High performance materials for new challenges in O&G exploration

Thermoplastic unidirectional composite solutions

Camila Farias, Carsten Schütt, Dr. Silke Witzel
SAMPE Brazil Advanced Composites Week 2017
Who we are
Evonik at a glance

~13 Billion Euro turnover in 2016

172 Sites

>35,000 Employees in over 100 countries

~500 R&D projects
Where we can be found
Evonik operates worldwide

In Brazil since 1953
> 500 employees

Manufacturing Plants:
Hydrogen Peroxide
Aracruz (ES)

Biotechnological production of Biolys®
Castro (PR)

Silica Production
Americana (SP)

Ingredients for the cosmetics industry and home care
Americana (SP)

North America
2,699 M€ turnover
4,660 employees
39 sites

Central & South America
563 M€ turnover
793 employees
15 sites

Western Europe (incl. Germany)
5,534 M€ turnover
23,919 employees
42 sites

Eastern Europe
767 M€ turnover
639 employees
11 sites

Middle East & Africa
403 M€ turnover
194 employees
12 sites

Asia-Pacific North
1,947 M€ turnover
3,688 employees
30 sites

Asia-Pacific South
818 M€ turnover
1,616 employees
23 sites

Turnover in 2016
Our main markets
In each market our experts are deeply involved

Oil & Gas, Automotive, Aerospace, Consumer Goods, Gas Separation, Medical Applications, Additive Manufacturing
Our competencies

Extrusion, Powders, Structural Foam, Composites, Polymer Design, Additive Manufacturing, Membranes, Fibers, Polymer Specialties
High Performance Polymers for the Oil & Gas industry

The bundle of Energy

Onshore
- Gas separation Membrane
- Gas Pressure Pipes PA12
- Liner PA12, PEEK
- Steel pipe protection PA12
- HT/HP Components PEEK, PPA

Offshore
- Steel pipe protection PA 12
- Gas separation Membranes

Subsea
- Flexibles PA 12, PEEK
- Composites PA12, PEEK
- Liner PA 12
- Downhole Liner PEEK
- Umbilicals PA12/PVDF MLT

Commercial

Market introduction

SAMPE Brazil - October 2017
VESTAMID® PA12 Performance & Reliability

VESTAMID® NRG PA12 established since 2006

VESTAMID® NRG PA12 is used in flexible oil pipelines for safe and reliable offshore operations since 2006. Over 1000km of flexible pipes VESTAMID® NRG PA12 have been installed.
Taking Challenges

- **Oil Price**: low oil price needs smart and cost effective solutions

- **Ultra Deep and Corrosion**: ultra deep offshore and highly corrosive media show technology gaps
  - Composite Solutions available
  - Developing new materials, e.g. crosslinked PEEK
  - Active participation in Standards Development (DNV-GL Composites JIP, ISO 23936, ELEMENT JIP, API 17 TR2, …)

- **Changing Standards**: new standards need more testing data (which we deliver)
  - New CIV tests for production
  - Media Compatibility Testing
Unbonded flexible vs. bonded TCP - corrosion free lightweight solutions

- Long and successful track record
- At their limit for cost efficiency regarding corrosion resistance for newer more challenging environments in greenfield applications
- Alternative with foregoing metal parts
- Completely taking strength from bonded thermoplastic UD composite tapes
- Reinforced by corrosion insensitive carbon fiber
- Multilayer solutions possible
Evonik HP expects potential applications in established markets based upon the existing polymer portfolio - main focus is Oil & Gas.
Evonik thermoplastic UD tapes – High performance material solutions

Material combinations
• Diverse material combinations
• Fiber volume fractions 45-60%

Benefits
• Strong media resistance
• Strength or toughness optimized systems
• Stable against environmental influences (temperature and humidity)
• Easy processing on standard equipment* (<300°C)

*excluding PEEK
Unidirectional reinforced plastics promise mechanical performance on the level of metals

Lightweight materials offer new markets and applications

- Mobility (fuel economy, CO₂ emission)
- Easier handling of lightweight solutions
- Performance advantages vs. metal (corrosion …)
- Integration of different functions

- Mechanical properties
- Fiber length l/d
- Long fiber
- Short fiber
- Chopped fibers
- Continuous fibers
- Non-woven fabric
- Unidirectional fabric
- Needed for e.g. overmolding

SAMPE Brazil - October 2017
EVONIK has decided to mainly focus on melt impregnation technology to achieve highest performance of UD tapes.

<table>
<thead>
<tr>
<th>process principle</th>
<th>melt impregnation</th>
<th>powder impregnation</th>
</tr>
</thead>
<tbody>
<tr>
<td>fibres +</td>
<td>melt extruder + die</td>
<td>fibres +</td>
</tr>
<tr>
<td>+</td>
<td>tape +</td>
<td>powder suspension +</td>
</tr>
<tr>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>matrix</td>
<td>granules (incl. compounds)</td>
<td>powder, d50 $\approx$ 10 – 20 µm</td>
</tr>
<tr>
<td>evaluation</td>
<td>optimization of matrix polymer possible (e.g. to achieve good fiber polymer adhesion)</td>
<td>due to low viscosity of suspension good impregnation of fibers</td>
</tr>
<tr>
<td></td>
<td>specially designed die necessary to achieve full wetting of fibers with viscous polymer melt</td>
<td>normally higher costs of powders compared to granules</td>
</tr>
<tr>
<td></td>
<td></td>
<td>some polymers are hardly to be processed into powders</td>
</tr>
</tbody>
</table>
A lab and pilot line is available for development and small batch production, expansion to 300 mm tape width is under construction

**Lab Line**

- Tape width/thickness:
  - 40 mm x 0.2 – 0.3 mm
  - 80 mm x 0.2 – 0.3 mm
- Suitable for PA12 … (PVDF and PEEK under development)
- GF, CF, (45-60%)…

**Pilot/ Production Line**

- Tape width/thickness:
  - 150 mm x 0.2 – 0.3 mm
- Suitable for PA12 … (PVDF and PEEK under development)
- GF, CF, (45-60%)…
Work with thermoplastic composites means developing test strategies and methods to ensure quality

**Tape level testing**
- Quality assurance / Visual inspection for defects
- Single ply test procedures (modified from DIN, ASTM standards)

**Coupon level testing**
- Material data for simulation models
- Existing composite test standards (DIN, ISO, ASTM...)
- AVK working group “Continuous fiber reinforced thermoplastics”
Microscopy pictures help to evaluate impregnation quality

- Poor fiber distribution
- Poor impregnation level
- Misalignment + voids
Evonik has put significant effort in build-up of composite testing facilities

**Ultrasonic inspection**

**Testing machine and equipment with climate chamber**

- **250kN universal testing machine**
  - Tensile test
  - in plane shear (IPS)
  - interlaminar apparent shear strength (ILSS)
  - compression test in plane direction

- **Tapes: 0°**
- **Coupons: 0° and 90°**

- Static testing up to 25t and dynamic testing up to 10t
Additional test equipment for O&G applications is available in Evonik test facilities

O&G Rapid Gas decompression and high pressure hydrolysis testing

- Implementation of 1.000 bar @ 150°C HT-HP device
- capable of performing Rapid Gas Decompression Tests with supercritical CO2 as per API 17 J and long term high pressure hydrolysis tests
EVONIK‘s PA12-CF tape is being qualified acc. to DNV-GL RP F-119

- RP F-119 “describes a way by which TCPs can meet the technical provisions and documentation requirements of DNV-OS-C501, and thus achieve the standardized safety levels prescribed there”

But: descriptive technical solutions are not enforced!

EVONIK‘s PA12-CF tape will be tested acc. to DNV-GL RP F-119

- Testing involves creep and fatigue testing of composite coupons in situ at MOT and MOP
- Set up of highly specialized high strength equipment
- High level of repetitions - keeping safety and design factors in check
- Intensive cooperation with TCP manufacturer and DNV-GL
- RP-F119 is prone to revision due to changes in long term stress rupture assessment for CF systems

EVONIK is going this route together with the partner to get the PA12-CF tape qualified for the specific TCP design and application the partner is focusing on!
Umbilical Hoses: Thermoplastic Composite Pipe

Ultra Deep Water Challenge:
Replace hoses of PA11 + steel carcass by steel pipes

The deepest ever installed umbilical in South America

PA11 + stainless steel carcass
Umbilical Hoses: Thermoplastic Composite Pipe

Main challenges to replace steel pipes by VESTAKEEP:

- Mechanical properties to resist high collapse pressures due to ultra deepwater;
- Minimum bending radius to spool the hoses to transport and installation;
- Competitive price with the super duplex steel.

FINITY Elements Analysis Simulations:

- Hose temperature for maximum collapse pressure: 23°C
- Collapse pressure for 3000m deph: 6500 psi (450 bars)
- Collapse pressure for 2500m deph: 5400 psi (375 bars)

Project Schedule:

- Technical feasibility study
- Commercial evaluation

VESTAKEEP + CF10 Extrusion trials for qualification of sample tubes

VESTAKEEP 5000 Extrusion trials for qualification of sample tubes
Umbilical Hoses: Thermoplastic Composite Pipe

Data samples that were produced

- Material: VESTAKEEP 5000G
- Internal diameter: 12.5 mm

Collapse tests results:

<table>
<thead>
<tr>
<th>Wall Thickness</th>
<th>Sample</th>
<th>Deep water (meters)</th>
<th>Testing pressure (psi)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm</td>
<td>Test 1</td>
<td>3.000</td>
<td>6.600</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 2</td>
<td>2.750</td>
<td>6.000</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 3</td>
<td>2.600</td>
<td>5.750</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 4</td>
<td>2.560</td>
<td>5.600</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 5</td>
<td>2.500</td>
<td>5.500</td>
<td>Approved</td>
</tr>
<tr>
<td></td>
<td>Test 6</td>
<td>2.500</td>
<td>5.500</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 7</td>
<td>2.500</td>
<td>5.500</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 8</td>
<td>2.500</td>
<td>5.500</td>
<td>Collapsed</td>
</tr>
<tr>
<td>3 mm</td>
<td>Test 1</td>
<td>2.000</td>
<td>4.400</td>
<td>Collapsed</td>
</tr>
<tr>
<td></td>
<td>Test 2</td>
<td>2.000</td>
<td>4.400</td>
<td>Collapsed</td>
</tr>
</tbody>
</table>

Burst tests results:

- 4 mm → 7032.5 psi
- 3 mm → 5698.5 psi
Umbilical Hoses: Thermoplastic Composite Pipe

Finity Elements Analysis Simulations

Data samples that production is ongoing
- Material: VESTAKEEP + 10% carbon fiber
- Internal diameter: 12.5 mm
- Thicknesses: 3.0 and 3.5mm