminium Cable Corrosion Testing

Design
- High strength Aluminium 6000 series corrosion resistant conductor material.
- Conductor strands water blocked to prevent longitudinal water migration

Corrosion Tests
- Hydrostatic test at 300bar, 90°C for 1-year.
- Model samples with thinner walls also tested at 300 bar 90°C for 6-months and conductors subjected to SEM examination.
- DC voltage applied for 6 months on model samples in attempt to accelerate corrosion.
- Ion permeation into XLPE limited to below 200 µm depth.

Conclusion
- Aluminium cable will be suitable for a design life in excess of 30 years.
Aluminium Cable Thermal Investigation

- **Tensile Testing - Aged Samples**
  - Tests on aged Al at 80 degrees, with samples taken at 0days, 28days to 4yrs.
  - Results demonstrate that Aluminium does not suffer a reduction in strength due to thermal aging.

- **Tensile at Elevated Temperature**
  - Samples of both Al and Cu strands, were tested at varying temperatures: 20 to 80°C.
  - The effect on Yield, Tensile Strength and Modulus were investigated.
  - Results show a reduction of tensile strength (Al 4.5%, Cu 8%). No affect to modulus.

- **Creep**
  - Testing for 1000hrs at 25% and 50% utilisation at 20 to 80°C.
  - Creep on Cu wire at 40°C and 50% utilisation, none on Al until 80°C.

- **Fatigue**
  - Tests on aluminium and copper at 70°C.
  - Aluminium fatigue life at temperature reduced 2.5-3x but still well above Cu at ambient.
  - Copper tests on going but showing similar reduction in fatigue life.
Aluminium Cable Splicing

- **Aluminum Conductor Welding**
  - Fill and Braze Process with automatic welder to give consistent low resistance, high quality joint.

- **Insulation**
  - Insulation tapes cured and cross linked by oven heating.

- **Inspection and Testing**
  - X-ray of conductor and insulation.
  - High Voltage AC testing to $3.5U_0$. Partial discharge testing to $1.73U_0$.

- **Qualification Tests**
  - Tension and bending.
  - IEC 60502-2 Type Tests, ie Bending, HVAC and Partial Discharge.
Subsea Connector Qualification Program

- **Connector**
  - Qualification undertaken on wet mate 18/30kV connector system.
  - Connector housing and sealing would remain unchanged regardless of conductor material.
  - Therefore qualification has focused on conductor / connector interface.

- **Standards**
  - Qualification testing performed in accordance with :-
    - SEPS JIP – Subsea Electrical Power Standardisation
    - (Statoil Spec) TR2313 – Subsea Electrical High Voltage Connector Assemblies
    - IEC 61238-1 - Compression and mechanical connectors for power cables for rated voltages up to 30kV

- **Test Programme**
  - Successfully passed all tests including : Temperature rise, Heat cycling, Short circuit, Mate-demate, Contact resistance and Pull Test.
Umbilical Manufacture

Main focus for qualification:
- 300mm² 18/36kV High strength aluminium umbilical + steel strand strength members manufactured.
- 150mm² electrically equivalent copper design manufactured for comparison testing.

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductor Area</td>
<td>150mm²</td>
<td>300mm²</td>
</tr>
<tr>
<td>Umbilical OD</td>
<td>200mm</td>
<td>258mm</td>
</tr>
<tr>
<td>Mass in Air (kg/m)</td>
<td>55.3kg/m</td>
<td>45.2kg/m</td>
</tr>
<tr>
<td>Weight in Water (N/m)</td>
<td>287N/m</td>
<td>51N/m</td>
</tr>
<tr>
<td>Cable Stress Utilization at 3000m water depth</td>
<td>1.75</td>
<td>0.21</td>
</tr>
<tr>
<td>Maximum Water Depth at 0.80 cable stress utilization – ISO 13628</td>
<td>1370m</td>
<td>4000m +</td>
</tr>
</tbody>
</table>

Umbilical Manufacture
- 100m long sample.
- Electrical triad sub-bundles laid.
- Main umbilical laid in single pass on VHAM at DUCO Inc.
- PE Outer sheath extruded.
- Includes 2 complete aluminium cable splices.
# Umbilical Qualification Overview

To qualify the umbilical design, a testing programme was defined:

<table>
<thead>
<tr>
<th>Test</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tensile</td>
<td>Axial stiffness, torque, rotation, termination UTS</td>
</tr>
<tr>
<td>2 Bend Stiffness</td>
<td>Characterise bending stiffness property</td>
</tr>
<tr>
<td>3 Tension &amp; Bend</td>
<td>Installation simulation, crush force, low cycle fatigue</td>
</tr>
<tr>
<td>4 Crush</td>
<td>Caterpillar tensioner simulation, deformation / function</td>
</tr>
<tr>
<td>5 Friction</td>
<td>Caterpillar tensioner simulation, slip plane and COF</td>
</tr>
<tr>
<td>6 Impact</td>
<td>Rock dumping simulation, energy to consequence</td>
</tr>
<tr>
<td>7 Fatigue</td>
<td>Conductor fatigue performance for service conditions</td>
</tr>
<tr>
<td>8 Clamp</td>
<td>Ancillary equipment simulation, deformation / function</td>
</tr>
<tr>
<td>9 Thermal</td>
<td>Ampacity of design within simulated I-tube</td>
</tr>
<tr>
<td>10 Creep</td>
<td>Creep property within umbilical structure</td>
</tr>
<tr>
<td>11 Axial Compression</td>
<td>Characterise behaviour for axial compressive force</td>
</tr>
</tbody>
</table>

- Qualification regime to be assessed by DNV for Qualification of New Technology in line with RP A203
Umbilical Qualification Programme

- **Tensile**
  - Characterise umbilical elongation, induced torque, rotation and end termination strength by application of tensile force.

- **Bend Stiffness**
  - Determine bend stiffness property for comparison to calculation.

- **Fatigue Test**
  - Demonstrate 25 year service life. Analysis based on 3000m water depth.

- **Crush Test**
  - Understand the effect of installation (caterpillar tensioner) crush load on umbilical and component deformation / functionality
Umbilical Testing

- **Thermal Test**
  - Determine the ampacity of the aluminium umbilical design in comparison to the electrically equivalent copper umbilical design

- **Test Description and Key Parameters:**
  - Sample current loaded via transformers
  - Temperature monitored via thermocouples
  - 2, 3 & 4 circuit configurations tested

- **Result (3 circuits):**

- **Conclusion:**
  - Umbilical Testing has confirmed superiority of aluminium design
Summary

- **High Strength Aluminium Power Cables**
  - Light weight, high strength corrosion resistant aluminium conductor.
  - Load share capability.
  - Extensive risk based technology qualification program, including:
    - Corrosion, Fatigue, Electrical, Splicing, Termination

Commercial Benefits;
- Water depth capability > 3000m
- Superior reliability at any water depth
- Greater fatigue capacity
- Reduced electrical stress
- Dynamic mass can be optimised
Thank You