
# Lighter, safer and more sustainable through lifetime prediction

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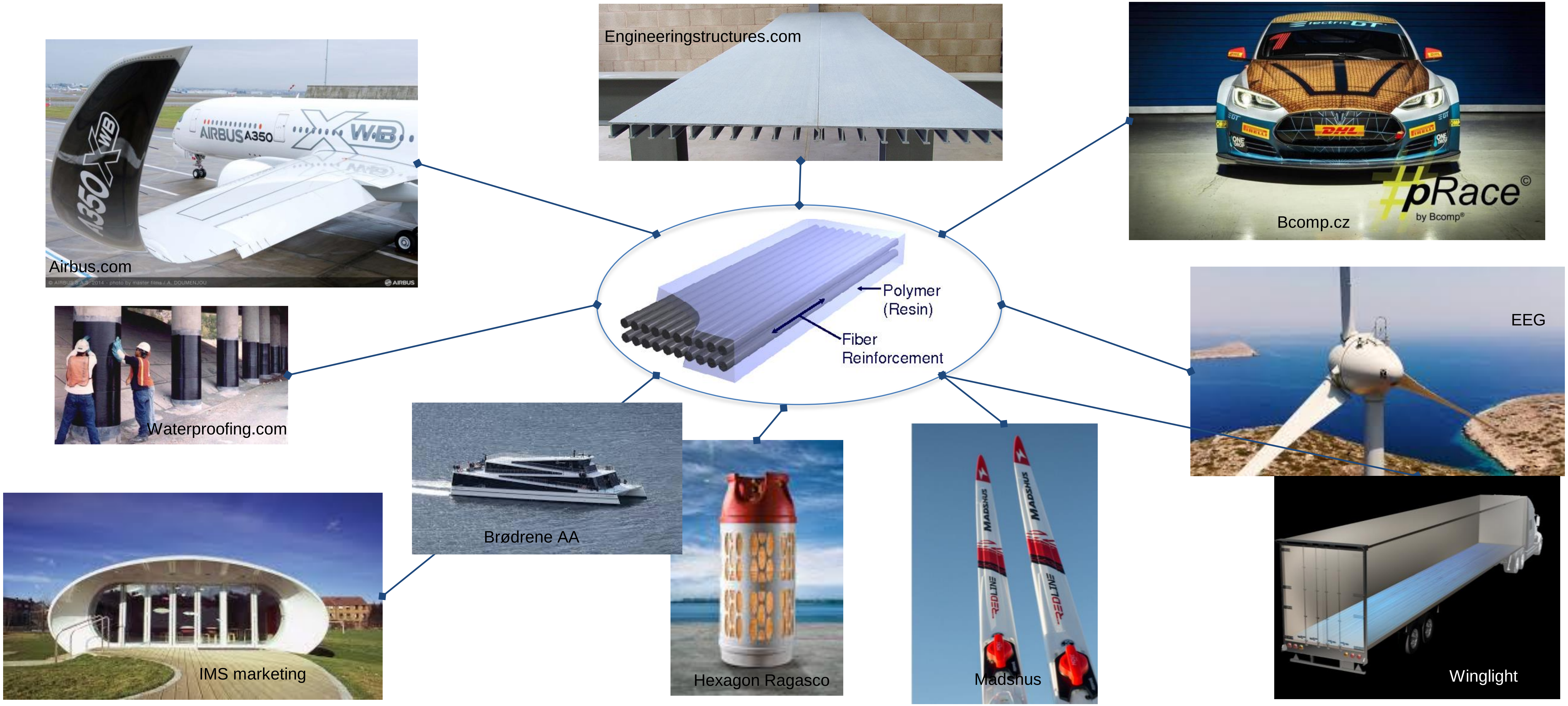
# Content

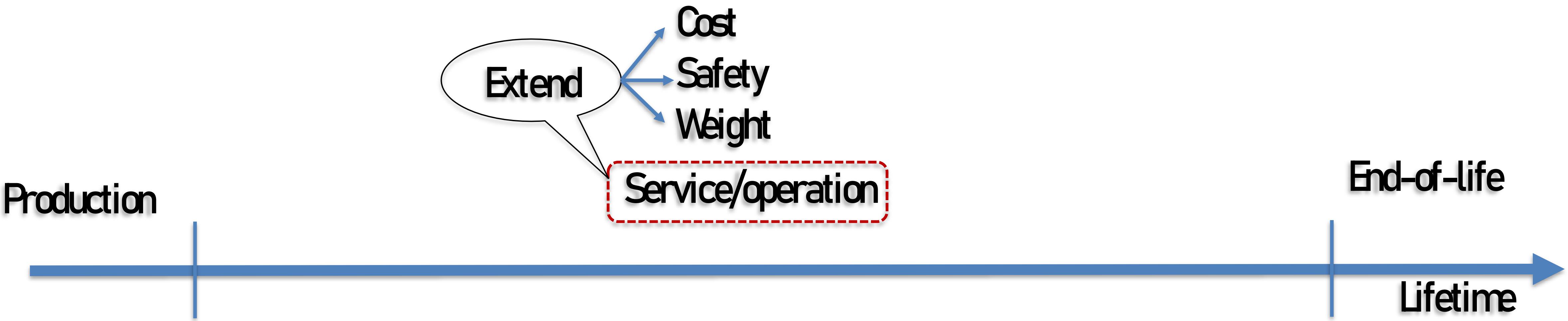
- Introduction
- The problem & motivation
- Experience so far
- Research work at NTNU & Chalmers and collaboration with industry
- Conclusions
- Acknowledgments

# Polymers & fibre-reinforced polymer composites use



# The problem (s)

1. Long term performance of composites in non-linear
2. Lack of understanding of underlying degradation mechanisms
3. No tools to predict accurately lifetime
4. Yet a Eurocode to design civil engineering structures with polymer composites



# Civil engineering FRP structures

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Kolding, Denmark. Pedestrian and cycle bridge from 100% pultruded GFRP profile, 1992

'Bronlibelle' Bridge in Harderwijk, the Netherlands. A 6.3 m wide, 22 m long GFRP bicycle / footbridge connecting two new districts of Harderwijk.

Plessis Robinson (92) France. Helipad made with pultruded GFRP profiles

Lock gates, GFRPs made with VARTM, 2000

Klipphausen (Dresden), Germany. It is the first road bridge built from 100 % GFRP pultruded beams and deck, 2002

Train station, Pultruded GFRPs, Moscow, Russia, 2004

Pultruded GFRPs, Italy, pedestrian bridge, 2004.

Golf Club in Aberfeldy bridge, UK, 1992

# Besides nearly a century of work – lifetime prediction is still a bottleneck


**vs.**


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# Design guidelines with FRPs missing

**2016**

European Commission

JRC SCIENCE FOR POLICY REPORT

PROSPECT FOR NEW GUIDANCE IN THE DESIGN OF FRP

*Support to the implementation, harmonization and further development of the Eurocodes*

Authors

Luigi Ascione, Jean-François Caron, Patrice Godonou, Kees van IJselmuijden, Jan Knippers, Toby Mottram, Matthias Oppe, Morten Gantriis Sorensen, Jon Taby, Liesbeth Tromp

Editors

Luigi Ascione, Eugenio Gutierrez, Silvia Dimova, Artur Pinto, Steve Denton

2016

**2018**

ciria

Fibre-reinforced polymer bridges – guidance for designers

Composites UK
Trade Association

# Why preparing standards takes so long?

- relatively short polymer/FRP history:
- continual development of new composites
- engineering judgment' remains paramount

*Toby Mottram*
*Warwick University*

# Weaknesses with published research

- no clear definition of the domain of applicability of the work
- no critical review of previous research
- test results that omit crucial data on properties of specimens
- testing of <u>non-representative</u> specimens

*Toby Mottram*
*Warwick University*

# Why is it so hard?

- 2019 testing and assessment is similar to 1926
- Engineers and companies need accurate predictions to avoid risks
- Academia tests for ranking & qualification of materials – no lifetime output
- A disconnect arises between what specifying engineers want, need, and expect when qualifying materials and how materials degrade.
- Engineers want fast answers – they are property-centric but material agnostic
- Most structural degradation is due to chemistry, a topic that is outside the traditional focus of most engineers
- Many standard tests protocols but they do not adhere to service life prediction

Survey of Long-Term Durability Testing of Composites, Adhesives and Polymers Issue 2, NPL 2017, UK
Service Life Prediction of Polymers and Plastics Exposed to Outdoor Weathering, Elsevier, 2018

# Main factors that affect structural performance

Composites are resistant to degradation, but over time..

- Mechanical loads
- Solar irradiation
- Thermal changes
- Elevated temperatures
- Moisture
- Weathering (UV+erosion)
- Chemicals
- etc.

→

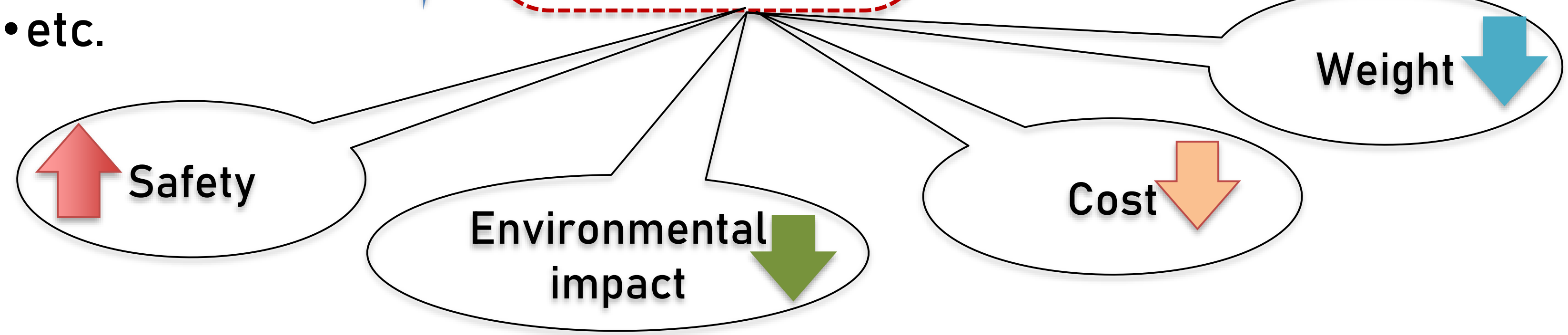
- Residual curing
- Plasticization
- Oxidation
- Chain-scission
- Decomposition
- etc.

→

Structural degradation & failures difficult to predict

→

- Over-design
- Early decommission
- Over maintenance




*Everyone is talking about the effects of aging but few about lifetime prediction*

# How to investigate the effects of aging exposure on the performance of composites

## Accelerated aging

- Heat
- Heat & moisture
- Pressure & moisture
- Chemical agents
- etc.

Fast

Unrealistic sometimes

**VS.**

## Natural/real aging

- Leave in real service conditions

Slow

Rare

## Combination of accelerated aging and real aging

Realistic

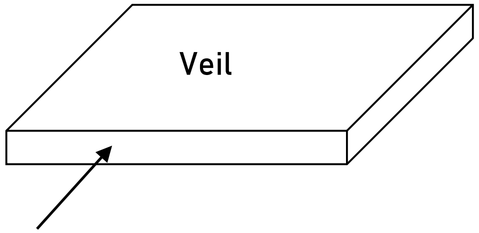
Ideal

# Effects of accelerated aging

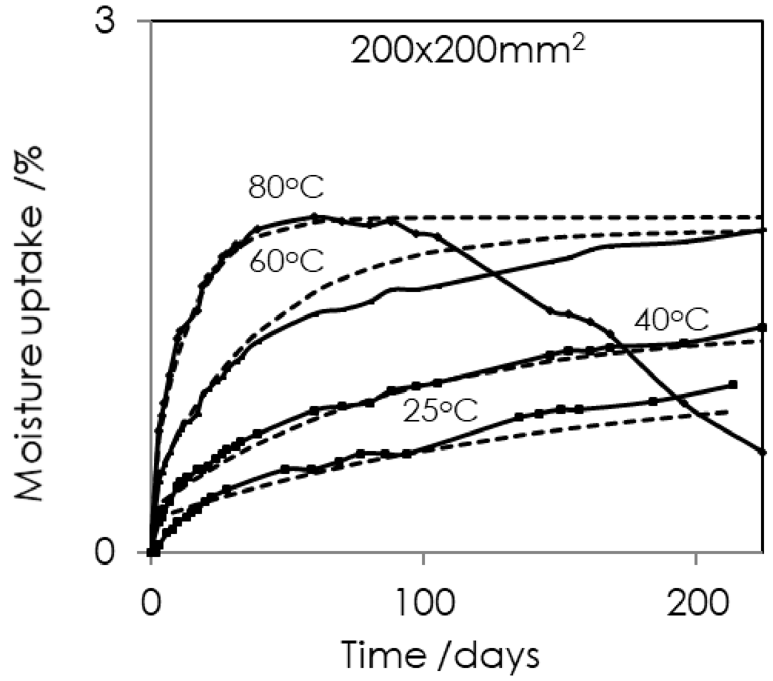
1. **Physical aging is a reversible** process (below the polymer's $T_g$). Leads to changes in stiffness, yield stress, density (swelling), viscosity, diffusivity, fracture energy etc.
2. **Chemical aging** is **irreversible**. It includes chain scission reactions and/or additional **crosslinking**, **hydrolysis**, depolymerization, **softening**, **plasticizization** and decomposition (leaching species in the water medium).

# Moisture uptake behaviour

## Fick's 2nd law




Cross-section edge

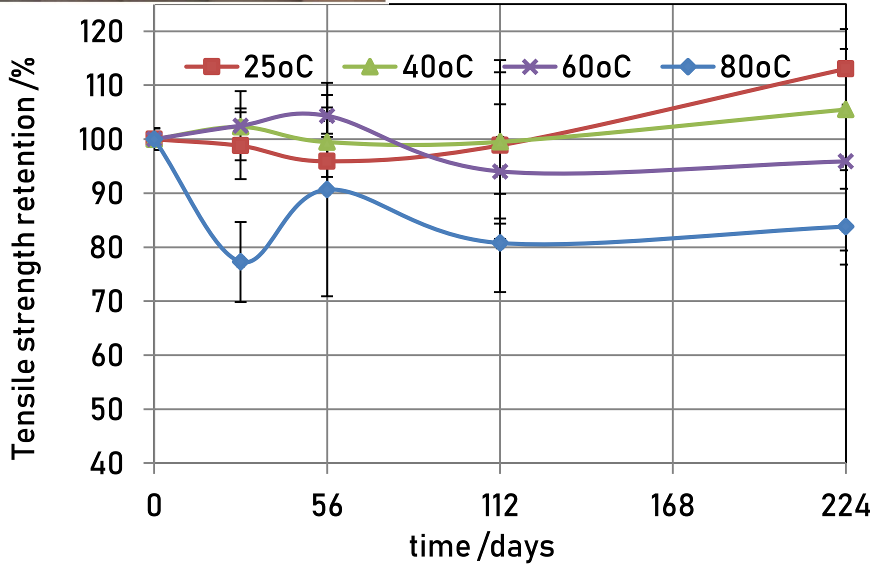


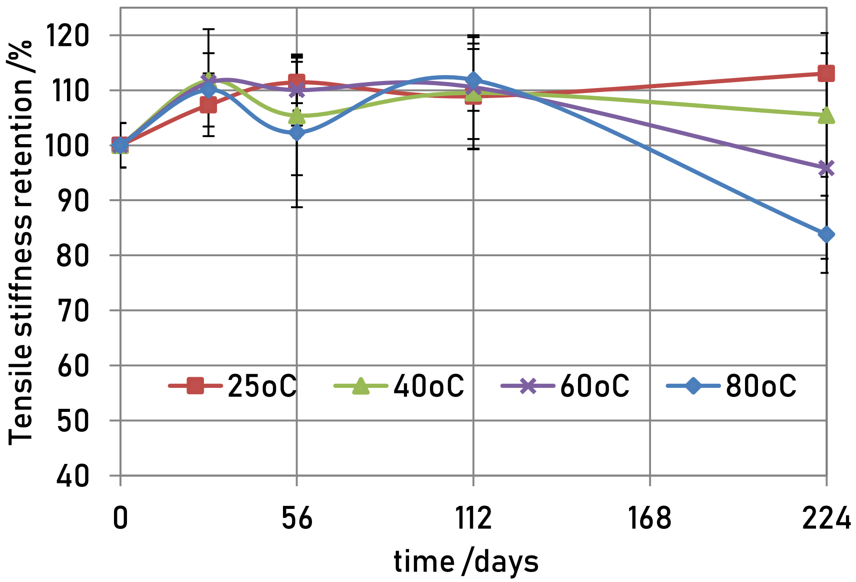


| Side dimensions (mm$^3$) | $M_\infty$ (%) | | | | $D$ (×10$^{-6}$ mm$^2$/s) | | | | Mass loss (%) | | | | Veil /cross section ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25°C | 40°C | 60°C | 80°C | 25°C | 40°C | 60°C | 80°C | 25°C | 40°C | 60°C | 80°C | |
| 40×40×6.4 | 1.85 | 2.04 | 2.34 | 2.49 | 0.47 | 0.77 | 1.60 | 4.25 | 0.241 | 0.335 | 1.03 | 5.31 | 3.12 |
| 80×80×6.4 | 1.20 | 1.58 | 1.85 | 1.80 | 0.81 | 0.19 | 2.34 | 6.60 | 0.257 | 0.291 | 0.862 | 4.03 | 6.25 |
| 200×200×6.4 | 0.98 | 1.27 | 1.82 | 1.89 | 0.42 | 0.52 | 1.15 | 3.26 | 0.270 | 0.982 | 0.788 | 3.69 | 15.6 |

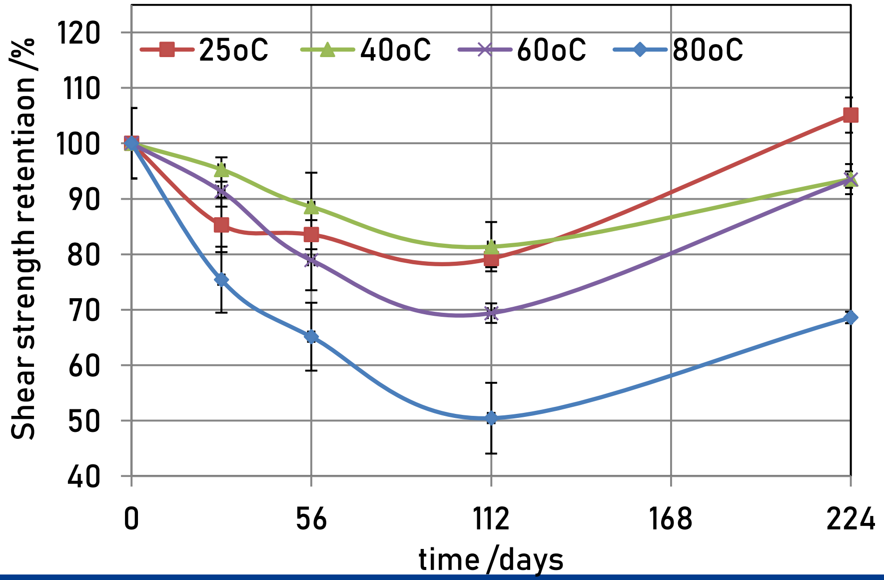
significant decomposition masks the moisture uptake data !!

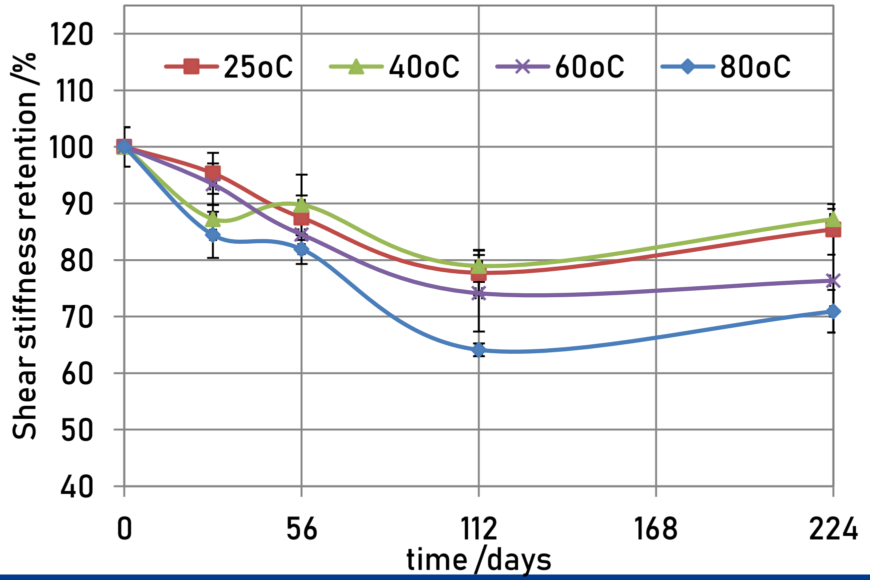
# Anomalous mechanical behaviour due to aging

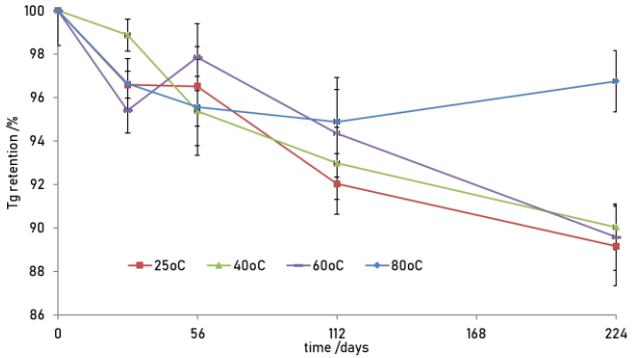







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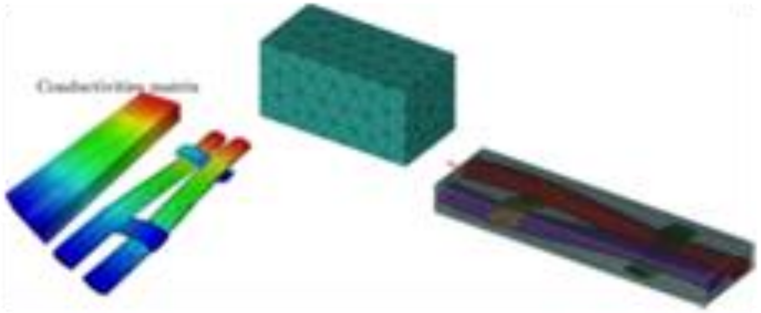
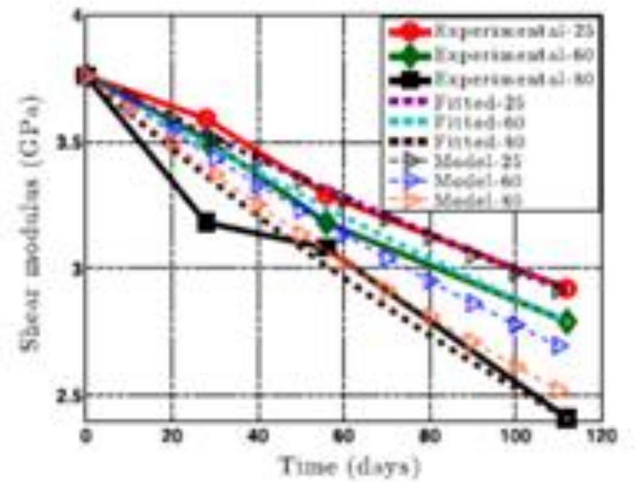
# Difficult to model the reality

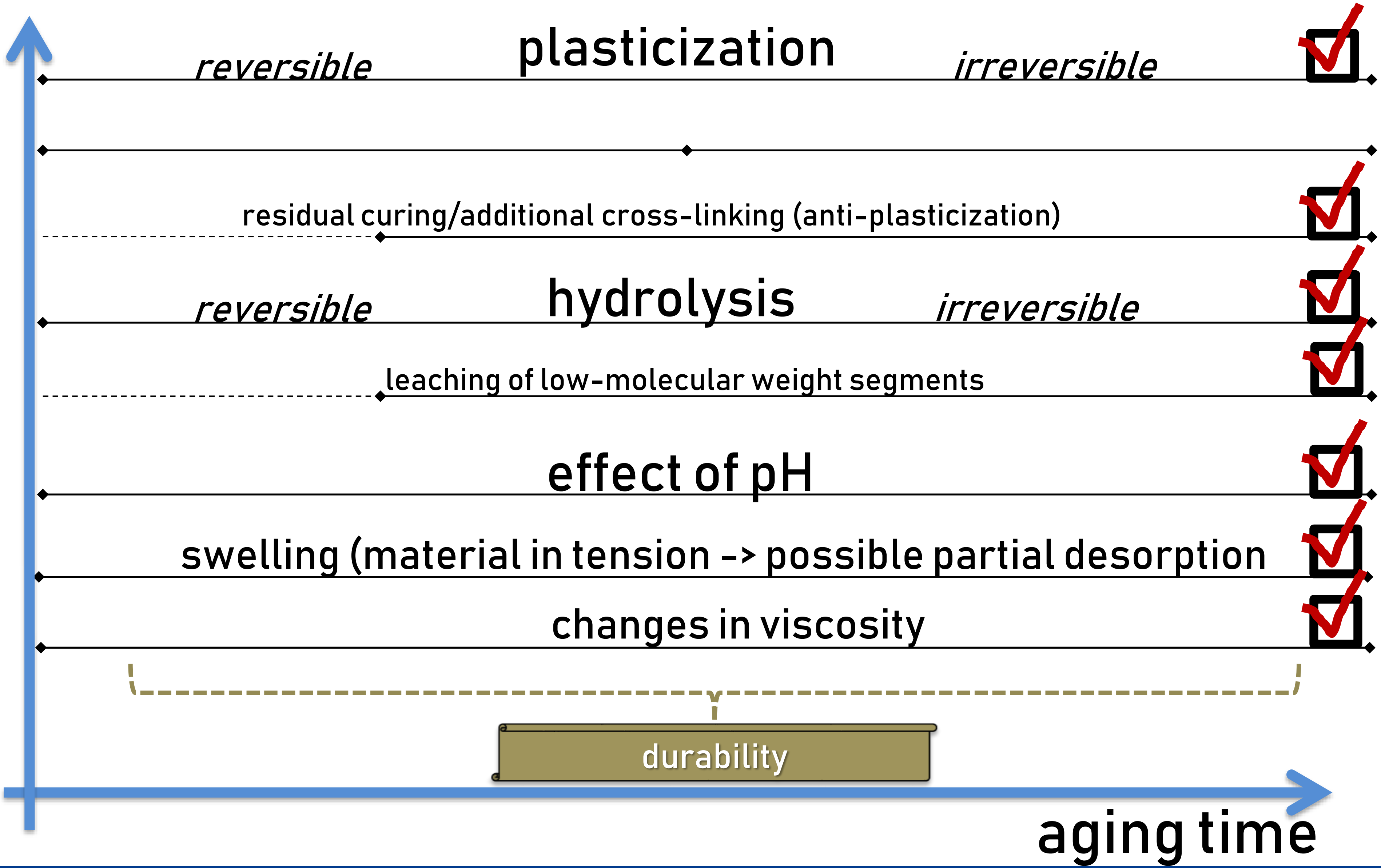
- Complicated impractical models
- Unknown nature of data
- Mostly projections for rough estimations of lifetime






Z. Ullah, L. Kaczmarczyk, S.A. Grammatikos, M.C. Evernden, C.J. Pearce. Multi-scale computational homogenisation to predict the long-term durability of composite structures. Computers and Structures. 2017;181:21-31.

# Effects of hygrothermal aging

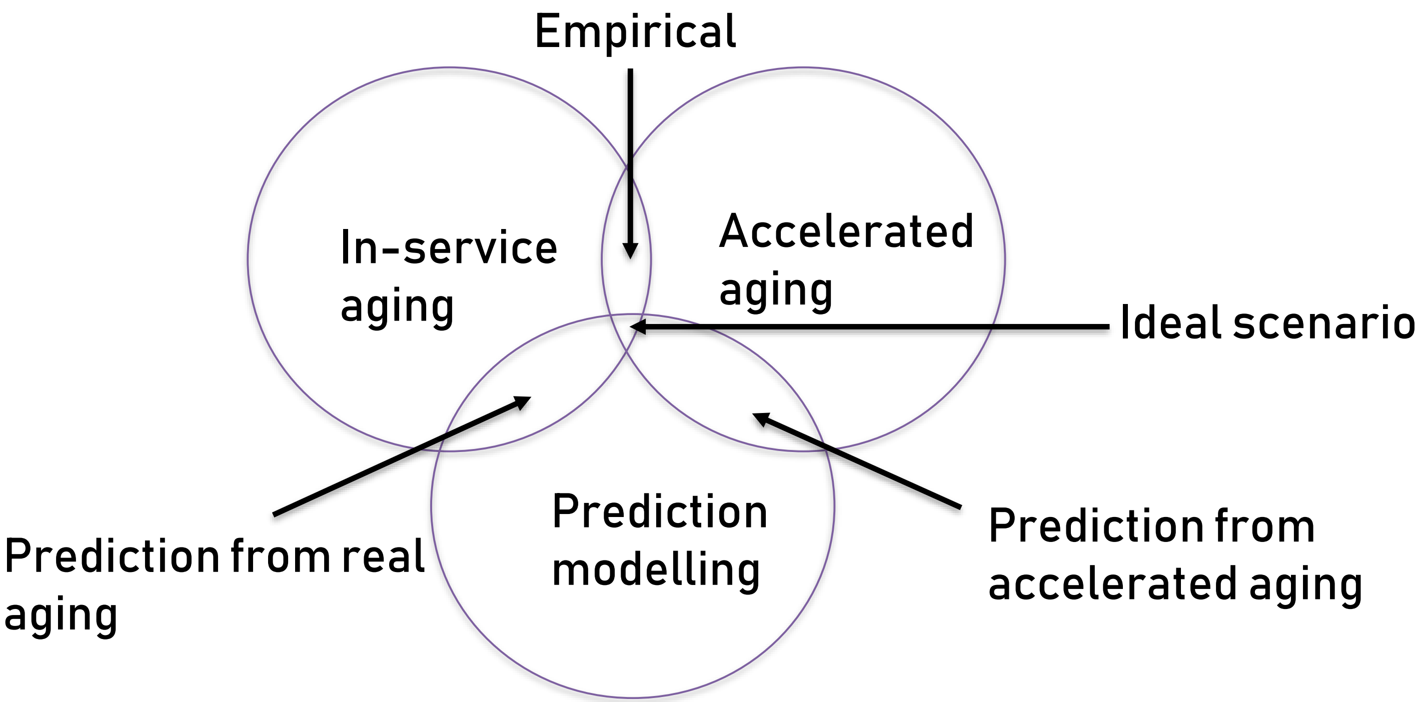


# Still unknown how material degradation relates to structural degradation


vs.

https://theconstructor.org/structures/causes-failure-of-bridge-structures/20853/

# How to bridge the gap?



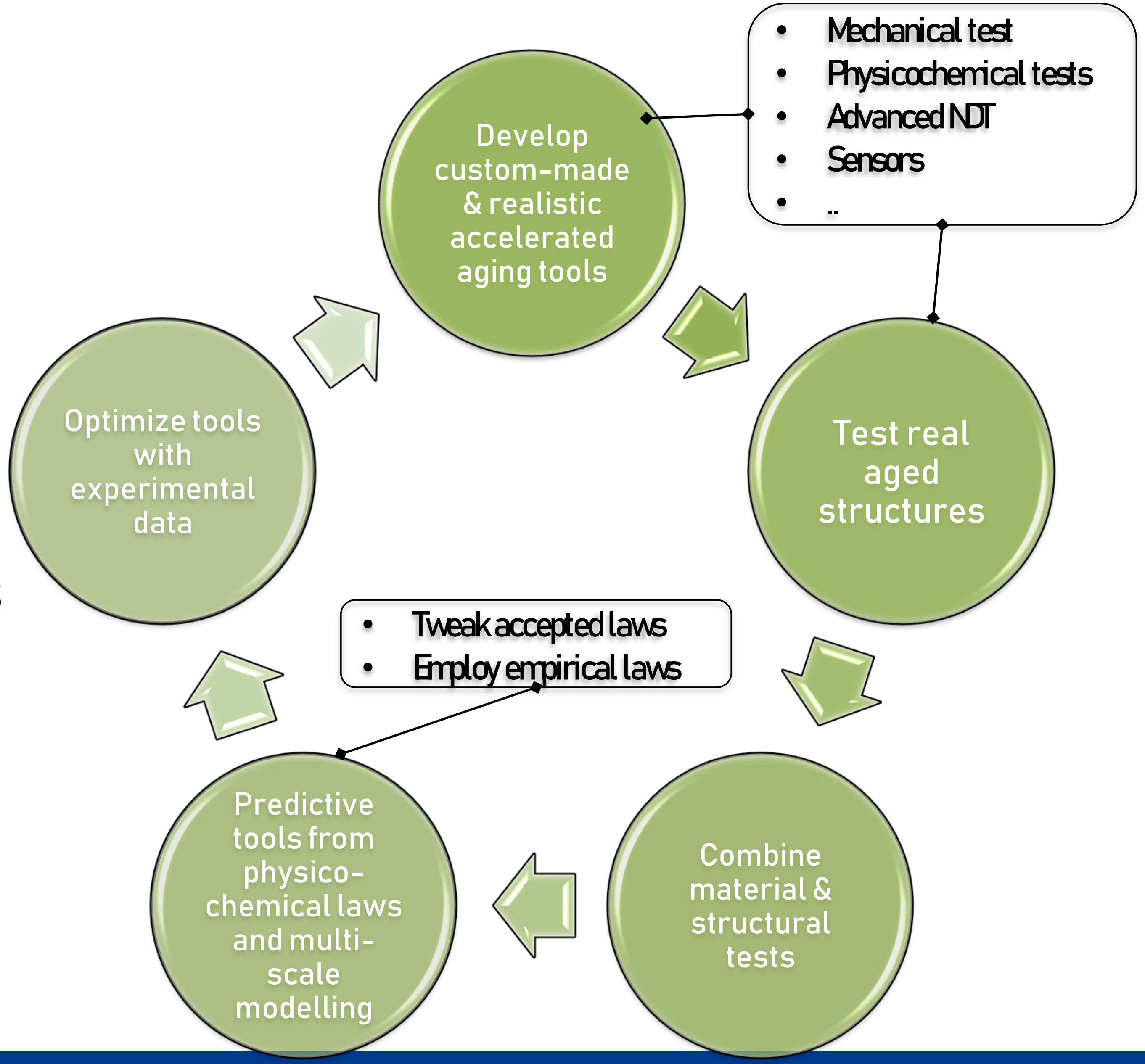

*Accelerate degradation but maintain realism – 'cheat the physics'*

Dr. James Pickett, General Electric Polymer Expert

Survey of Long-Term Durability Testing of Composites, Adhesives and Polymers Issue 2, NPL 2017, UK
Service Life Prediction of Polymers and Plastics Exposed to Outdoor Weathering, Elsevier, 2018

# What is the solution?

- Focus on one product each time
- Create re-producible tests routines
- Test representative samples to generate useful data for designers
- Avoid getting lost with modelling!



- NDT
- Self-sensing nanocomposites

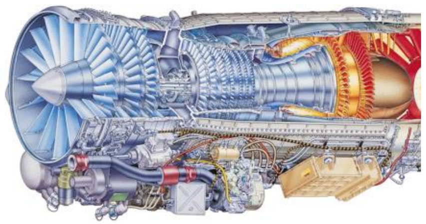
- IAPETUS project, EU/FP7, Ref: ACP8-GA-2009-234333 (Innovative repair of aerospace structures with curing optimization and life cycle monitoring abilities, 2009-2012)

- Accelerated aging
- Modelling
- Understanding

- DuraComp project, EPSRC/UK, Ref:EP/K026925/1 (Providing Confidence in Durable Composites, 2013-2016)

Case study 1

- LightSURF project – LIGHTER, Vinnova, Ref: 2019-02623 (Lighter through surface protection, 2019-2021)



Case study 2

- MEGAMOULD project – Norwegian Research Council, Ref: 256819 (Extra large injection molded components, 2018-2020)

Case study 3

- PREDICT project – Norwegian Research Council, Ref: 297069 (Prediction of service life of fibre-reinforced polymer composites used for gas cylinders, 2019-2020)

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# Acknowledgements


- For financial support:
  - PREDICT – RFF Innlandet, Norwegian Research Council [Ref: 297069, Prediction of service life of fibre-reinforced polymer composites used for gas cylinders – 2019-2020]
  - MEGAMOULD – Norwegian Research Council [Ref: 256819, Extra large injection molded components, 2016-2020]
  - LightSURF – Vinnova, Swedish Research Council [Ref: 2019-02623, Lighter through surface protection, 2019-2021]

REGIONALE FORSKNINGSFOND

LIGHTer

Forskningsrådet

VINNOVA




NTNU


# Thank you!


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