Mooring with HMPE rope

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Segment Manager Offshore for DSM Dyneema
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Why & Agenda

- Dyneema®
- MODU mooring
- Permanent mooring of production platforms
- Specialty moorings (backup lines, 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 coincident 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 (Vlasblom)

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 (more length on reel / winch)
- Offer excellent fatigue properties
- Be 3-4 times stiffer

Courtesy Lankhorst Ropes - 630 mt MBS MODU rope
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

<table>
<thead>
<tr>
<th>Typical mooring line (2286 m WD)</th>
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</thead>
<tbody>
<tr>
<td>Rig wire</td>
</tr>
<tr>
<td><strong>PET</strong></td>
</tr>
<tr>
<td><strong>SK78</strong></td>
</tr>
<tr>
<td>Chain</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

Horizontal Tension (kips)

MODU Offset (% water depth)

- Polyester
- HMPE
- Hybrid
- Catenary
- Steel Semi-Taut

-33%
-50%
Case - storm stiffness
GOM - MODU mooring reliability - API 95F 2006

MODU 6 Intact Limit States
7500' water depth

- --- API FOS = 1.67
- --- 7500' PET Upgrade (additional lines)
- --- 7500' Hybrid Upgrade (additional lines)
Case - storm stiffness
GOM - MODU mooring reliability - API 95F 2006

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 as an insert in a catenary mooring system
- Semi continuous service, severe use on MODU’s and hotel facilities with peak loads to 156 tons (29% MBL) at Safe Scandinavia

- Rope section tested in ‘13: 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
- Used as 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 fail
- Anchor penetrated about 100 feet into seabed
- After retrieval fiber cores showed almost no strength loss

Courtesy Samson Rope
Permanent mooring with HMPE
HMPE Permanent Mooring

Why develop Max Technology, the HMPE fiber that “does not creep”

- Offshore 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 70°C 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 over time

![Graph showing accelerated creep experiments at 70°C and 300 MPa.](image)
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

Elongation [%]
Rel. Creep rate [1/s]
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</td>
<td>16</td>
</tr>
<tr>
<td>Load on rope</td>
<td>MPa</td>
<td>300</td>
</tr>
<tr>
<td>Time</td>
<td>Yrs</td>
<td>25</td>
</tr>
<tr>
<td>Elongation (reversible)</td>
<td>%</td>
<td>0.8</td>
</tr>
<tr>
<td>Elongation (irreversible)</td>
<td>%</td>
<td>&lt;0.5 (design)</td>
</tr>
<tr>
<td>Estimated creep failure time</td>
<td>Yrs</td>
<td>&gt; 500</td>
</tr>
</tbody>
</table>
Backup lines for wire or chain
Previous mooring integrity user group

- Damaged chain or wire rope, potentially leading to failure
- Several backup systems with Dyneema® already in place (or taken out of service again)

![Graph showing degradation due to marine life contamination](image)
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 trawl wire 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

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

• Cover based on technology from Offshore & Trawl Supply AS
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 is used in offshore mooring, as strength member and cover material
- In MODU lines, permanent mooring lines, backup lines
- As trawl wire 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

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