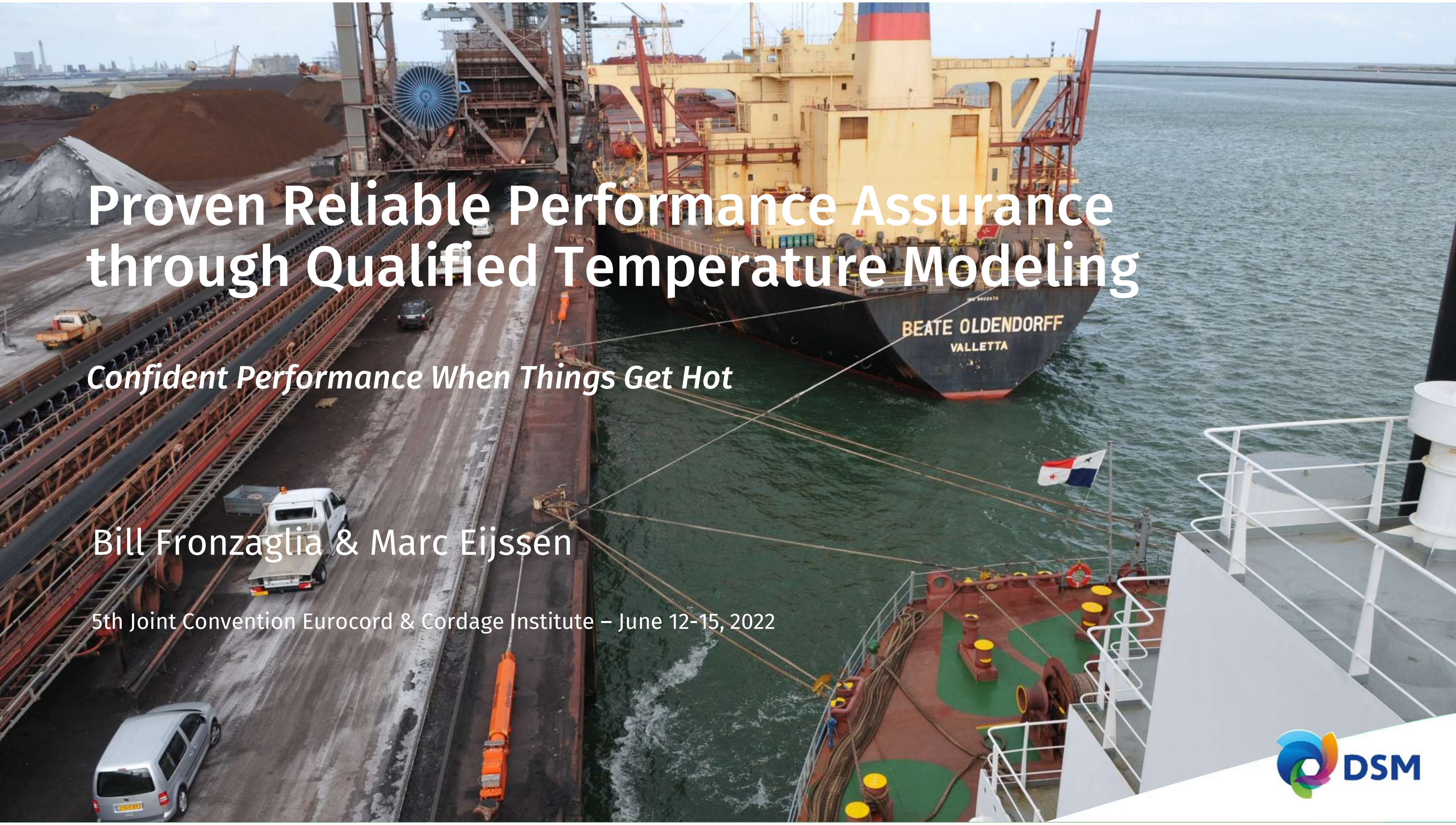

Proven Reliable Performance Assurance through Qualified Temperature Modeling

Confident Performance When Things Get Hot

Bill Fronzaglia & Marc Eijssen

5th Joint Convention Eurocord & Cordage Institute – June 12-15, 2022

DSM

Confident Performance When Things Get Hot

- Temperature has a big influence on rope performance
- Fiber thermal properties are well understood – 3T
- Modeling Thermal Performance in several applications
  - Heat Source/Sink Exposure
    - ❑ Static contact
    - ❑ Remote thermal radiation source
  - Cyclic Loading
    - ❑ Validated : 5mm, 21mm & 42mm
    - ❑ Safe Use Maps
  - Extrusion Process
    - ❑ Thermoplastic & Thermoset Jacket Extrusion & Laminating

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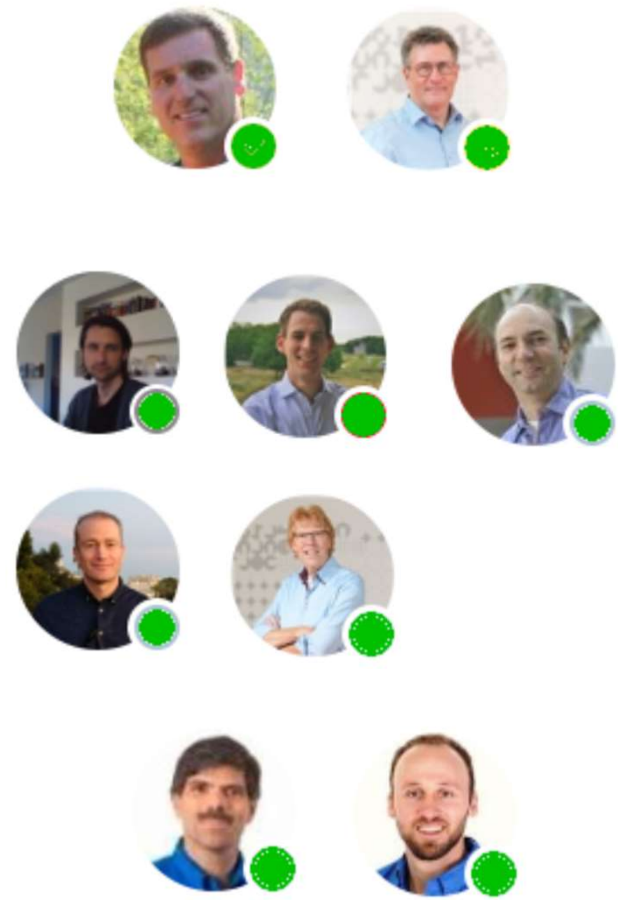
Thanks to the work of many!

Thanks to the work of many dedicated DSM engineers & technicians

- Temperature modelling of Dyneema® ropes under cyclic loading
  Tom Engels, Alessandro Gualdi, Peter Roozemond, Martin Vlasblom

- Thermal analysis of extrusion coating process
  Marcel Meuwissen

- Mooring line performance in warm climate and dynamic conditions
  Alessandro Gualdi, Peter Roozemond, Jac Spijkers, Jim Plaia (Samson), Kris Volpenhein (Samson)



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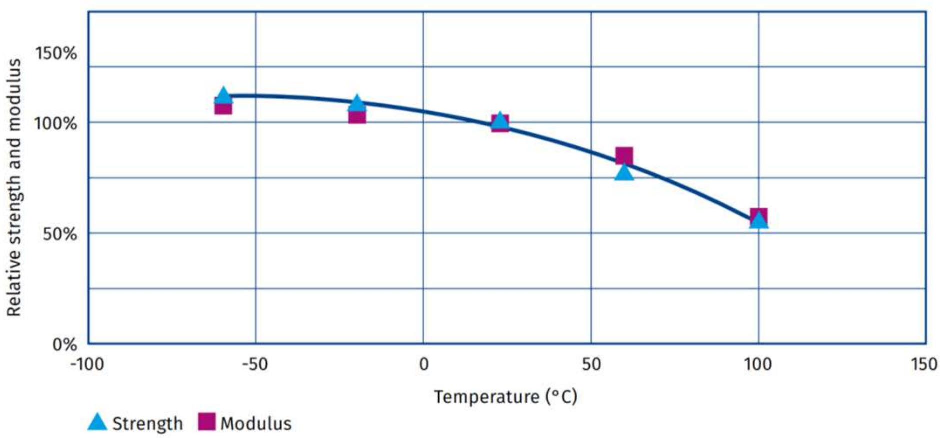
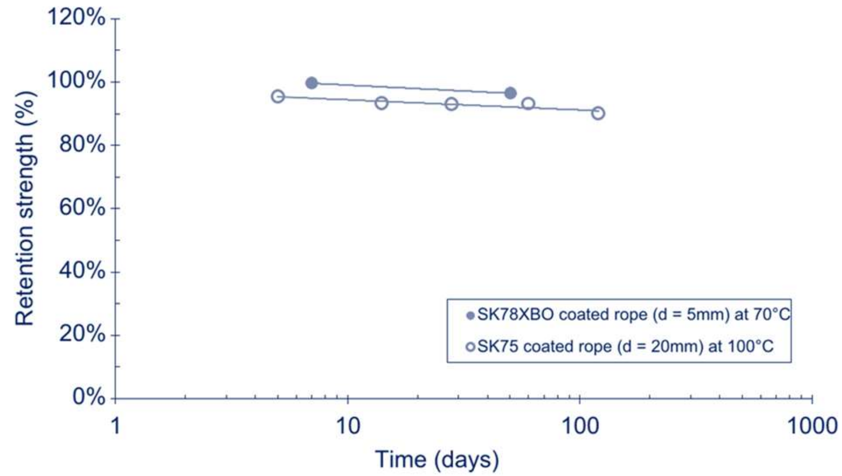
Dyneema® Fiber-Thermal Properties

Thermal		
Melting range	144 - 152	°C
Decomposition temperature	> 300	°C
Advised lowest temperature	No limit	
Advised long duration temperature limit	70*	°C
Advised short duration temperature limit (non-constrained fiber)	130	°C
Advised short duration temperature limit (constrained fiber)	145	°C
Coefficient of linear thermal expansion	-12×10^{-6}	1/K
Specific heat capacity	1,850	J/kg.K
Thermal conductivity (axial)	20	W/m.K
Thermal conductivity (transverse)	0.2	W/m.K

* Limit is a practical limit for long duration (months to years) for cyclic loaded rope applications





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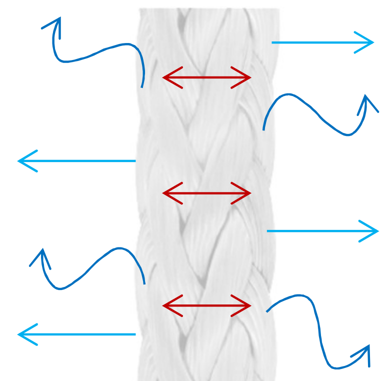
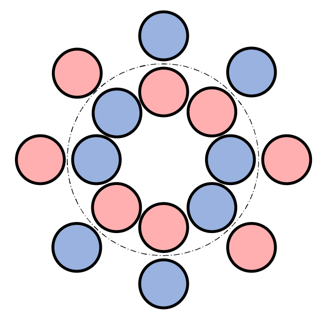
First Principles Model

- Heat is generated inside the rope:
  - Heat spreads because of conduction;
  - Heat is exchanged with the environment through convection and radiation.
- Steady-state temperature is achieved when the heat exchange mechanisms balance the heat production;
- Two types of heat sources are identified:
  - Visco-elastic contribution from the material:
    - Hysteresis.
  - Frictional contributions between the strands:
    - Axial slip;
    - Scissoring.



Schematic representation of heat transfer mechanisms.



The rope is modelled as a set of strands applying contact pressure on each other.

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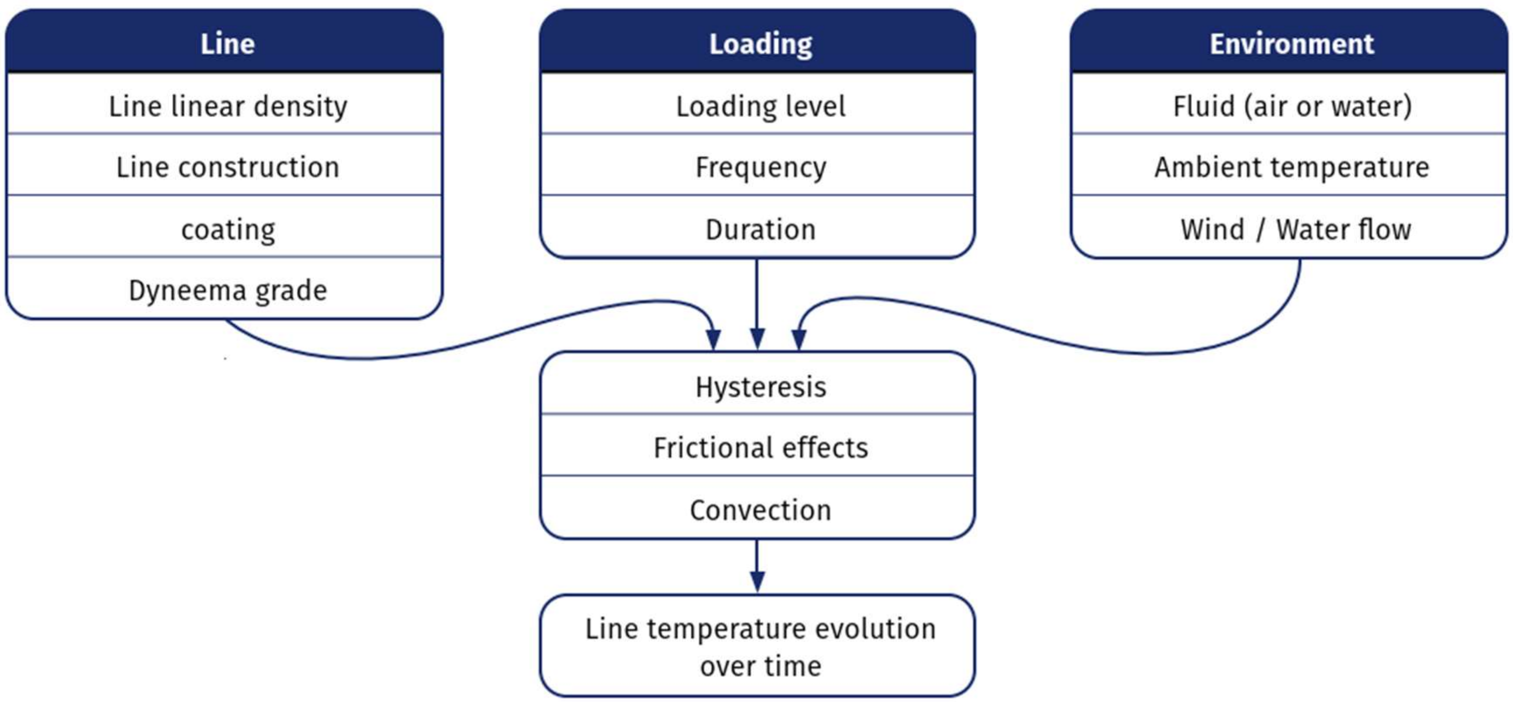
Temperature model for ropes with Dyneema®



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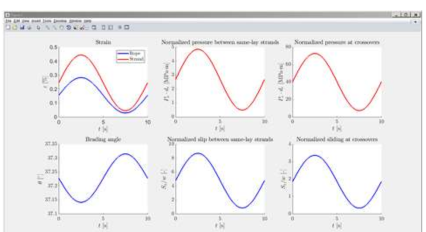
Model Input

A physics- and geometry-based model is developed.

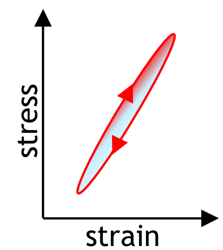
The model is able to describe the influence of the following parameters:

- Applied load
- Frequency
- Stress ratio
- **Construction (braiding angle, number of strands)**
- **Rope size**
- Material (Dyneema® grade)
- Coating



Three sources of energy dissipation are identified:

- Hysteresis
- Axial slip
- Scissoring



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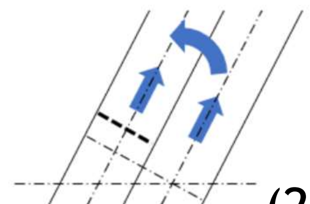

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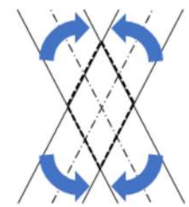

(3)

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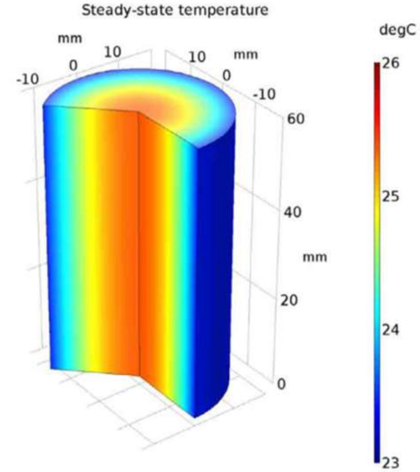
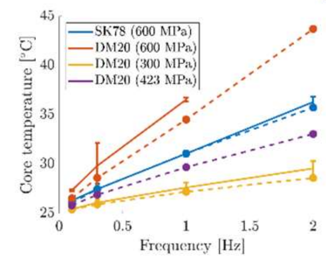
Model Results

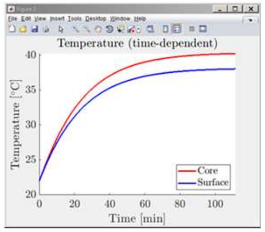
- Heat generation mechanisms
  - Visco-elastic (material) and frictional (geometry and coating) contributions are identified as heat sources.

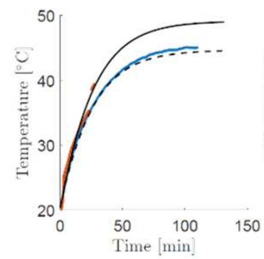
- Influence of parameters
  - Analytical model correctly describes all the parameters;
  - Validated for diameters up to 42mm.

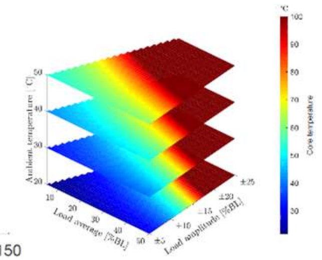
- Quantitative predictions
  - Good agreement with experiments;
  - Safe-use maps;
  - Tool for temperature predictions.











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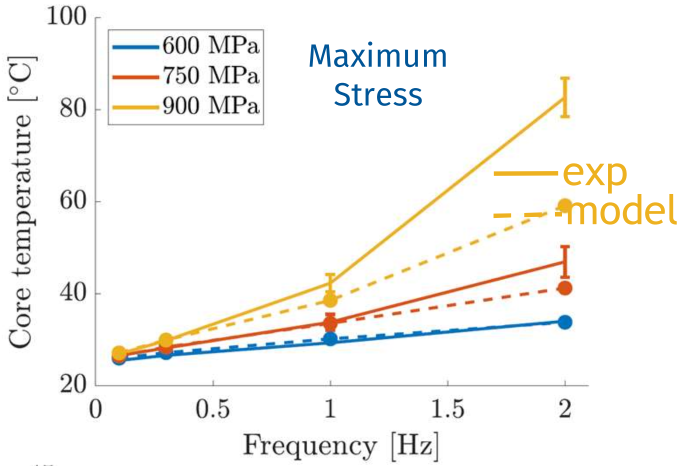
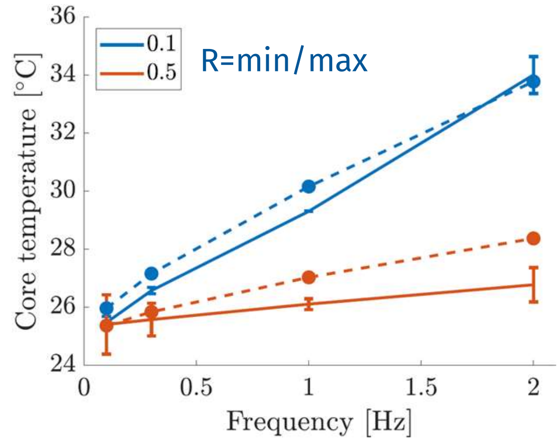
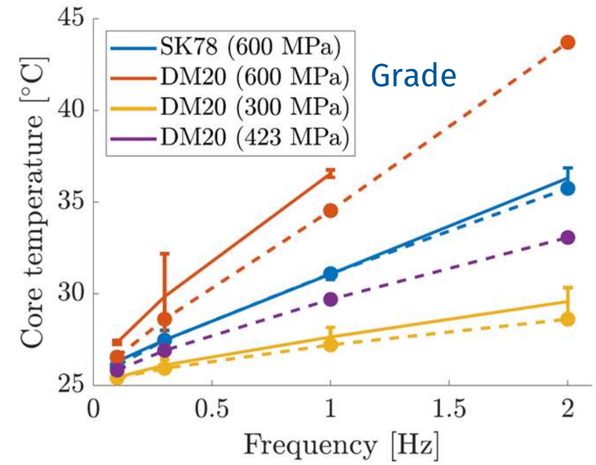
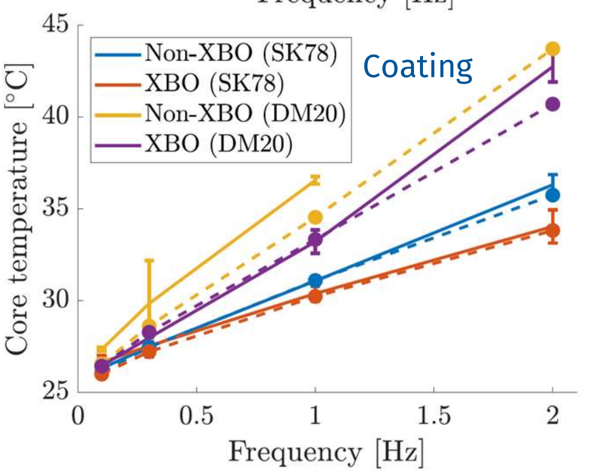
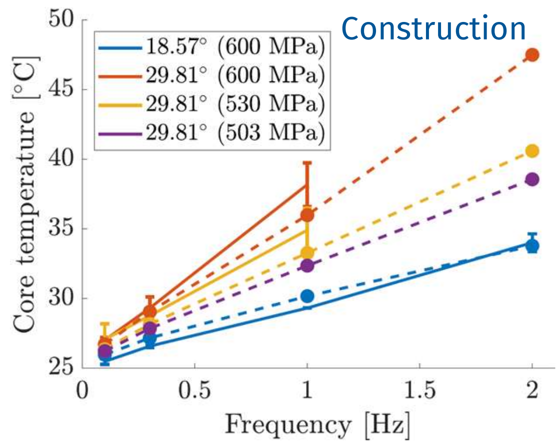
Validated Results – 5mm & 21mm

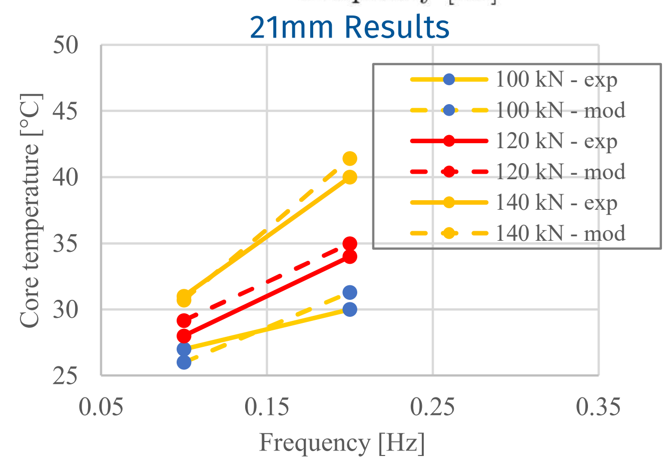












Tests performed internally by DSM; continuous lines: experiments; dashed lines: model.

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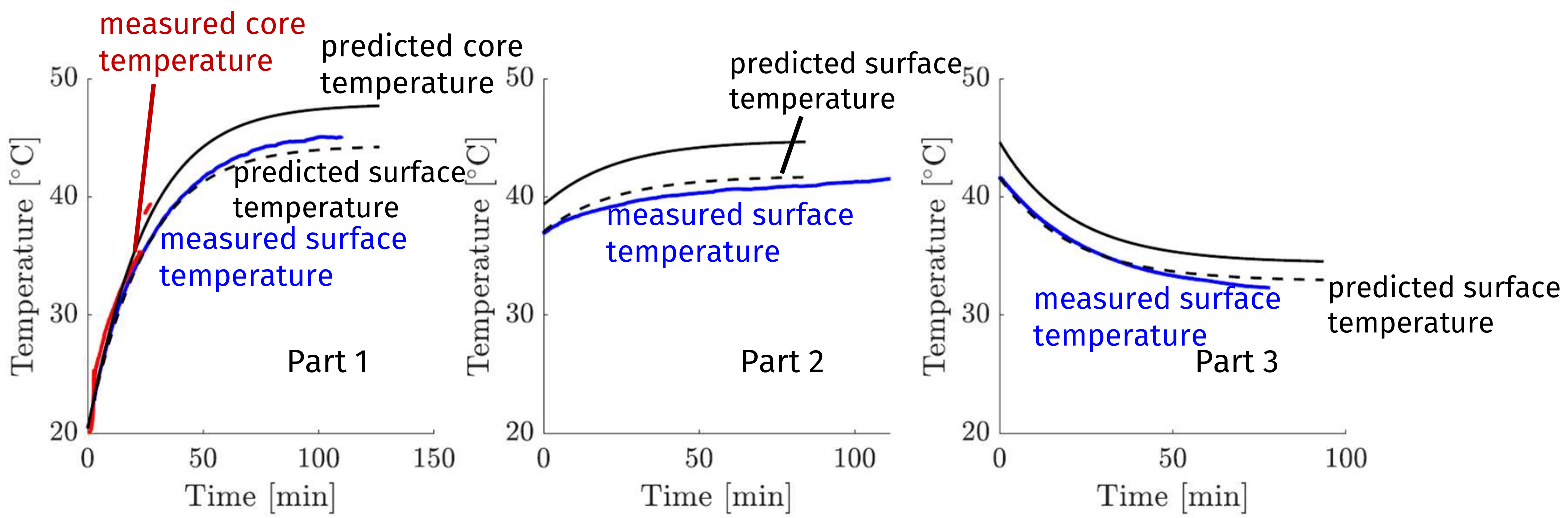
Validated Results – 42mm

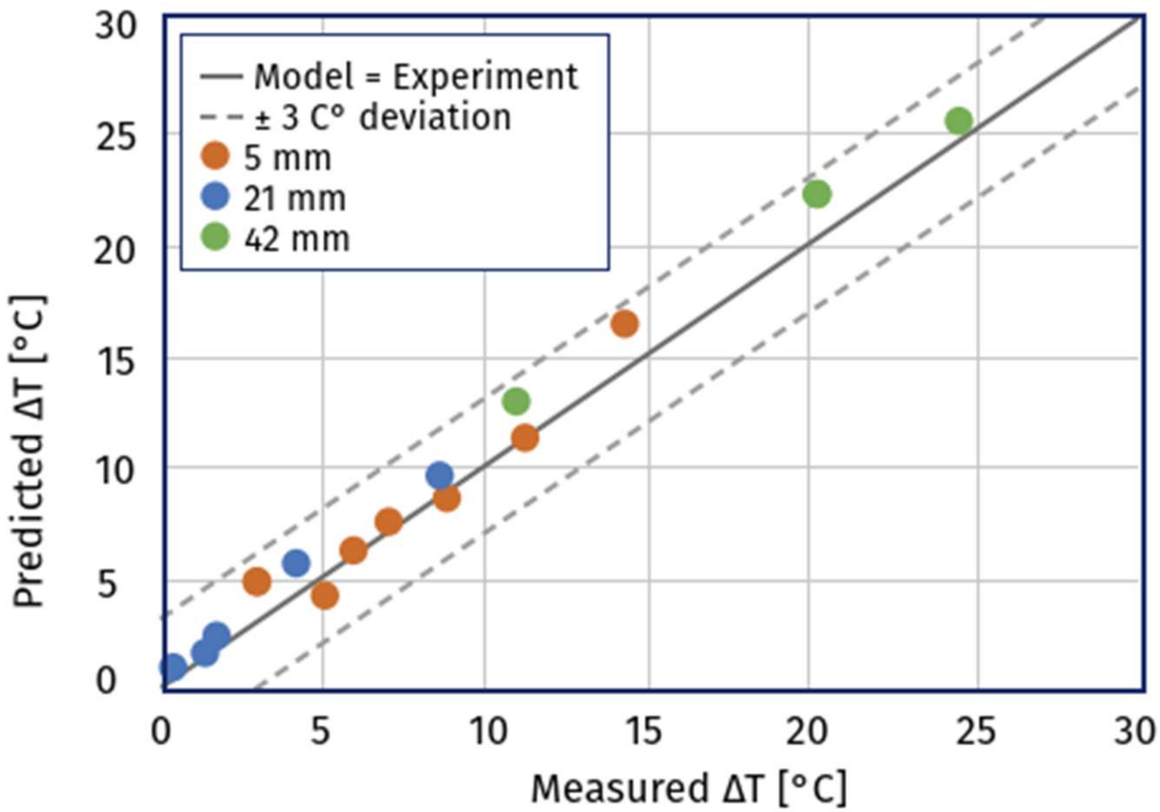
Tests performed external of DSM



Blue and red lines: surface and core temperatures (experiment), respectively.

Black dashed and solid lines: surface and core temperatures (model), respectively.

Qualified Temperature model



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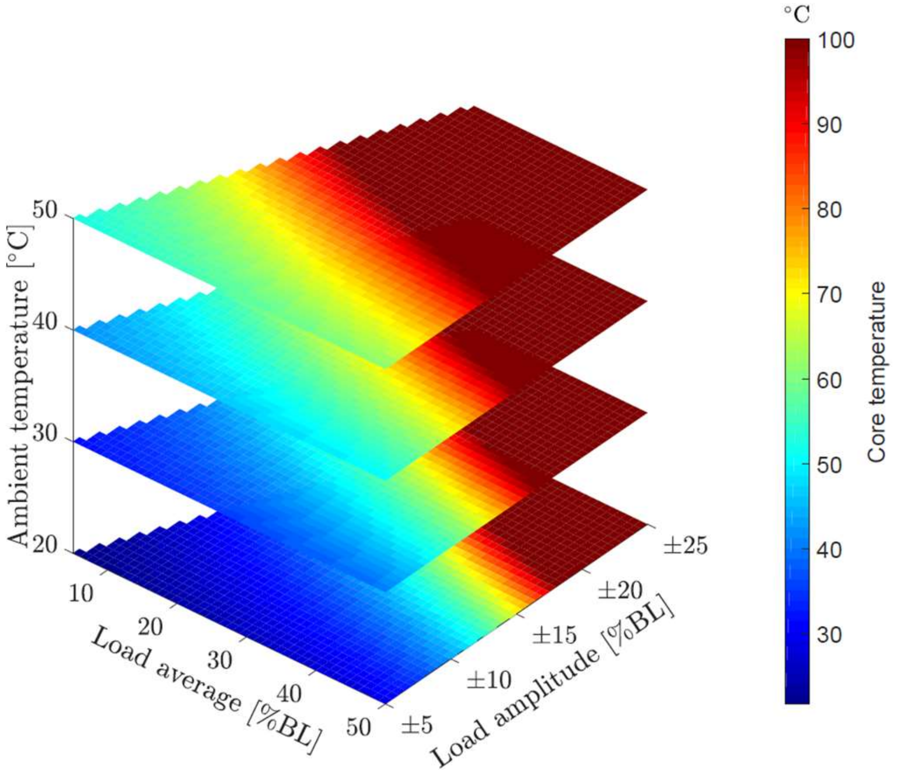
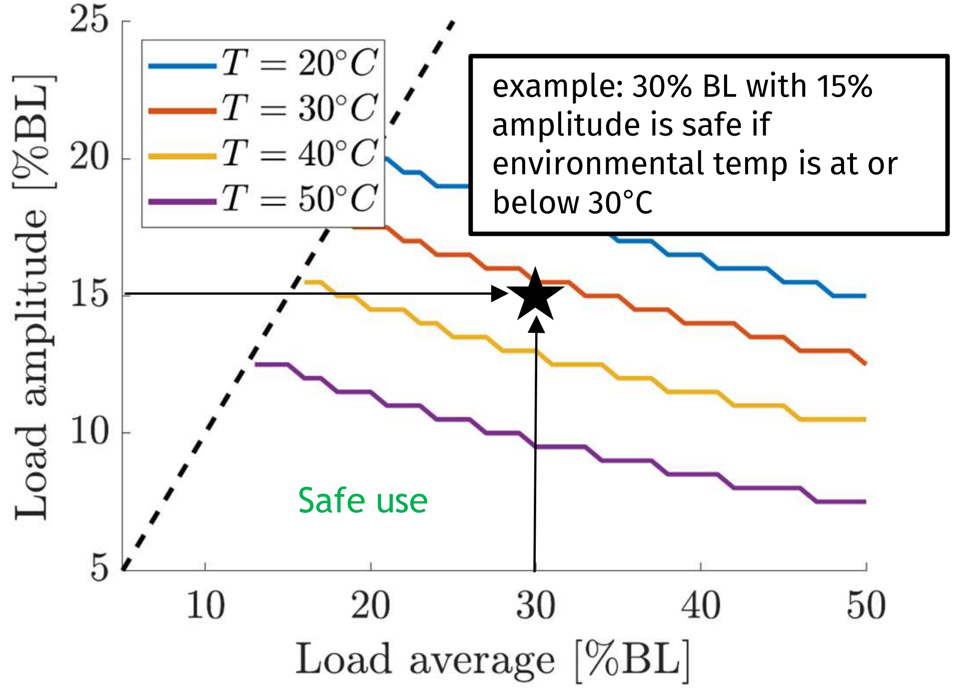
Application – Safe-use maps





Example of safe-use map for a 42mm rope. Light breeze (wind speed = 2 m/s) is assumed. Critical core temperature for applications is taken equal to 70°C.

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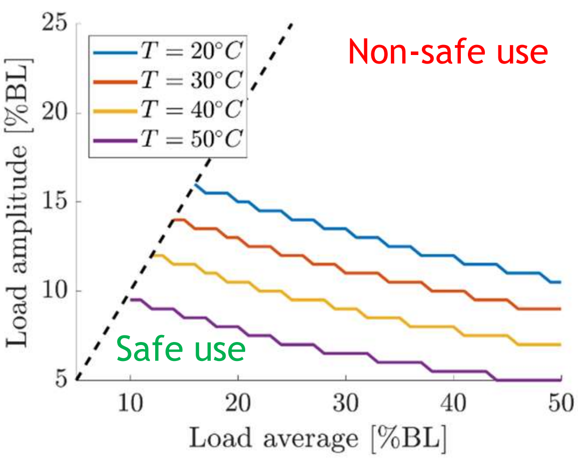
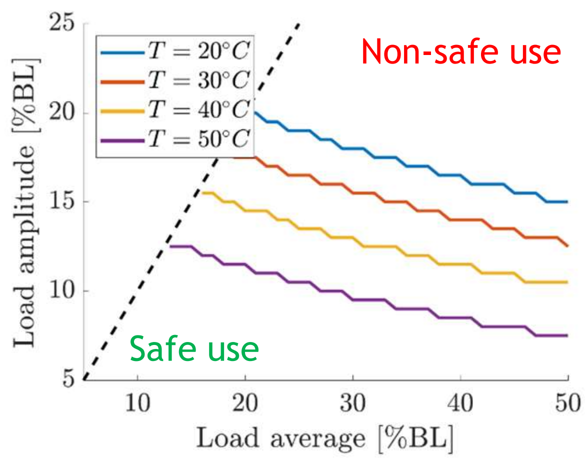
Safe Use Map – 42mm in air

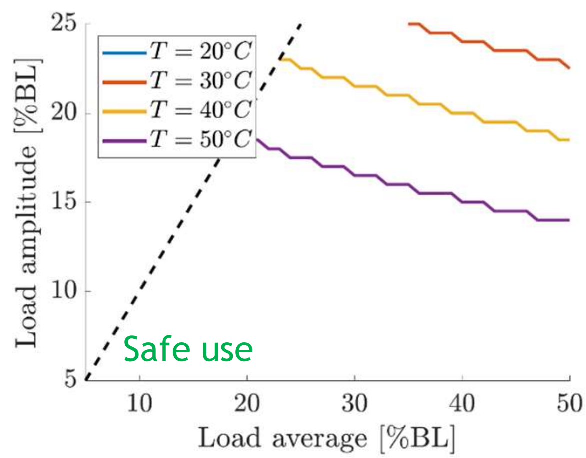
Summary of the safe-use boundaries for 42-mm ropes in air.



Natural convection (U=0 m/s).



Forced convection (U=2 m/s).



Forced convection (U=20 m/s).

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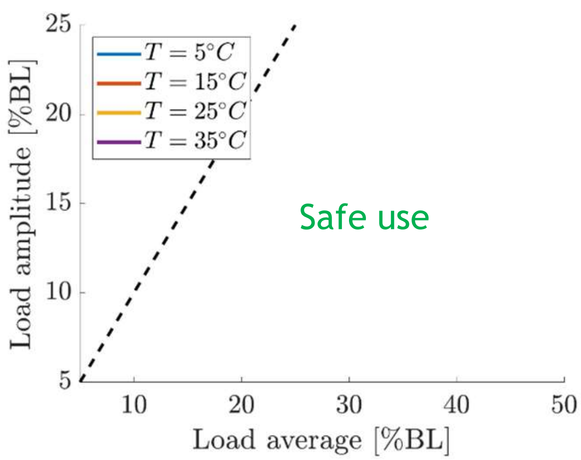
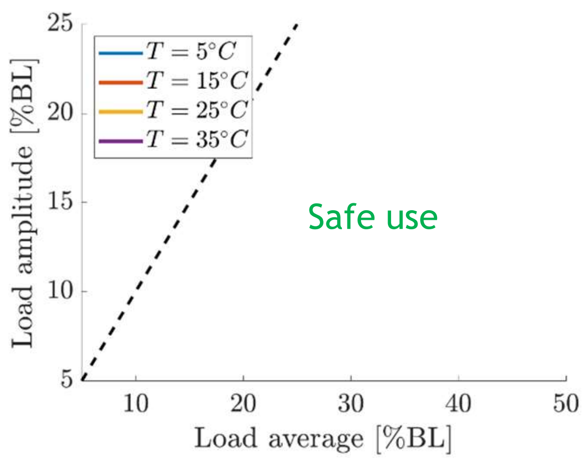
Safe Use Map – 42mm in water

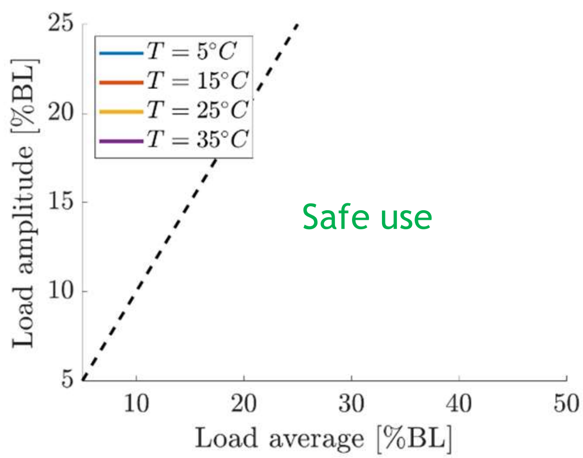
Summary of the safe-use boundaries for 42-mm ropes in water.



Natural convection (U=0 m/s).



Forced convection (U=5 m/s).



Forced convection (U=12 m/s).

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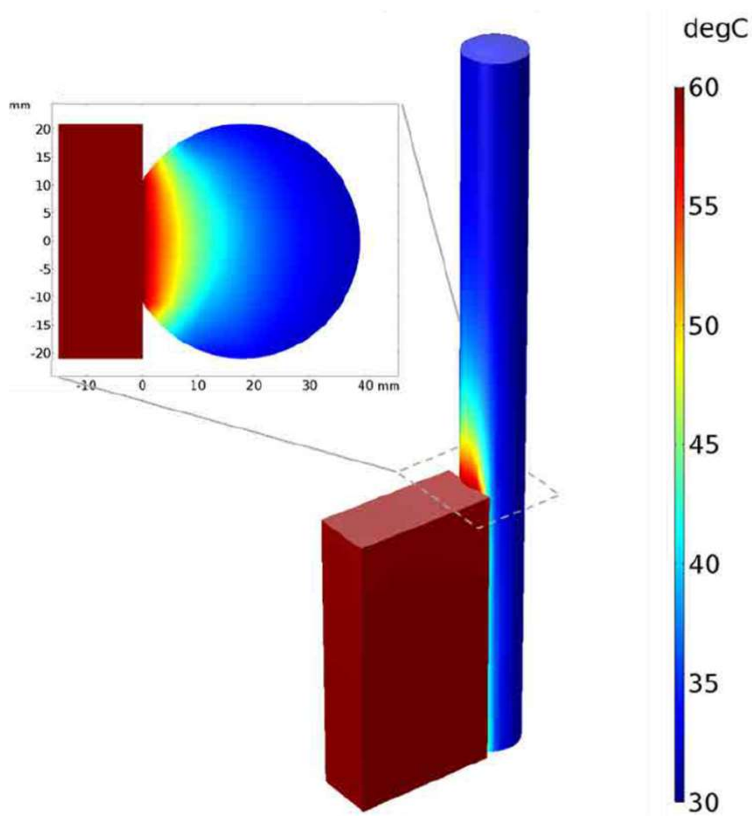
Static Contact

Steady State Temperature



Rope with Dyneema® SK78, 42mm
Contact with a metal block at 60 °C
Ambient : 30 °C

The rope reaches almost the same temperature as the block locally, but due to the high thermal conductivity of Dyneema® SK78, the majority of the cross section is unaffected.

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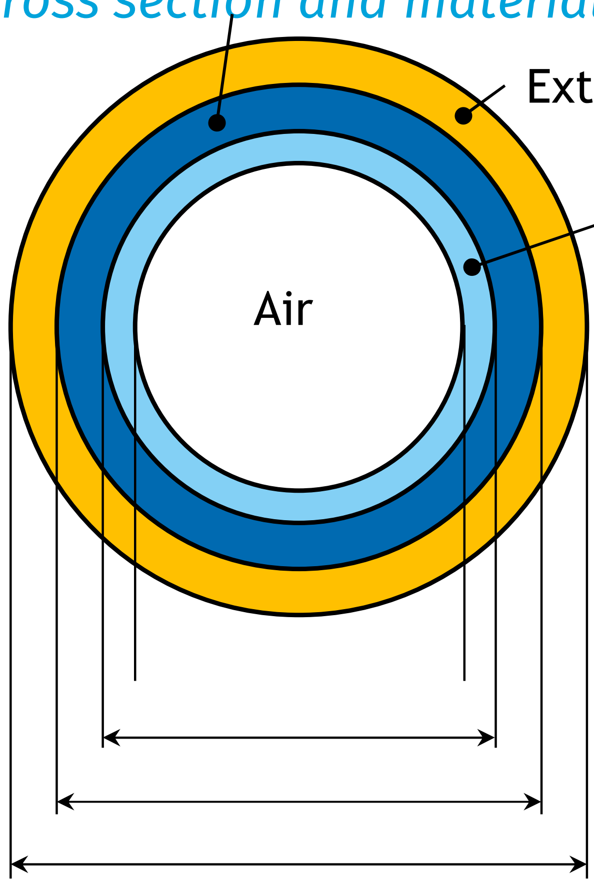
Extruded Hose Example

Cross section and materials' properties



Thermal properties

	Density	Heat capacity	Thermal conductivity
PA	1130 kg/m^3	1700 J/kgK	0.26 W/mK
Dyneema	970 kg/m^3	1500 J/kgK	0.3 W/mK
PU	1200 kg/m^3	1800 J/kgK	0.2 W/mK
Air	1.2 kg/m^3	1000 J/kgK	0.03 W/mK

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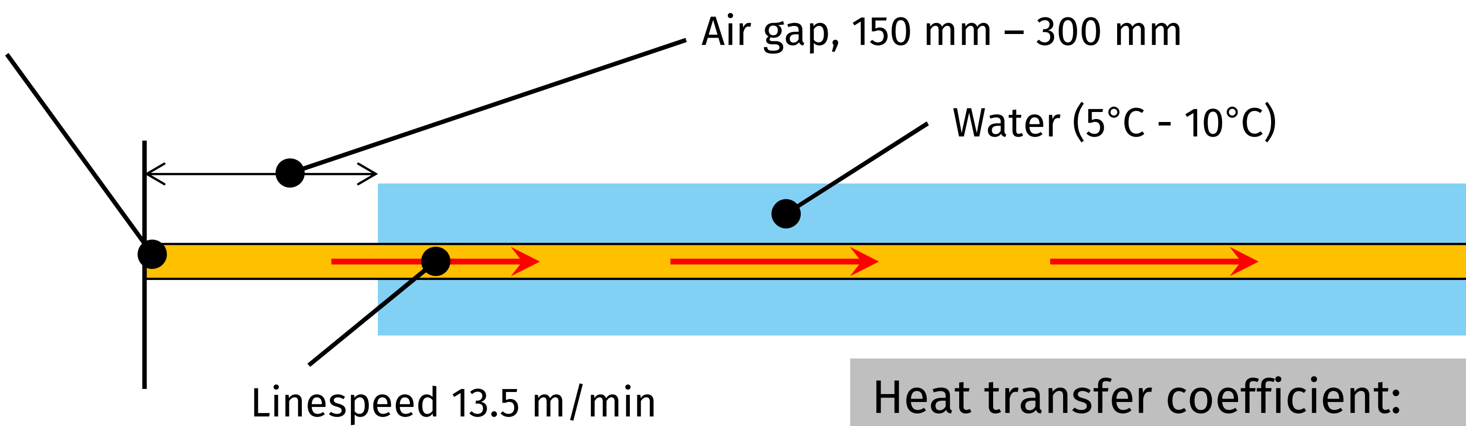
Extrusion process

- PA hose (initial temperature 23°C – 40°C)
- Dyneema reinforcement (initial temperature 23°C – 40°C)
- PU jacket (initial temperature 193°C – 205°C).



Heat transfer coefficient:
- PU jacket → air: h=5W/m^{2}K
- PU jacket → water: h=200 W/m^{2}K

(conservative estimates)

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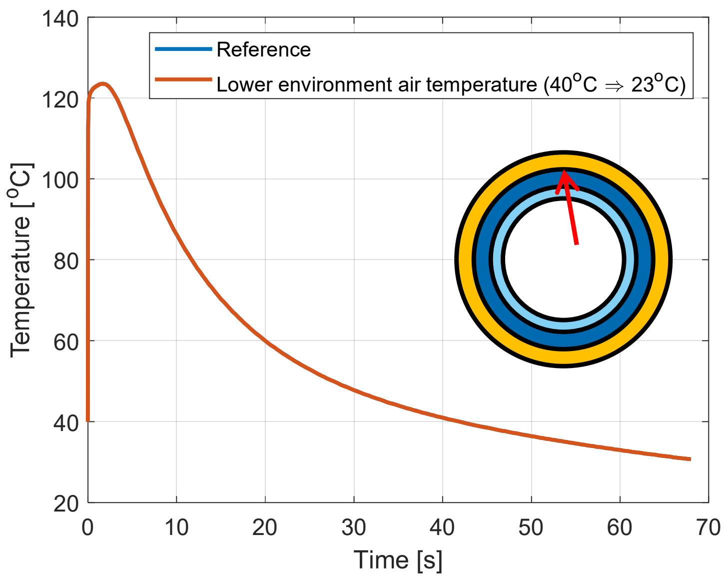
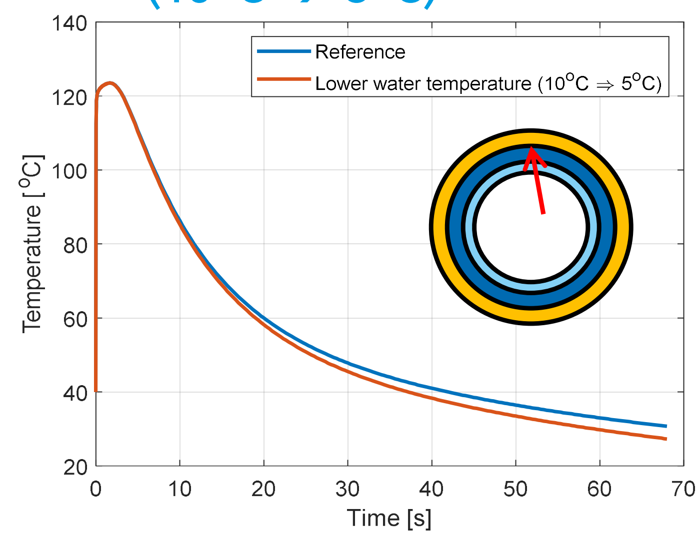
Model Sensitivity Analysis

Environment air temperature (40°C → 23°C)



Lower environment air temperature has no effect on peak temperature.

Water temperature (10°C → 5°C)



- Lower water temperature has no effect on peak temperature.
- Decrease after reaching peak temperature is slightly steeper.

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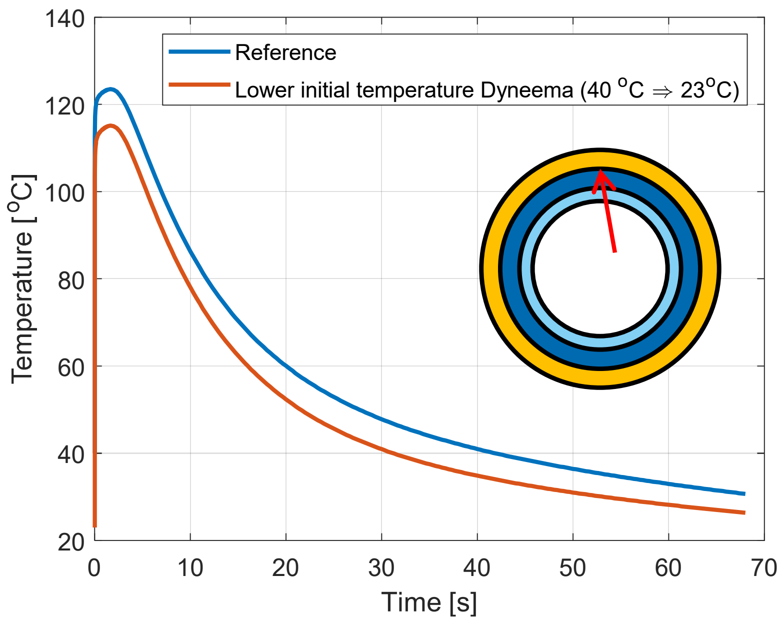
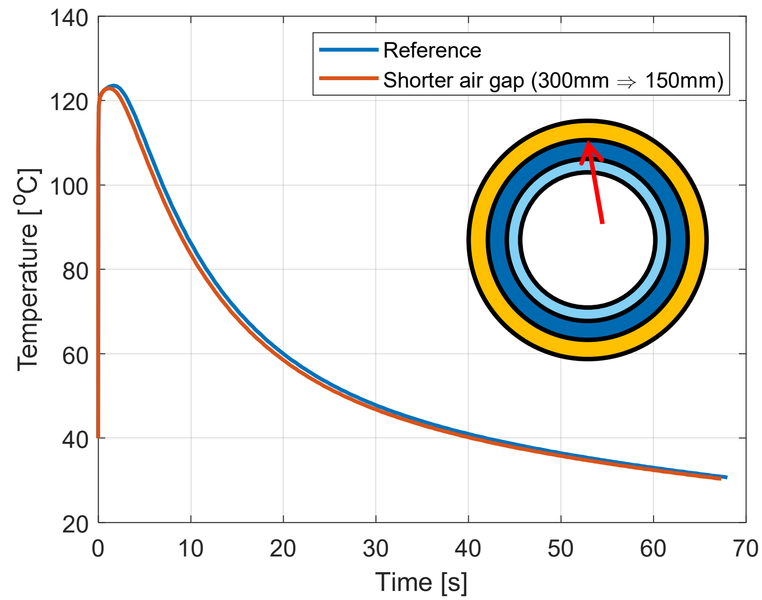
Model Sensitivity Analysis

Initial Dyneema temperature (40°C → 23°C)



Lower initial temperature of Dyneema lowers peak temperature by nearly 9°C.

Air gap length (300mm → 150mm)



Air gap length has only minor effect on peak temperature.

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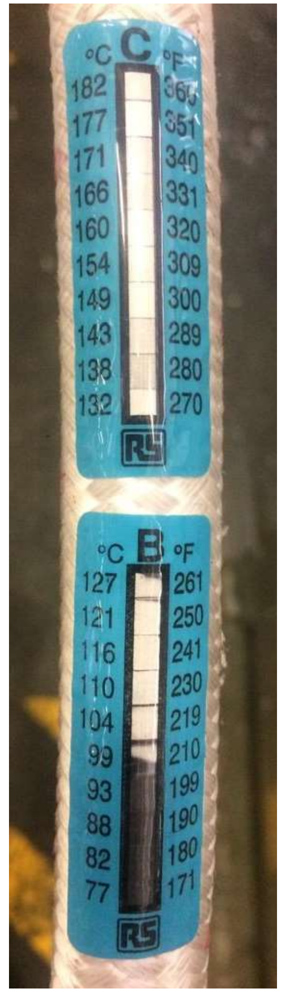
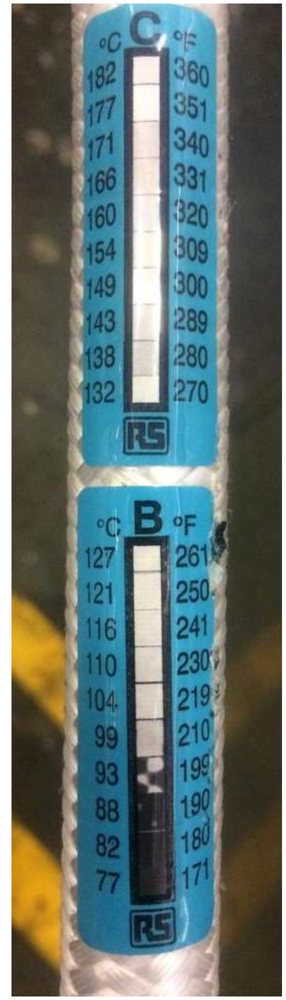
Validated Results

Actual temperatures
Max. temp recording stickers were used showed lower temps than predicted.

Observer effect: influence of sticker in process?

Extensive yarn analysis shows _NO_ heat damage.





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Conclusions

- Thermal Modeling is a useful tool to predict rope temperature in static and dynamic loading conditions.
- Based on first principles, the model has been validated with experimental data and has shown to give accurate predictions in a wide range of conditions.
- Combining the temperature model with DSM's Performance Model, the lifetime of a mooring line can be predicted more accurately than ever before

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Thank you.

Further information is available on www.dyneema.com

Bill Fronzaglia
bill.fronzaglia@dsm.com

Marc Eijssen
marc.eijssen@dsm.com