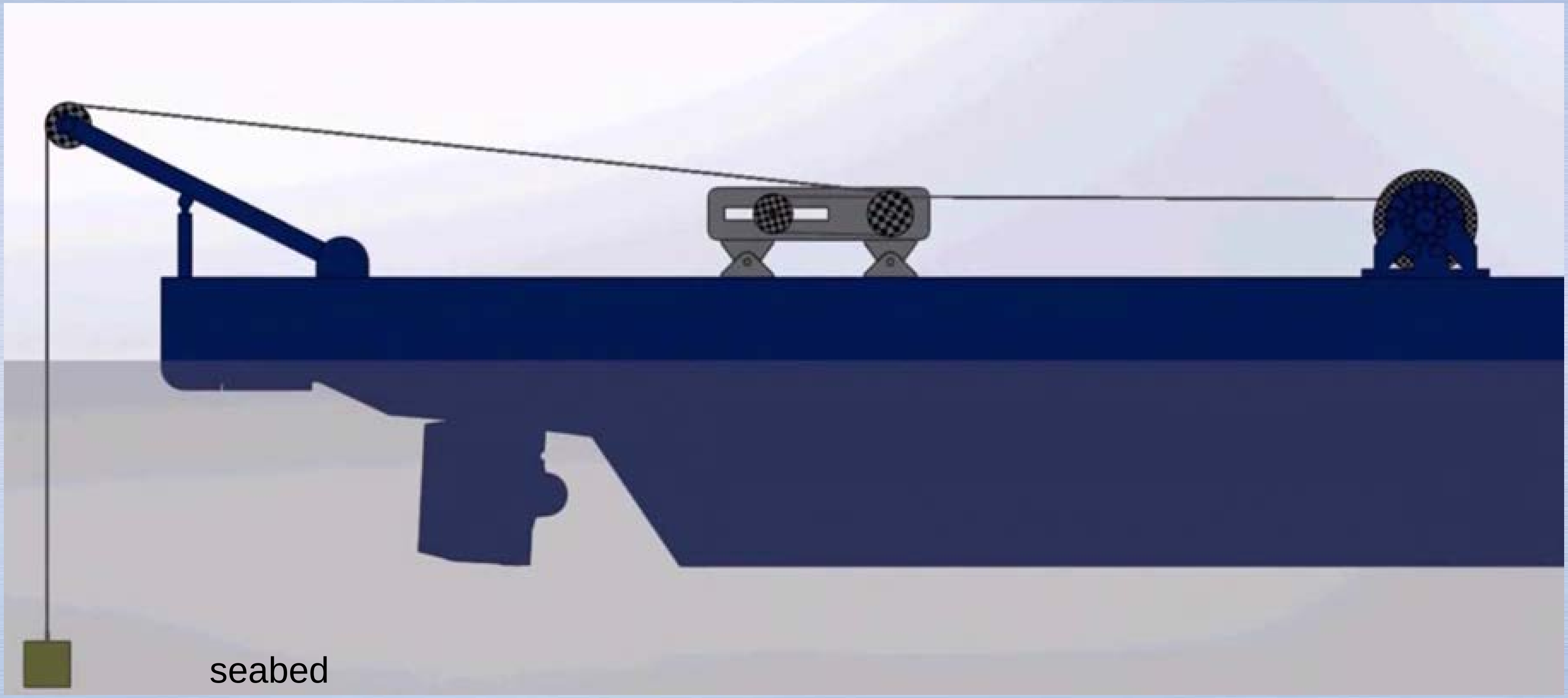
OIPEEC

La Rochelle

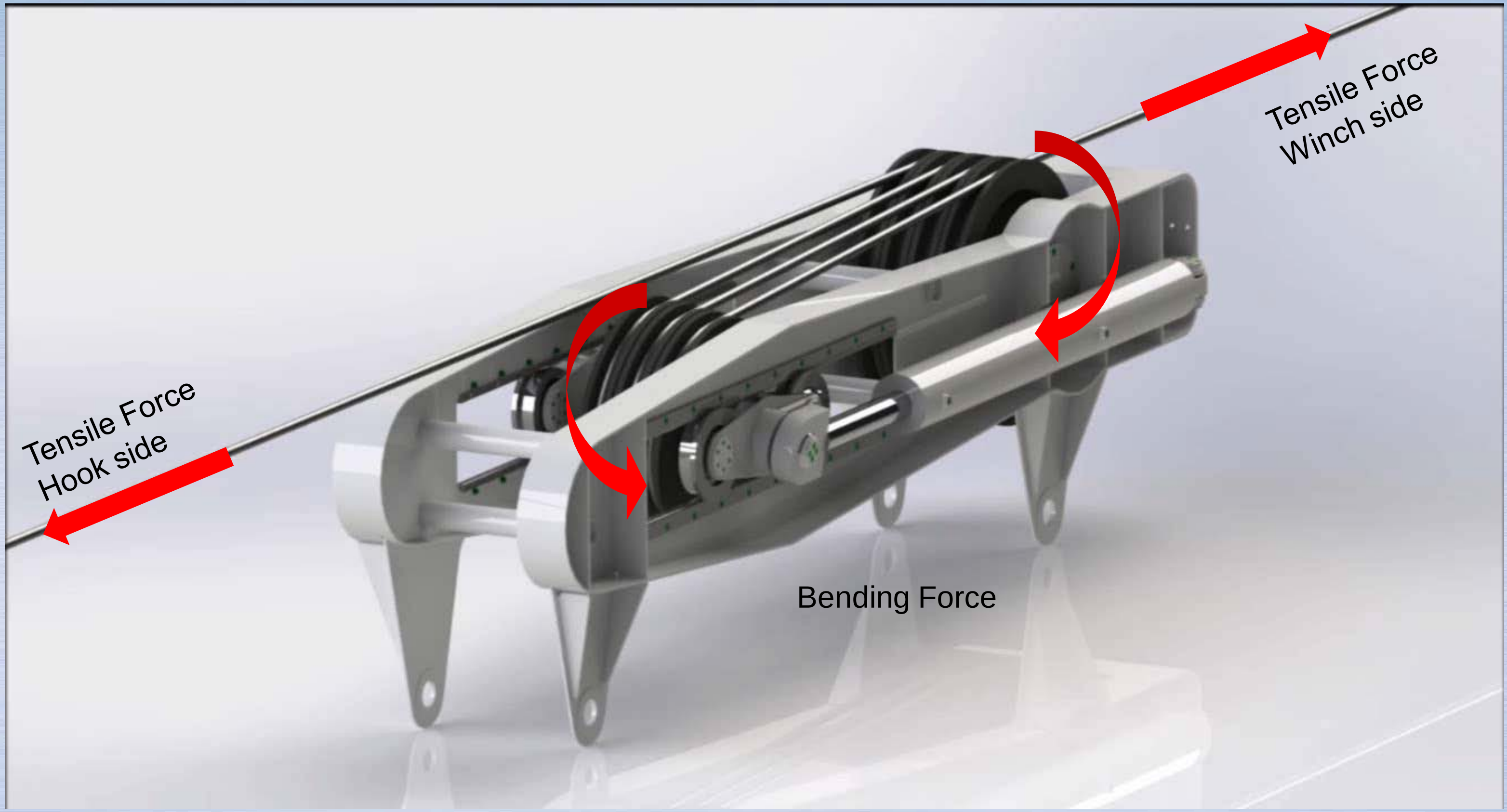
April 2017

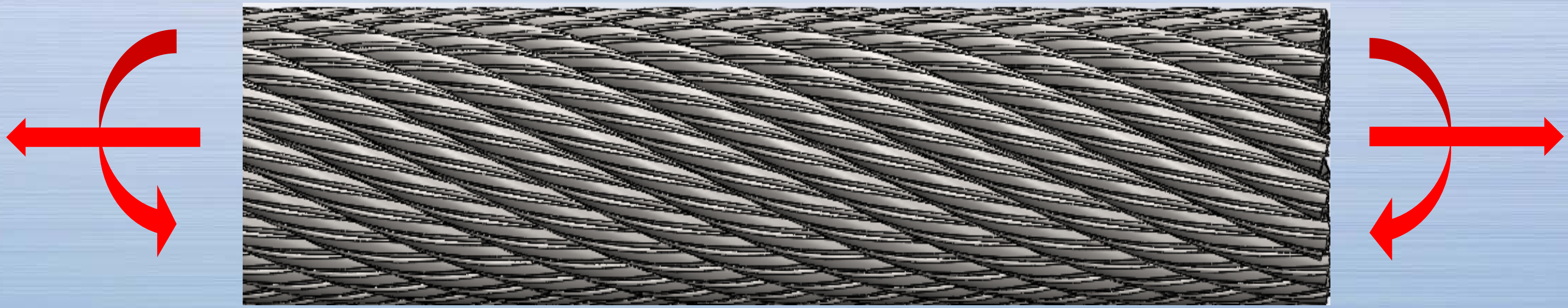
Temperature in Active Heave Compensation Rope

Effect of AHC on wire rope temperature

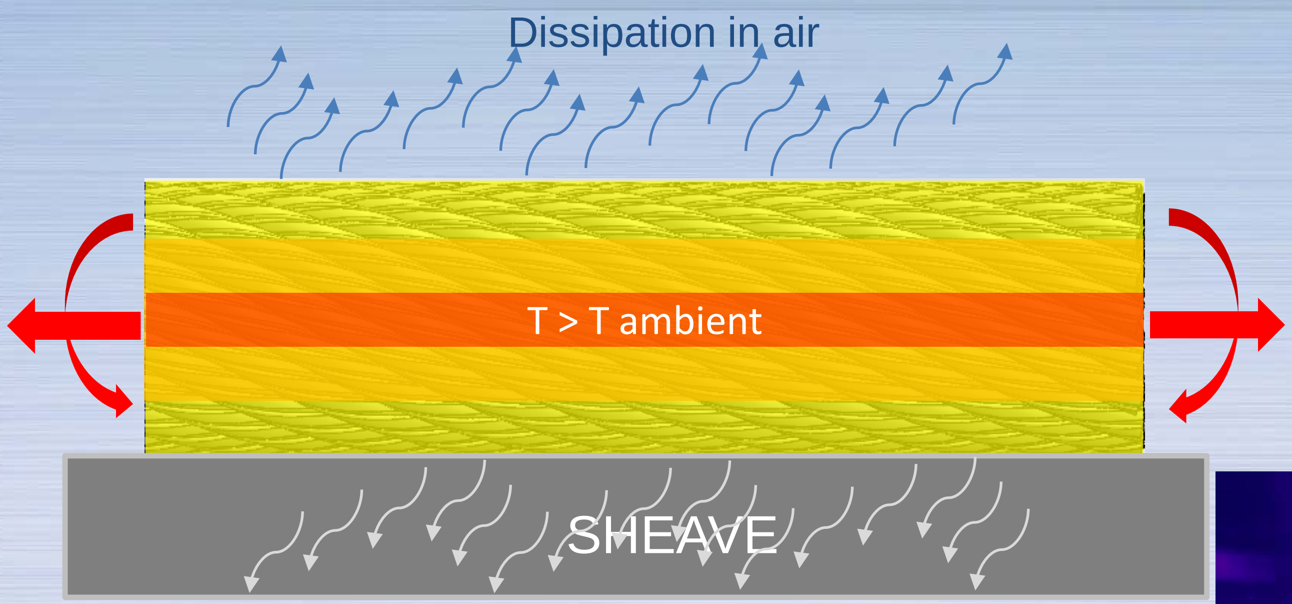


Stress induced by the AHC on the wire rope

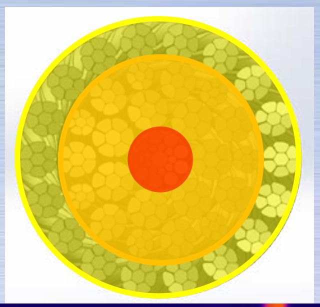




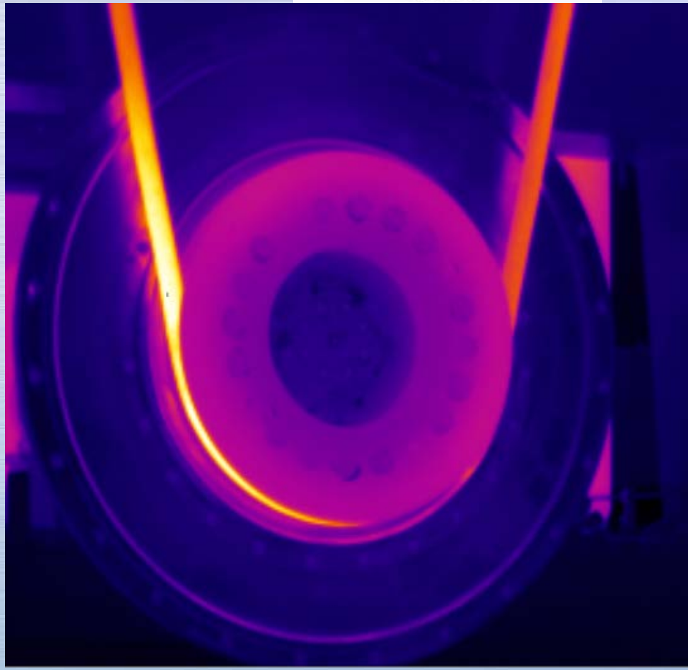
Heating generation for bending



T = ambient temperature



Continuous bending and Straightening actions generate friction forces within wires and strands. Consequently the heating rises



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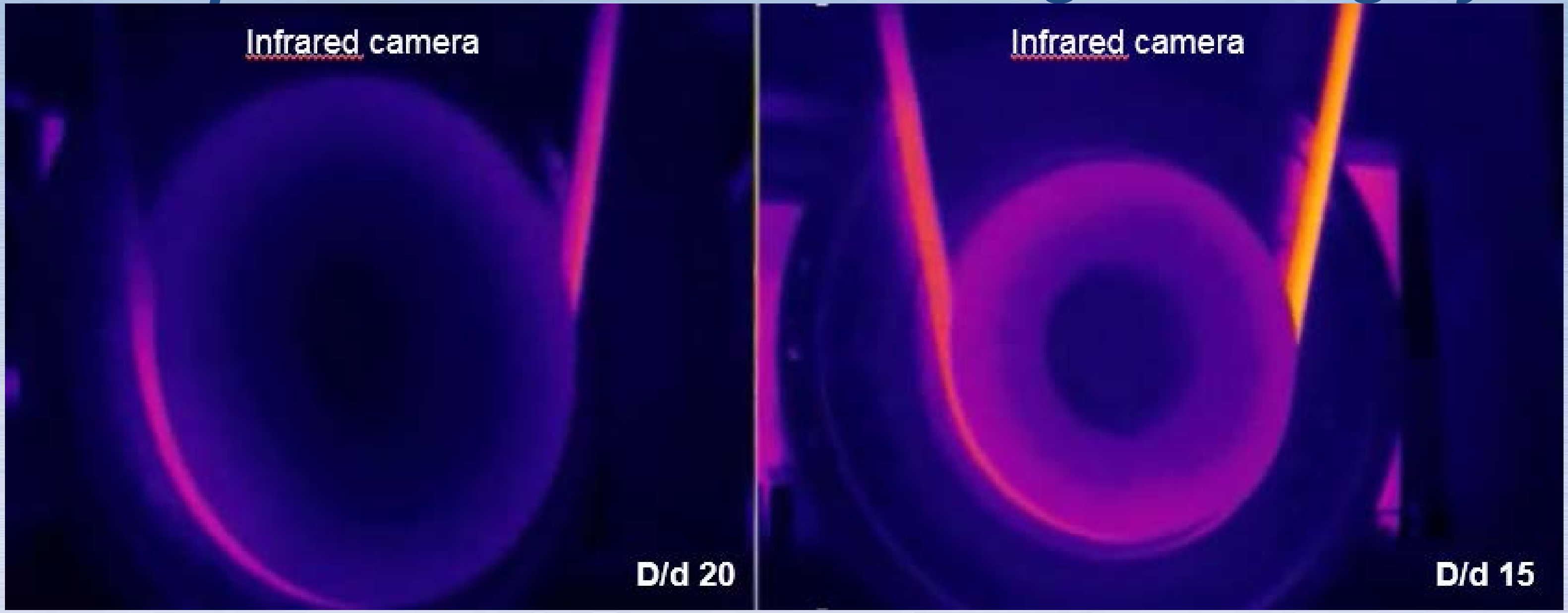
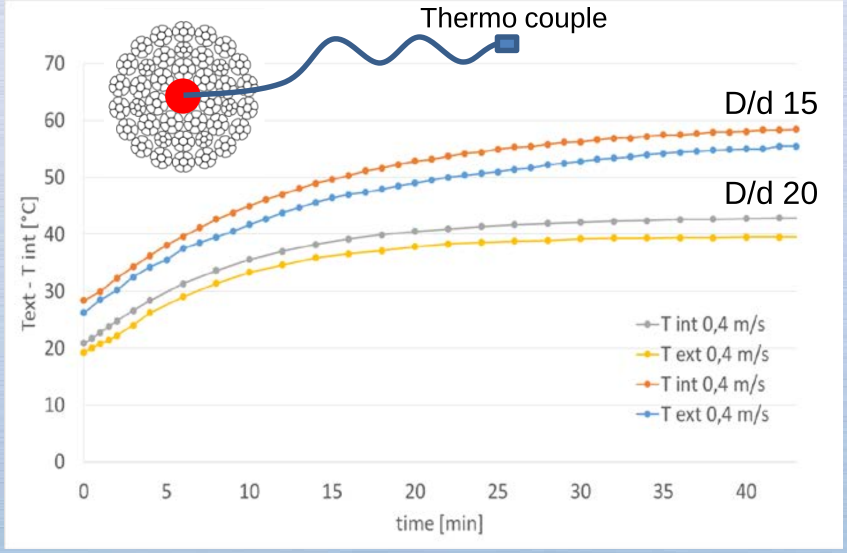
Rope Temperature variation during bending cycles





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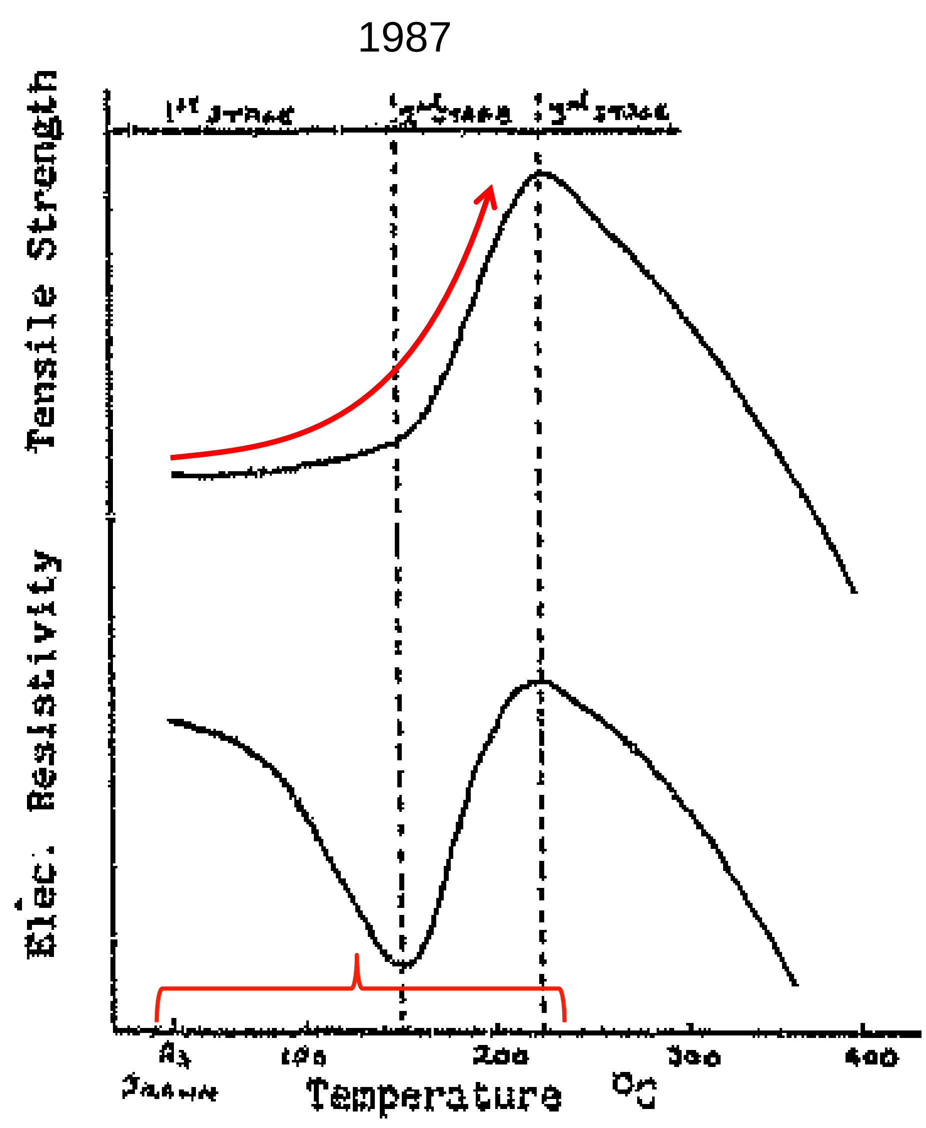
Ageing effect over the temperature



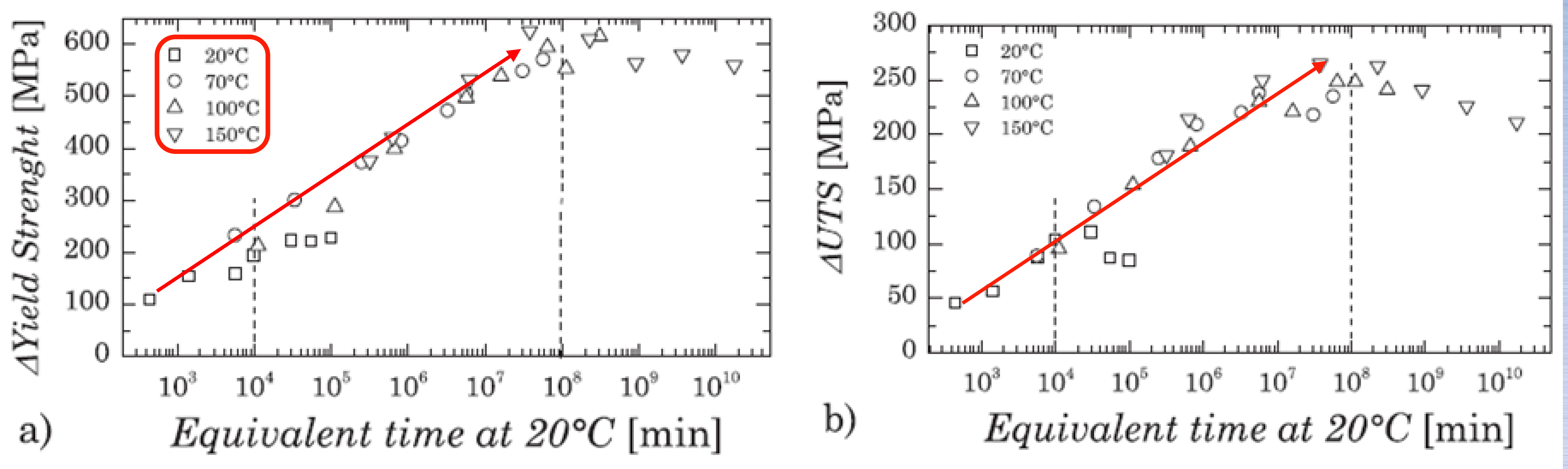
STRAIN AGEING IN ULTRA-HIGH STRENGTH DRAWN PEARLITIC STEELS

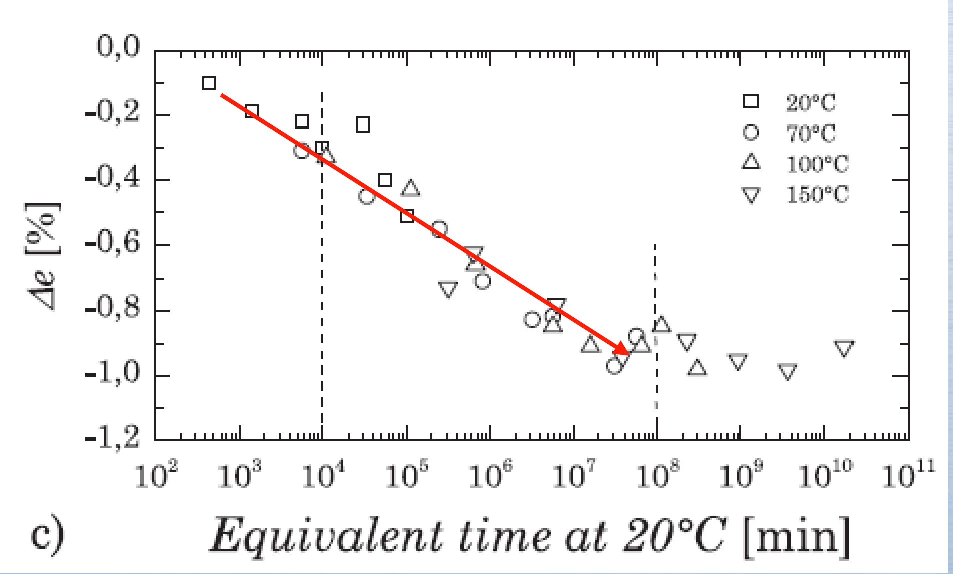
Nicholas TauJ Widdrington Davies
Department of Metallurgy and Materials Engineering
University of the Witwatersrand
April, 1987

M. Meleddu, F. Foti, L. Martinelli

Ageing effect over the temperature

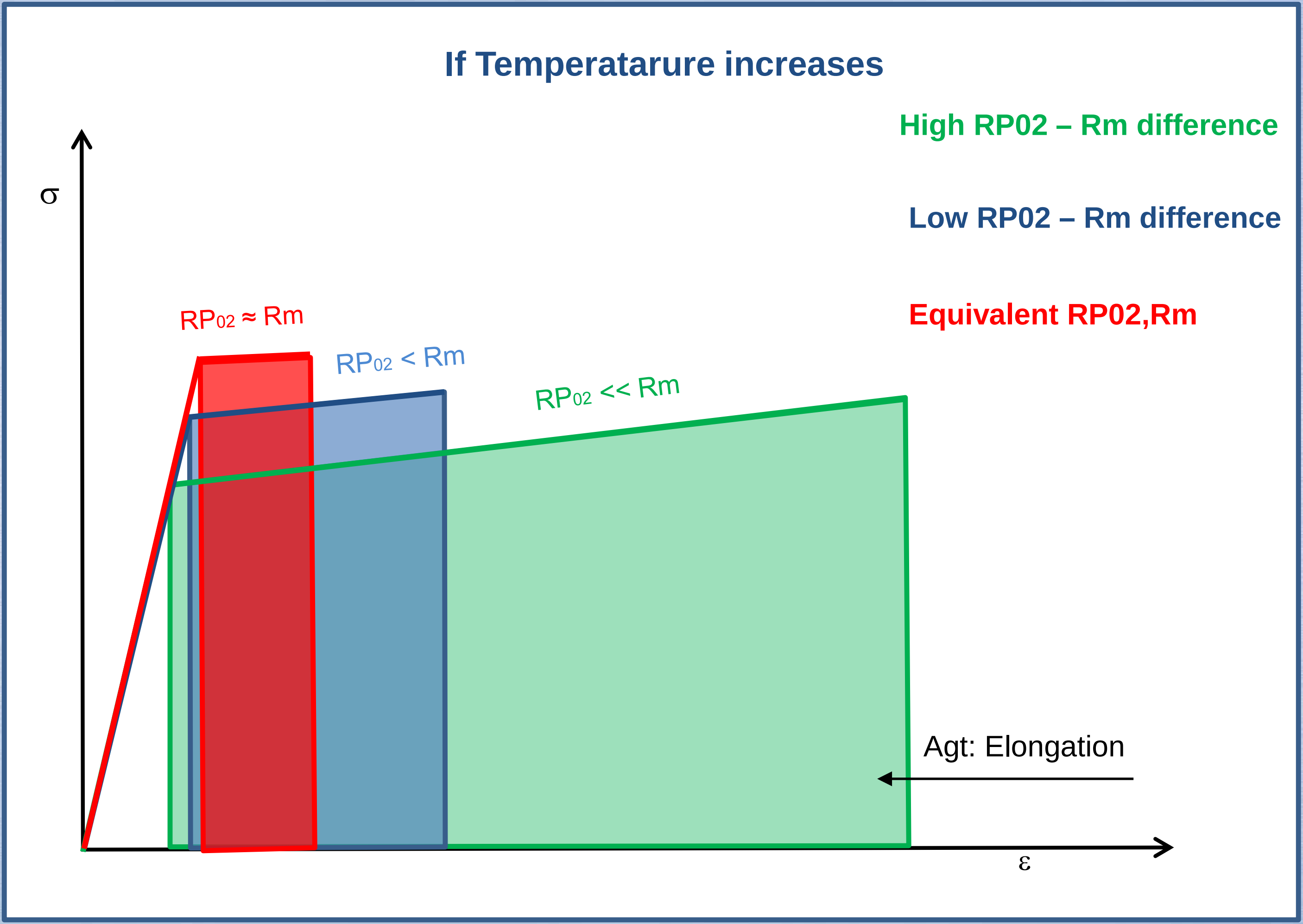
2016





Evolution of carbon distribution and mechanical properties during the static strain ageing of heavily drawn pearlitic steel wires
A.Lamontagne a, V.Massardier a,n, X.Sauvage c, X.Kléber a, D.Mari b

What if heating acts on wire?



POLITECNICO DI MILANO

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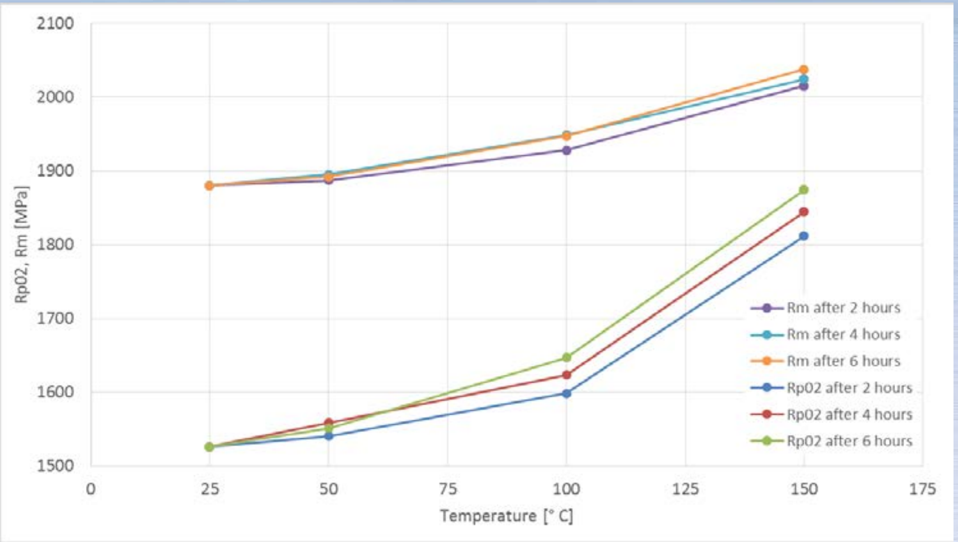
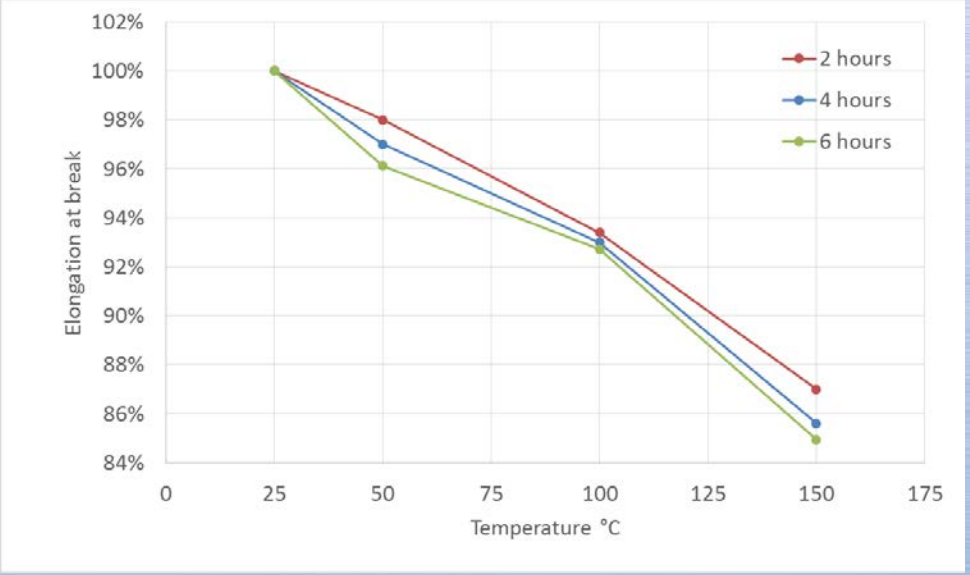
Ageing effect over the temperature





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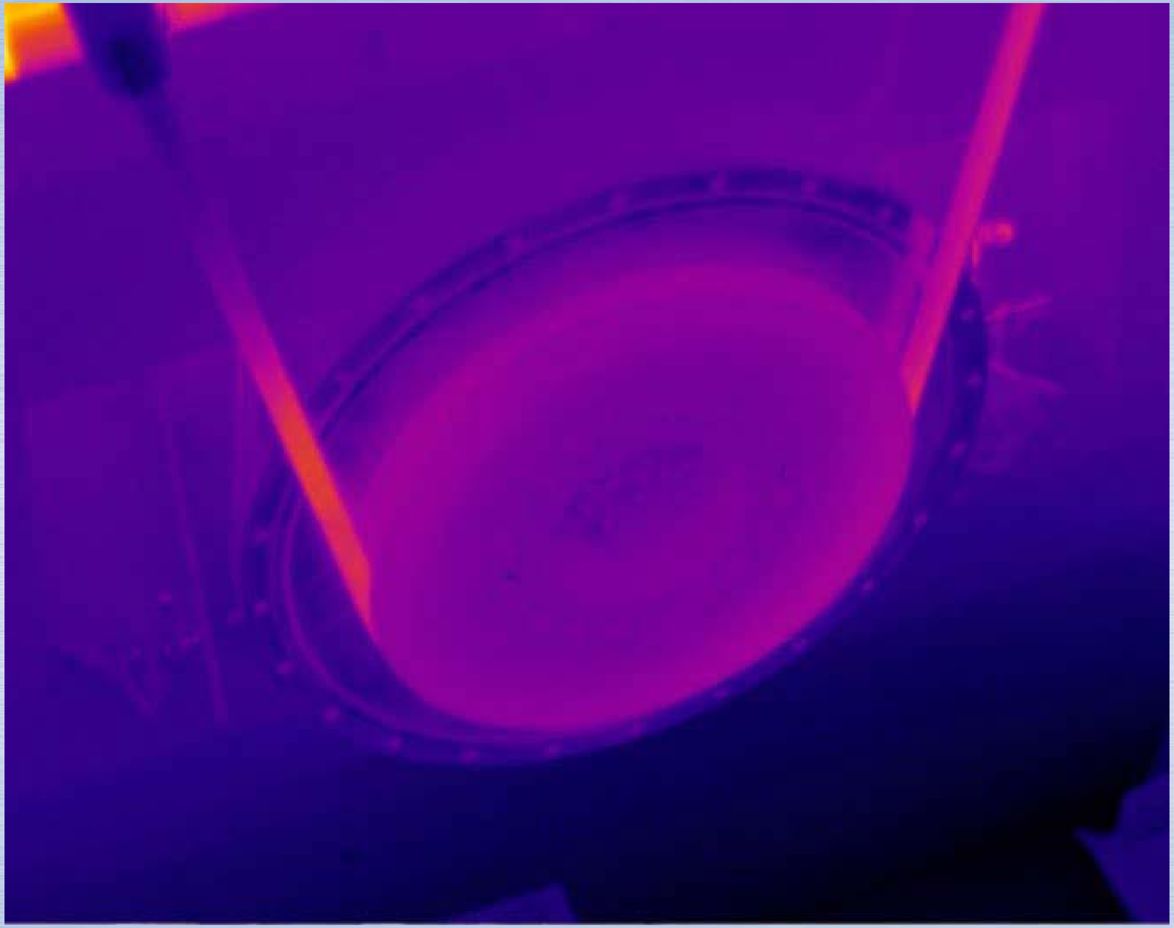
Effect of AHC on wire rope temperature



Test 1 - D/d = 20			
Load [kN]	speed [m/s]	time cycle[s]	safety factor
250	0.1	64	10
	0.4	32	10
357	0.1	64	7
	0.4	32	7
500	0.1	64	5
	0.4	32	5

Test 2 - D/d = 15			
Load [kN]	speed [m/s]	time cycle[s]	safety factor
250	0.1	64	10
	0.4	32	10
357	0.1	32	7
	0.4	32	7
480	0.1	32	5
	0.4	32	5

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Experimental Results

ΔT with respect to the ambient temperature for D/d 20 and D/d 15 at 0,1 m/s

D/d 20 @ 0.1 m/s		
Load (kN)	**ΔText measured °C**	**ΔTint measured °C**
250	5.6	7.8
357	9.8	11.9
500	11.7	13.6

D/d 15 @ 0.1 m/s		
Load (kN)	**ΔText measured °C**	**ΔTint measured °C**
250	8.0	10.1
357	10.7	12.7
480	15.4	17.3

Numerical modelling of the tests

Objectives

1) Modelling of the thermo-mechanical behavior of non-rotating ropes running over a sheave, starting from the knowledge of:

- their internal geometry;
- the mechanical behavior of their basic components (i.e. wires);

2) Estimate the maximum increment of the rope temperature under different loading and speed conditions.

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The mechanical model of the rope

Proposed approach

➢ ***Discrete approach: each strand of the rope is modeled as an elastic curved thin rod*** *(with helicoidal centerline), according to the Kirchhoff-Clebsch-Love structural theory and accounting for the interactions with the neighbours. The response of the rope is then obtained by summing the contributions stemming from all the components.*

Methodology

✓ *Mathematical description of the internal structure of rope;*

✓ ***Kinematic model*** *to relate the generalized strain variables of the rope to that of each strand.* ***Alternative incremental expressions are introduced to evaluate the axial strain of the strands*** *in the case of:* ***(a) no-sliding*** *(sticking state) and* ***(b) sliding*** *(slipping state);*

✓ ***Contact model to account for the interaction between strands.***

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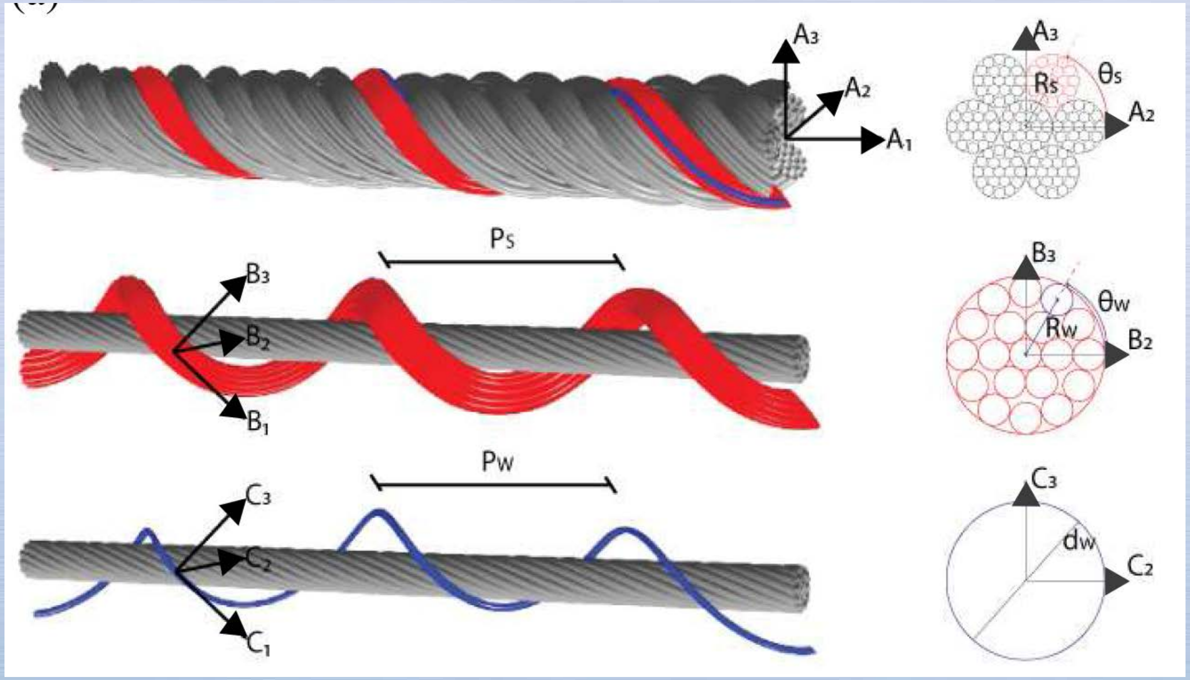
Geometric model of the rope

***Nested hierarchical geometric model** of the rope: each component is described as a circular helix in the local reference frame of the higher hierarchical level.*



Level '2': *Wire rope*
Local ref. frame: {$\mathbf{A}_i$}, *i=1,2,3*

Level '1': *Strand*
Local ref. frame: {$\mathbf{B}_i$}, *i=1,2,3*
Helix parameters: R_S, P_S.

Level '0': *Wire*
Local ref. frame: {$\mathbf{C}_i$}, *i=1,2,3*
Helix parameters: R_W, P_W.

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Mechanical model of the strand

Cross sectional response of the strand:

$$\begin{cases} F_s = EA_s\varepsilon_s + C_s\chi_{s1} \\ M_{s1} = C_s\varepsilon_s + GJ_s\chi_{s1} \\ M_{s2} = EI_s\chi_{s2} \end{cases}$$

ε_s = axial elongation;

χ_{s1} = torsional curvature;

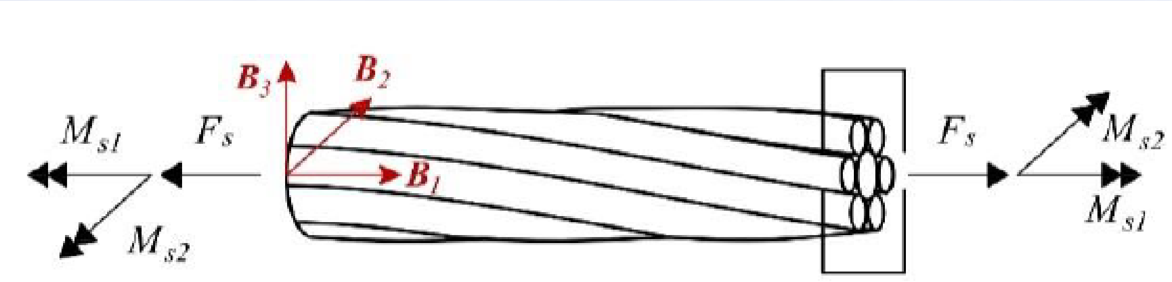
χ_{s2} = bending curvature;

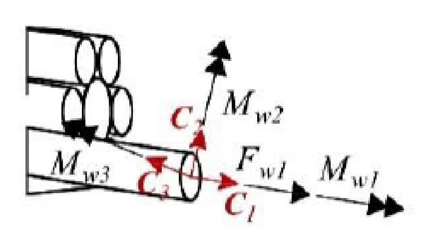
EA_s = direct axial stiffness coefficient;

GJ_s = direct torsional stiffness coeff.;

C_s = axial-torsional coupling stiffness coeff.;

EI_s = direct bending stiffness coefficient (evaluated under the full-slip assumption).





Reference:

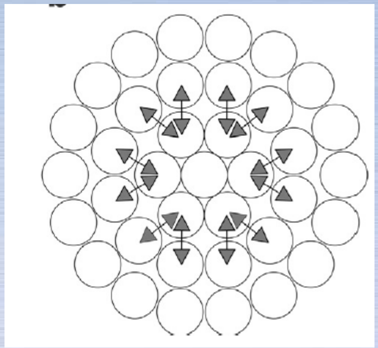
F. Foti, L. Martinelli (2016) *Mechanical modeling of metallic strands subjected to tension, torsion and bending*, International Journal of Solids and Structures 91: 1-17.

Contact model

- **Contact model**: a generic strand is assumed in **radial contact** with the strands of the adjacent (internal and external) layers;

The contact problem can be **numerically solved** (within an incremental analysis) **at a discrete set of points along the contact patches** under the following assumptions:

- **Amontons-Coulomb friction model**;
- **Non-deformable contact surface** (i.e. neglecting both normal and tangential contact compliance).

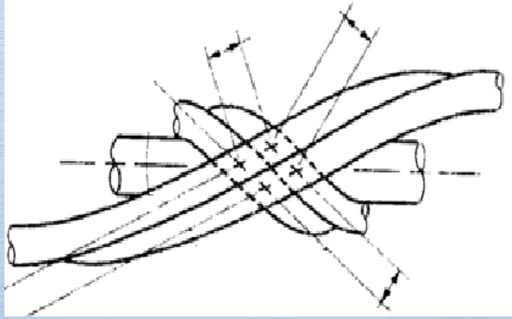


Schematic representation of radial contacts on the rope cross section

The solution strategy is fully detailed in:

F. Foti and L. Martinelli (2016) *Mechanical modeling of metallic strands subjected to tension torsion and bending*, Int. J. Sol. Struct. 91, 1-17.

F. Foti, L. Martinelli and F. Perotti (2016) *A new approach to the definition of self-damping for stranded cables*, Meccanica 51: 2827-2845.



Contact patches along the length of a strand (Figure adapted from LeClair, 1990)

Cross sectional response of the rope

Two stage approximate approach (see e.g. [*]): the solution of the bending problem is superimposed to the initial state of stress and strain due to the tensile load F_r.

Linear axial response

(Hp.: zero torsional rotation)

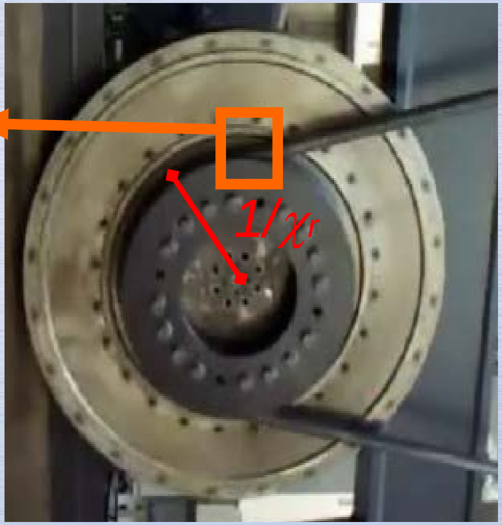
$$\begin{cases} F_r = \boxed{EA_r \varepsilon_r} \\ M_r = \boxed{EI_{\min} \chi_r} + \boxed{M_r^{add}(\varepsilon_r, \chi_r)} \end{cases}$$

Linear contribution to the bending response

Non-Linear contribution to the bending response

ε_r = axial strain of the rope;

M_r = cross sectional bending moment of the rope



F_r

F_r

Reference:

[*] A. Cardou, C. Jolicoeur (1997) *Mechanical models of helical strands*, Applied Mechanics Reviews ASME 50: 1-14.

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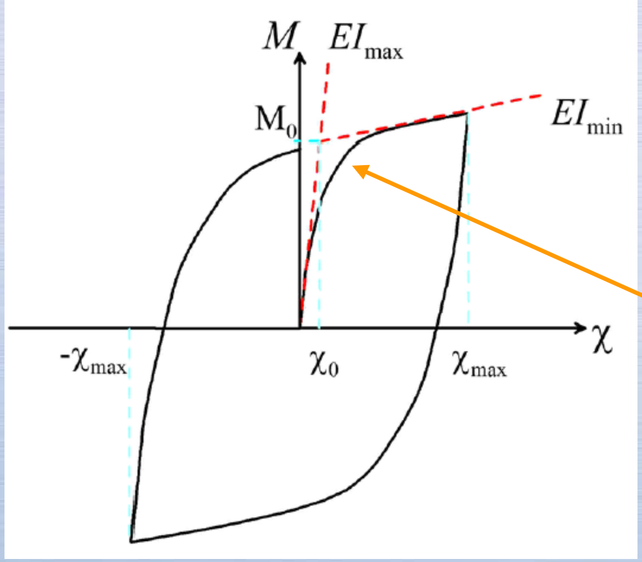
Cross sectional response of the rope

Linear axial behaviour

$$F_r = \boxed{EA_r}\,\varepsilon_r$$

$$\boxed{EA_r = \sum_{j=0}^{m} n_j \cos^3\left(\alpha_{s,j}\right) EA_{s,j}}$$

Hysteretic Bending behaviour



Typical bending response predicted by the proposed model

- *Limit kinematic behaviours:*

  (a) *Ideal plane cross section ("Full-stick" state);*

  (b) *Individual wire behaviour ("Full-slip" state)*

- *Non-linear transition governed by* ***inter-strand sliding*** *in presence of friction (Amontons-Coulomb model)*

- *Dissipated energy:* $A_c = \oint_{\pm\chi_{max}} M_s(\chi_s)\,d\chi_s$

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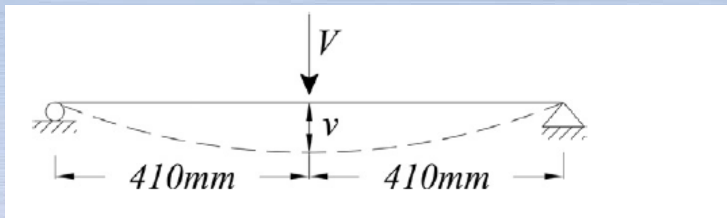
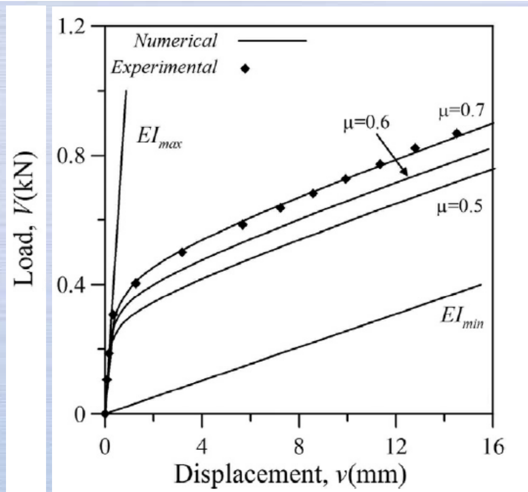
Calibration of the hysteretic model: example

Numerical example from [1]. Calibration of the internal friction coefficient, μ, from quasi-static loading test. Steel strand with diameter d=38 mm. Experimental results from [2].



Schematic representation of the experimental test setup.



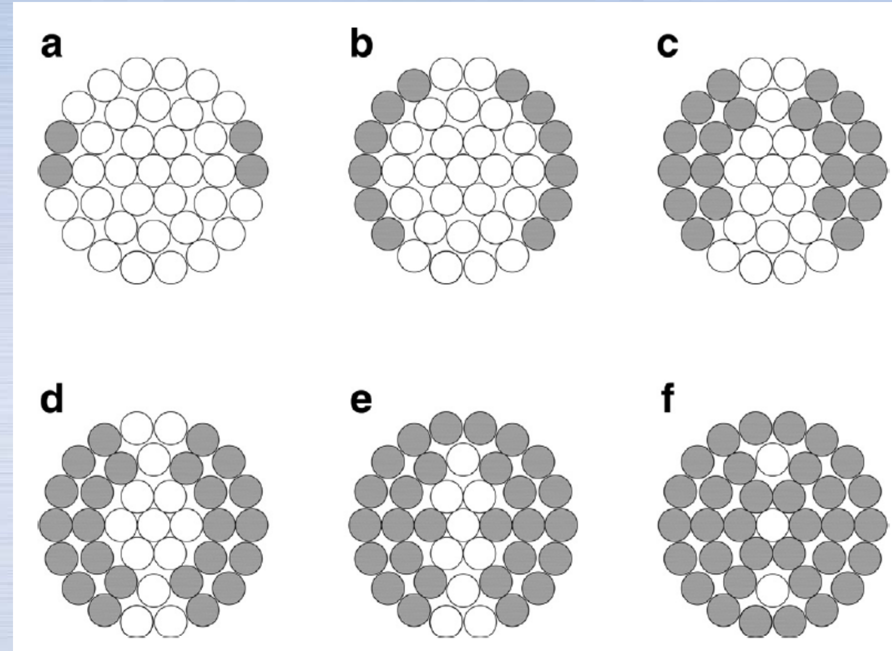


Fig. 18. Distribution of wires in slip-state (hatched) for the section at the mid span, in the loading range $V = 200–460$ N. Friction coefficient $\mu = 0.7$; residual radial contact force: $R = 4$ N/mm. (a) $V = 200$; (b) $V = 260$; (c) $V = 300$; (d) $V = 360$; (e) $V = 400$; (f) $V = 460$; .

[1] F. Foti, L. Martinelli (2016) *Mechanical modeling of metallic strands subjected to tension, torsion and bending*, Int. J. Sol. Struct. 91: 1-17.
[2] Z. Chen et al. (2015) Experimental research on bending performance of structural cable, Constr. Build. Mater. 96: 279-288.

Thermal model

Experimental tests show that the temperature increase is highly localized in the region subjected to alternate bending, with a small heat transfer to the straight regions of the rope (see also [*]).

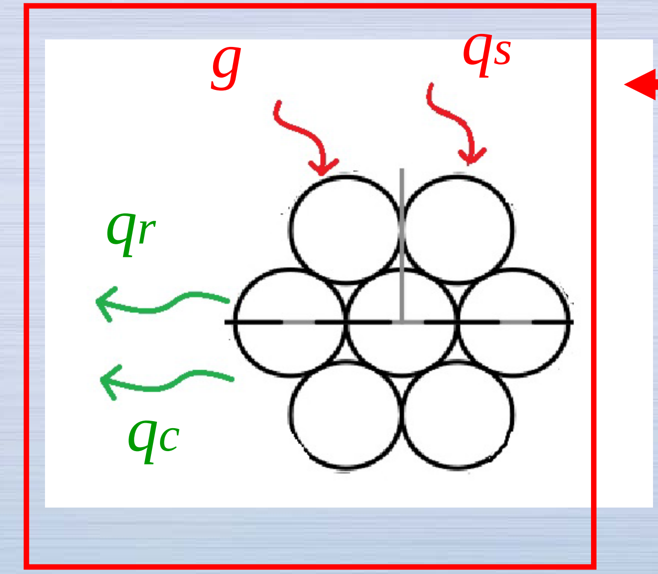
Heat balance for a cross section subjected to alternate bending:

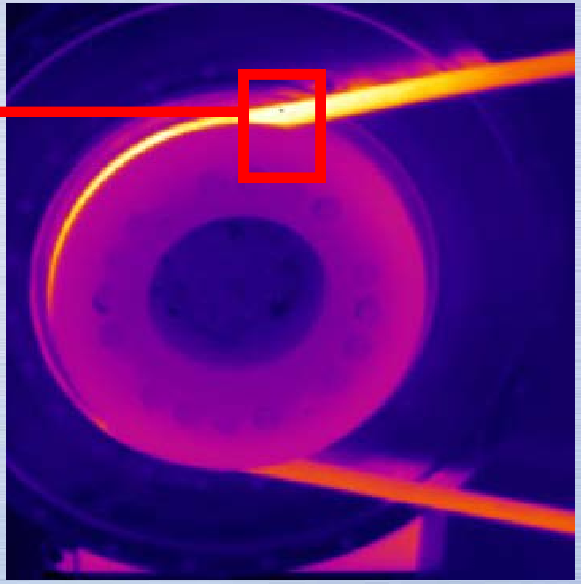
g = heat source;

q_s = solar heat gain;

q_r = radiated heat loss;

q_c = conducted heat loss.



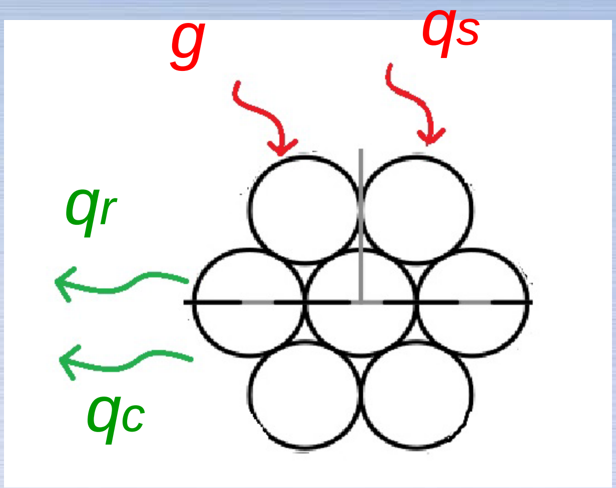


Reference:

[*] O. Venneman et al. (1997) *Bending fatigue testing of large diameter wire rope for subsea deployment application*, in: Prooc. 8° Int. Offshore and Polar Eng. Conf, 6-11 July, Vancouver (Canada).

Thermal model

Heat balance for a cross section subjected to alternate bending



Heat generation mechanisms:

1) *Friction between the components of the rope (strands):* *In steady-state conditions, this term can be evaluated from the value of the dissipated energy A_c predicted by the proposed hysteretic bending model;*

2) *Friction between the rope and the sheave:* *This term, which can be relevant in practical conditions, is neglected, in this work, to simulate laboratory testing conditions.*

Heat exchange between the rope and the environment:

The terms q_c, q_r and q_s are calculated by means of the definitions provided by the American National Standard (IEEE, 1986)

Standard for the Calculation of Bare Overhead Conductor Temperature and Ampacity Under Steady State Conditions. ANSI/IEEE Std 738-1986

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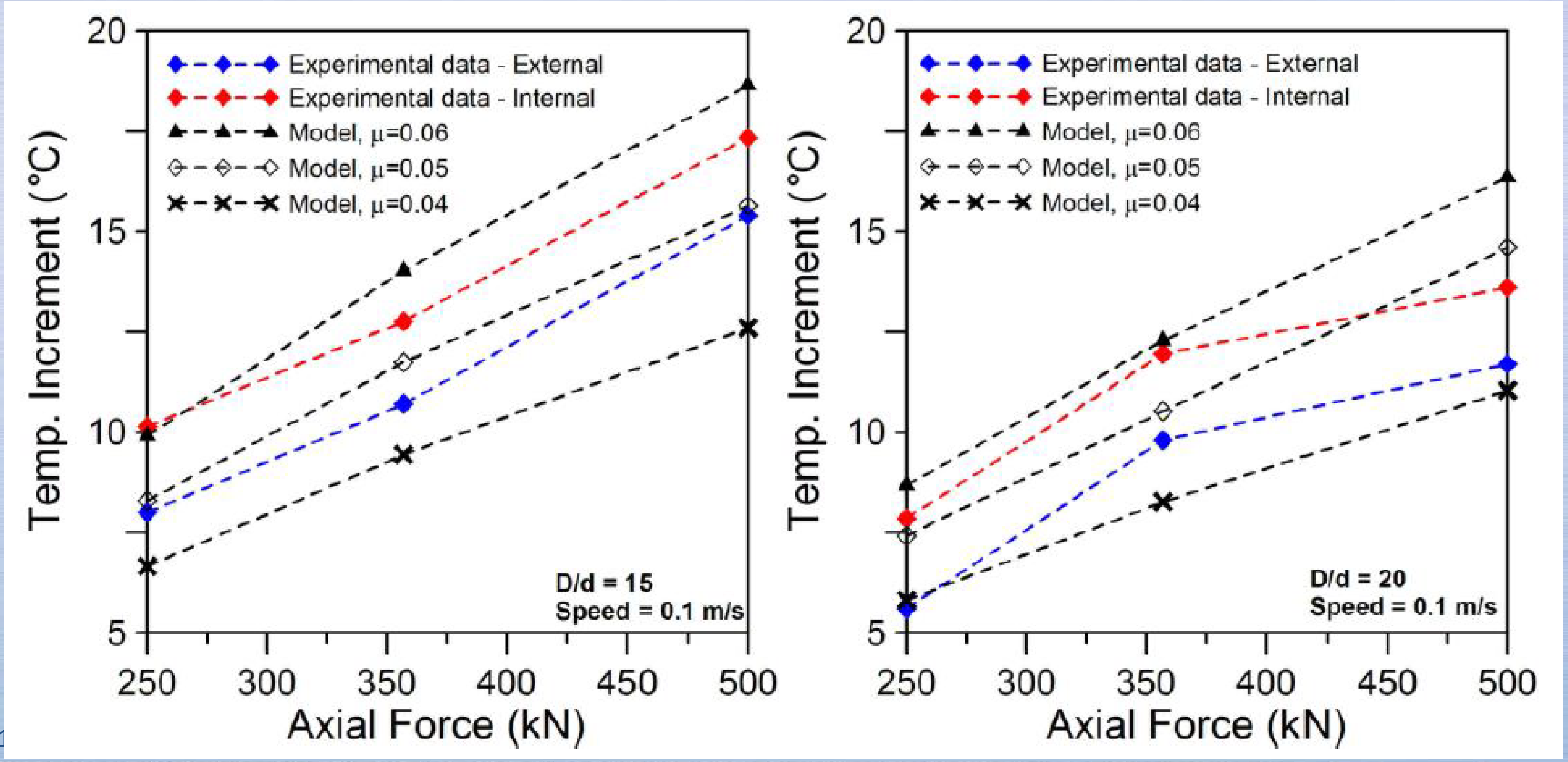
Simulation of experimental tests

Comparison among the measured internal and external temperature increments of the rope and the average temperature predicted by the proposed model. Three different values of the inter-strand friction coefficient are considered for comparative purposes.



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Thank you