Carbon Fiber PA12 TCP for Deep Water WI Service

From development to deployment of CF/PA12 commercial grade TCP

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Contents

• TCP Overview
• CF-PA12 as an Oil & Gas material
• Qualification approach
• Material qualification
• Project Deployment
Thermoplastic Composite Pipe (TCP): Concept

- Solid pipe structure: bonded
- Fit for purpose polymer: liner, matrix & coating
- Glass or carbon fibres fully embedded (true composite)
- Optional weight coating for on-bottom stability

- No corrosion
- Flexible
- Light weight

A plastic liner is over-wound with polymer impregnated fibre tapes and melt fused using Airborne Oil & Gas propriety production technology to form a single walled structure.

Monolithic wall reduces permeation and allows for high pressure applications including gas service.
Thermoplastic Composite Pipe (TCP): Concept

- Terminated within hours
- Vertical and horizontal, small space requirement
- Fully qualified and field proven
- Can be fitted with bend restrictors, bend stiffeners and clump weights (TCP Downline)
- Various flange options available (API, ANSI, etc)
- Various material options available (carbon steel, CRA etc)

The TCP can be terminated in the field, both onshore and offshore. This allows for flexibility in tie-in as well as pulling through J-tubes without end-fitting.

The liner is reamed prior to stem insert, maximising bore dimensions.

CRA options include weld inlays.
Thermoplastic Composite Pipe – Range & Application

<table>
<thead>
<tr>
<th>Onshore</th>
<th>SURF</th>
<th>Subsea Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP Light</td>
<td>Flowlines &amp; Spools</td>
<td>Dynamic Jumpers &amp; Hoses</td>
</tr>
<tr>
<td></td>
<td>Risers</td>
<td>Downlines</td>
</tr>
</tbody>
</table>

- **Fully qualified and track record**
  - Glass-PE: 65°C
  - Carbon-PA12: 80°C
  - Carbon-PVDF: 121°C

- **2018 commercially available**
  - Glass-PE: 65°C
  - Carbon-PA12: 80°C

- **2019 Pilot potential**
  - Carbon-PVDF: 121°C
TCP Jumpers Spools provide lowest total Installed Cost

Cost elements

Pipe fabrication
- No steel welding qualification, or expensive quayside fabrication yards
- TCP more cost effective than flexible pipe

Transportation
- TCP transported on (wooden) transport drums
- End-fittings can be pre-installed or terminated on site

Installation
- No metrology required
- Fast subsea pallet or crane wire installation

Business case for 5 well jumpers
TCP material selection – the business case

• In todays Oil & Gas Market, higher temperature is key ➢ Hard Oil & Deep Oil typically require higher temperature rated systems

• Prior to developing CF/PA12 AOG could reach circa 60% of the historical flexible pipe market temperature range of 65degC or below.

• AOG study to ascertain the next natural step in temperature capability development showed in todays market >60°C is becoming the norm
TCP material selection – the business case

• Combining a industry recognized polymer with TCP technology that allowed an incremental step-up change in addressable market conditions was agreed and PA12 was chosen for this.

• Combining PA12 with the higher strength of Carbon Fiber tapes has allowed AOG to move into the dynamic risers, deep-water and high pressure market

• In 2017 a global major approached us with a plan to qualify and deploy quickly a CF/PA12 pipe in the GoM. This led to a combined qualification and deployment project and the worlds first CF/PA12 TCP
CF-PA12 as an Oil & Gas material

PA12

Different grades are used for liner, reinforcement matrix material, cover.

- Material with track record in the O&G industry (API qualified)
- Very good resistance to Oil & Gas hydrocarbons and corrosive environments
- Large temperature range: from arctic conditions to 72°C for 25 years
- Well known and predictable long-term ageing behavior

CF-PA12 UD-Tape

- Continuous unidirectional carbon fiber reinforced tape is under qualification for TCP application.
Qualification Approach - DNVGL ST F-119

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

- Predictive engineering approach
- Extensive material testing and modeling
- Limited full-scale validation tests

**Diagram Description**

- **Product specific design**
  - Full scale
  - Representative pipes
  - Laminate level
  - Ply level
  - Constituent level – Polymer & Fibre

- **Flowchart**
  - Material
  - Material test results
  - Material model
  - Stiffness
  - FEA
  - Loads & geometry
  - OK?
  - Stress & strain
  - Validation
  - TCP testing
  - Strength
Material Qualification – DNVGL ST F119

Generic

Materials

Design method

Production

Product

Project Specific design

Airborne Oil & Gas

Equipment: Thermoplastic Composite Pipeline

Manufacturers: Airborne Oil & Gas

Intended for: Intended to be used offshore in Dutch sector of the North Sea

DNV GL Project no.: DF1322900
Material Qualification – Test environments

• Different environments are considered for the assessment to cover the potential effects on fluids on the material
Material Qualification – Static testing

- Up to 900 specimens are tested for **static properties** at several temperatures and environments

<table>
<thead>
<tr>
<th>Static</th>
<th>Virgin</th>
<th>Physical impact (hydrocarbon representative fluid)</th>
<th>Chemical impact (H₂S / CO₂ environment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CTD</td>
<td>RTD</td>
<td>ETD1</td>
</tr>
<tr>
<td>Tension 0°</td>
<td>15 ✓</td>
<td>15 ✓</td>
<td>15 ✓</td>
</tr>
<tr>
<td>Tension 90°</td>
<td>15 ✓</td>
<td>15 ✓</td>
<td>15 ✓</td>
</tr>
<tr>
<td>In-plane-shear (IPS)</td>
<td>15 ✓</td>
<td>15 ✓</td>
<td>15 ✓</td>
</tr>
<tr>
<td>Compression</td>
<td>15 ✓</td>
<td>15 ✓</td>
<td>15 ✓</td>
</tr>
<tr>
<td>Inter-laminar shear strength (ILSS)</td>
<td>15 ✓</td>
<td>15 ✓</td>
<td>15 ✓</td>
</tr>
</tbody>
</table>

- 🔄 testing to be started
- 🔴 test in-progress
- ✔️ test completed
Material Qualification – Fatigue testing

- Testing for all potential failure mechanisms in three environmental conditions
- Setups ready to start testing after saturation in hydrocarbon environment

<table>
<thead>
<tr>
<th>Fatigue</th>
<th>Virgin</th>
<th>Physical impact (hydrocarbon representative fluid)</th>
<th>Chemical impact (H₂S / CO₂ environment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CTD</td>
<td>80°C</td>
<td>50°C</td>
</tr>
<tr>
<td>R=0.1</td>
<td>15 X</td>
<td>15 X</td>
<td>10 X</td>
</tr>
<tr>
<td>R=-1</td>
<td>15 ✓</td>
<td>15 ◇</td>
<td>10 X</td>
</tr>
<tr>
<td>R=-10</td>
<td>15 X</td>
<td>15 X</td>
<td>10 X</td>
</tr>
<tr>
<td>In-plane shear (IPS)</td>
<td>15 X</td>
<td>15 ◇</td>
<td>10 X</td>
</tr>
<tr>
<td>Inter-laminar shear strength (ILSS)</td>
<td>15 X</td>
<td>15 ◇</td>
<td>10 X</td>
</tr>
</tbody>
</table>

- X testing to be started
- ◇ test in-progress
- ✓ test completed
Material Qualification – Long-term testing

- DNVGL-ST-F119 correlates a service life of 30 years to 12,500h of exposure testing in stress rupture

- Tests in progress with the 5,000hrs mark cleared for tests in hydrocarbon at 80°C.

<table>
<thead>
<tr>
<th>Stress-rupture</th>
<th>Virgin</th>
<th>Physical impact (hydrocarbon representative fluid)</th>
<th>Chemical impact (H₂S / CO₂ environment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>23°C 80°C</td>
<td>50°C 80°C</td>
<td>50°C 80°C</td>
</tr>
<tr>
<td>Inter-laminar shear strength (ILSS)</td>
<td>15 ◐ 15 ◐</td>
<td>8 ◐ 15 ◐</td>
<td>8 ◐ 15 ◐</td>
</tr>
</tbody>
</table>

- ◐ testing to be started
- ◐ ◐ test in-progress
- ✓ test completed
TCP design – Burst pressure

Results:
• Material strength LCL is 1655 MPa,
• Acceptance is 2585 bar (LDV)
• Client specification corresponds with material LCL

NB:
• Test results based on 3 different TCP production batches
• COV = 3%

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NB:
• Test results based on 3 different TCP production batches
• COV = 3%
## Overview qualification test results

<table>
<thead>
<tr>
<th>Test description</th>
<th>Test acceptance</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short term</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burst</td>
<td>LDV &gt; 2584 bar</td>
<td>Passed</td>
</tr>
<tr>
<td>Collapse</td>
<td>&gt; 362 bar</td>
<td>Passed</td>
</tr>
<tr>
<td>Tension</td>
<td>&gt; 150 kN</td>
<td>Passed</td>
</tr>
<tr>
<td><strong>Long term</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 hr Internal pressure + vacuum test</td>
<td>Survival</td>
<td>Passed</td>
</tr>
<tr>
<td>1000 hr External pressure</td>
<td>Survival</td>
<td>Passed</td>
</tr>
<tr>
<td>1000 hr End fitting test</td>
<td>Survival</td>
<td>Passed</td>
</tr>
<tr>
<td>1000 hr Bending + residual burst</td>
<td>Residual burst</td>
<td>Passed</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bending fatigue at 4°C and 72°C</td>
<td>Residual burst</td>
<td>Passed</td>
</tr>
<tr>
<td>Pressure cycling fatigue at 4°C and 72°C</td>
<td>Residual burst</td>
<td>Passed</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 hr Seawater resistance at 92°C</td>
<td>Residual burst</td>
<td>Passed</td>
</tr>
<tr>
<td><strong>Sealing qualification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure cycling fatigue at 4°C and 72°C</td>
<td>Residual burst</td>
<td>Passed</td>
</tr>
<tr>
<td>1000 hr End fitting test</td>
<td>Survival</td>
<td>Passed</td>
</tr>
</tbody>
</table>
CFPA12 jumper spool development

Situation
- Tight schedule
- Material to be developed
- High pressure (10 ksi) at large diameter (5.2"")
- In parallel with riser development (Libra) and EGFPE Jumper Spool qualification

Key enablers
- Small, dedicated, motivated and highly skilled project team (4 FTE)
- First time right design
  - Model based design & process
- Partnership
  - Evonik

Decision to develop CFPA12
CFPA12 Development
- Material
- Process
- Product
Product Qualification

Achievements
- Product development & qualification within 17 months
- Qualification testing completed
- Project within budget and on time
- Positive outlook for pilot in GoM
# Project description

**TCP Jumper for Water Injection**

<table>
<thead>
<tr>
<th>TCP Jumper characteristics</th>
<th>Metric units</th>
<th>Imperial units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Carbon / Polyamide 12</td>
<td></td>
</tr>
<tr>
<td>Internal diameter</td>
<td>132 mm</td>
<td>5.2 in</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>215 mm</td>
<td>8.5 in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational Envelope</th>
<th>Metric units</th>
<th>Imperial units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life</td>
<td>30 years (11,000 pressure cycles)</td>
<td></td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>4 to 72 °C</td>
<td>39 to 162 °F</td>
</tr>
<tr>
<td>Maximum Allowable Operating Pressure</td>
<td>689 bara</td>
<td>10,000 psia</td>
</tr>
<tr>
<td>Design water depth</td>
<td>2400 m</td>
<td>7874 ft</td>
</tr>
<tr>
<td>Design installation tension (TLR)</td>
<td>50 kN</td>
<td>11,240 lbf</td>
</tr>
<tr>
<td>Minimum equipment radius for storage (MBR)</td>
<td>3.0 m</td>
<td>9.9 ft</td>
</tr>
<tr>
<td>Operational minimum bend radius</td>
<td>6.0 m</td>
<td>19.7 ft</td>
</tr>
</tbody>
</table>
Fitting Termination, CF/PA12 10ksi – Onsite Louisiana

Inserting the stem

Stem Inserted

Wedges being placed

Wedges being secured in place

Bolting sleeve to stem flange

Pressure Test at 1.5 X DP = 15KSI
GoM Water Injection Jumper

• First application of TCP in GoM
• Landmark project for AOG
• Challenging schedule to meet the window of opportunity
• Joint collaboration: Qualification of new product, pilot project and installation within two years
• 4,000 manhours, no LTI

• Jumper has been delivered and assembled onsite in Louisiana
• Site Acceptance Test of Jumper completed
• Fit-up & Hydrottest of complete assembly (Jumper + Torus Connectors)
• On schedule for mobilisation
Thank you for your attention !