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Realife,
a new project on the ageing of polymers in NPP's
and some examples on what we do at KTH (and with partners)

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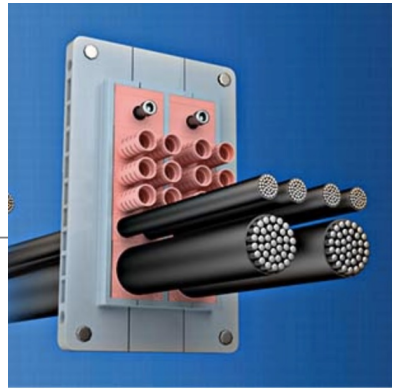

Polymeric Materials - KTH

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https://www.kth.se/fpt/polymeric-materials/division-of-polymeric-materials-1.20099

Content:

Instrumentation to assess aging at KTH

Examples related to NPP

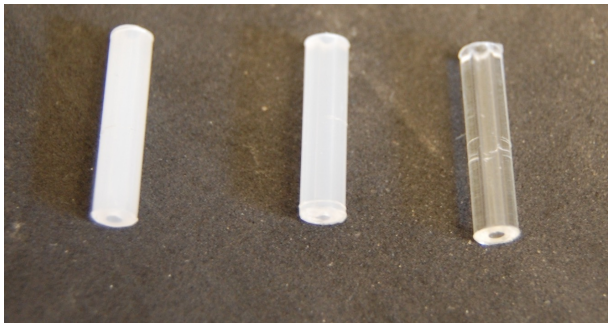
Examples related to automotives

New Project

Why are polymers interacting with the environment?

An important reason!

They are not tight like glass and metals!

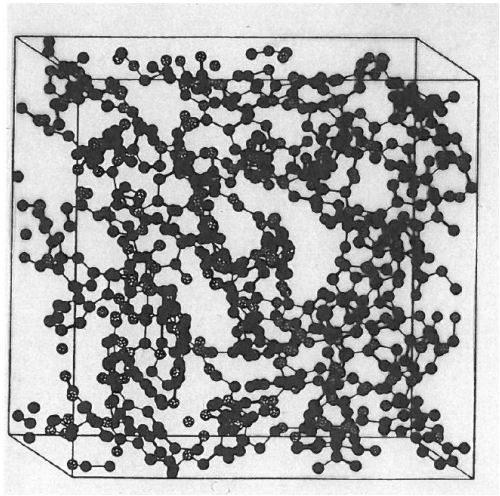


Methanol Ethanol Water

PLA

What is the free volume at 0 K?

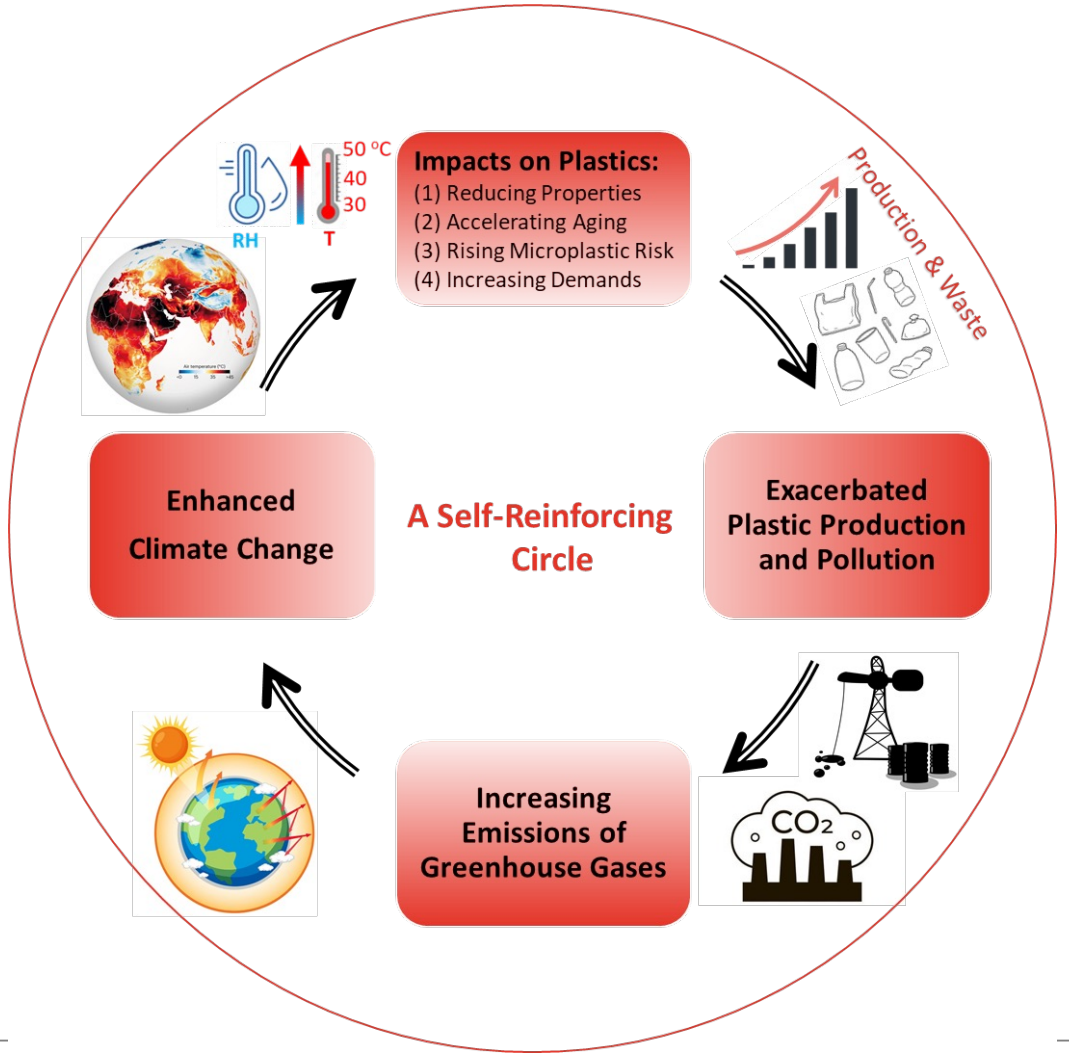
PET



Ageing phenomena

oxidation, hydrolysis, depolymerization, cross-linking, pyrolysis, migration, extraction, swelling, crazing, dehydration, plasticisation, anti-plasticisation, physical ageing, recrystallisation, isopeptide formation, retrogradation, biodegradation, mould growth, bacteria, enzymes, microplastics, fire, partial discharge and voltage break-down

Plastic pollution amplified by a warming climate



X.-F. Wei, W. Yang, M. S. Hedenqvist, *Nature Commun.* **15** (2024) 2052.

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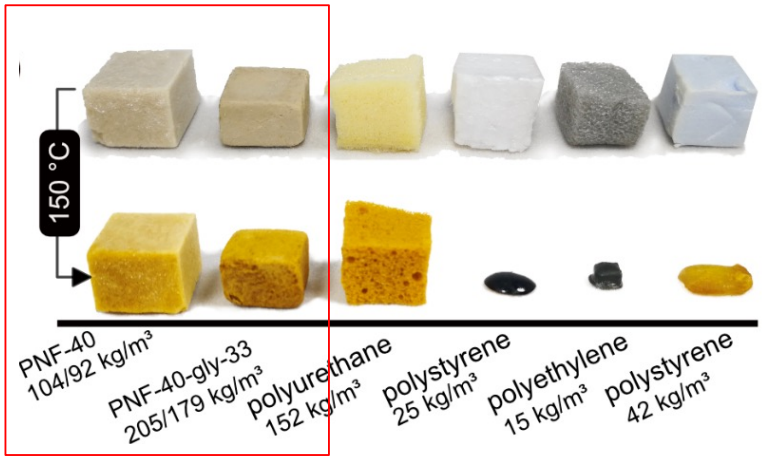
Long-term properties
Life-time prediction, Accelerated ageing

Examples from past and present projects at KTH

- Cables and seals (air, water, radiation) - Nuclear power plants
- Plastic pipes/tubes (gas, oil, fuel, water)
- Quick connectors/fuel pumps (fuel)
- Polymer films and coatings (flourinated polymers)
- Cables – high voltage electric transmission
- Coated wires in electric motors
- Foam stability
- Monomer migration
- Malaria nets

Milk proteins (whey protein nanofibrils)

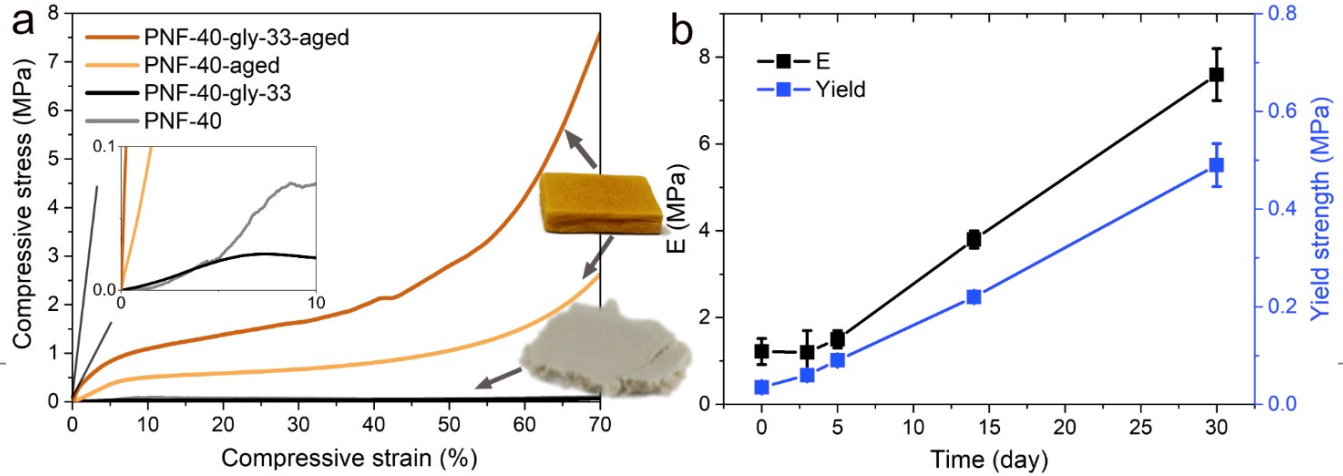
Getting better at harsh conditions!!



Isopeptide bond formation

1 month, Air

Proteins – better fire properties than polyurethane, polyolefins…..

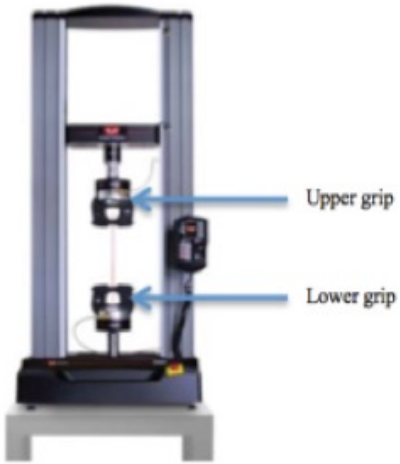


X. Ye, A. J. Capezza, V. Gowda, R. T. Olsson, C. Lendel, M. S. Hedenqvist, *Adv. Sust. Syst.*, **5** (2021) 2100063.

Instrumentation used at KTH

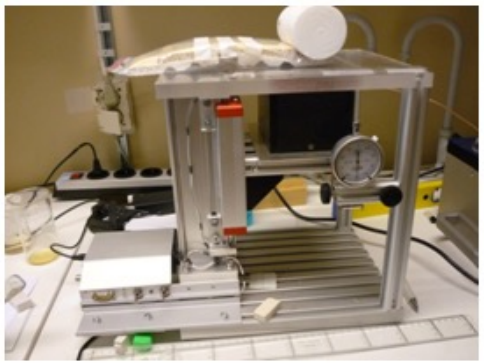
Indenter modulus profiling

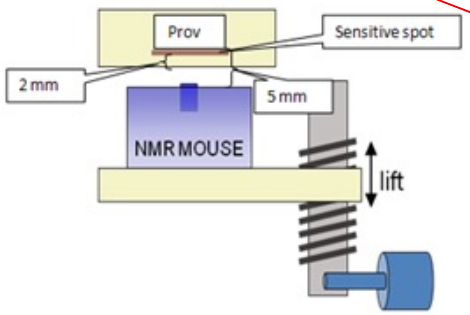
- Modified Instron 5566 universal testing machine.

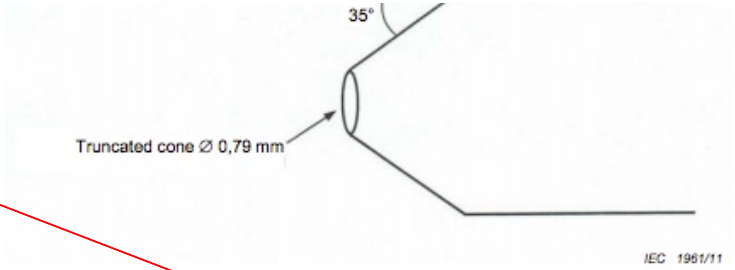


Heat set
DSC
FTIR

NMR - mouse







IEC/IEEE 62582-2

NMR In-situ…..

Source: (A. Guthausen, G. Zimmer, P. Blümler and B. Blümich. Analysis of polymer materials by surface via the MOUSE. 1997)

Microcalorimetry, testing closer to real conditions

Large samples (grams)

M. Pushp et al., *J. Calorim. Therm. Anal.*, **147** (2022) 8271-8278.

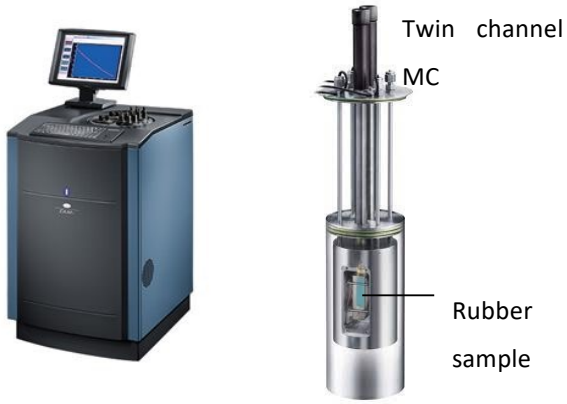
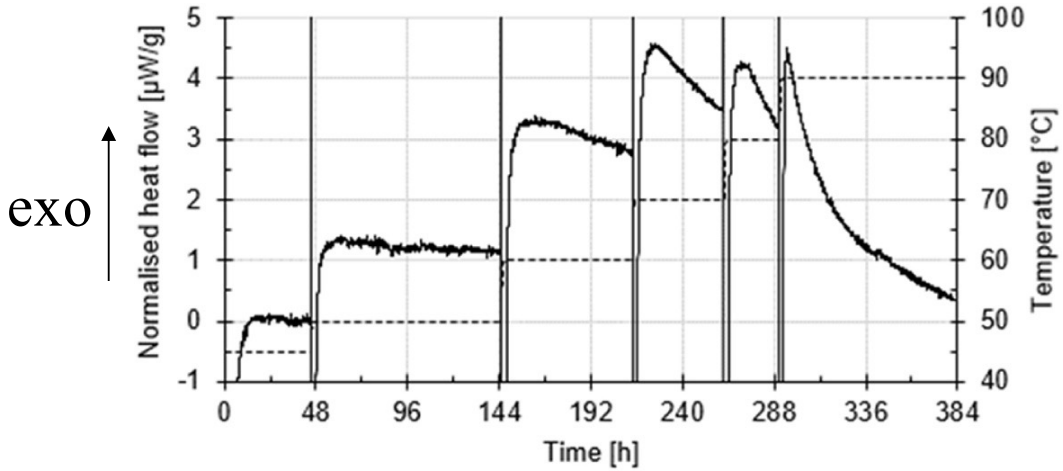


Figure 10. TAM III and a Twin channel MC

EPDM, air



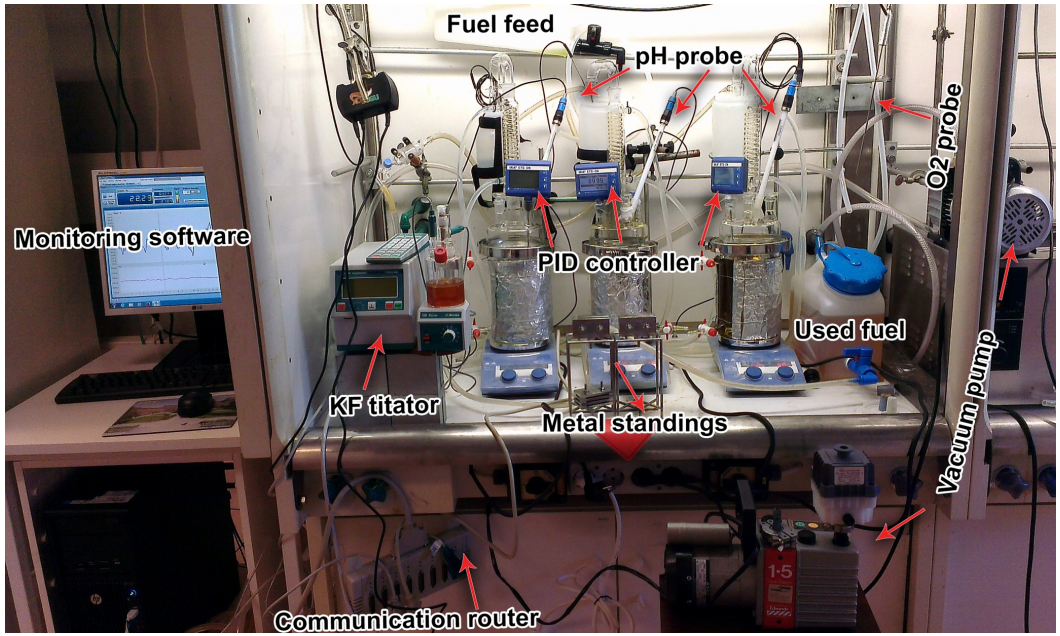
Thesis, Pushp

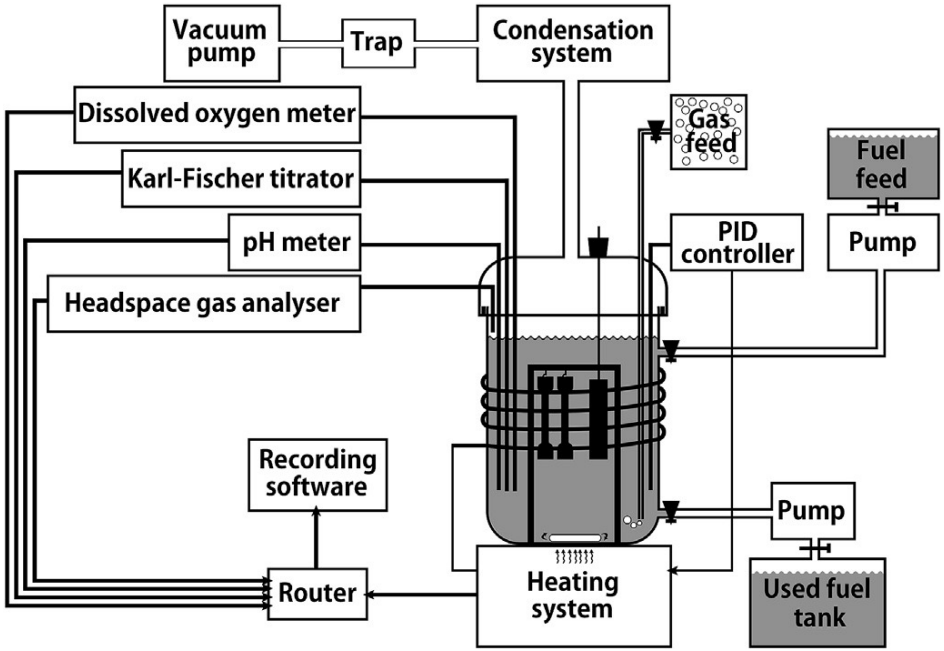
1000 times higher sensitivity than DSC

M. Pushp, A. Lönnermark, P. Vikegard, X.-F. Wei and M. Hedenqvist, *Polym. Test.*, **120** (2023) 107948

Plastic/rubber immersed in fuel

fuel: water/O_2 content, acidity





Nitrogen/oxygen gas purge into the fuel

Creating different $p_{O2,}$ removal of headspace if necessary

Nuclear Power Plants
examples of previous work

47 % EPDM
39 % carbon black
5 % $CaCO_3$
6-7 % paraffine oil
1 % S
….

30 % EPDM
6 % $CaCO_3$
35 % $Al(OH)_3$
6-7 % stearine/waxes
2 % S
……

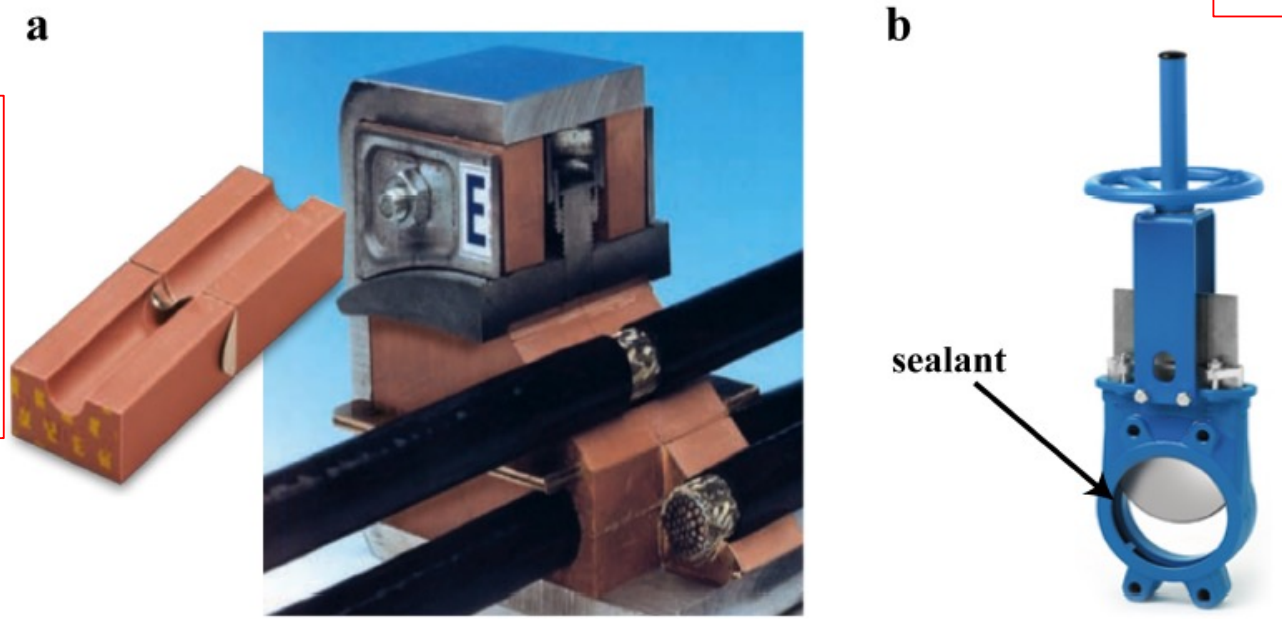
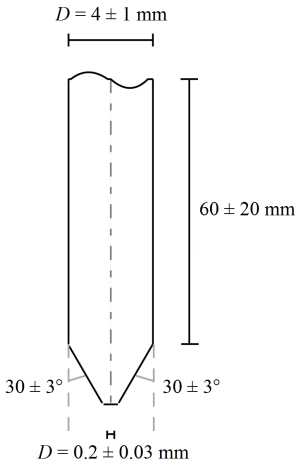
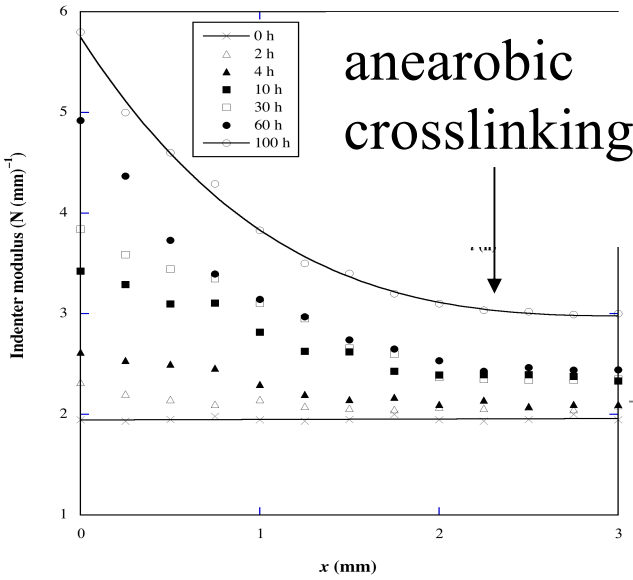


Fig. 1 a) A cross-section of a cable transit system. Lycron seal blocks (pink) can be seen packed in the frame structure. b) Carbon black-containing EPDM seal installed in a transportation valve (knife-port valve).

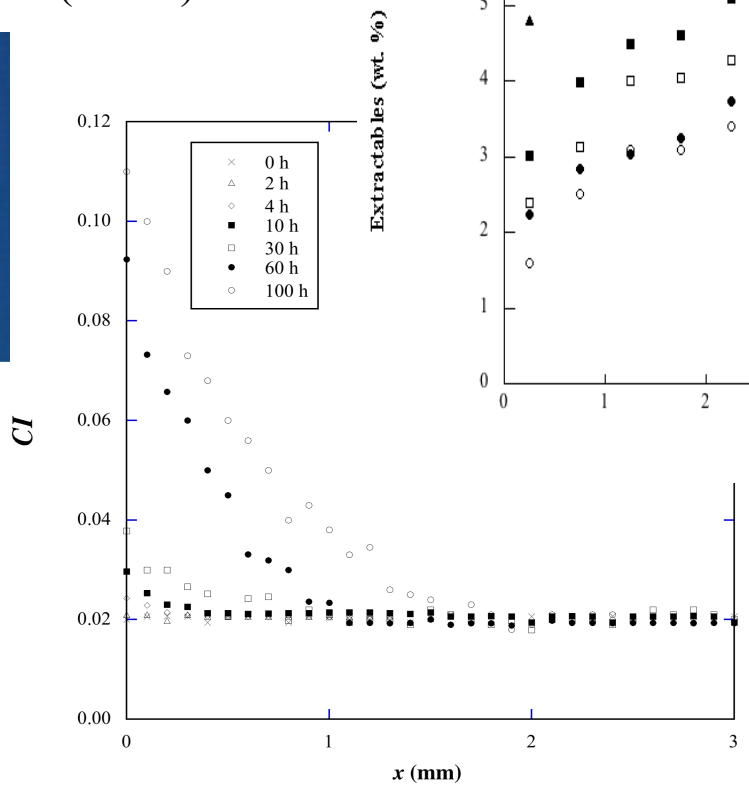
Profiling of thermally aged EPDM seals using portable NMR, indenter measurements and IR spectroscopy facilitating separation of different deterioration mechanisms

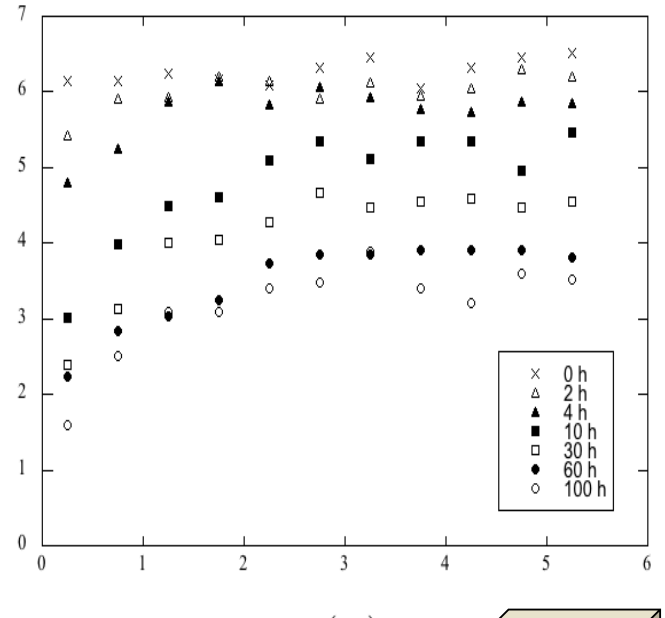


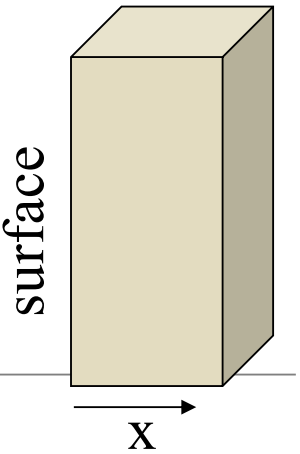
Oxidation, anearobic crosslinking and loss of oil extender (170 C)



anearobic crosslinking

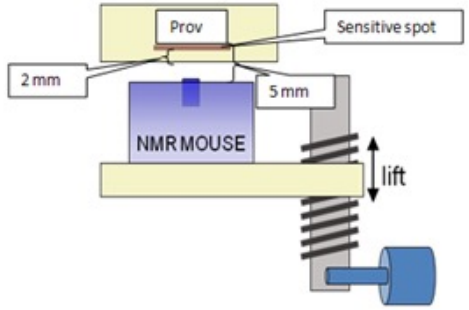


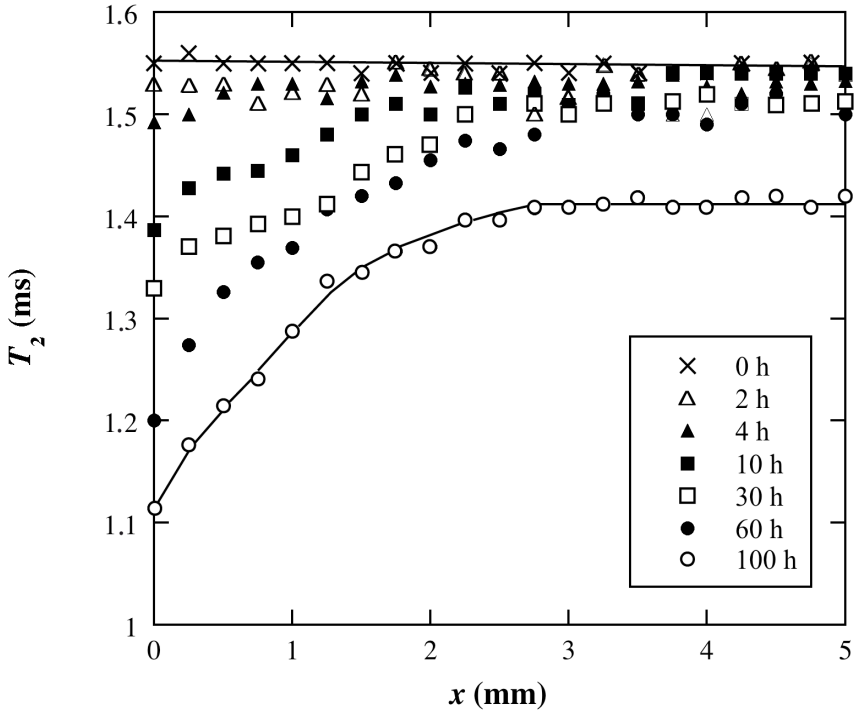




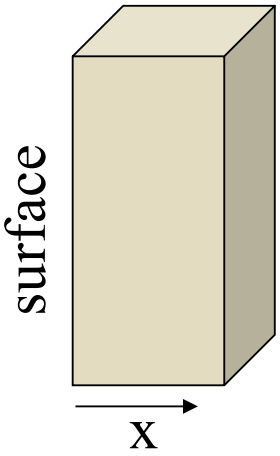
P. Pourmand, E. Linde, M. Hedenqvist, I. Furo, S.V. Dvinskikh, U. W. Gedde, *Polym. Test.* **53** (2016) 77-84.

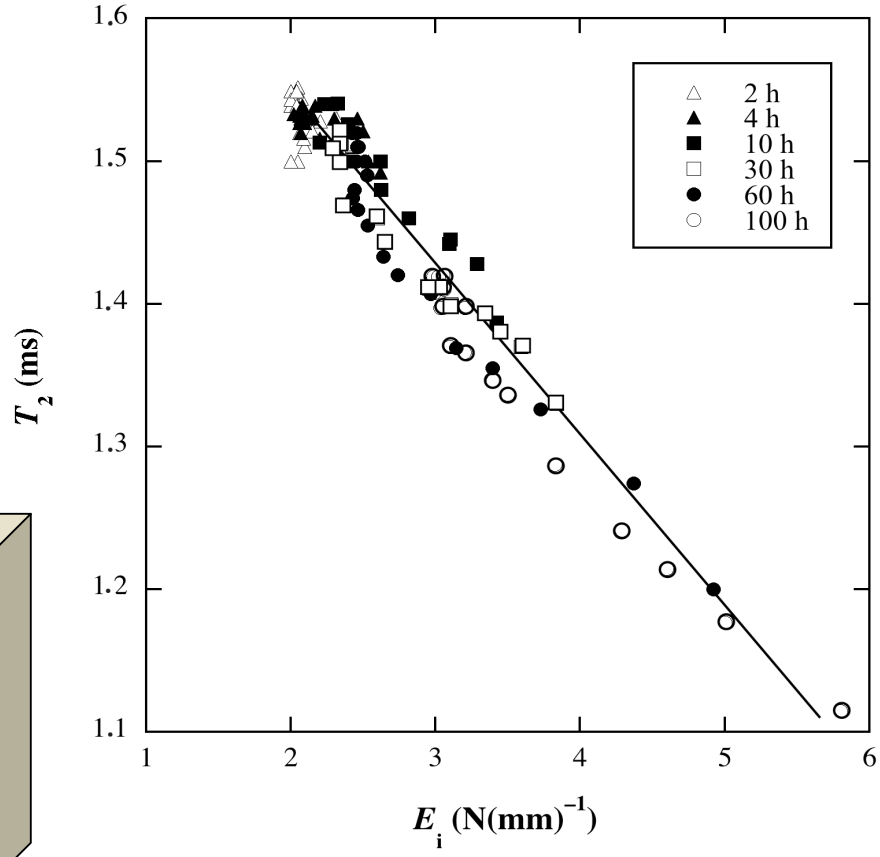
NMR mouse=Non-invasive
No specimen preparation





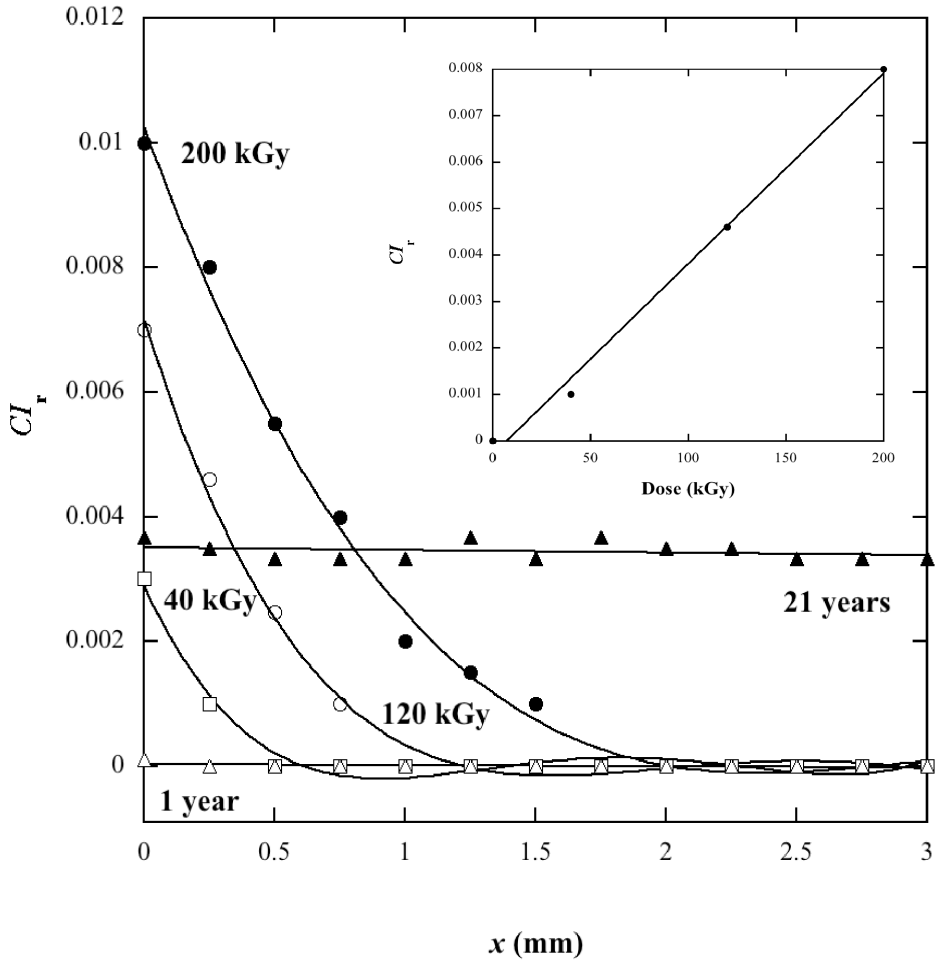
170 C





Radiochemical ageing of highly filled EPDM seals as revealed by accelerated ageing and ageing in-service for 21 years

DLO effects and accelerated ageing
Gamma radiation

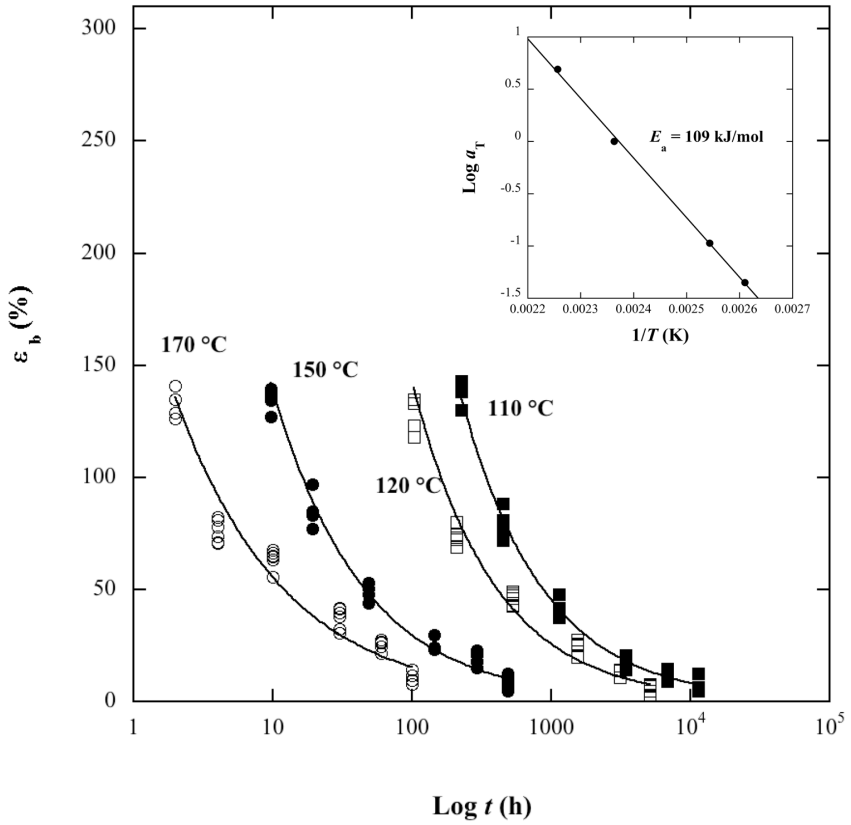


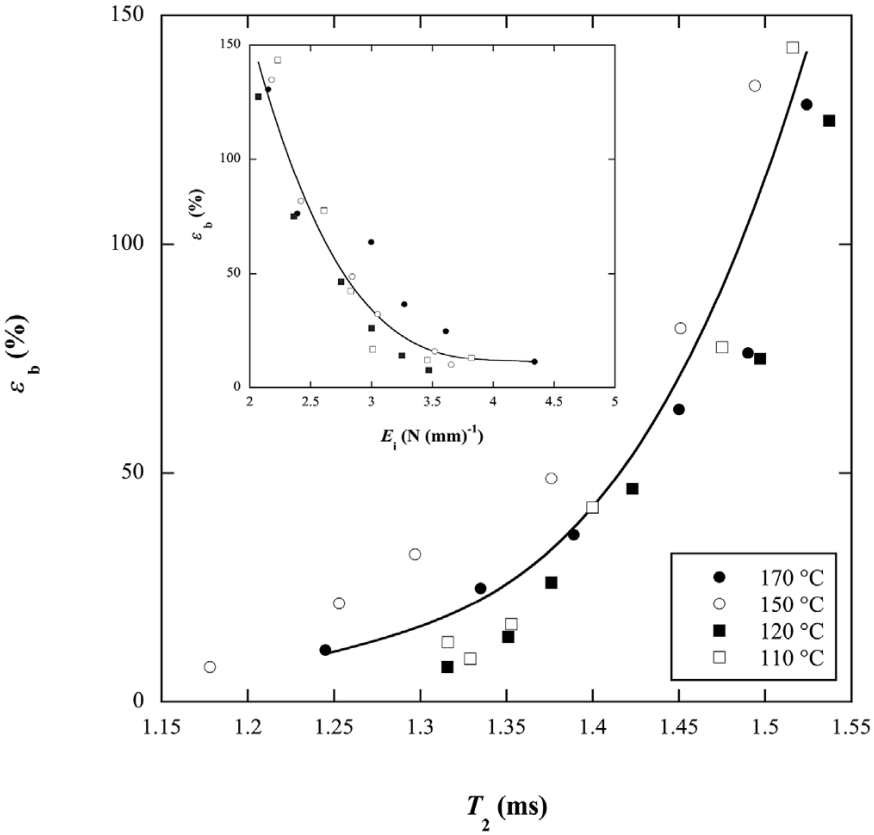
23 C, p_{O2}=1 kPa using ^{60}Co gamma-ray source that yielded a dose rate of 0.31 kGy/h

Service conditions
23 C, p_{O2}=1 kPa
0.15 kGy/year.

P. Pourmand, M. S. Hedenqvist, I. Furó, U. W. Gedde, *Polym. Degr. Stab.* **144** (2017) 473-484.

Deterioration of highly filled EPDM rubber by thermal ageing in air: kinetics and non-destructive monitoring



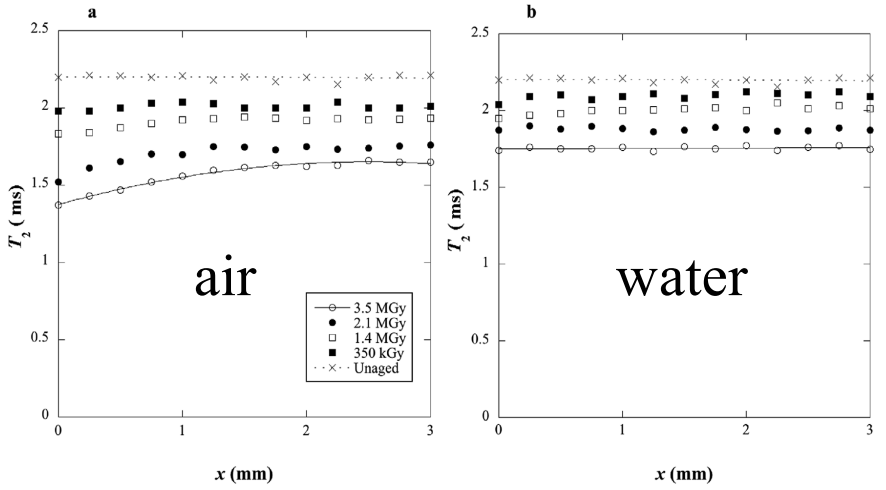


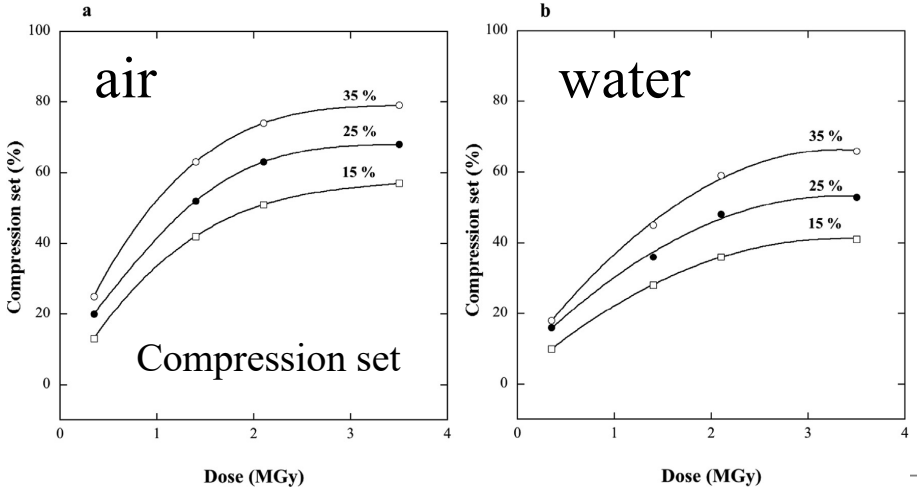
ε_b=50 %, 3000 years at 23 C

P. Pourmand, M.S. Hedenqvist, I. Furó, U.W. Gedde, *Polym. Test.* **64** (2017) 267-276.

Effect of gamma radiation on carbon-black-filled EPDM seals in water and air

oxidative crosslinking
(but also anaerobic crosslinking)





$$H_2O \xrightarrow{\gamma} (H_2O^{\bullet+})^* + e^- \rightarrow e_{aq}^-$$
$$\downarrow 10^{-13}\ s$$
$$H_{aq}^+ + {}^{\bullet}OH_{aq}$$

oxygen dissolved in water is consumed during irradiation, less oxygen available for oxidation

short exposure (40 h) to 350 kGy once per year

P. Pourmand, L. Hedenqvist, A. M. Pourrahimi, I. Furó, T. Reitberger, U.W. Gedde, M.S. Hedenqvist, *Polym. Degr. Stab.* **146** (2017) 184-191.

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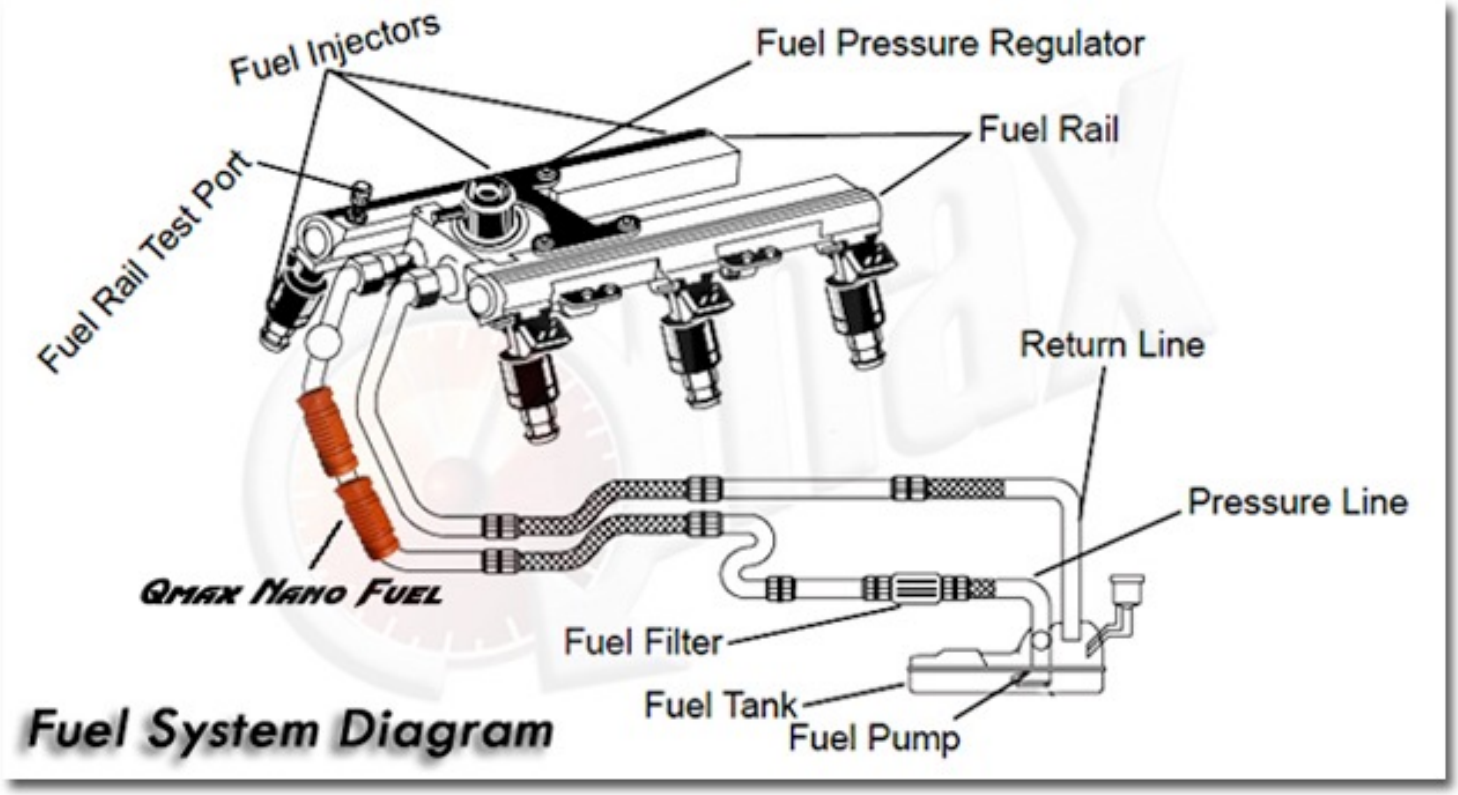
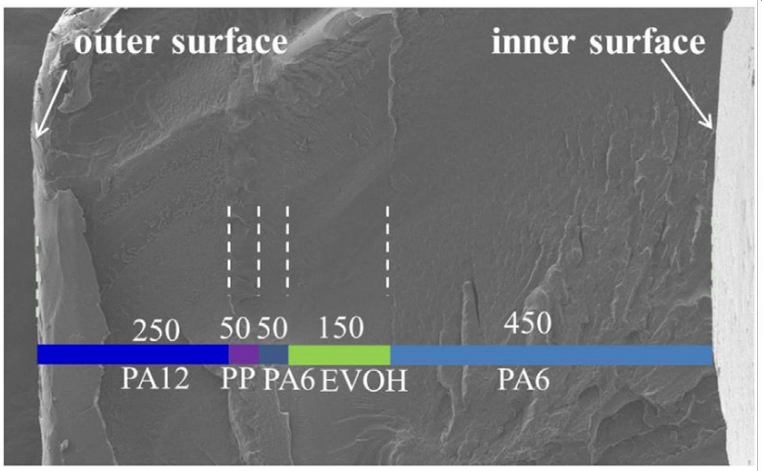
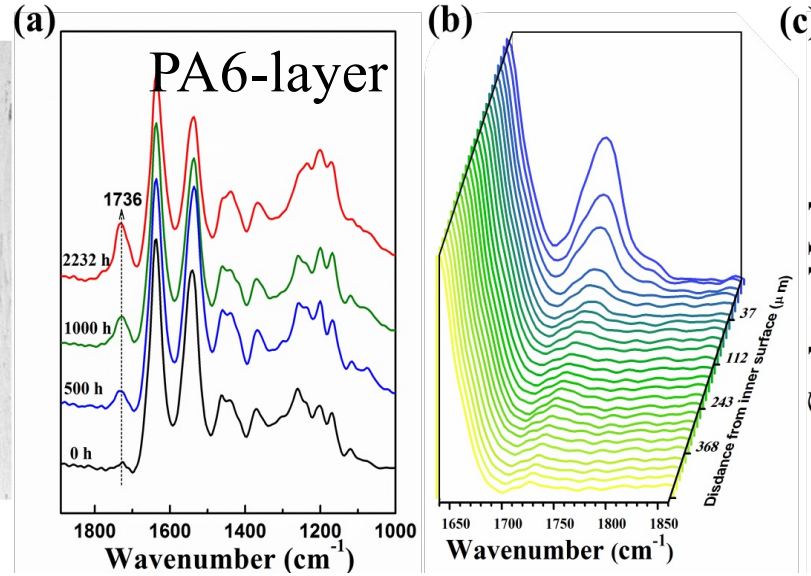
Automotives

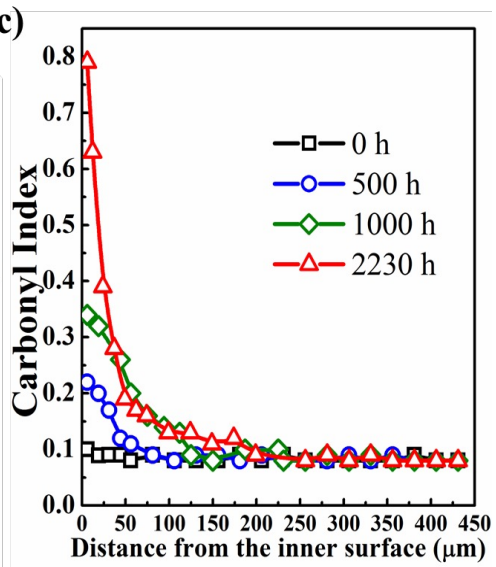
Fuel lines

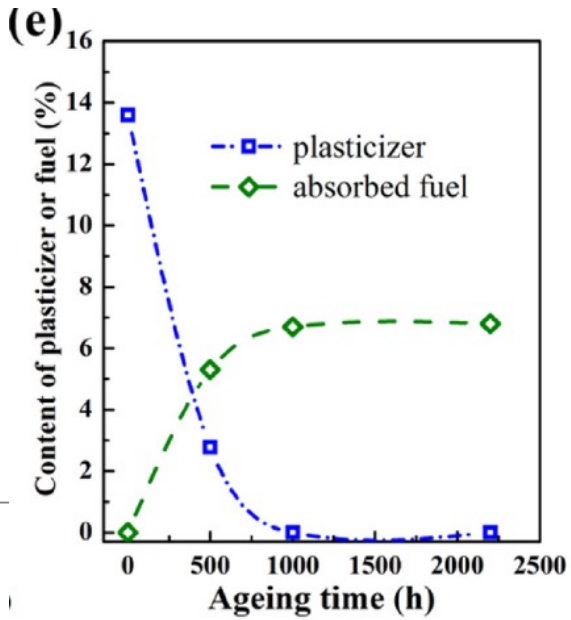


Long-term performance of polyamide-based multilayer (bio)diesel fuel lines aged under "in-vehicle" conditions



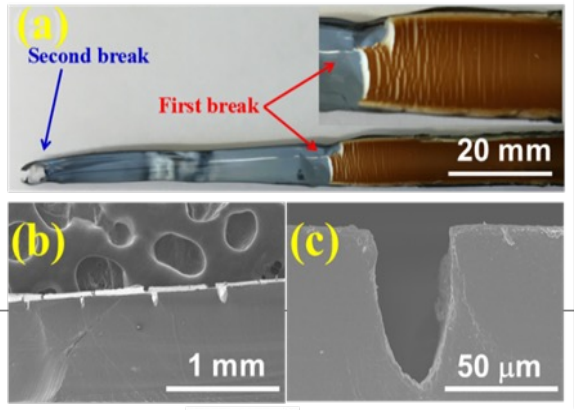


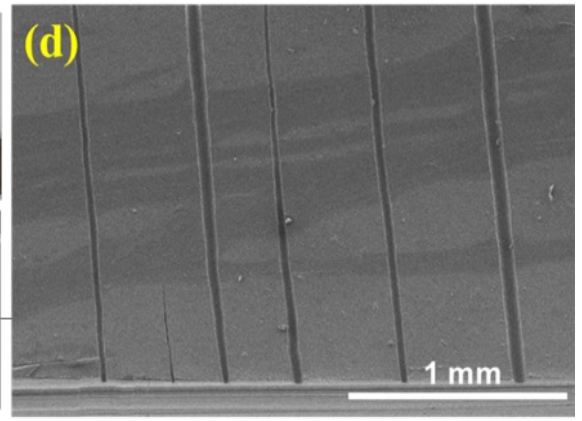




Alternating between petroleum-diesel (B0) and B0 with 20 % biodiesel (B20)

Stress release

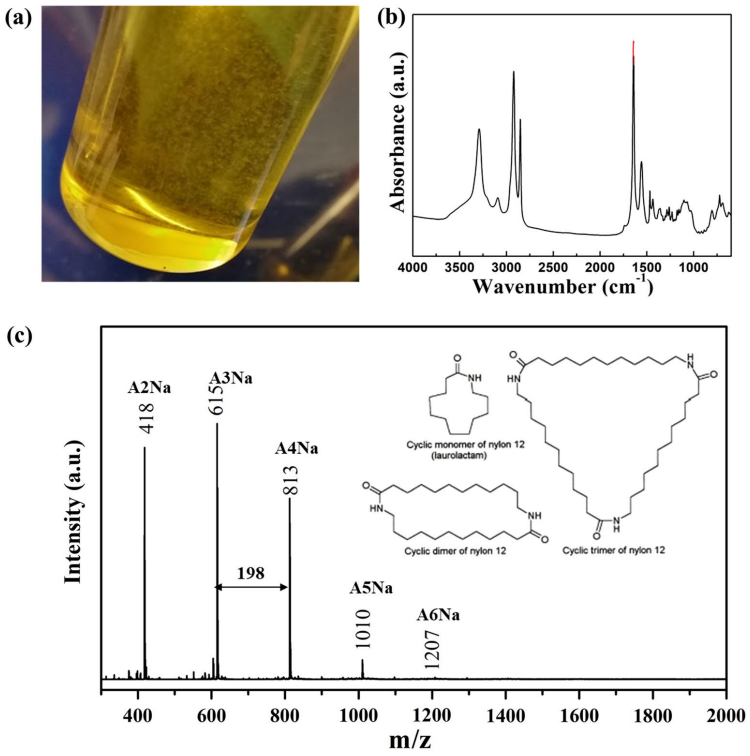


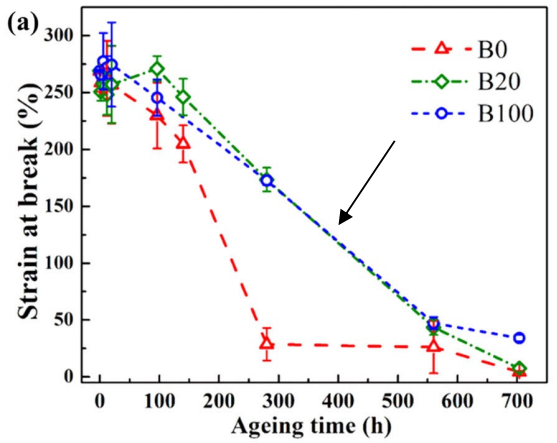


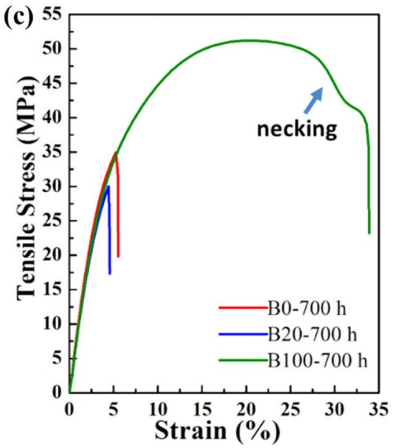
X. Wei, S. Akhlaghi, K. J. Kallio, S. Bruder, M. Bellander, U. W. Gedde, M. S. Hedenqvist, *Polym. Degr. Stab.*, **144** (2017) 100-109.

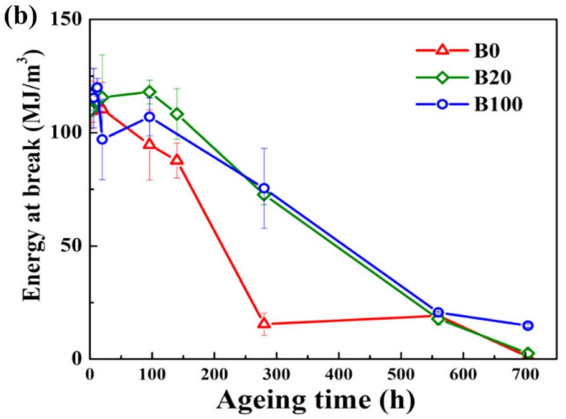
Polyamide 12 exposed to (bio)diesel at high temperature

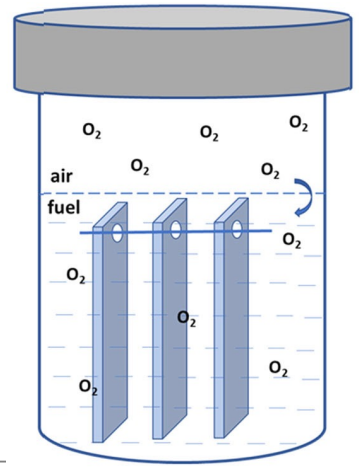
125 C





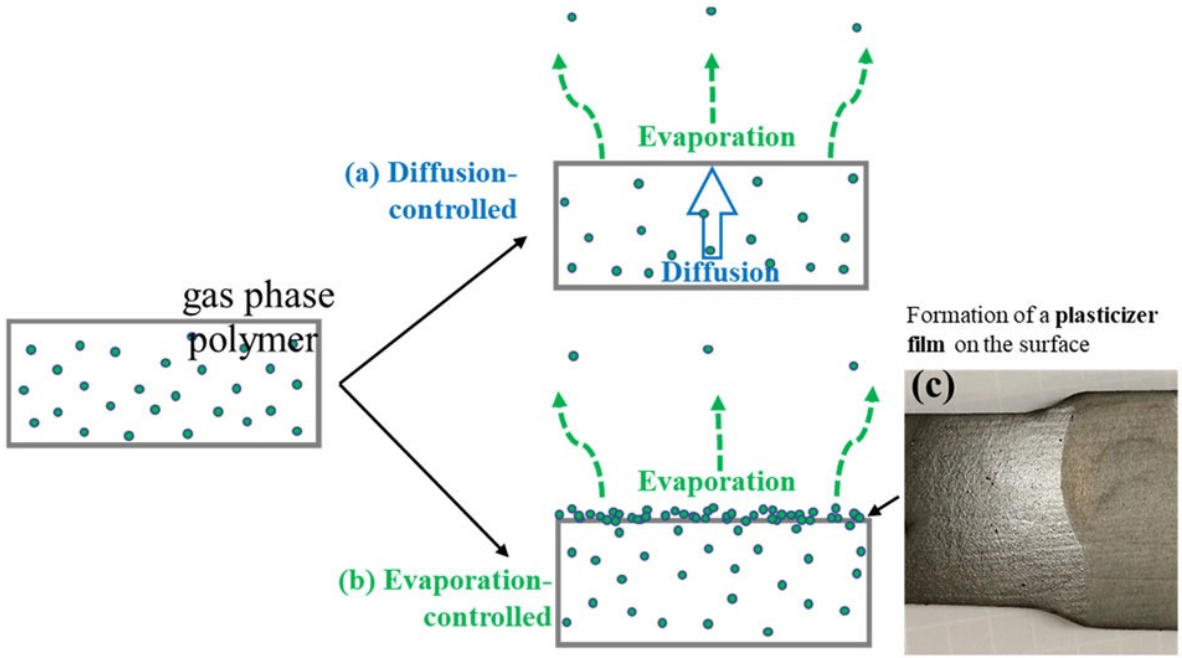


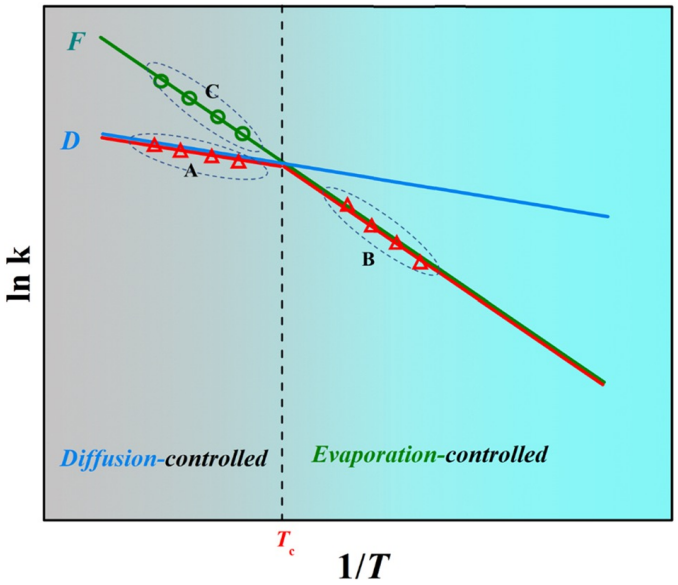


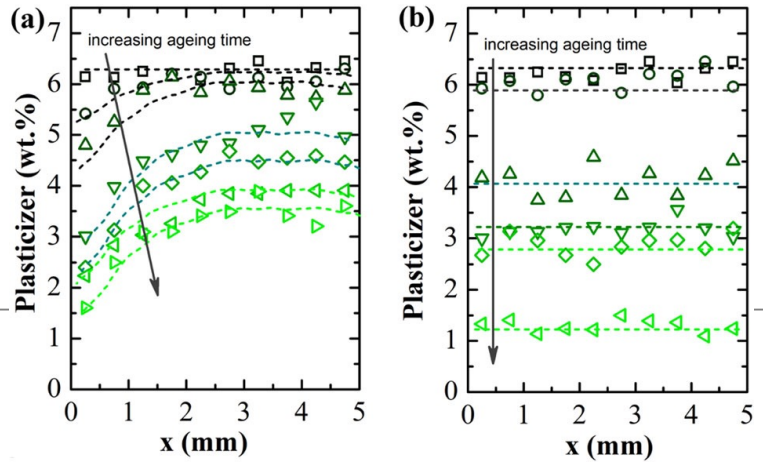


X.-F. Wei, L. De Vico , P. Larroche, K. J. Kallio, S. Bruder, M. Bellander, U. W. Gedde, M. S. Hedenqvist, *npj Mater. Degrad.*, **3** (2019) 1-11.

Plasticiser loss from plastic or rubber products through diffusion and evaporation







Prediction over Tg
Complex, safety factor
Case: PA12, 125 C to 60 C

X.-F. Wei, E. Linde, M. S. Hedenqvist, *npj Mater. Degrad.*, **18** (2019) 1-8.

Rubbers in fuel/engine parts of vehicles

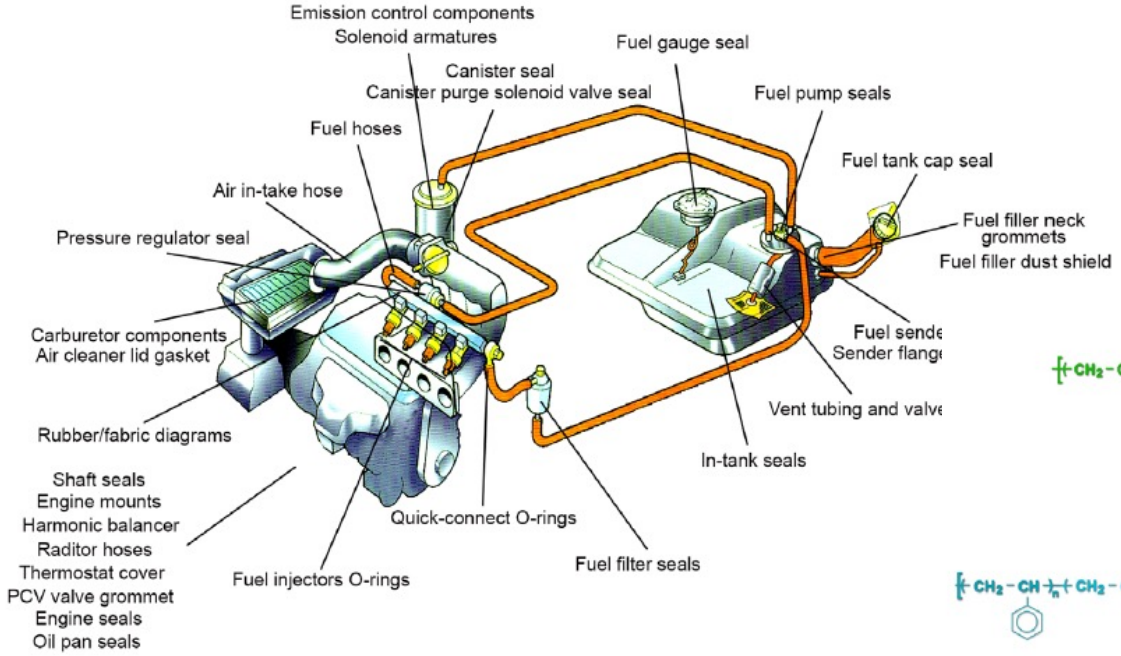


Fig. 1. The location of some of the rubber parts in a conventional fuel system

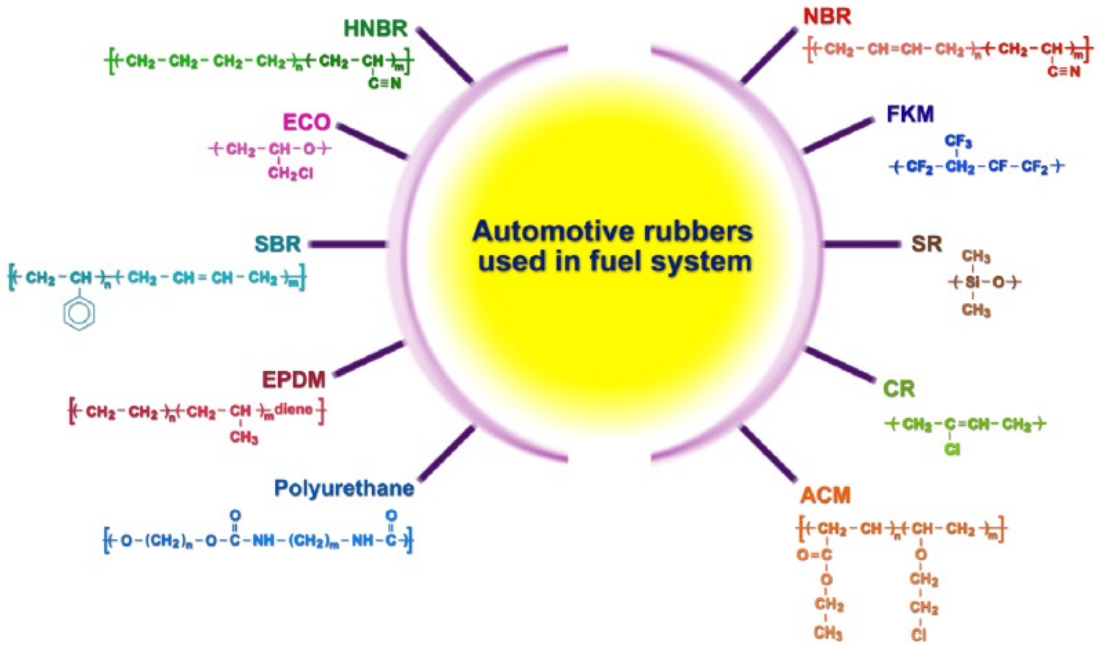
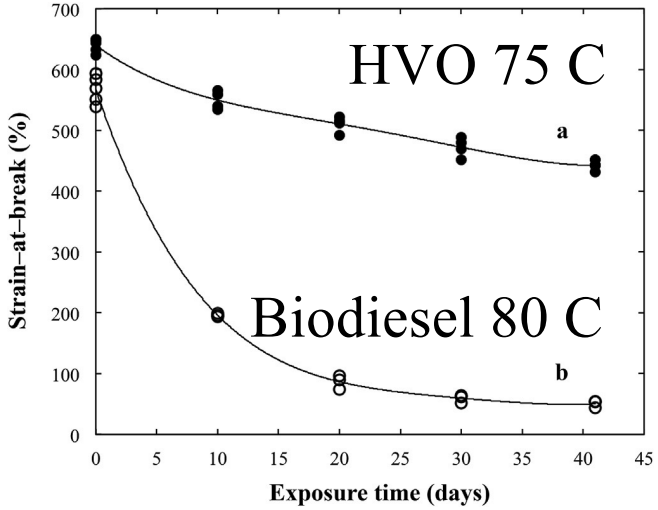


Fig. 2. Chemical structures of the rubbers most frequently used in automobile fuel systems.

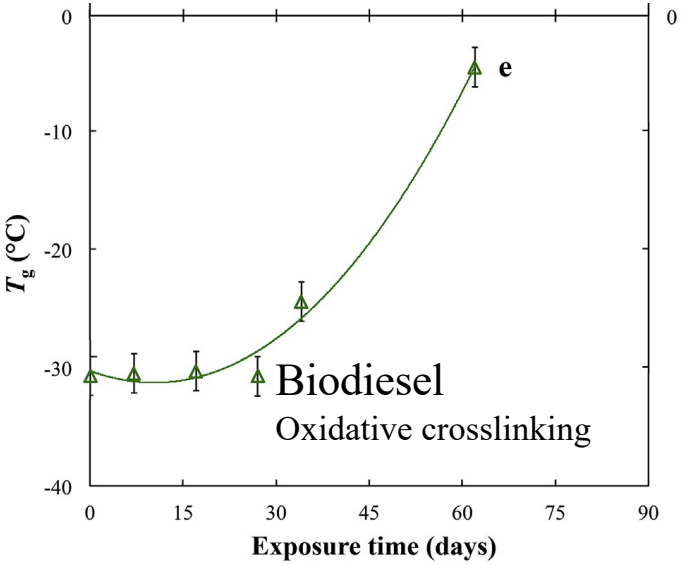
"Deterioration of **Automotive Rubbers in Biofuels**: A Review", S. Akhlaghi, M. S. Hedenqvist, M. T. Conde Braña, M. Bellander and U. W. Gedde, *Renew. Sustain. Energy Rev.* **43** (2015) 1238-1248.

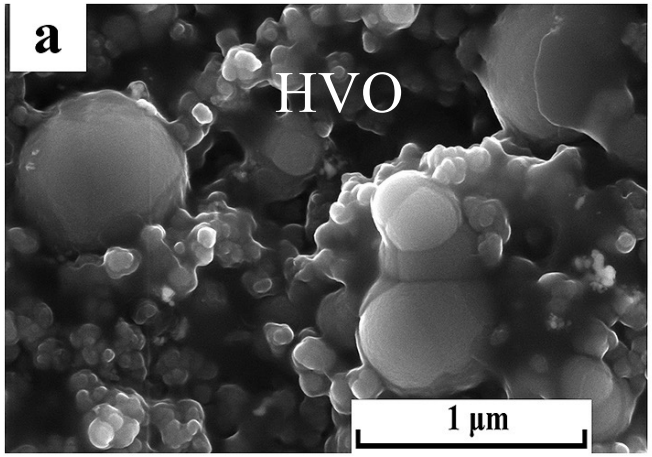
Degradation of carbon black–filled–**NBR** in **biodiesel** and HVO

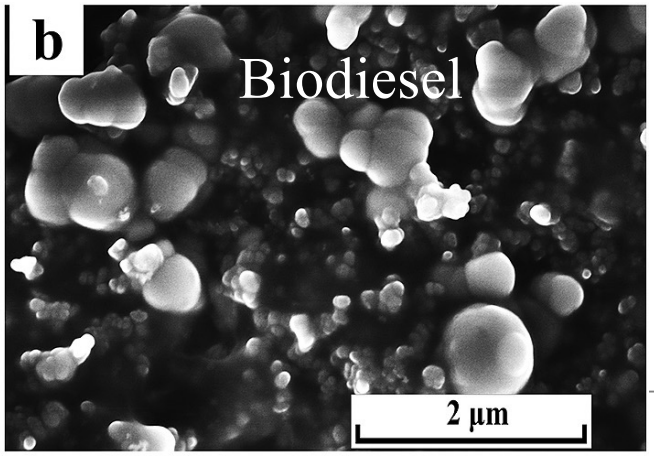


Loss of plasticiser

Cavitation in the filler-rubber interphase (biodiesel)





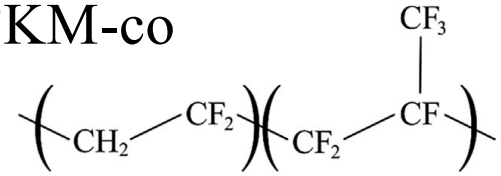


S. Akhlaghi, A.M. Pourrahimi, M. S. Hedenqvist, C. Sjöstedt, M. Bellander, U. W. Gedde, *Polym. Degrad. Stab.* **123** (2016) 69-79.

Degradation of **fluoroelastomers in rapeseed biodiesel**

100 C

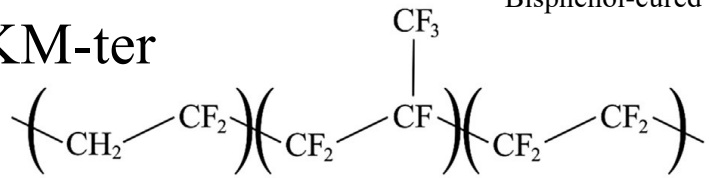
FKM-co

(a) 

”Dehydroflourination causing chain cleavage”

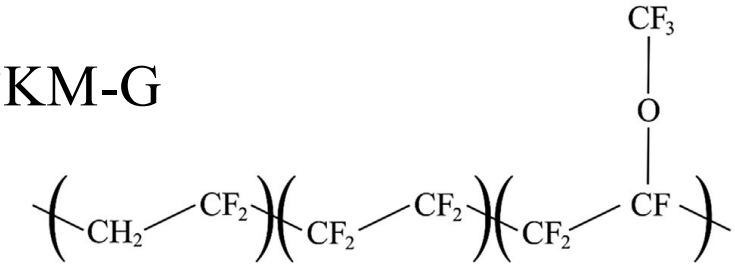
Bisphenol-cured

FKM-ter

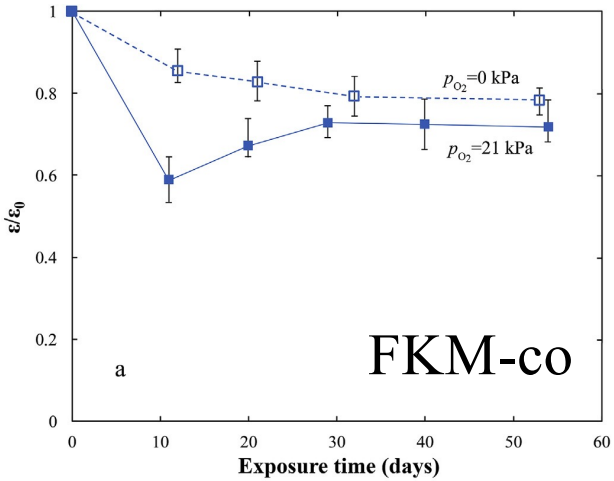
(b) 

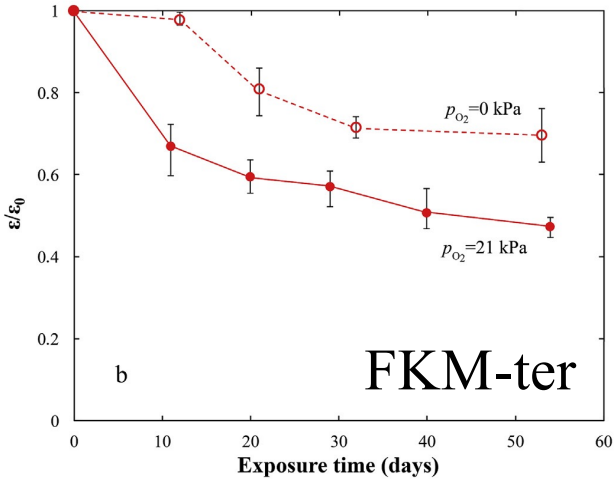
extensive dehydrofluorination driven by metal ions and rupture of the bound rubber-carbon black network

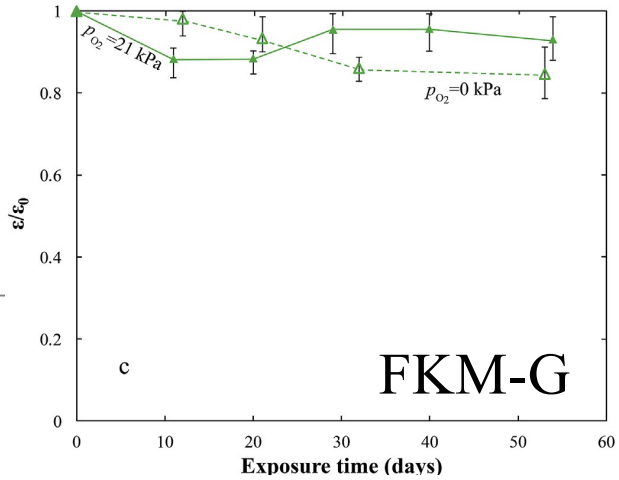
FKM-G

(c) 

least amount of unsaturations (where biodiesel attack) and metal oxide/hydroxide particles (peroxide cured)



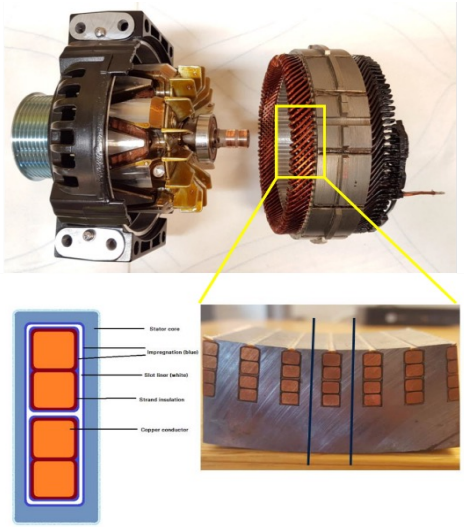




S. Akhlaghi, A. M. Pourrahimi, C. Sjöstedt, M. Bellander, M. S. Hedenqvist, U. W. Gedde, *Polym. Degr. Stab.* **136** (2017) 10-19.

InElect

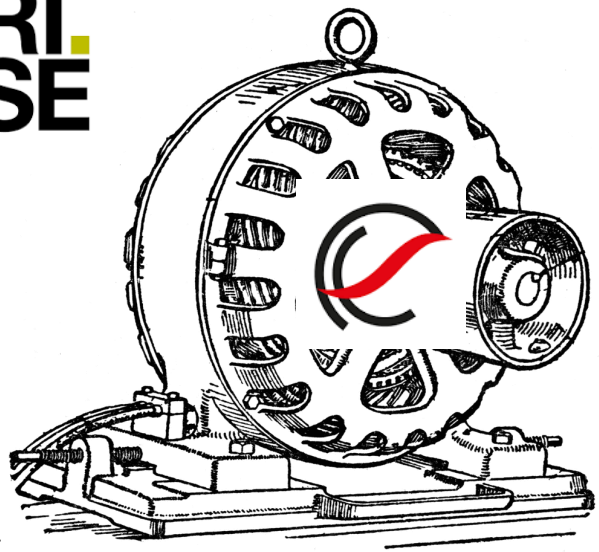
Plastics in electric machines: Ageing mechanisms and the development of new sustainable solutions



Enamel (PI), PPS, PEEK

The main reasons of using the insulation are:

Preventing short circuits
Dissipate heat (Joule heating)
Minimize vibration-induced mechanical stress.



www.ri.se/en/what-we-do/projects/plastics-in-electric-machines-ageing-mechanisms-and-the-development

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Challenges;
accelerated testing versus real conditions

Thank you!