Mooring with HMPE rope

Jorn Boesten
Segment Manager Offshore for DSM Dyneema
FPSO Forum Monaco March 25 2014
Why & Agenda

- Dyneema®
- MODU mooring
- Permanent mooring
- Specialty moorings (backup, mudlines, hybrids..)
- Covers for PET mooring ropes
Dyneema® HMPE fiber
Active for over 25 years in offshore and marine industry

Dyneema® fiber
• First “created” by accident on lab scale in 1963
• Gel spinning process developed by DSM, patented in 1978
• First fiber spun in 1986 by JV of DSM and Toyobo, into rope
• First MODU moored in 1996

Creep Design Tool
• Creep modelling started in 1978 (Ward), 1993 (Govaert). DSM Creep Design Tool developed since 1999

DSM Dyneema is part of Royal DSM, a global science-based company active in health, nutrition and materials.
Dyneema® HMPE fiber for offshore

- Dyneema®, the world’s strongest fiber™
  - Lowest weight rope for a given break strength
  - Diameter for diameter exchange of wire rope possible

- Low stretch, 2-2.5% in a rope
- Neutral buoyancy (floats on water)
- High tension and flex fatigue
- Excellent chemical and UV resistance
- High abrasion resistance
- No water absorption

- Grades for semi permanent (SK78) and permanent mooring (DM20)
MODU mooring with HMPE
HMPE - PET comparison
Lighter, compacter, stiffer

Rope made with Dyneema® (SK78 or DM20), when compared with polyester will

- Be 60% lighter
- Have a 30% smaller diameter
- Offer excellent fatigue properties
- Be 3-4 times stiffer

![Gama 98® rope with Dyneema® vs Polyester Rope weight comparison](image)
Mooring rope with HMPE
Load extension properties

- Extension at break of 2%
- Similar to steel wire rope
- ~3-4 times less than Polyester
HMPE - PET mooring evaluation
Delmar study

- Study by Delmar (source: OTC paper 22486)
- Comparative study investigating performance of HMPE, PET and hybrid moorings
- 7500 ft (2286m) water depth
- API RP 95F 2006 metocean conditions

### Typical mooring line

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rig wire</td>
<td>610m</td>
<td>1,2</td>
</tr>
<tr>
<td><strong>PET</strong></td>
<td>915m</td>
<td>4</td>
</tr>
<tr>
<td><strong>SK78</strong></td>
<td>1372m</td>
<td>5</td>
</tr>
<tr>
<td>Chain</td>
<td>915m</td>
<td>6</td>
</tr>
</tbody>
</table>
MODU rope with HMPE
3-4 times stiffer than Polyester

- HMPE part is 3-4 times stiffer than Polyester
- Up to 50% reduction on watch circle

Typical EA Values (*MBL) for rope with PET or HMPE

<table>
<thead>
<tr>
<th>Stiffness Mode</th>
<th>Polyester EA</th>
<th>SK78 EA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Storm</td>
<td>30</td>
<td>105</td>
</tr>
</tbody>
</table>
Intact system performance curves
Conclusion Delmar study*:
- An HMPE MODU mooring system can be engineered to have similar performance and survivability as a PET system in deepwater applications
  - with the benefit of improved station keeping
  - added benefits of faster relocations / smaller boats
- Hybrid configuration allows the system designer the ability to engineer system stiffness to optimize FoS and station keeping

* Source OTC 22486: HMPE mooring lines for deepwater MODUs. S Leite (Lankhorst Ropes), J Boesten (DSM Dyneema)
North Sea experience

- Bridon Superline Steelite Xcel 88mm (540 mt)
- Rope owned by Shell
- Start use in 2007 at JW McLean drill rig in a catenary mooring system
- Semi continuous service, severe use on MODU’s and hotel facilities with load peaks to 156 tons (29% MBL) at Safe Scandinavia

- Rope section tested: 79% residual strength
"Mud lines"
Mud lines used on Delmar OMNI-Max™

- Used to moor MODU’s in GoM since 2007 (OTC 20155 Gilmore (Samson)/ Zimmerman (Delmar))
- Mudline connects directly to the OMNI-Max™ anchor, through sea floor
- Mooring line and retrieval line
- Rope core from SK78, cover from PET, made by Samson

System performance
- First installation was hit by Hurricane Gustav
- The Mudline was the only component that showed no failure on any of the 8 mooring lines, all other components did
- Anchor penetrated about 100 feet into seabed
- After retrieval fiber cores showed almost no strength loss
Permanent mooring with HMPE
HMPE Permanent Mooring

Why develop Max Technology, HMPE fiber that “does not creep”
- Industry likes working with HMPE
- Successes with large global players
- “We like your fiber, can we use it for production mooring”

Fiber engineered towards FPSO mooring spec
- Maximum 0,5%* creep over 25 years
- Creep lifetime matching industry safety factors
  API 10 / DNV 5-8 / ABS 5-10

→ Dyneema® DM20 fiber

* Final product characteristics of DM20 fiber show much lower creep (see later slide)
** Details on development Max Technology, Dyneema DM20 fiber in OTC 23333

Development of HMPE fiber for permanent deepwater offshore mooring.
M Vlasblom, J Boesten (DSM), Leite (Lankhorst Ropes), P Davies (Ifremer)
DM20 fiber
Step change in creep properties

• Elongation as function of time
• Accelerated tests at 70C and 300MPa

→ values along axes have no relationship with MODU or FPSO mooring conditions. These testing conditions are used to speed up testing.
DM20 fiber
Step change in creep properties - elongation
DM20 fiber
Step change in creep properties - creep rate

Accelerated creep experiments at 70°C and 300 MPa

- SK75
- SK78
- DM20

Running over 6 months

Experiments until creep rupture

1% / 2 min
1% / 3 hrs
1% / 12 days
1% / 38 mths
Rope with DM20 fiber
Confirming step change in performance

- 29mm rope, 67 tons break strength
- Tested at Ifremer, France. 30°C / 45% rope MBL
**Elongation case studies**

**Typical mooring conditions**

- Creep elongation is better than original design: ~0.0% at 25 years service

<table>
<thead>
<tr>
<th>All calculations with DM20 fiber rope</th>
<th>“Design case”</th>
<th>“50 years”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>C 16</td>
<td>16</td>
</tr>
<tr>
<td>Load on rope</td>
<td>MPa 300</td>
<td>300</td>
</tr>
<tr>
<td>Time</td>
<td>Yrs 25</td>
<td>50</td>
</tr>
<tr>
<td>Elongation (reversible)</td>
<td>% 0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Elongation (irreversible)</td>
<td>% &lt;0.5 (design)</td>
<td>0.0 (actual)</td>
</tr>
<tr>
<td>Estimated creep failure time</td>
<td>Yrs &gt; 500</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>
Backup lines for wire or chain
Previous integrity user group

- Damaged chain or wire rope, potentially leading to failure
- Several backup systems already in place (or removed again) with Dyneema

**DEGRADATION DUE TO MARINE LIFE CONTAMINATION**

![Graph showing degradation over time for different materials: chain, six-strand wire rope, and polyester samples.](image)

Degradation $\times$ Time

[Courtesy R Celio - Haach Expertize]
Specialty moorings - backup lines

- *NanHaiKaiTuo* FPSO is stationed in the Xijiang Oil Field, approximately 130km from Hong Kong.
- ConocoPhillips and CNOOC. Production start 1994
- During a ROV inspection of the *NanHaiKaiTuo* FPSO, two bottom sockets mooring legs #4 and #5 of the Xijiang Buoyant Turret Mooring (BTM) showed broken wires.
- SBM Services designed the backup solution
NanHaiKaiTuo backup line

- SBM Services designed 2 special connectors with a backup line from Dyneema® SK78, supplied by Bexco
- The upper end of the line is at 25m below sea-level and the lower end at 85m below sea-level
- System is DNV approved

The blue line is the back-up line
Polyester mooring line covers
PET moorings - covers from Dyneema®

- ENI Goliat, Barents Sea
- Hull designed by Sevan Marine
- 291mm polyester rope, DNV certified, MBL 25300 kN with “trawl resistant jacket”
- Rope manufactured by Lankhorst Ropes
- Jacket made with Dyneema®
Goliat, activities Sevan Marine

• Sevan Marine reviewed the fishery activities in the Goliat field
• Established test procedures to replicate realistic trawler interface with Goliat mooring system
• Full scale testing + select best jacket material
Aasta Hansteen

- Statoil project
- Norwegian Sea
- Hull + mooring design by Technip
- More severe overtrawling conditions (pelagic trawling) compared to Goliat

- Rope MBS = 1905 ton, Gama98 rope construction by Lankhorst Ropes with special cover with Dyneema®

- Cover based on technology from Offshore & Trawl Supply AS

Courtesy Statoil
Statoil’s test conditions
(example)

• Applies for polyester mooring lines in areas with pelagic trawling

Statoil requirement (2011)
• PET mooring line at 10% of MBS
• 28mm trawl wire rope running over it
• Wire tension builds up to 15 tons (contact force few tons)
• At 3.5 knots (1.8 m/sec)
• Minimum few 100 meters wire rope runs along the PET rope

• PET rope needs to have minimum 40% MBS left after the test
Development: Hybrid wire rope moorings
Hybrid wire rope

- Development by Bekaert and DSM Dyneema (OMAE 11460)*
- High Modulus Hybrid Ropes for permanent mooring
- Multi strand wire rope with core made with Dyneema®
- Same diameter as SWR at equal strength
- 40-50% weight savings over SWR

* OMAE 2013 11460. Increasing water depth window for moored subsea structures and operations with low weight hybrid ropes.
X Amils, B Durmus (Bekaert), P Smeets J Boesten (DSM Dyneema), P Davies (Ifremer)
Conclusions & Questions

• HMPE fiber widely used in offshore mooring, as strength member and cover material
• In MODU lines, permanent mooring lines, backup lines
• As trawl resistant jacket for polyester mooring lines

• DM20 fiber allows use of HMPE fiber in permanent moorings
• Creep design tool is available for SK78 and DM20

• Offers designers new choices
• At lower total cost of ownership

Jorn.Boesten@dsm.com
Segment Manager Offshore
DSM Dyneema
BRIGHT SCIENCE. BRIGHTER LIVING™