Bend-over-Sheave Testing of Blended HMPE/LCP Fiber Ropes

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Many offshore applications require bending over sheaves….

Crane ropes
Riser tensioners
Deployment systems
Heave compensators
Multiple-fall lifting
.
.
.

But to replace wire rope requires an excellent fatigue life…

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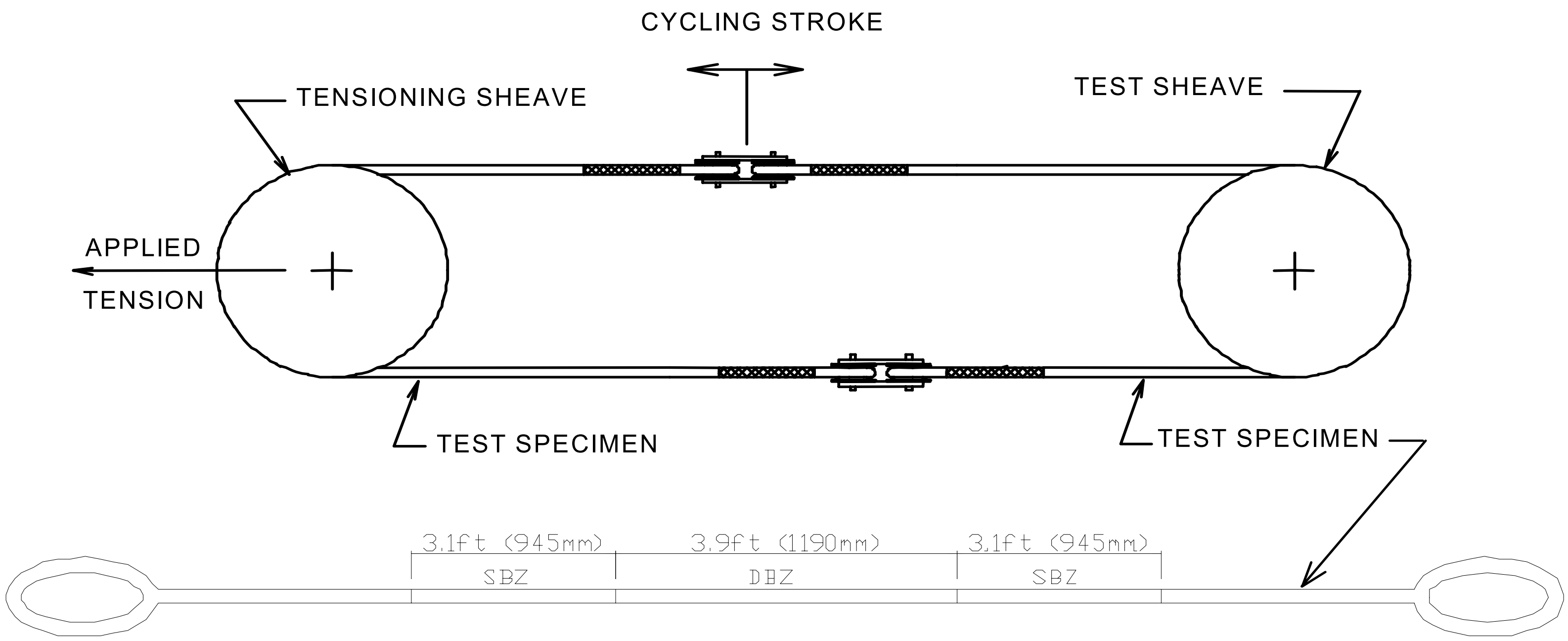
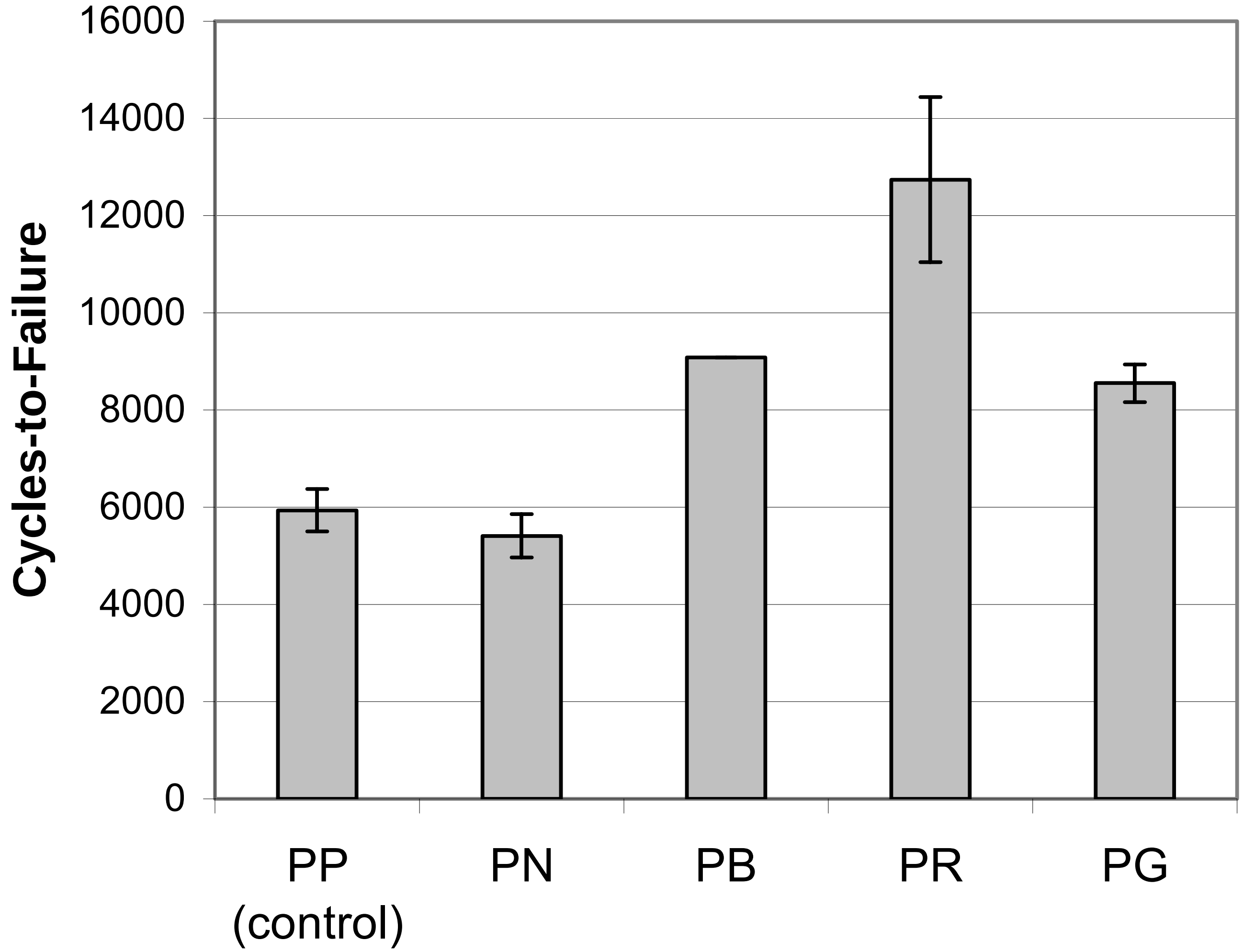
Testing program initiated in 2000

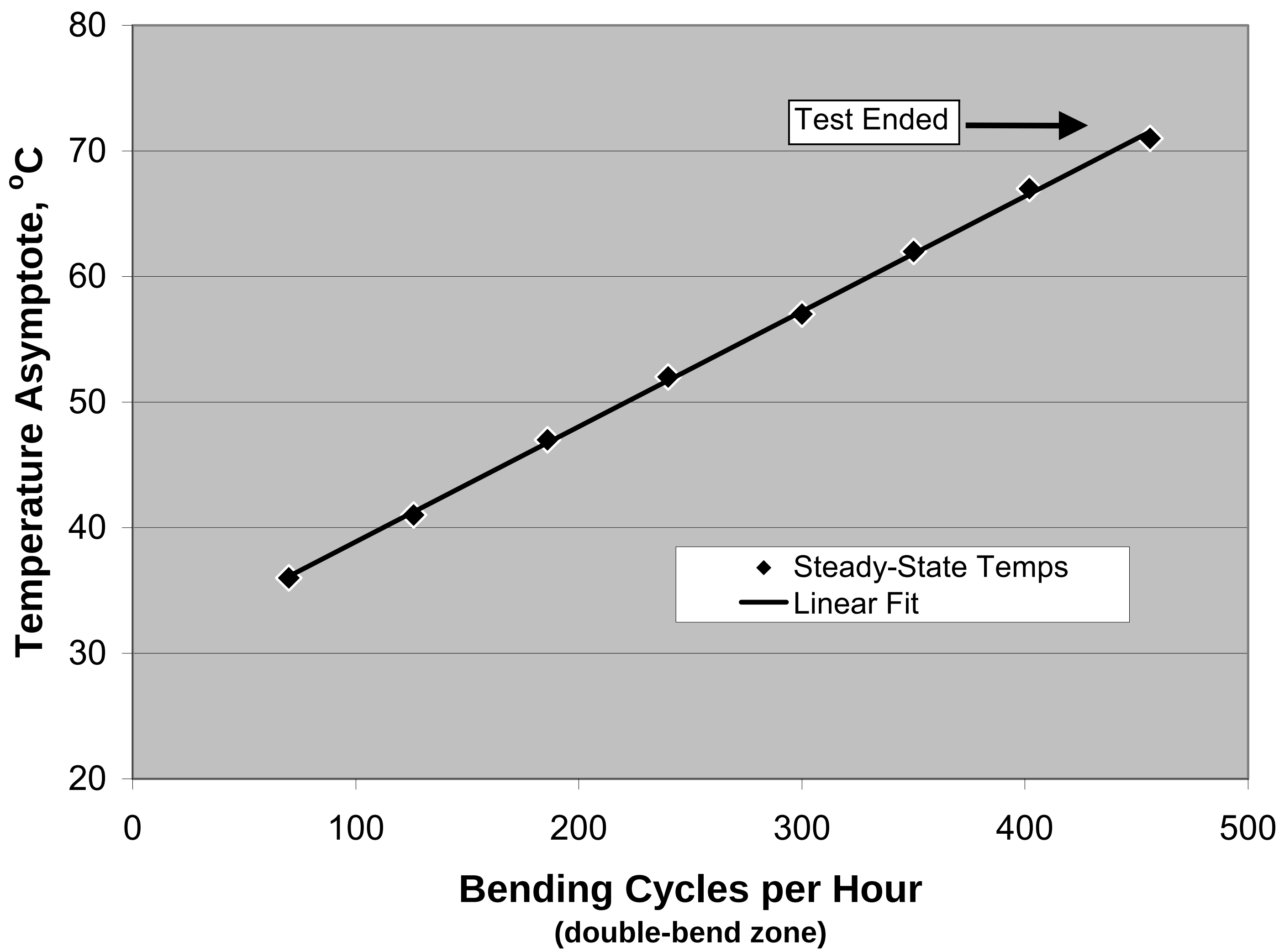
- Aimed at improving bend-over-sheave on overboarding sheaves
- Initial work focused on advanced coatings
- One blend tested because of reports of improved fatigue behavior in small cords (bowstrings)
- Only 12-strand ropes tested

Bend-over-Sheave test rig at TMT



Effect of Advanced Coatings





Effect of Cycle Rate

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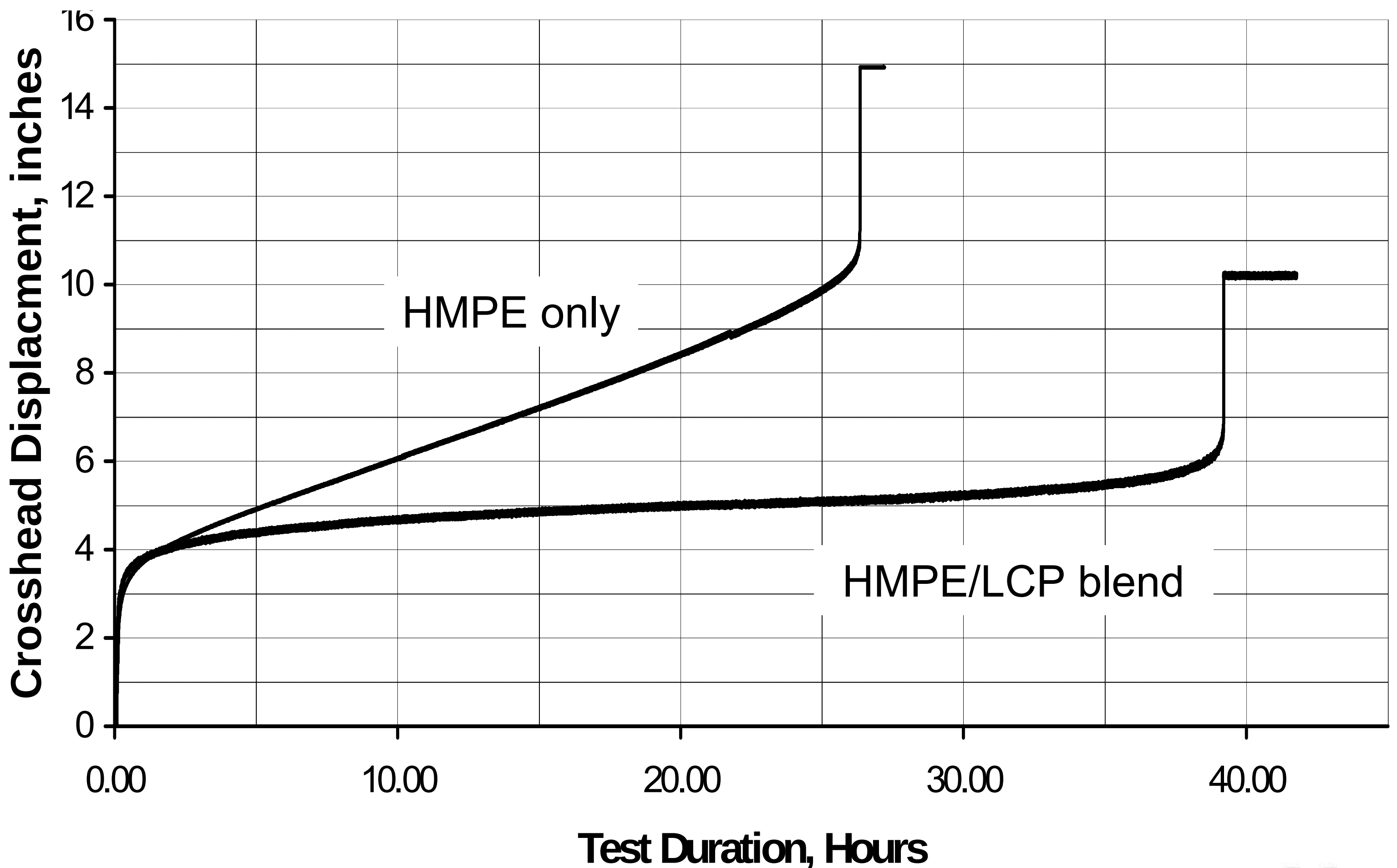
LCP can delay creep mechanism



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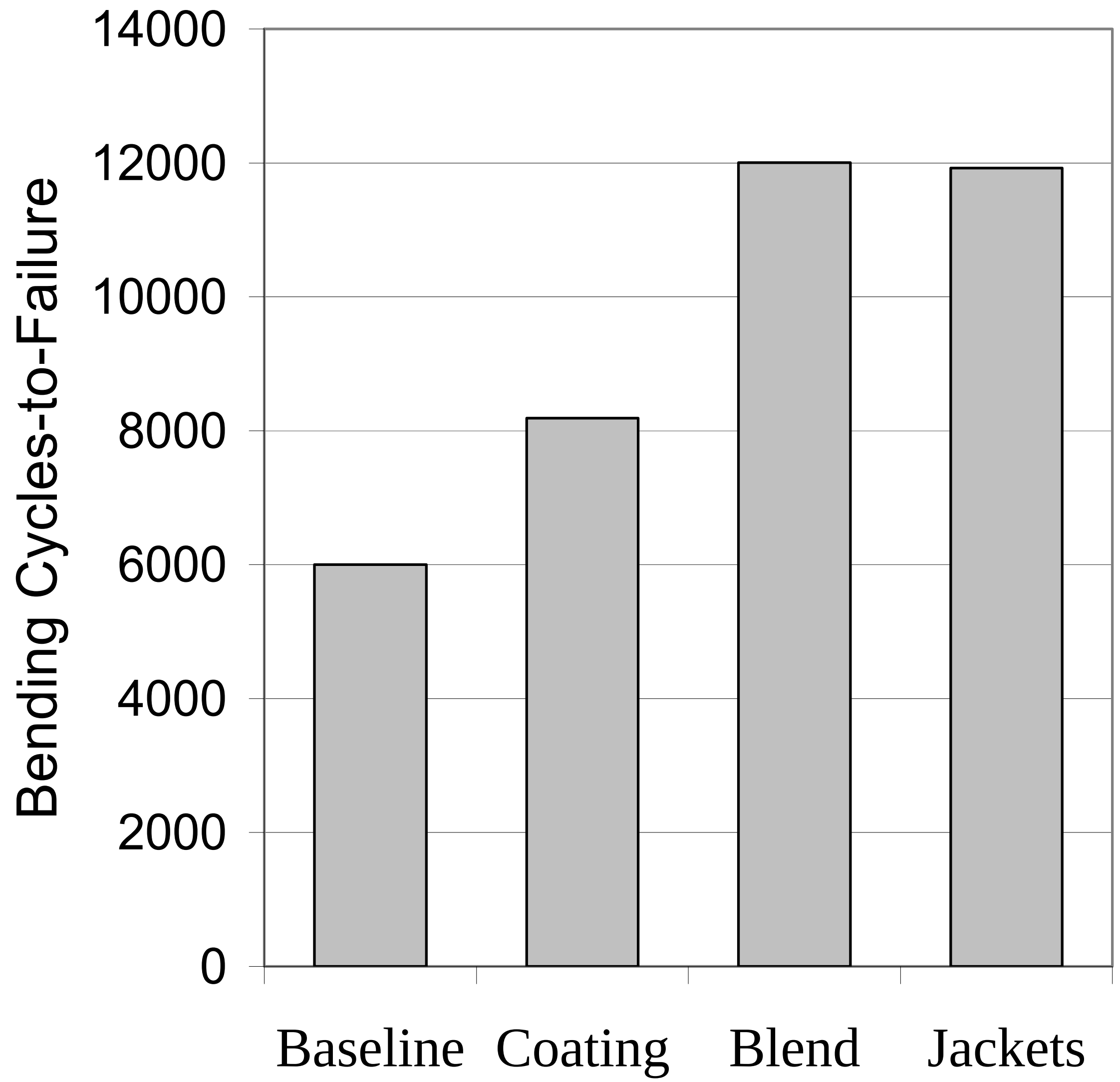
40mm rope testing results



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Conclusions from study (ref 3, 4)…

*** Damage was concentrated at strand crossovers

*** LCP's failed by yarn-to-yarn abrasion

- lubricants required for long life
- can be viscous lubricants (e.g. coatings)
- can be solid lubricants (e.g. HMPE fibers)

*** HMPE's creep failure mechanism accelerated as temperatures increased

- lubricants required to keep rope cool
- can delay creep by blending with LCPs

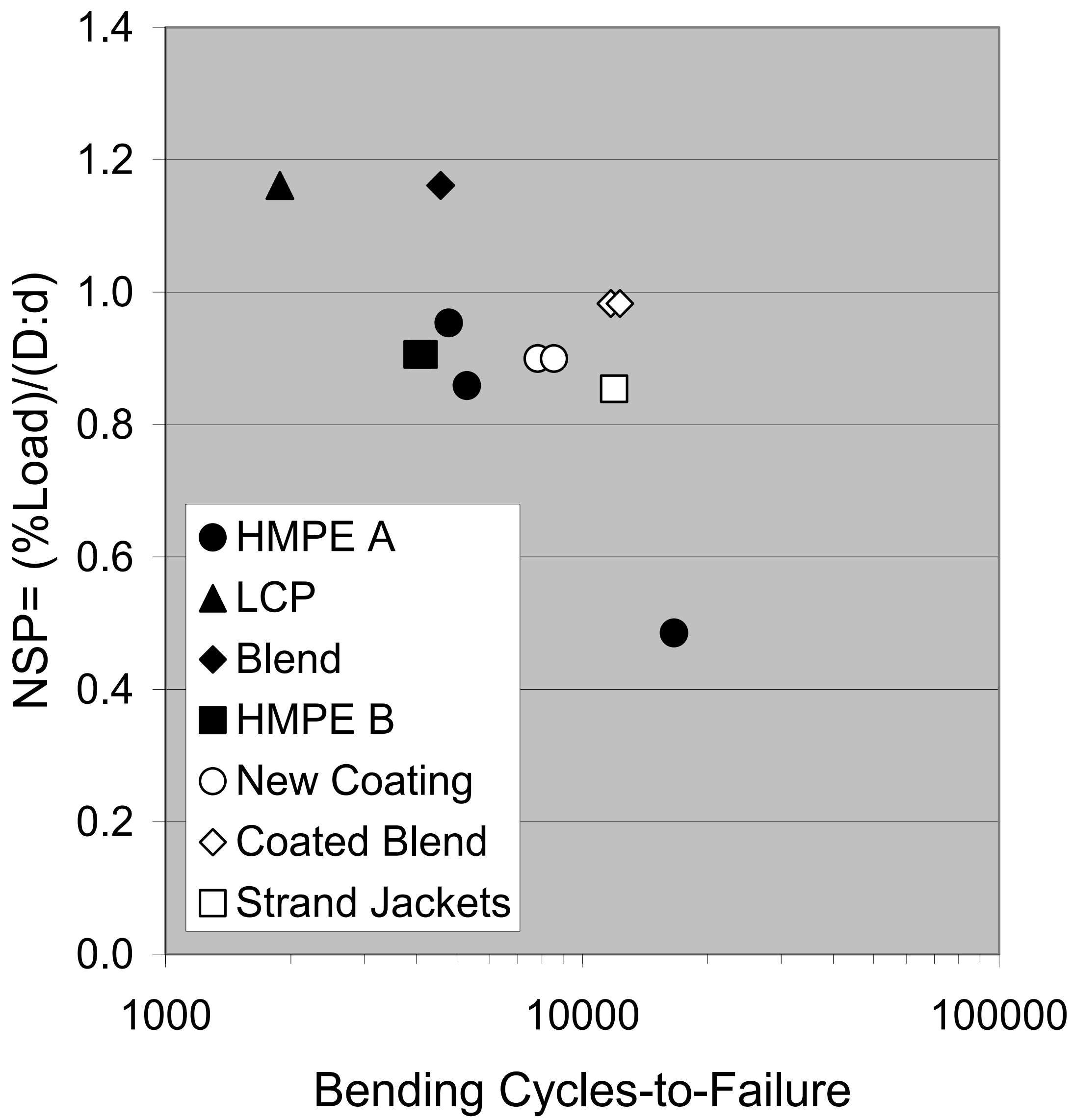
Normalized Sheave Pressure (NSP):

Bearing pressure $= \dfrac{2T}{D \cdot d}$, let U = material strength, then

define Drucker-Tachau Ratio, $\beta \equiv \dfrac{2T}{U \cdot (D \cdot d)}$

assume $\%MBL \propto \dfrac{T}{U \cdot d^2}$

$$NSP \equiv \frac{\%MBL}{(D:d)}$$



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Limitations on NSP:

- Useful to compare same rope at different loads and sheaves
- does not account for
  - cycle rate
  - material
  - rope size

  } heat generation
- strength in ropes not linear with d^2

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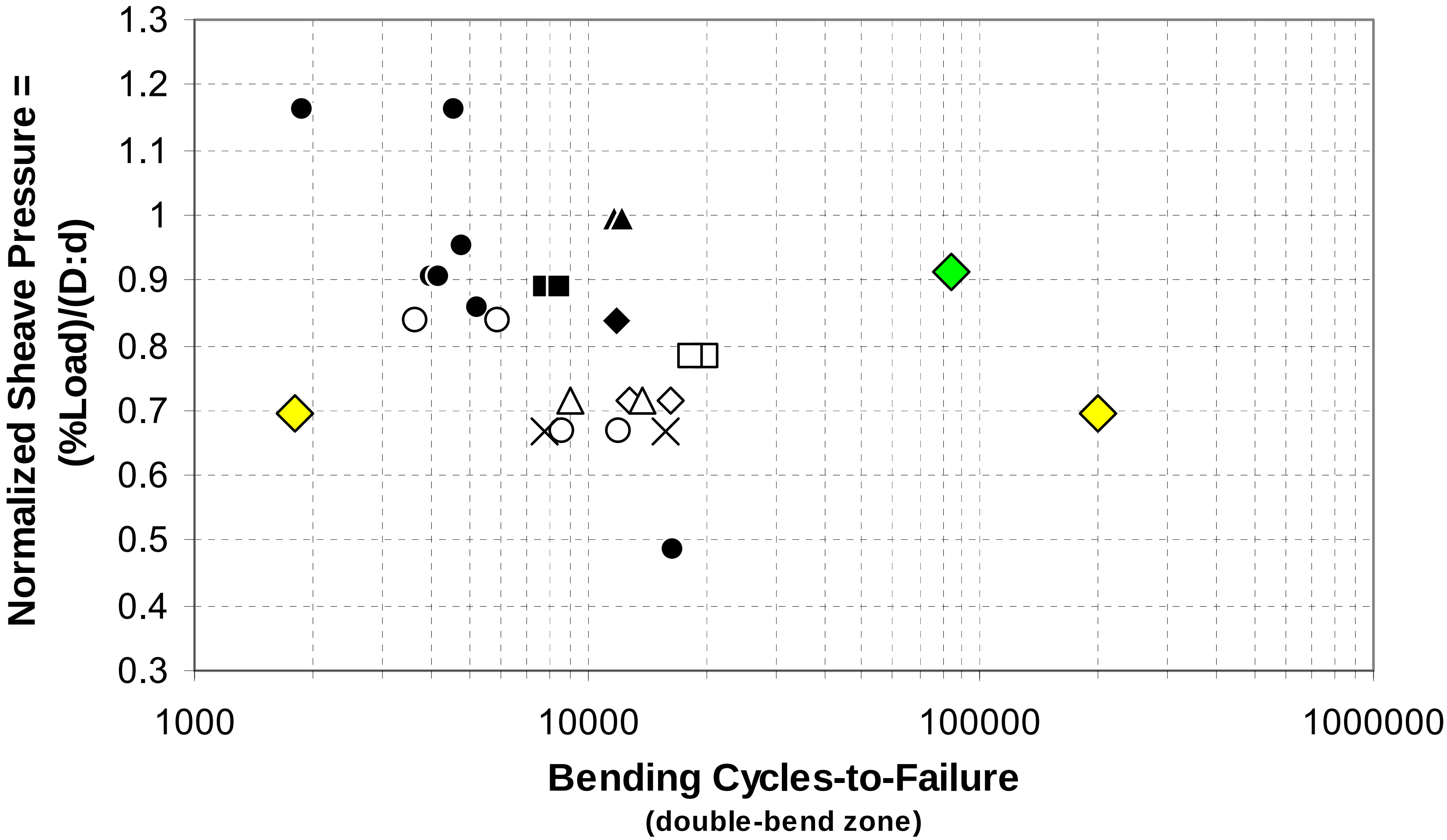
Additional testing…

- Effect of fiber finishes
  - Interaction between rope coating and fiber finish
- Effect of fiber types
  - Heat sensitivity
  - Creep rates
- Tested solid PTFE lubricants

New 40mm data (white) + 18mm data (refs 5, 6)…



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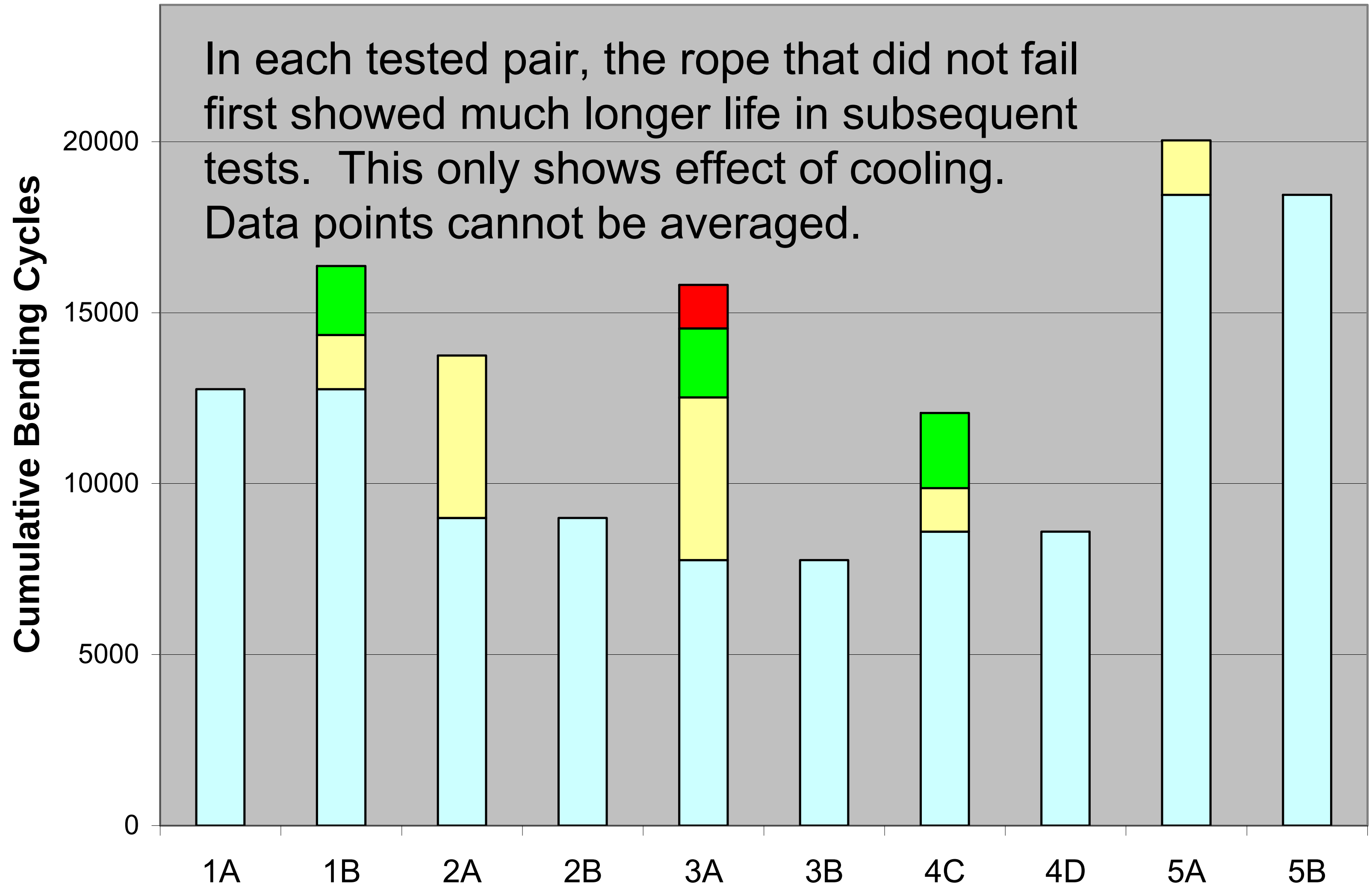

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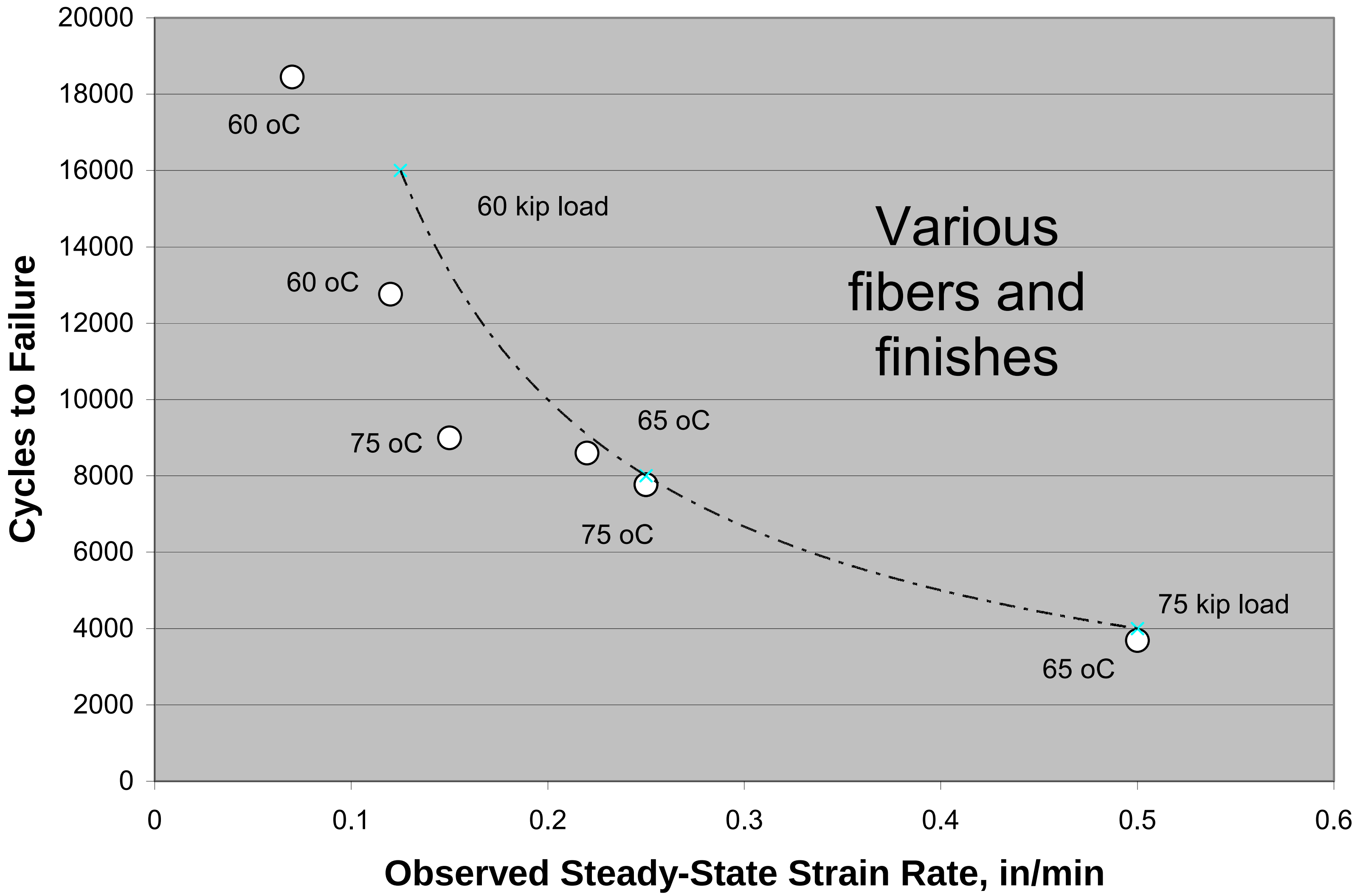

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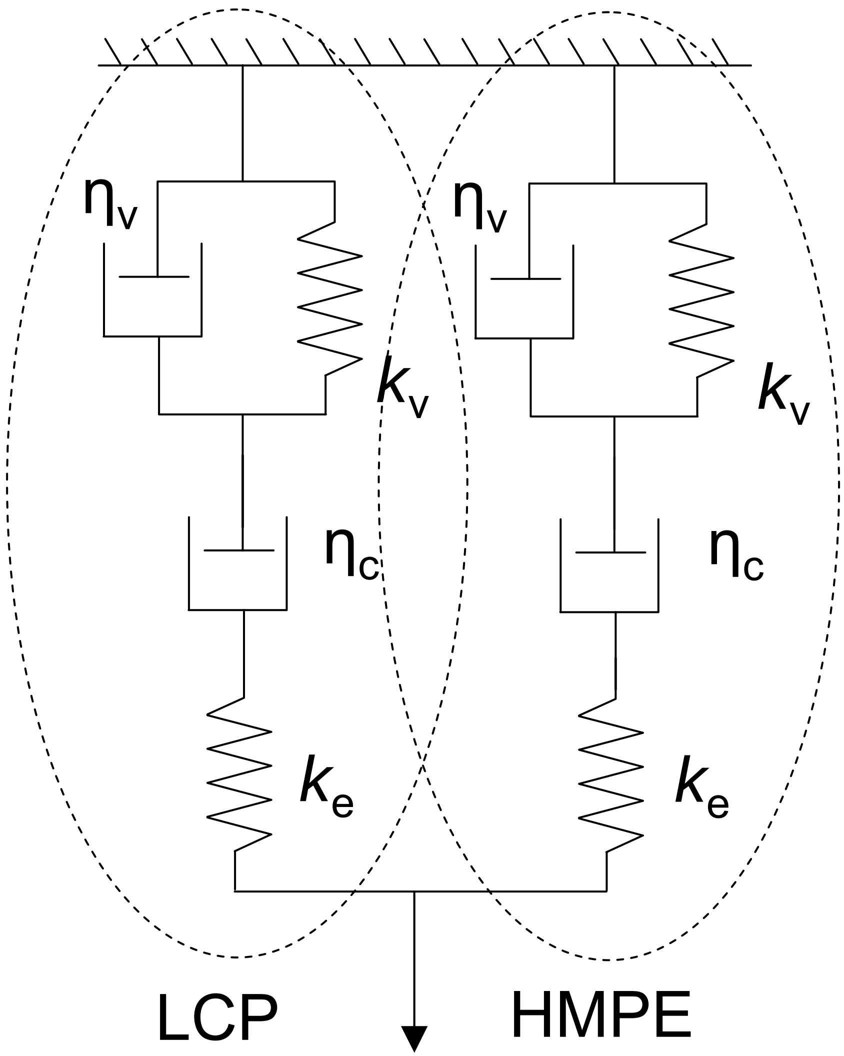
Importance of Temperature

- Best results when operating temps kept to 60 ^{o}C or below
- Re-start of testing after cool-down can lead to non-conservative results
- Residual strength measurement should account for observed operating temperature

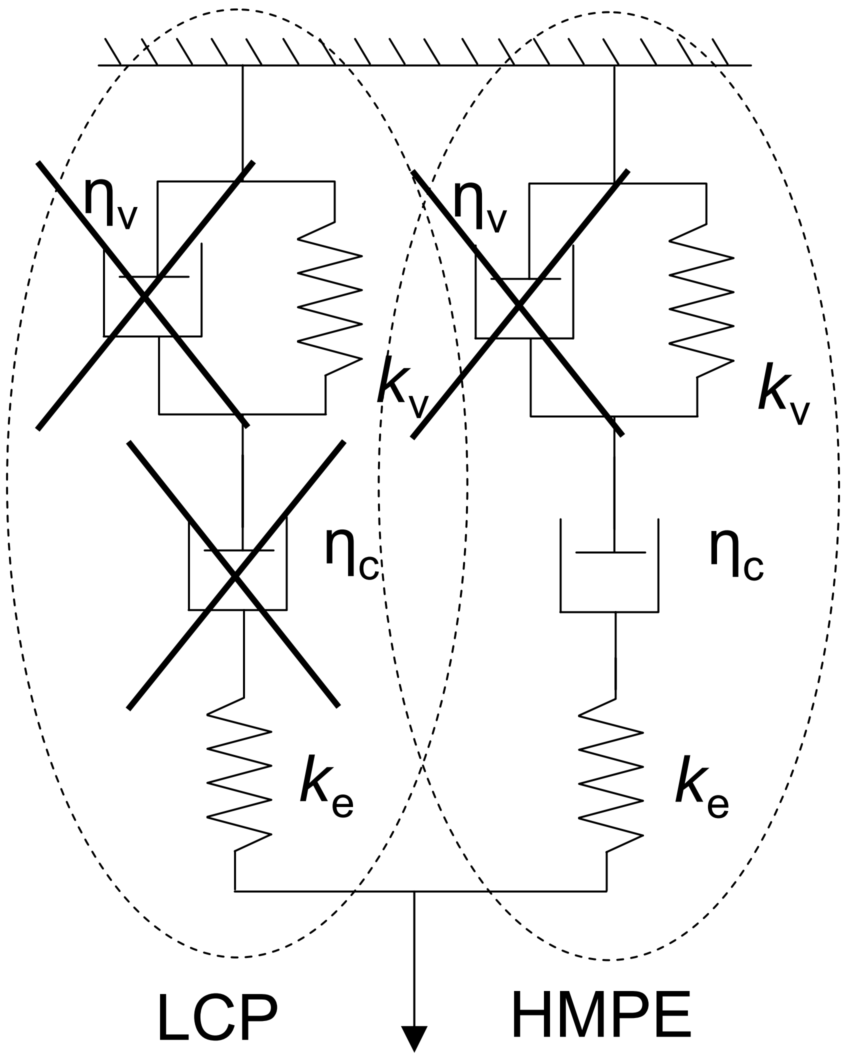
Conclusions

- Temperature is key
  - For long life, limit operating temps to 60oC or below (by speed, load, or active cooling)
- Continuing cycle counts on companion ropes is not recommended
- Continuous cycling on one rope section is worst case. For more realistic results
  - Stochastic cycling is better
  - Random movement of center section
- Studies of rope fatigue require multiple replicates of data points



Parallel Fibers Spring-Dashpot Model:

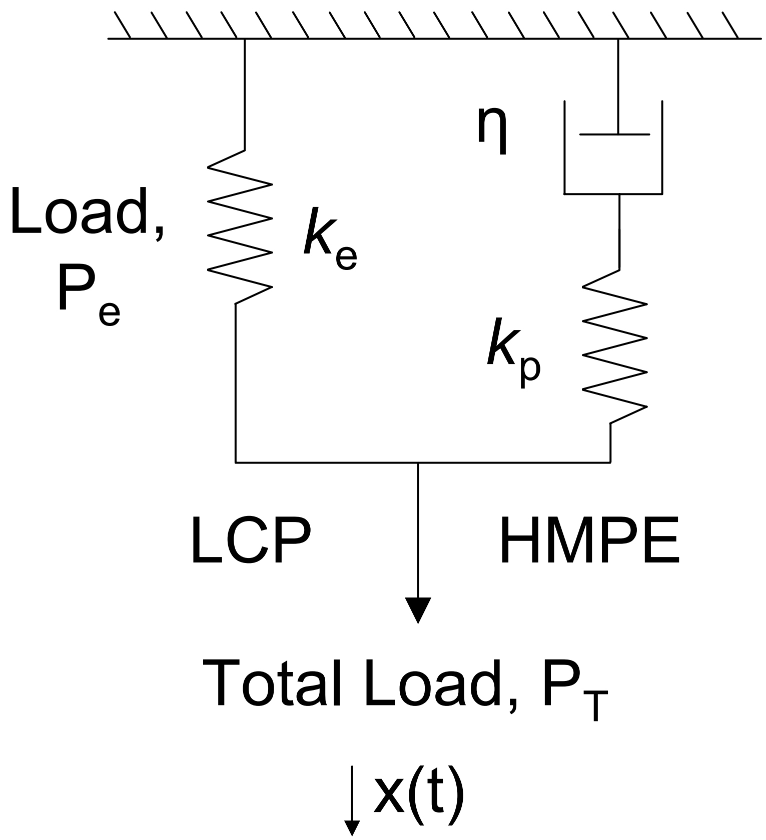
η_v = viscoelastic recovery
k_v = viscoelastic stiffness
η_c = creep component
k_e = elastic stiffness



Simplifying assumptions:

η_v neglectable for long-term

η_c neglectable for LCP



Parallel Fibers
Simplified Model:

k_e = LCP stiffness
k_p = HMPE stiffness
η = inverse of creep rate

Solutions already exist!

$$x(t) = P_T \cdot \left[\left(\frac{1}{k_e + k_p} \right) + \left(\frac{1}{k_e} - \frac{1}{k_e + k_p} \right) \cdot \left(1 - e^{-\alpha t} \right) \right]$$

where

$$\alpha = \frac{1}{\eta} \cdot \left(\frac{k_e \cdot k_p}{k_e + k_p} \right)$$

$$\%P_e \equiv \frac{P_e(t)}{P_T(t)} = \left(\frac{1}{1 + k_p / k_e} \right) + \left(1 - \frac{1}{1 + k_p / k_e} \right) \cdot \left(1 - e^{-\alpha t} \right)$$

Now really simplify, assume $k_p \approx k_e \approx EA/2L$! This gives

$$\%P_e = 1 - \frac{1}{2} e^{-\alpha t} \qquad \text{where} \qquad \alpha = \frac{1}{\eta} \left(\frac{EA}{4L} \right)$$

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Some interesting outcomes…

$$x(t) = \frac{2P_T L}{EA}\left(1 - \frac{1}{2}e^{-\alpha t}\right)$$

Reverts to simple stiffness equation at time zero. (Analysis ignores curvature in fibers, cross section changes, etc.)

$$t = \frac{4L\eta}{EA} \cdot \ln\left(\frac{1}{2(1-\%P_e)}\right)$$

Time to load shift onto LCP fibers is (1) directly proportional to rope length and (2) inversely proportional to creep rate. Creep rate is function of P and T.

$$\frac{x(t)}{x(0)} = 2 \cdot \%P_e$$

e.g. if load in LCP portion was 10% higher than HMPE portion ($\%P_e$=55), there would be a 10% additional stretch in the rope. Severe overloading of one rope component would be accompanied by extreme elongation of the rope.

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Acknowledgements/References /Abbreviations

- 1. Vectran® is a registered trademark of the Kuraray Co., Ltd., Tokyo, Japan. www.vectran.net.
- 2. Testing conducted at TMT – Tension Member Technologies, Inc., Huntington Beach, CA, www.tmtlabs.com
- 3. F. Sloan, S. Bull, and R. Longerich, "Design Modifications to Increase Fatigue Life of Fiber Ropes," Proc. Oceans 2005, Marine Technology Society, Sept. 2005.
- 4. F. Sloan, R. Nye, and T. Liggett, "Improving Bend-over-Sheave Fatigue in Fiber Ropes," Proc. Oceans 2003, Marine Technology Society, Sept. 2003.
- 5. "BOB Beats Bending Fatigue," Puget Sound Rope, Anacortes, WA. www.psrope.com
- 6. WLGore & Assoc., Omnibend Fiber, www.gore.com