UiT The Arctic University of Norway

Understanding Physical Properties of Fresh Water and Marine Ice using Multiphysics Modelling and Infrared Thermography

ID:32 Spray Icing: A major marine operational barrier in the Arctic
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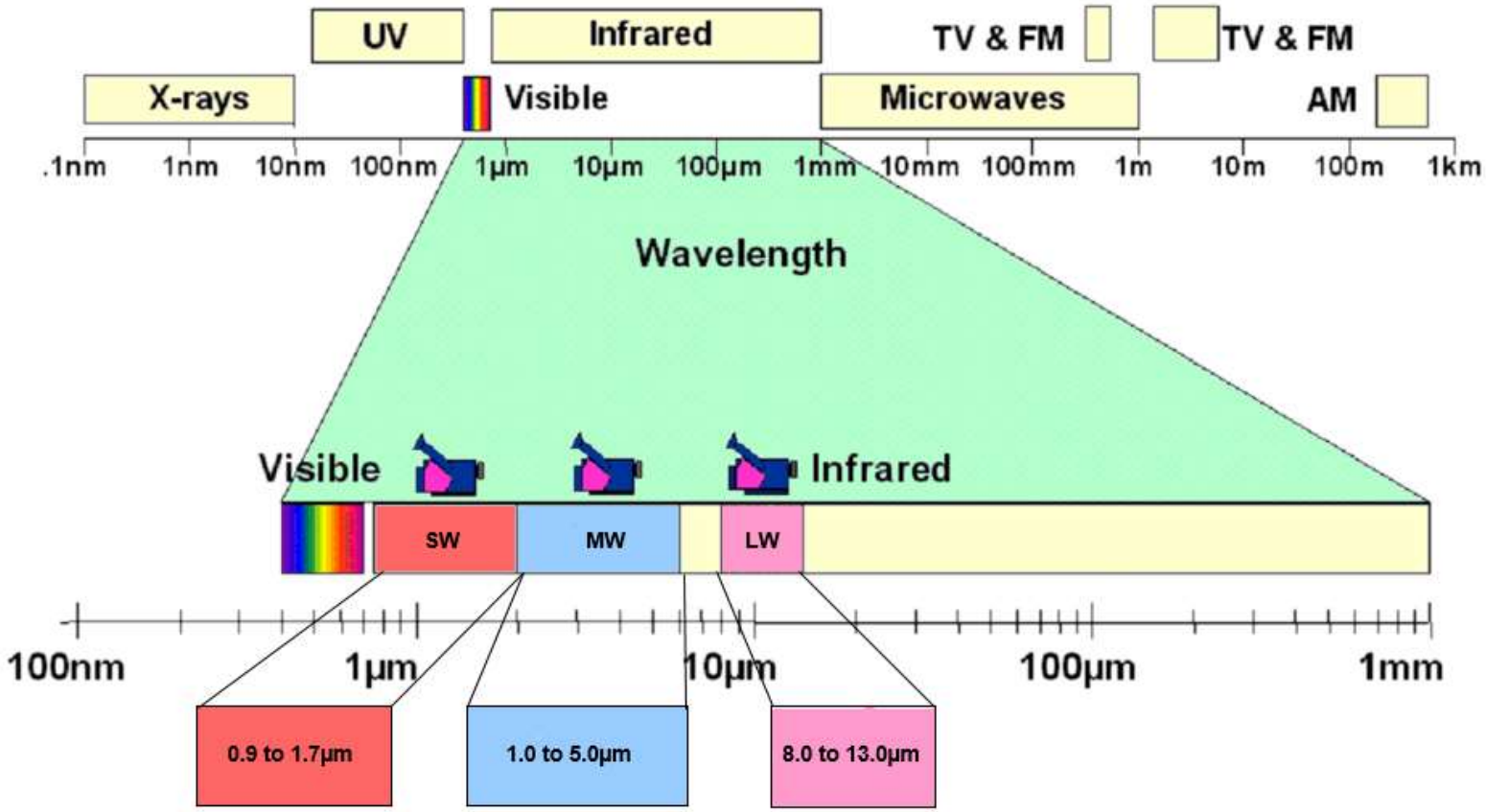
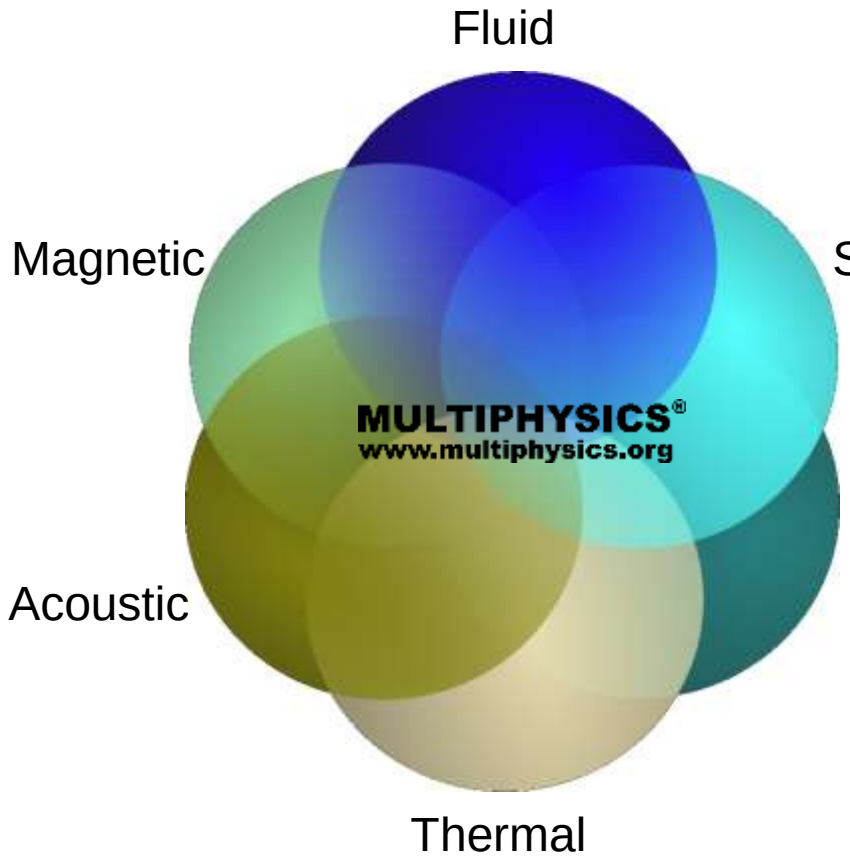
Infared Thermography



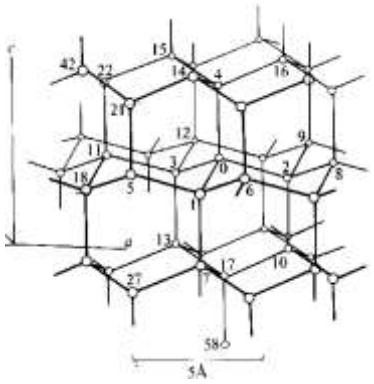
Multiphysics

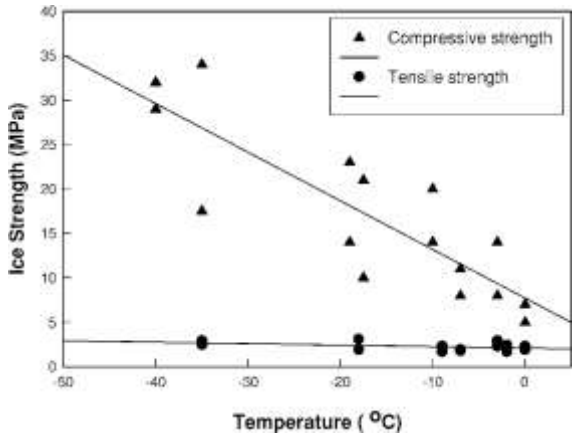


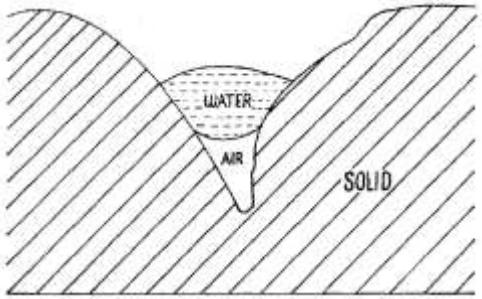
Ice Shedding

Table 1 Typical properties of accreted atmospheric ice [11, 13]

Type of ice	Density (kg/m³)	Adhesion and cohesion	General appearance	
			Colour	Shape
Glaze	900	Strong	transparent	evenly distributed/icicles
Wet snow	300 to 600	weak(forming) strong (Frozen)	white	evenly distributed/eccentric
Hard rime	600 to 900	strong	opaque	eccentric, pointing windward
Soft rime	200 to 600	Low to medium	white	eccentric, pointing windward







Hui Xue, Hassan Khawaja. Review of the Phenomenon of Ice Shedding from Wind Turbine Blades. The International Journal of Multiphysics, 2016, 10(3): pp. 265 - 276. http://dx.doi.org/10.21152/1750-9548.10.3.265

Ice Adhesion (PVC)

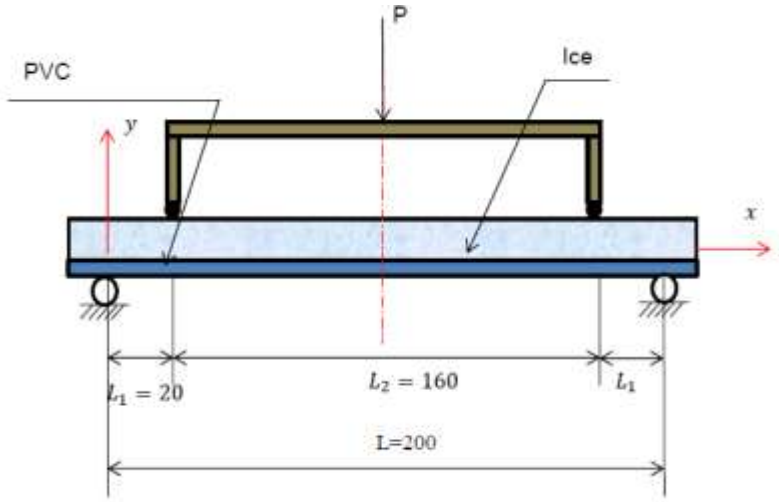
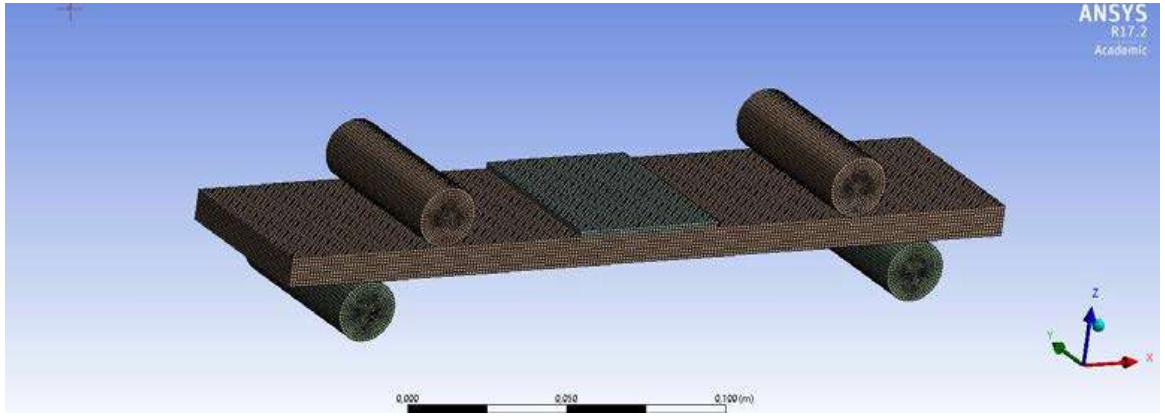


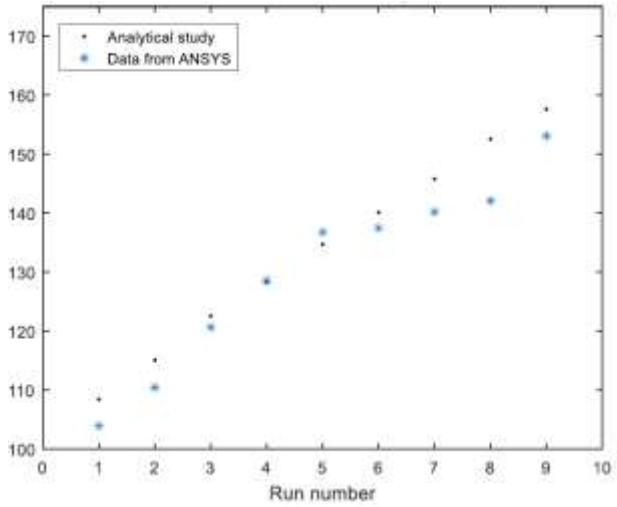
Table 6: Comparison of longitudinal tensile stresses (MPa) (E_{ice} = 4 GPa and E_p = 15 MPa)

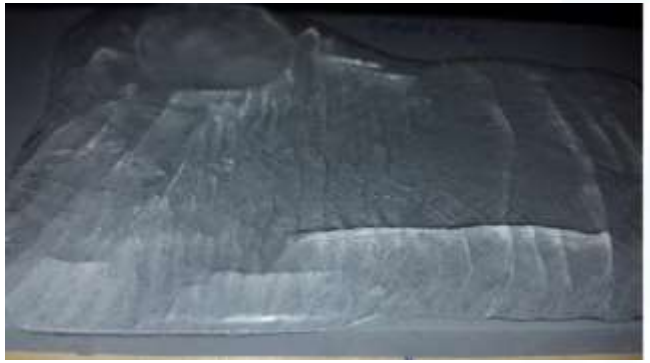
Ice thickness on 1 mm thick PVC sample	Load at the time of failure (g)	Theoretical analysis using rule of mixture and beam theory	Experimental results	Numerical results using FEM (ANSYS® Multiphysics)
3 mm	1800	1.96	1.96	2.08
5 mm	3500	1.37	1.37	1.56

Hui Xue, Hassan Khawaja. Investigation of Ice-PVC separation under Flexural Loading using FEM Analysis. The International Journal of Multiphysics, 2016, 10(3): pp. 247 - 264. http://dx.doi.org/10.21152/1750-9548.10.3.247

Ice Adhesion (PU)

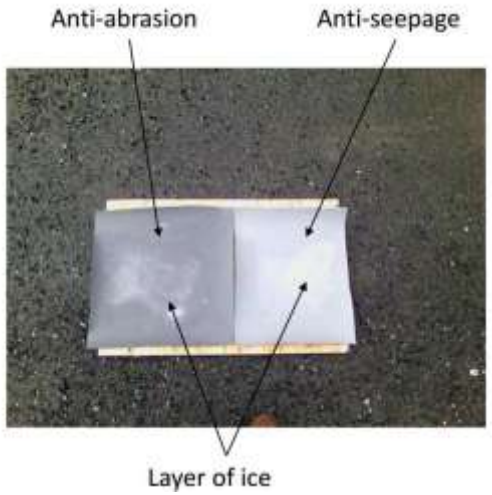




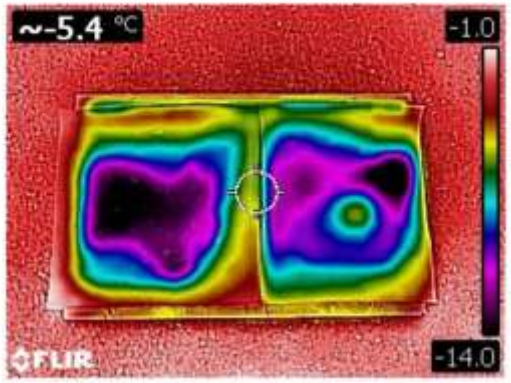


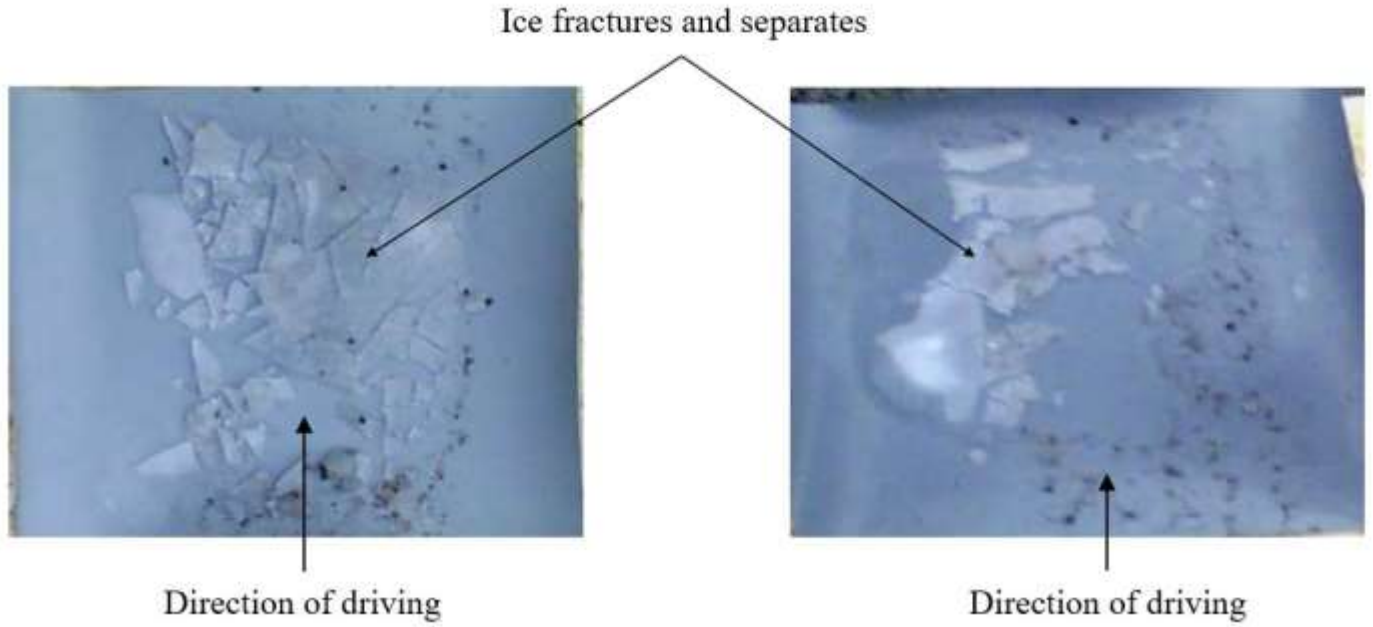
Hans-Kristian Eidesen, Hassan Khawaja, Zahra Andleeb, Mojtaba Moatamedi. Multiphysics Analysis of Ice-Polyurethane Adhesion under Flexural Loading using FEM. The International Journal of Multiphysics, 2021, 15(4), pp. 437-452. http://dx.doi.org/10.21152/1750-9548.15.4.437

Ice Adhesion (Roads/Highways)



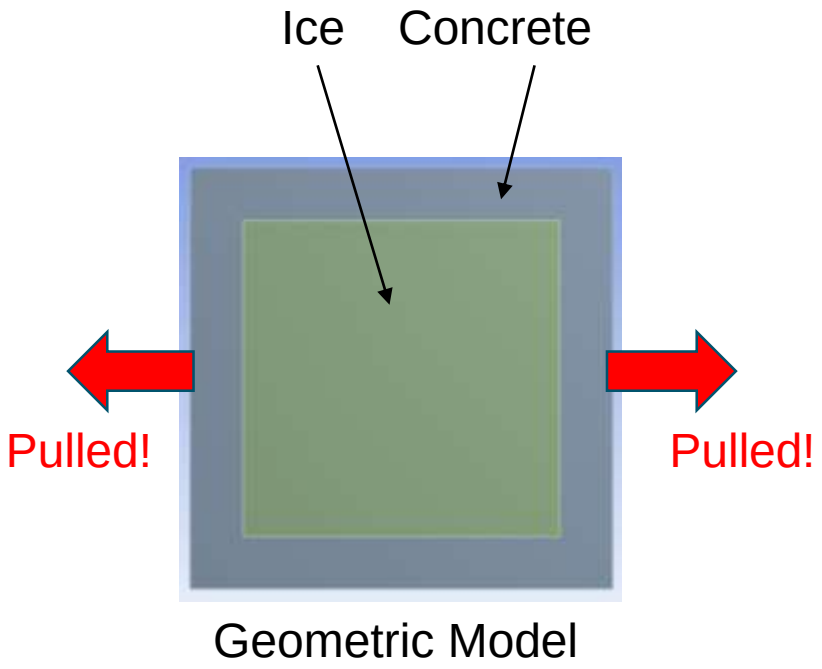
Corresponding IR Image

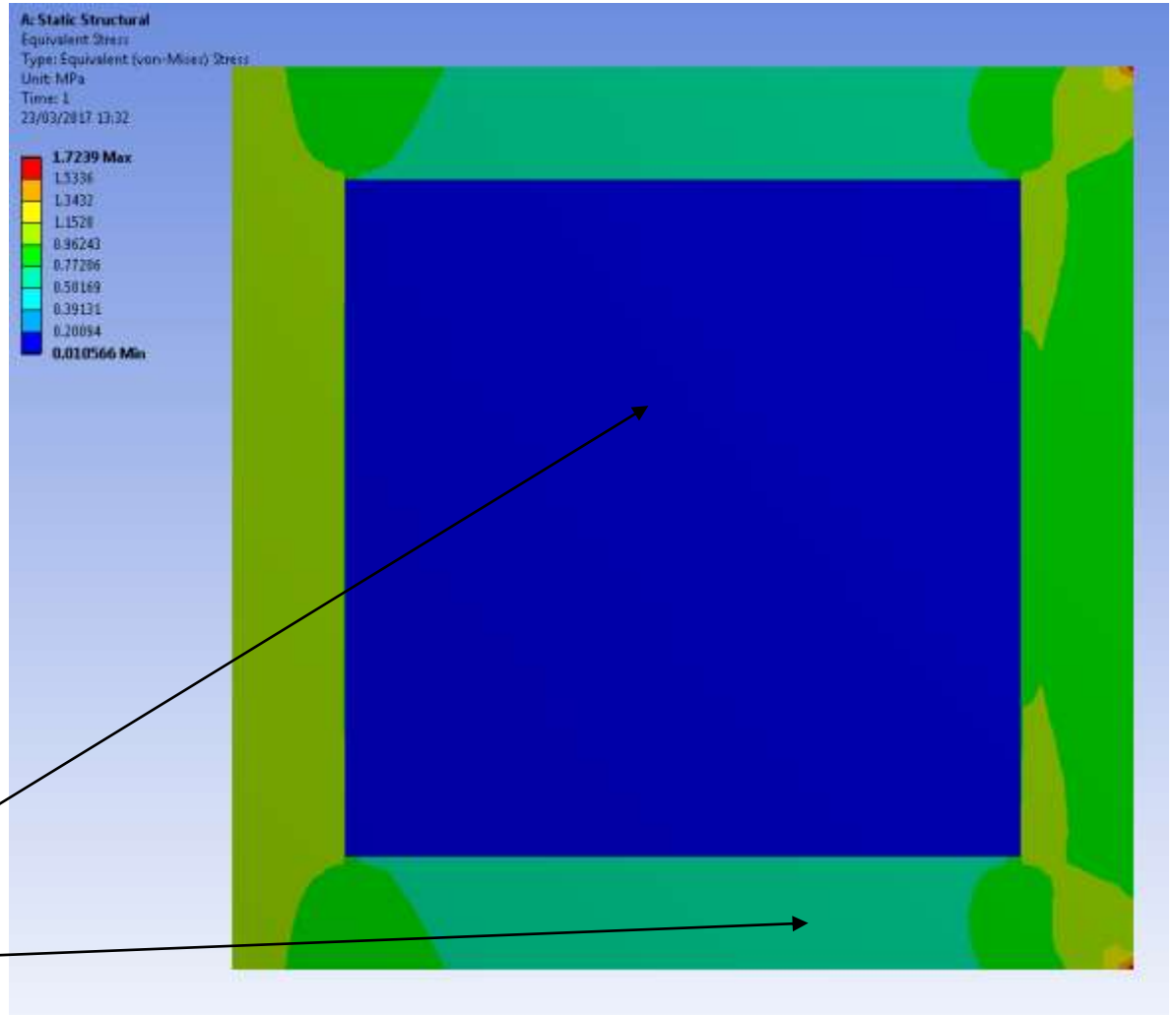




Zahra Andleeb, Hassan Khawaja, and Mojtaba Moatamedi. Multiphysics based Analysis of Materials for Roads in Cold Regions to Prevent Ice Adhesion and Low-Temperature Crack Developments. The International Journal of Multiphysics, 2022, 16(4), pp. 437-447. https://doi.org/10.21152/1750-9548.16.4.437

Ice Adhesion (Roads/Highways) contd.





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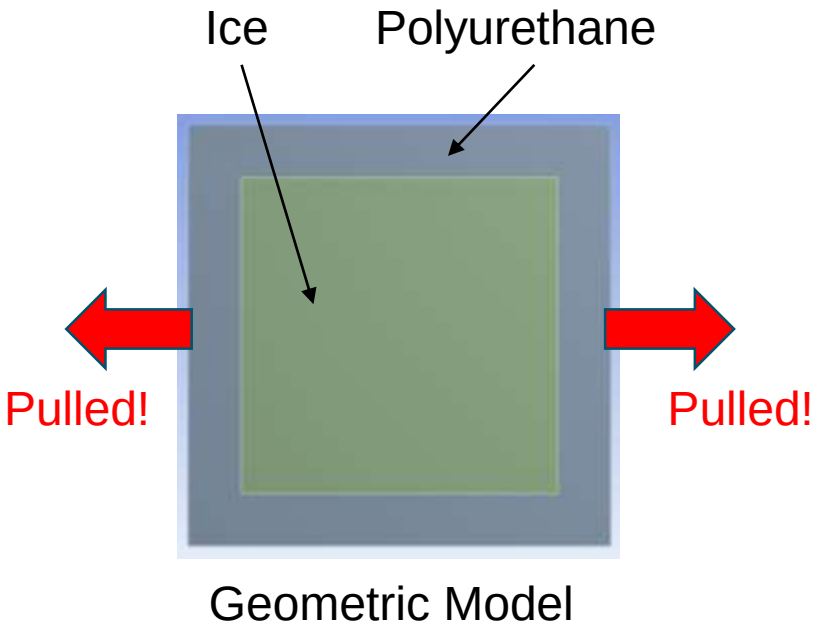

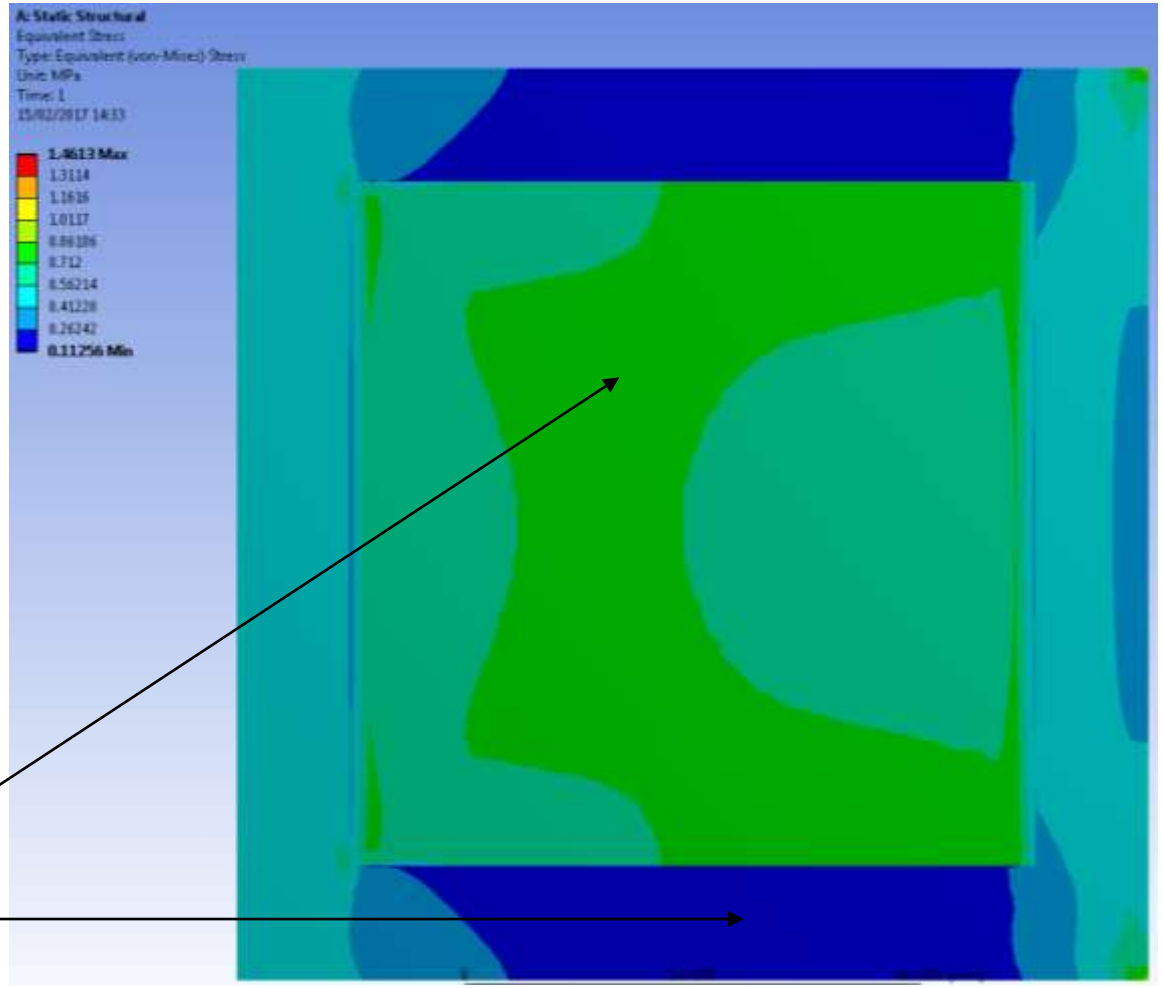

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Ice Adhesion (Roads/Highways) contd.

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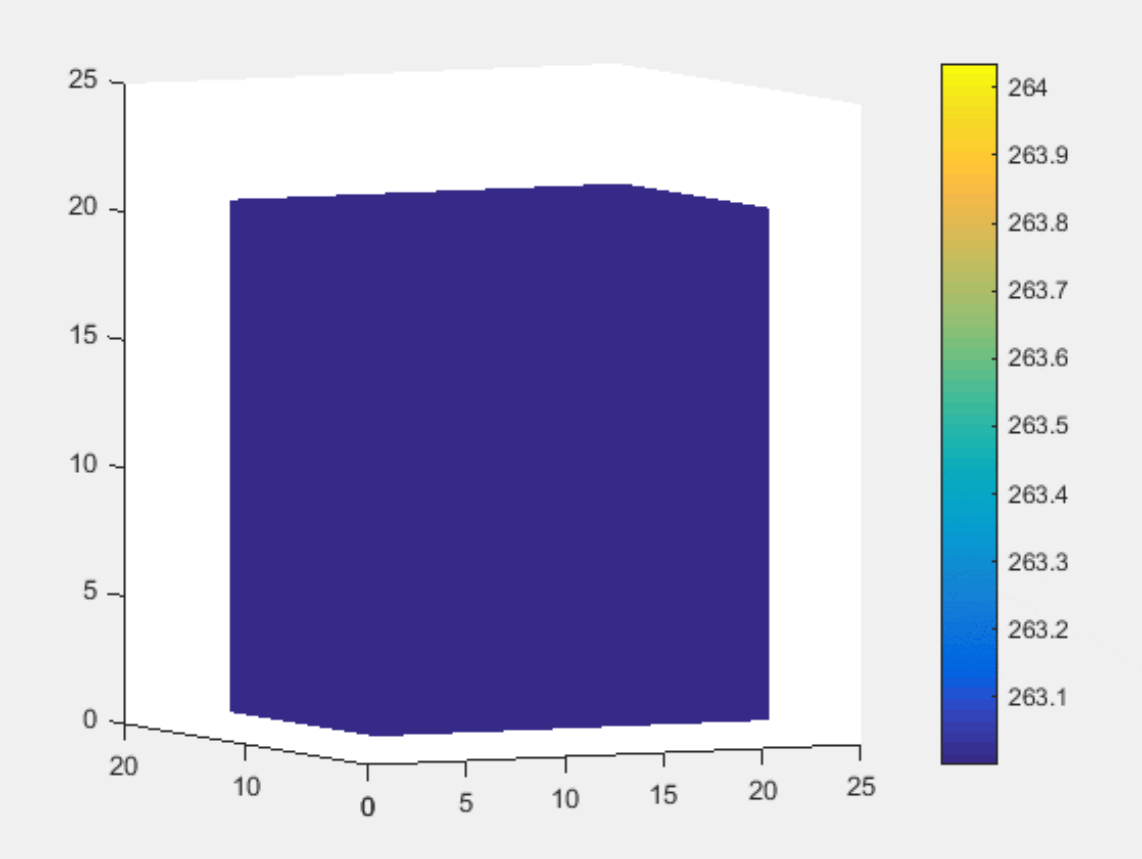
Thermal Diffusion in Ice (Model)



$$\frac{\partial T}{\partial t} = \frac{k}{\rho c}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

Khawaja, Hassan Abbas; Rashid, Taimur; Eiksund, Oddmar; Brodal, Eivind; Edvardsen, Kåre. Multiphysics Simulation of Infrared Signature of an Ice Cube. The International Journal of Multiphysics 2016; Volum 10 (3). ISSN 1750-9548.s 291 - 302.s doi: 10.21152/1750-9548.10.3.29

Thermal Diffusion in Ice (Validation)

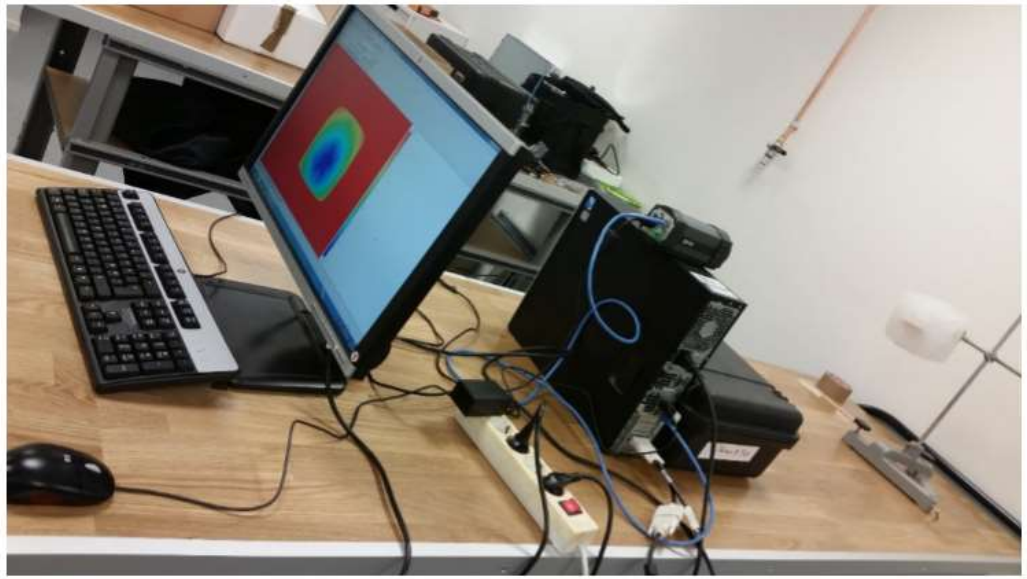


Figure 5: Actual Infrared Imaging Experiment Setup

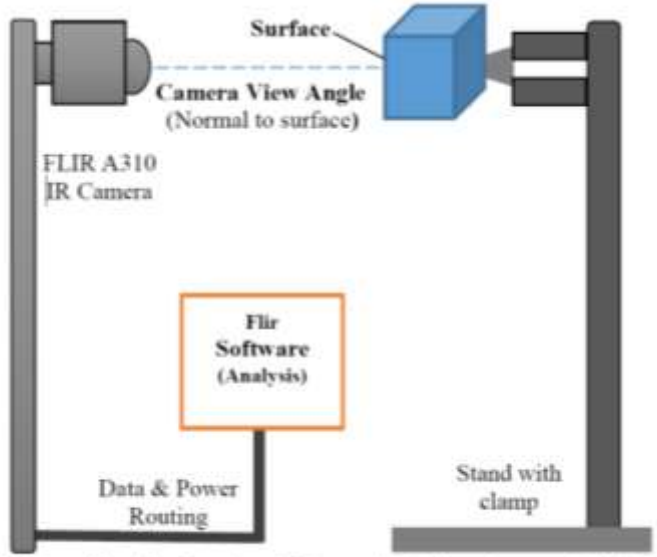


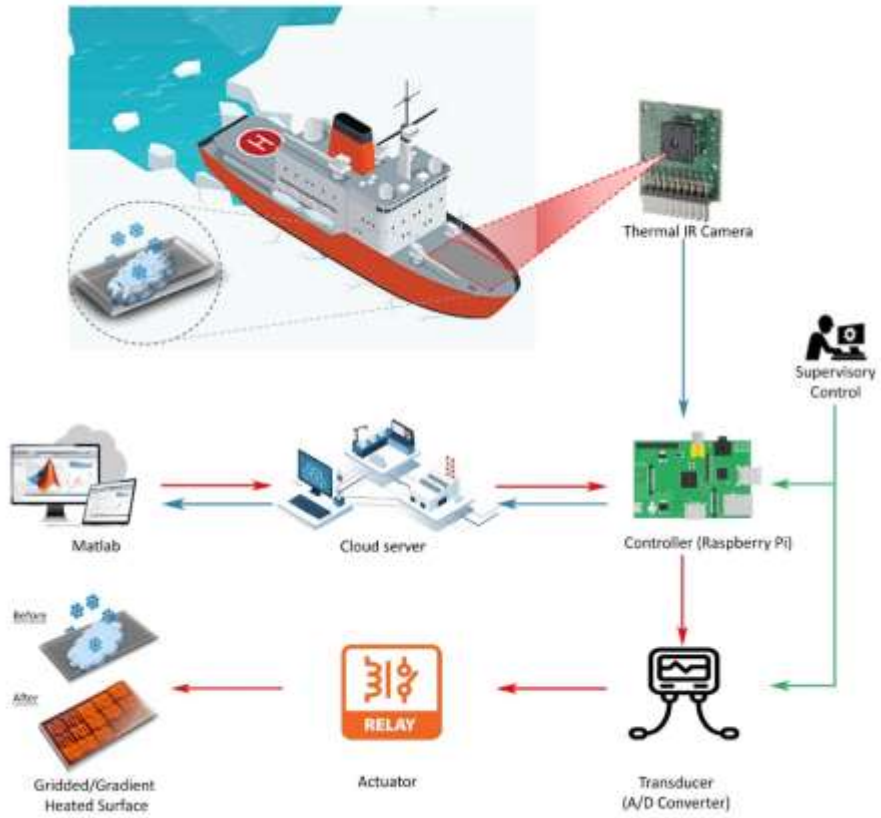
Figure 4: Infrared Imaging Experiment Schematics. Infrared camera is facing the surface of ice block [22, 23].

Table 1: Coefficient of Thermal Conductivity of Fresh Water and Saline Water Ice

Coefficient of Thermal Conductivity of Ice (λ)	Value (W/(m.K))
Fresh Water Ice	2.35
Saline Water Ice	0.8

Taimur Rashid, Hassan Khawaja, Kåre Edvardsen. Determination of Thermal Properties of Fresh Water and Sea Water Ice using Multiphysics Analysis. The International Journal of Multiphysics, 2016, 10(3): pp. 277 - 291. http://dx.doi.org/10.21152/1750-9548.10.3.277

Ice Detection and Mitigation



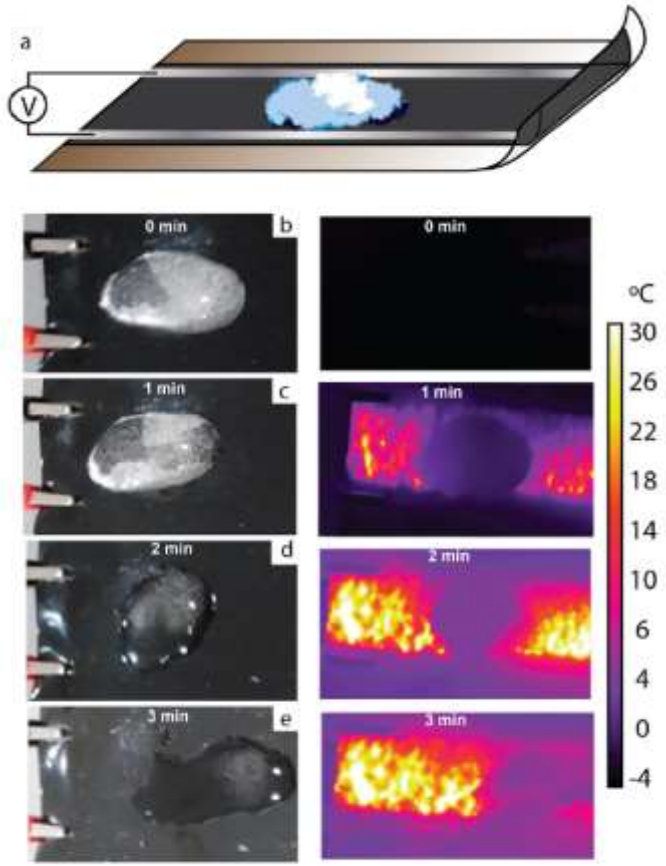


Fig. 4. De-icing demonstration of R2R CNT coated sheet (IR and colour images), when ice is frozen inside cold room at steady state temperature of −2 °C.

Taimur Rashid, Hsin-Ling Lang, Madiha Taimur, Nicolò Chiodarelli, Michael De Volder, Kåre Edvardsen, Hassan Khawaja. Roll to Roll coating of carbon nanotube films for electro thermal heating. Cold Regions Science and Technology, 2021, 182: 103210. https://doi.org/10.1016/j.coldregions.2020.103210

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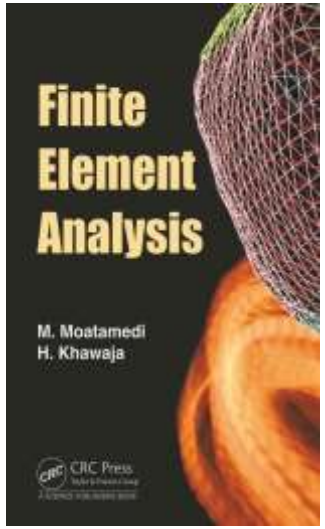

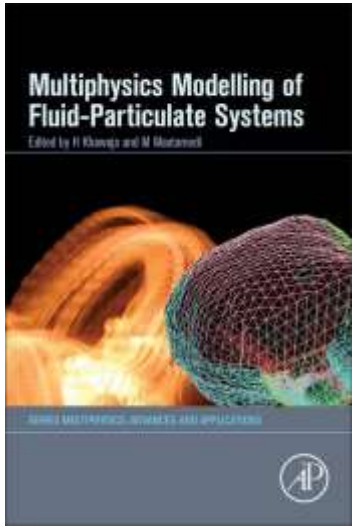

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Thank you and questions!