Carbon Fiber PA12 TCP for Oil and Gas applications - Qualification

Alexandre Paternoster
Airborne Oil & Gas -
Team Lead Material Technology

Carsten Schuett
Evonik Resource Efficiency GmbH
Sen. Project Manager Composite Development Oil & Gas

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Background – Answering Oil & Gas industry challenges

Challenges for the offshore Oil and Gas industry

• Current development focus on deep-water fields
• Water depth of more than 2000m
• High pressure / high temperature reservoirs: 600 bar / 110°C
• High corrosive load of crudes and gases: organic acids, H₂S, CO₂

How to ensure production in a most economical and most reliable way and at minimal environmental risk???
Outline

• Introduction
  • Flexible pipes for Oil & Gas
  • Thermoplastic Composite Pipe
  • Materials for Oil & Gas
  • DNV standard for Composite Pipes

• Qualification and Design Approach
  • Material Qualification
    • Testing conditions
    • Extensive testing
    • Testing durations

• Material models

• Current status
  • Static test results
  • Test setup development
  • Model matching from coupon to pipe performance

• Concluding remarks
Introduction (1) – Flexible pipes for Oil & Gas industry
Introduction (2) – TCP overview

- Unbonded layers of steel and polymers
- Long and successful track record
- At their limit for cost efficiency regarding corrosion resistance for newer more challenging environments in greenfield applications
- Weight limitations for dynamic risers can occur with greater water depths

- Fully bonded polymer/composites system
- Novel approach for challenging projects
- Design foregoing steel armor
- Strength from thermoplastic UD composite tapes taking combined load cases
- Corrosion insensitive carbon fiber
- Spoolable onto small diameter reel
- Multilayerliner solutions possible
Steel is the de-facto standard in the Oil & Gas industry
- Low cost
- Long track record
- Standards and procedures are build around steel

Polymers have key advantages over steel
- Corrosion resistance
- Low density

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature rating</th>
<th>Chemical resistance</th>
<th>Handling/ processing</th>
<th>Price/ performance</th>
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<tbody>
<tr>
<td>Steel</td>
<td>+++</td>
<td>-</td>
<td>-</td>
<td>+++</td>
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<tr>
<td>Polyolefins</td>
<td>0</td>
<td>+</td>
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<tr>
<td>PVDF</td>
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<tr>
<td>PEEK</td>
<td>+++</td>
<td>+++</td>
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</table>
Introduction (4) – CF-PA12 as an Oil & Gas material

**PA12 VESTAMID NRG®**
- Different PA12 grades are in use for unbonded flexibles (liner, cover, wear tapes, etc.)
- Material with successful track record in O&G flexibles since 2006 (API qualified)
- Very good resistance vs. Oil & Gas hydrocarbons, corrosive environments and Rapid Gas Decompression (RGD)
- Large temperature range: from arctic conditions to 72°C for 25 years
- Well known and predictable long-term ageing behavior

**CF PA12 UD-Tape VESTAPE®**
- Continuous unidirectional carbon fibre reinforced tape is under full qualification for TCP applications in water, hydrocarbons and sour service
Introduction (3) – DNV standard for Composite Pipes

Flexible pipe for offshore use

Metal based
- Unbonded
  - API 17J
- Bonded
  - API 17K

Composite based
- Unbonded
  - API 17B Annex H
- Bonded

Thermoplastic composite pipes
Introduction (3) - DNVGL-ST-F119 – Oil & Gas qualification
Qualification and Design Approach

Specific
• Product

Generic
• Materials
• Design: TCP & End-fitting
• Production

• Predictive engineering approach
• Extensive material testing and modeling
• Limited full-scale validation tests
Material Qualification (1) – Challenging test conditions

• Acc. to ST-F119 conditions in testing need to be representative to oilfield/application condition

• Standardized candidates for crudes, gases, drilling or completion fluids, scale inhibitors, hydrate blockers and many more are:
  • Water, Pentane, Cyclohexane, Toluene, Ethanol, Methanol, Hydrochloric acid, Sulfuric acid, Carbon dioxide, Hydrogen sulfide, Methane, ...
  • Many of them in combination at elevated temperatures and pressures
  • Impact CF PA12 physically and/or chemically

• But: condition also refers to state of the product (virgin to end of life) and needs to be assessed as critical part in the qualification
Material Qualification (2) – Extensive testing

• A typical TCP qualification includes a large amount of coupon testing for static, stress rupture and fatigue to cover all possible failure mechanisms and shifts thereof
• Up to 900 specimens can be needed for basic static alone at several temperatures and environments when qualifying for low safety factors

<table>
<thead>
<tr>
<th>static</th>
<th>virgin</th>
<th>physical impact</th>
<th>chemical impact</th>
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<tr>
<td></td>
<td>CTD</td>
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<td>ETD1</td>
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<tr>
<td>Tension 0°</td>
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<td>15</td>
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<td>Tension 90°</td>
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<td>In-plane-shear (IPS)</td>
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<tr>
<td>Compression</td>
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<td>15</td>
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<tr>
<td>Inter-laminar shear strength (ILSS)</td>
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</tr>
</tbody>
</table>
Material Qualification (3) – long test durations

- Time of testing and end of life criteria
- ST-F119 correlates a service life of 30 years to 12,500h of exposure testing in stress rupture
- Task: predict long term behavior of exposed specimen in terms of different failure modes in order to design setups
Material Models – Towards all application conditions

**Solubility**
- Determination of swelling based on cohesive energy

**Time-Temperature superposition**
- Relation between viscoelastic dependent properties, time and temperature

**Arrhenius equation**
- Determination of the rate of chemical effects with temperature

Reduction of test environment

Reduction of test duration

Accelerated ageing
Status (1)

On-going material qualification

• Technical difficulties solved

• First results show good resistance in the representative fluid (NORSOK M710)
  • Close to unconditioned material
  • Across all failure mechanisms

• Long-term behavior as expected
• Fatigue behaviour as expected

• End of live performance testing: ongoing
Status (1) - Static Test results (partial)

- **Tensile strength in fibre direction**
  - Performance relative to dry: 23°C, %
  - Temperature: -20, 23, 80°C
  - Data for dry and norsok conditions

- **Interlaminar shear strength (ILSS)**
  - Performance relative to dry: 23°C, %
  - Temperature: -20, 23, 80°C
  - Data for dry and norsok conditions

- **Compression strength in fibre direction**
  - Performance relative to dry: 23°C, %
  - Temperature: -20, 23, 80°C
  - Data for dry and norsok conditions

- **Shear stress at 5% shear strain (IPS)**
  - Performance relative to dry: 23°C, %
  - Temperature: -20, 23, 80°C
  - Data for dry and norsok conditions
Status (2) - Test setup development

Stress rupture:

- Design and construction
- Requirements:
  - Testing in pressurized hydrocarbon environments
  - Need to test in parallel sharing heating and fluid circulation and recirculation for precise equalization of conditions
  - Stable conditions over 12,500h
Status (2) Test setup development

Fatigue:

• Analogue to stress rupture fatigue setups needed to be designed to test in parallel for different failure mechanisms
Status (3) - matching model to pipe performance
Burst pressure CPA12 6” 10ksi

Procedure:
1. Material strength from coupon testing
2. FE simulation using nonlinear multi-scale material model
3. Full scale TCP burst test data
4. Project Test data on curve from FE simulation
5. Material strength as measured in full scale test
Status (3) - matching model to pipe performance
Concluding remarks

- DNV qualification for Oil & Gas is a knowledge based-approach
- Testing focused on laminate level to limit full-scale testing
- Joint Industry Program by DNV-GL to further improve ST-F119 approach
Thank you for your attention!