Development of HMPE fiber for deepwater permanent mooring applications

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Jorn Boesten
Agenda and opening remarks

- The challenge: Moor production units with HMPE
- Designing a solution
- Results
- Why use it?
- Conclusions
• Industry likes working with HMPE
• Successes with large global players
• “We like your fiber, can we use it for production mooring”
• DSM ready for it
Three world class players teaming up

**Lankhorst Ropes**
One of the largest rope manufacturers in the world
Almost 2 decades working with Dyneema®
Presence in Portugal and Brazil

**Ifremer**
French Ocean Research Institute
Over 20 years experience in testing of high performance fibers and ropes

**DSM Dyneema**
Inventor of the Dyneema®, the world’s strongest fiber™
Dedicated to innovation
Largest global supplier of HMPE fiber
• Rope made with DM20, when compared with polyester will
  - Be 60% lighter
  - Have a 30% smaller diameter
  - Offer excellent fatigue properties
  - Be 3-4 times stiffer
High dynamic stiffness, but windward stiffness of standard HMPE grades is low.

- 2011 OIPEEC paper by Petrobras (del Vecchio ea)
- Tests proposed
- Dynamic stiffness is high, but quasi static stiffness values are low, due to long interval under static load
- QSS will improve if creep is reduced

<table>
<thead>
<tr>
<th>Yarn stiffness based on Yarn Break Load</th>
<th>SK78 fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windward 24h.</td>
<td>6.8 x YBL</td>
</tr>
<tr>
<td>Leeward 24h.</td>
<td>13.0 x YBL</td>
</tr>
<tr>
<td>Dynamic stiffness (10-30%YBL)</td>
<td>43.7 x YBL</td>
</tr>
</tbody>
</table>
HMPE fiber and rope stiffness
Existing SK78 grade - stiffness too low

Experiment at room temperature

24 h. strain at 45% BL (1520 MPa)

Load (%YBL) vs. Strain (%)

SK78

windward stiffness
leeward stiffness

24 h. strain recovery at 5% BL
Design parameters for DM20
Step change in creep performance needed

- 0.5% Maximum elongation of a mooring rope after 25 years in service
- Matching the required creep lifetime safety factor
- These requirements were not achievable with any existing commercial HMPE grade, not even SK78

<table>
<thead>
<tr>
<th></th>
<th>SK75</th>
<th>SK78</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimated creep elongation</strong></td>
<td>6.6%</td>
<td>1.7%</td>
</tr>
<tr>
<td><strong>Creep failure safety factor</strong></td>
<td>Can not be met</td>
<td>Can be met</td>
</tr>
</tbody>
</table>

| **MODU mooring condition (5 years of 20%BL at 16°C)** | Failure                  |                           |
| **Permanent mooring condition (25 years of 20%BL at 16°C)** | Failure                  | failure                  |
# Norms and guidelines

<table>
<thead>
<tr>
<th>Guideline</th>
<th>NI 432 DTO Ro1E</th>
<th>DNV-OS-E303 DNV-OS-E301</th>
<th>Guidance notes on offshore mooring fiber rope</th>
<th>API-RP-2SM</th>
<th>ISO/PDES 14909</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Issuing body</strong></td>
<td>Bureau Veritas (7)</td>
<td>Det Norske Veritas (8), (9)</td>
<td>American Bureau of Shipping (10)</td>
<td>American Petroleum Institute (11)</td>
<td>International Organization for Standardization (12)</td>
</tr>
<tr>
<td><strong>Creep prediction</strong></td>
<td>Long-term creep of the rope based on fiber creep data.</td>
<td>Creep failure resistance to be specified by rope manufacturer. Yarn manufacturer to test to yarn creep failure.</td>
<td>Creep analysis to estimate the total creep strain during the design service life. Creep rupture analysis to estimate the creep rupture life. Creep model based on fiber creep data.</td>
<td>Creep analysis based on mean and maximum design loads. Creep failure analysis based on rope test data.</td>
<td>Estimate of creep rate and allowable creep elongations, in operating conditions on most critical area of the rope. Based on model of fiber creep properties.</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td>Number of discrete design conditions to calculate annual creep strain and predict total strain for</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

95% of initial rope strength or 10% of installed rope length.

Total creep strain limited to 10% of total length of HMPE rope.

- **NI 432 DTO Ro1E**
  - Creep failure safety factor of 3 for mobile moorings and 5-8 for long-term moorings.

- **DNV-OS-E303 DNV-OS-E301**
  - Factor of safety over the design service life against creep rupture: 5 (creep is monitored) or 10 (creep is not monitored).

- **Guidance notes on offshore mooring fiber rope**
  - Factor of safety for creep failure is 10 times the service life of the rope.
DM20 fiber
Step change in creep properties - elongation

- Elongation as function of time
- Accelerated tests at 70C and 300MPa
DM20 fiber

Step change in creep properties - elongation

Accelerated creep experiments at 70°C and 300 MPa

SK75, SK78, DM20 experiments until creep rupture

Experiments until creep rupture

Elongation (%) vs. Time (h)
DM20 fiber

Step change in creep properties - creep rate

- Creep rate as function of elongation
- Accelerated tests at 70°C and 300 MPa
DM20 fiber

Step change in creep properties - creep rate

Accelerated creep experiments at 70°C and 300 MPa

- DM20
- SK75
- SK78

Running over 6 months

Experiments until creep rupture

1% / 2 min
1% / 3 hrs
1% / 12 days
1% / 38 mths
Rope with DM20 fiber
Excellent properties for permanent mooring

- 29mm rope, 67 tons break strength
- Tested at Ifremer, France. 30°C / 45% rope break load
Rope with DM20 fiber
Excellent properties for permanent mooring

- 29mm rope, 67 tons break strength
- Tested at Ifremer, France. 30°C / 45% rope break load
Rope with DM20 fiber
Excellent properties for permanent mooring

- Fatigue test according ISO 14909 @ DNV Bergen (Norway)
- 34mm, 90 tons break strength subrope designed by Lankhorst
- 10,000 cycles
- 5-50% BS

Followed by tensile test
Break @: 106 tons (118%)
Rope with DM20 fiber
Excellent properties for permanent mooring

- Stiffness test

Experiment at 22°C

24 h. strain at 45% BL (675 MPa)

DM20

Windward stiffness

Leeward stiffness

24 h. strain recovery at 5% BL
DM20 fiber and rope
Excellent properties for permanent mooring

- Fiber and rope stiffness measured (22C)

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<th>Rope DM20</th>
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<tr>
<td>Windward 24 hour</td>
<td>6.8</td>
<td>40.3</td>
</tr>
<tr>
<td>Leeward 24 hour</td>
<td>13</td>
<td>27.8</td>
</tr>
<tr>
<td>Dynamic 10-30%</td>
<td>43.7</td>
<td>60</td>
</tr>
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</table>
Why DM20?
Operational benefits in every project stage

Design stage
- Optimizing between riser type and mooring line stiffness
- More vessels of opportunity for transport and installation
Why DM20?

Operational benefits in every project stage

Installation stage

- Smaller or fewer vessels required for transport and installation
- Lower weights thus faster and safer installation
- Longer rope lengths thus fewer connections
The concept of balancing OPEX savings and CAPEX investment has been proven by many in many applications....

MODU mooring lines, seismic lines, offshore lifting slings, deepwater lowering and lifting lines

Petrobras, Shell, Anadarko, ConocoPhillips, Transocean, Delmar, Statoil, SBM, APL, PGS, Prosafe
Conclusions

- DM20 is a new product in the HMPE portfolio with the known product benefits of HMPE
- Ropes made with the new DM20 fiber match industry requirements for permanent mooring
- Creep prediction model is again available for DM20
- Discard criterion of 10% for creep, that is in several standards, needs to be reconsidered for DM20
- Mooring ropes with DM20 offer OPEX savings during design and installation stage of deepwater systems.
Obrigado / Thank you / Questions

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