Das Kunststoff-Zentrum

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Oxidative lifetime prediction of polypropylene geotextiles in an aqueous medium by using high-pressure autoclave tests

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EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 607

MARINE AGING OF POLYMERS

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Agenda

Examples of geotextiles in marine applications

Question:

When will the End-of-Life of a geotextile be reached?

High-pressure autoclave testing (HPAT)

- Test setup
- Test conditions

Test results of a GTX-W

- HPAT test results
- Extrapolations regarding T and $p(O_2)$

Service life estimation

Summary

Geotextiles in marine engineering

Chris R. Lawson (2016) in Geotextiles – From Design to Applications

- Geotextile containment units
  - Geotextile bags
  - Geotextile tubes (container)
- Marine revetments
- Containment dykes
- Protection dykes
- Artificial reefs
- Offshore engineering applications
  - Scour protection for offshore wind turbines
  - Support and protection for offshore pipelines

Jamuna-Meghna river

Erosion mitigation project, Bangladesh

Source: Heibaum/Oberhagemann

Jamuna-Meghna river

Erosion mitigation project, Bangladesh

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Jamuna-Meghna river

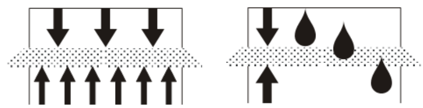
Erosion mitigation project, Bangladesh

Source: Heibaum/Oberhagemann

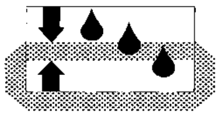
Geotextile bags

Source: Naue

Geotextile bag revetment



Geotextile bags for coastal protection



Geotextile container **revetment**

Source: TenCate

Artificial reefs with geotextile containers for erosion control and surf management

Geotextile containers for coastal protection

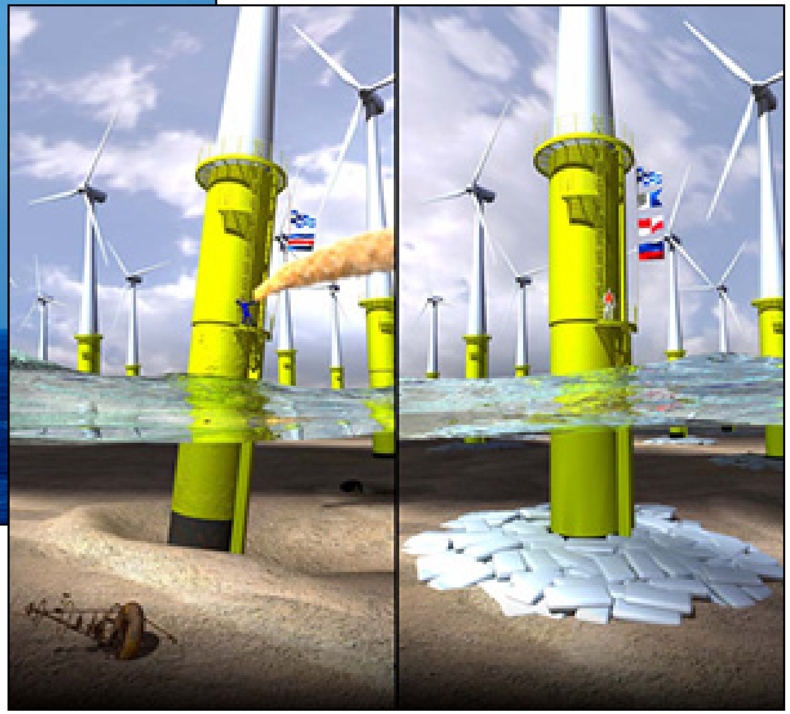
Sunlight exposed geotextiles

NOTE:

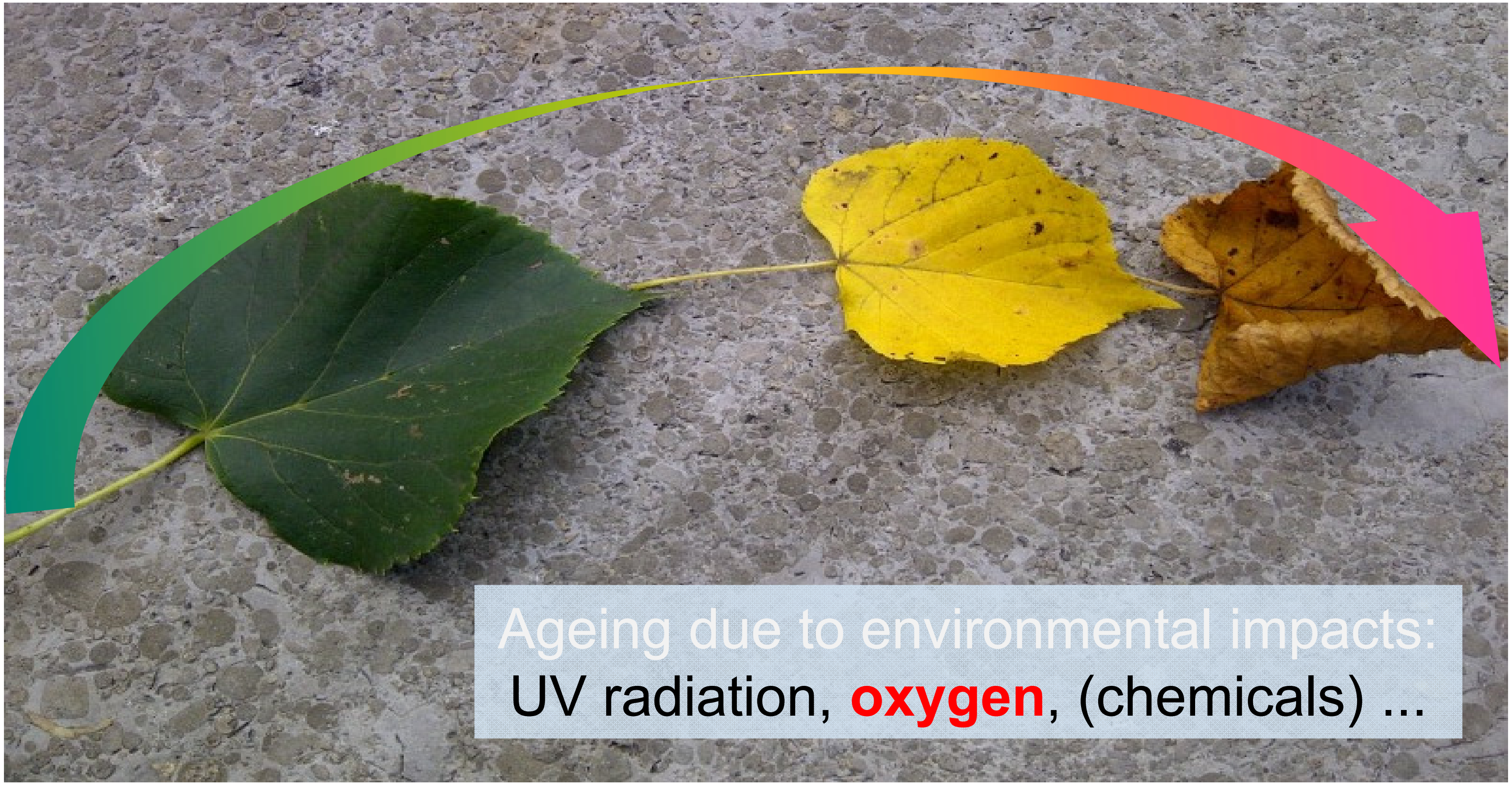
UV-resistance of exposed geotextiles is limited !

They may last a few years only.

Scour protection for offshore wind turbines with geotextile bags

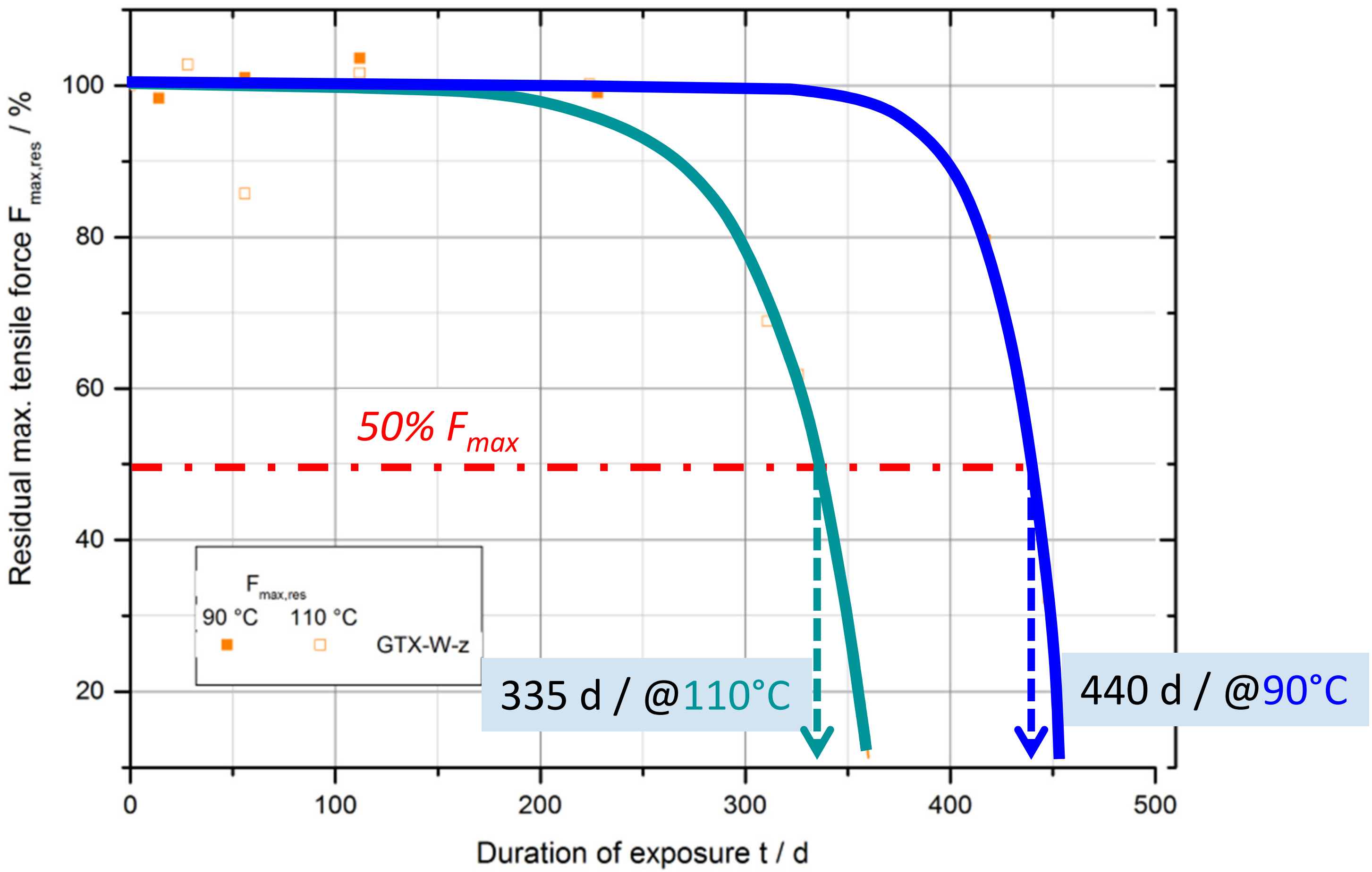


End-of-Life of PP-geotextiles



Woven geotextile

Oven test results



Simulation of Ageing in the Laboratory

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- **Leaching tests**

  wet ageing in water at elevated temperature

  (pH-value, stirring, temperature tolerance, size of container, …)

- **Oxidation tests**

  dry ageing in air in laboratory oven at elevated temperature

  (fresh-air intake, ventilation, circulation, air change rates, air velocity, temperature distribution, temperature tolerance, distance between specimens, volume of oven, …)

- **High-pressure autoclave tests (HPAT)**

  (screening tests acc. to ISO 13438)

  ageing in water at elevated temperature, elevated oxygen pressure and pH10

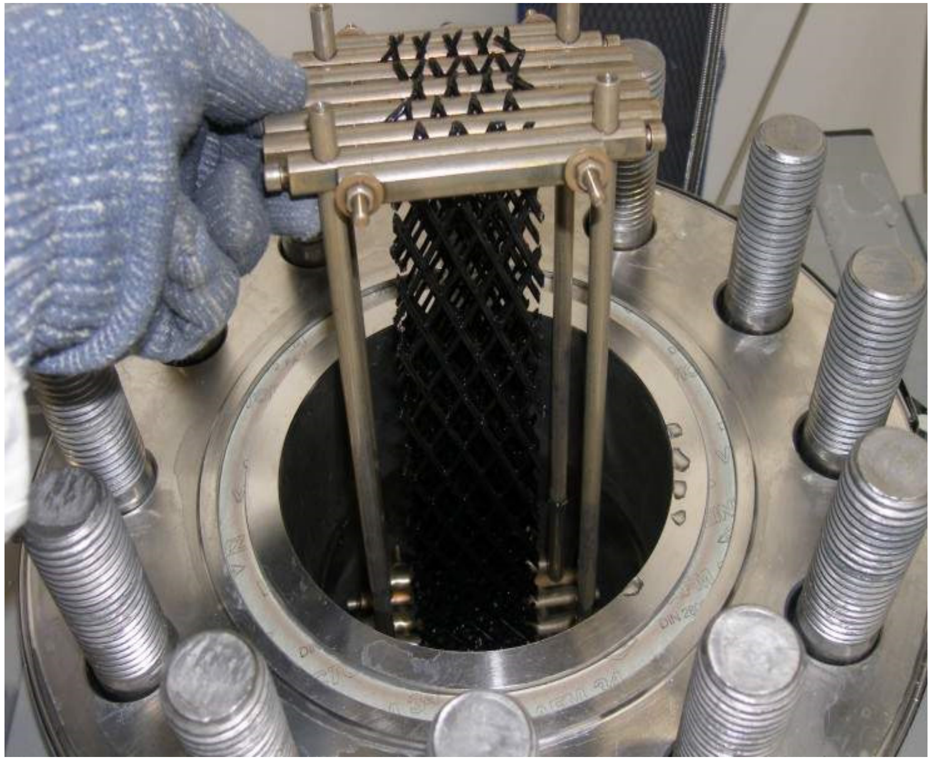
  (stirring, temperature tolerance, size of autoclave, …)

High-pressure autoclave test device

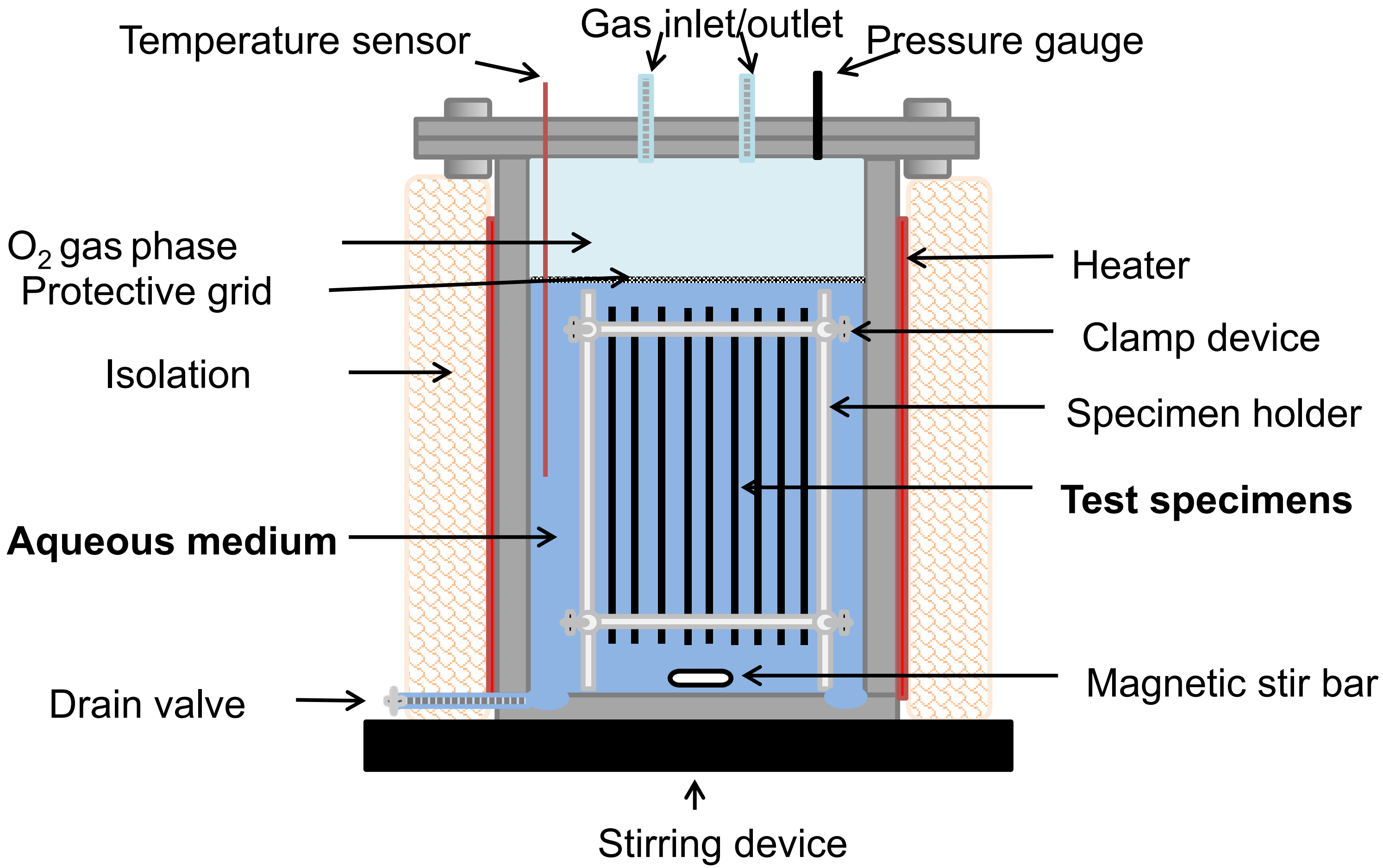
- **Test temperature:**
  typically 60°C to 90°C
- **Oxygen pressure:**
  typically 2 bar to 50 bar
- **Aqueous medium:**
  typically 0.01M $NaHCO_3$ /
  pH10 (alkaline)

→ Acceleration due to

- **elevated temperature**
- **availability of oxygen**
- **aqueous medium**

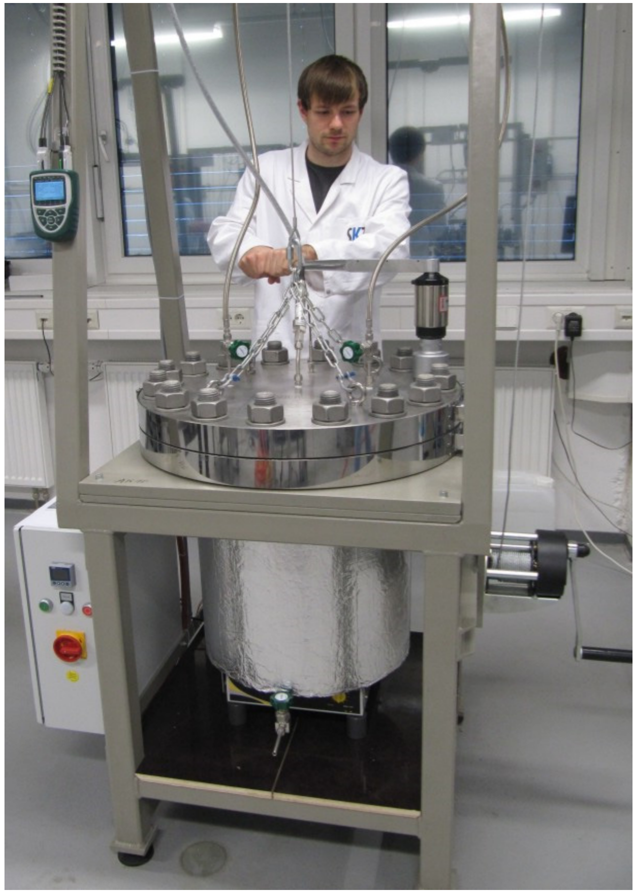


High-pressure autoclave test device



High-pressure autoclave test device

- Storage of samples in a high pressure autoclave
- Continuous recording of temperature and pressure
- Test temperature:
  75 / 80 / 90 ° C
- Oxygen pressure:
  0.4 / 0.9 / 2.0 / 3.0 / 5.0 bar

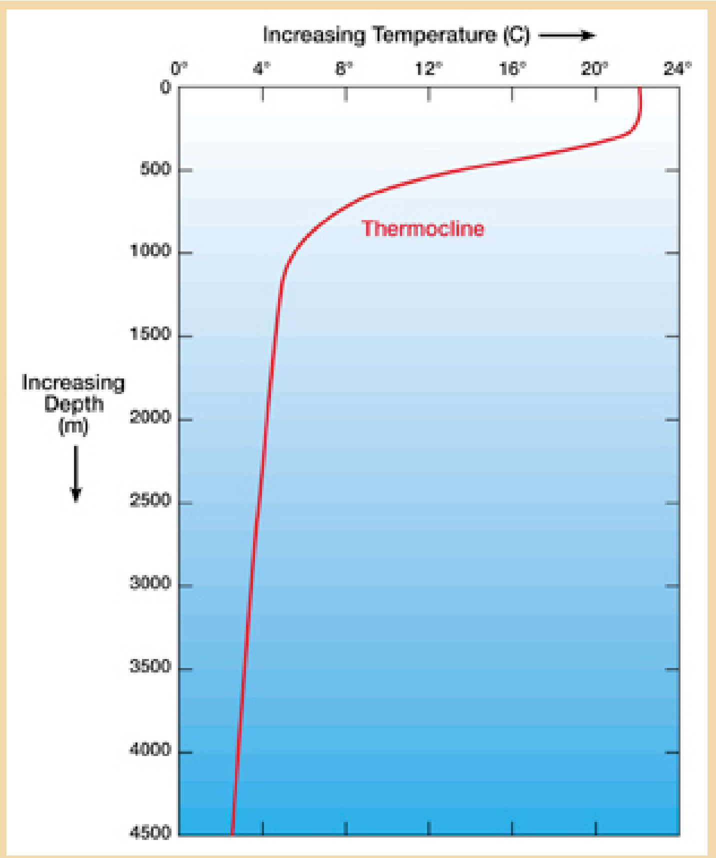


Note:
The sample is tested in solid state and not in melted state (as in OIT).

Factor

TEMPERATURE

Temperature of Ocean Water



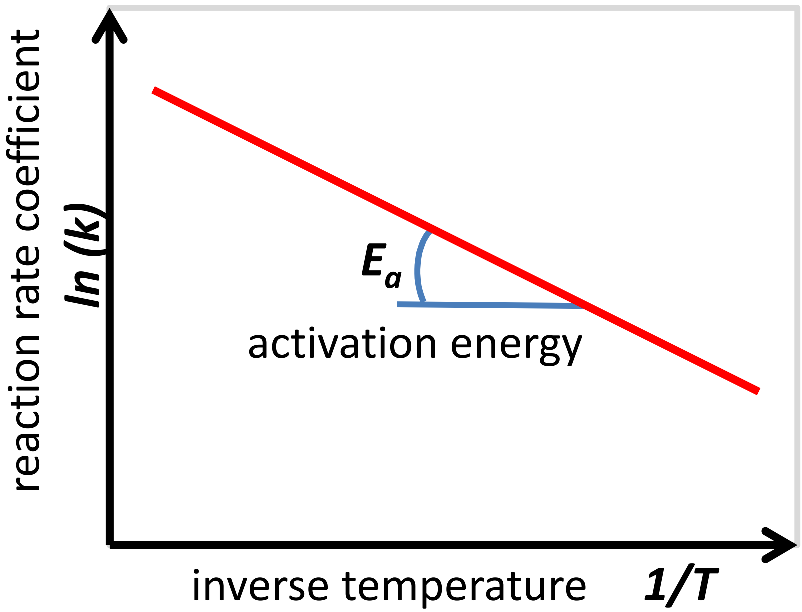
https://www.windows2universe.org/?page=/earth/Water/temp.html

Note:
In some hot areas
the surface water temperature
in the sea may rise up to 35°C.

Svante Arrhenius

1903: Nobel Prize in chemistry

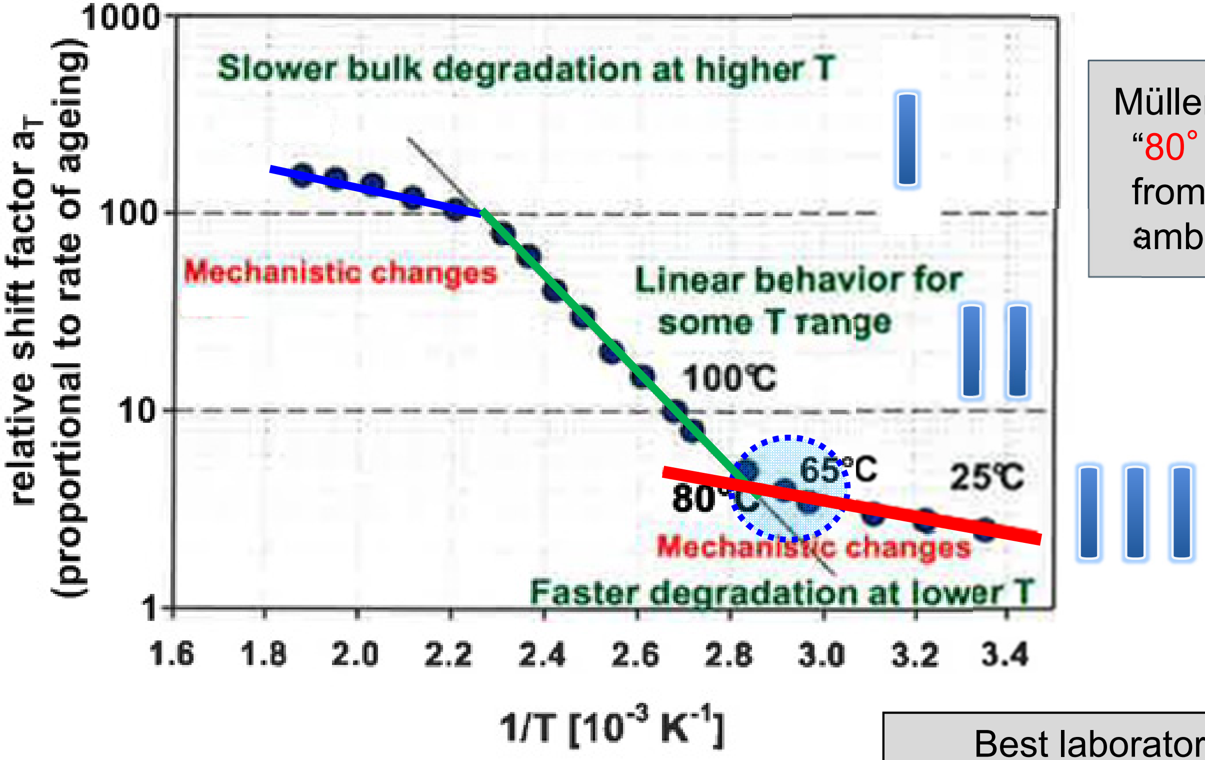
$$k = A\exp\left(-\frac{E_a}{RT}\right)$$



Studies through Europe

ARRHENIUS in Würzburg (1886/1887)

Temperature regime

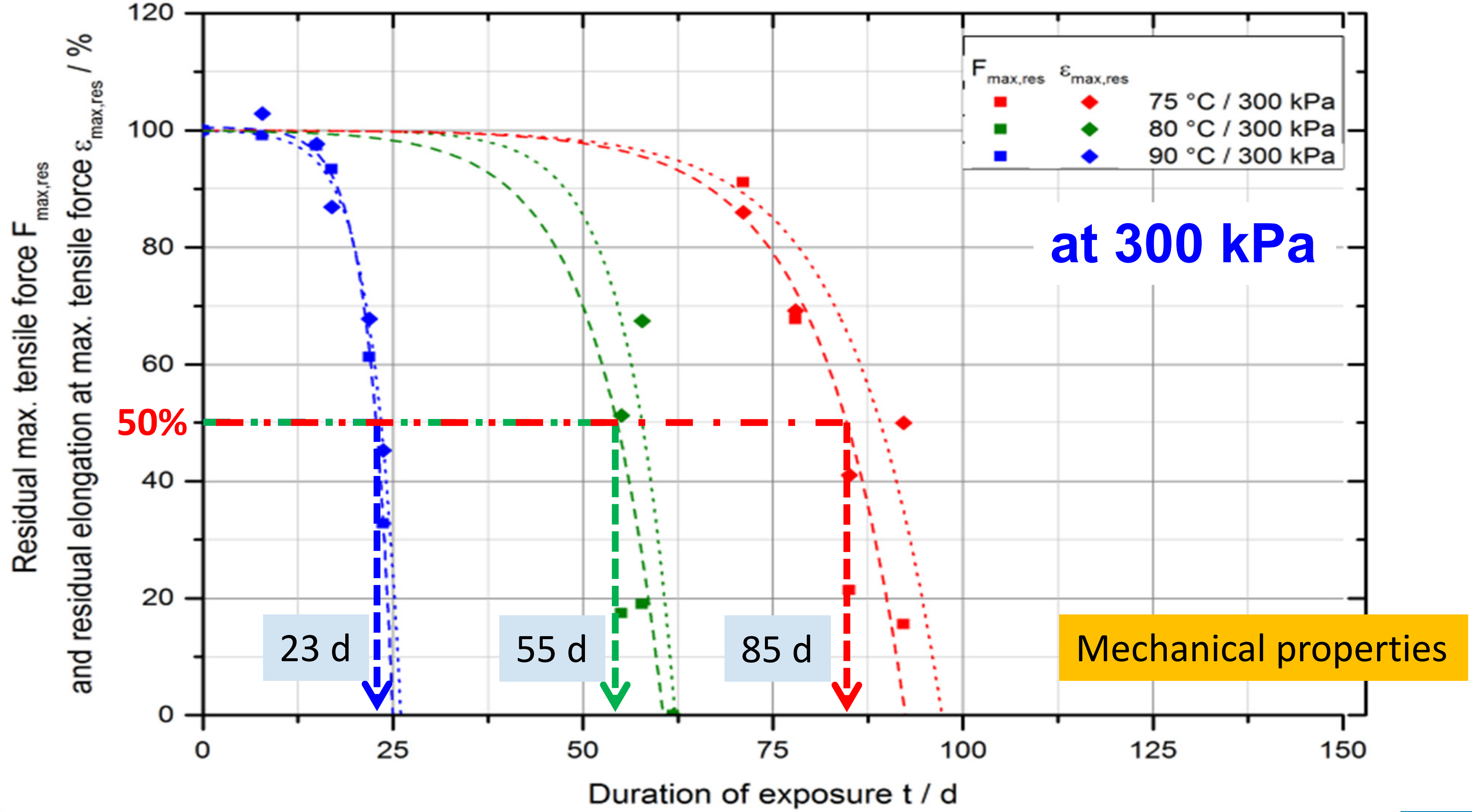


Müller & Jakob (2000):
"80° C is the highest test temperature from which Arrhenius extrapolation to ambient temperatures is possible for PE"

Best laboratory practice for lifetime prediction:
Ambient temperature + 40 K ≥ Lowest test temperature

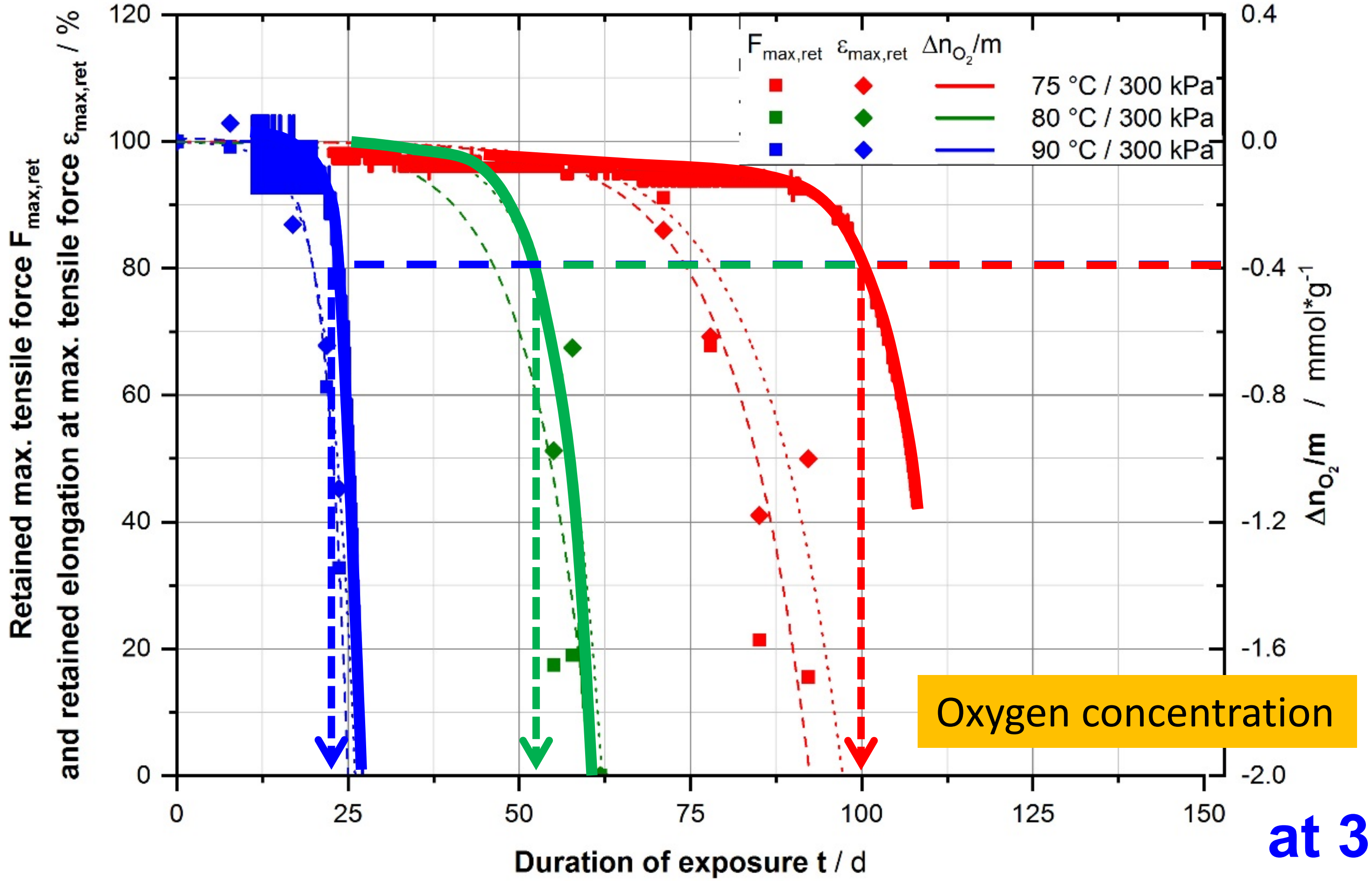
Woven geotextile

Autoclave test results at different T



Woven geotextile

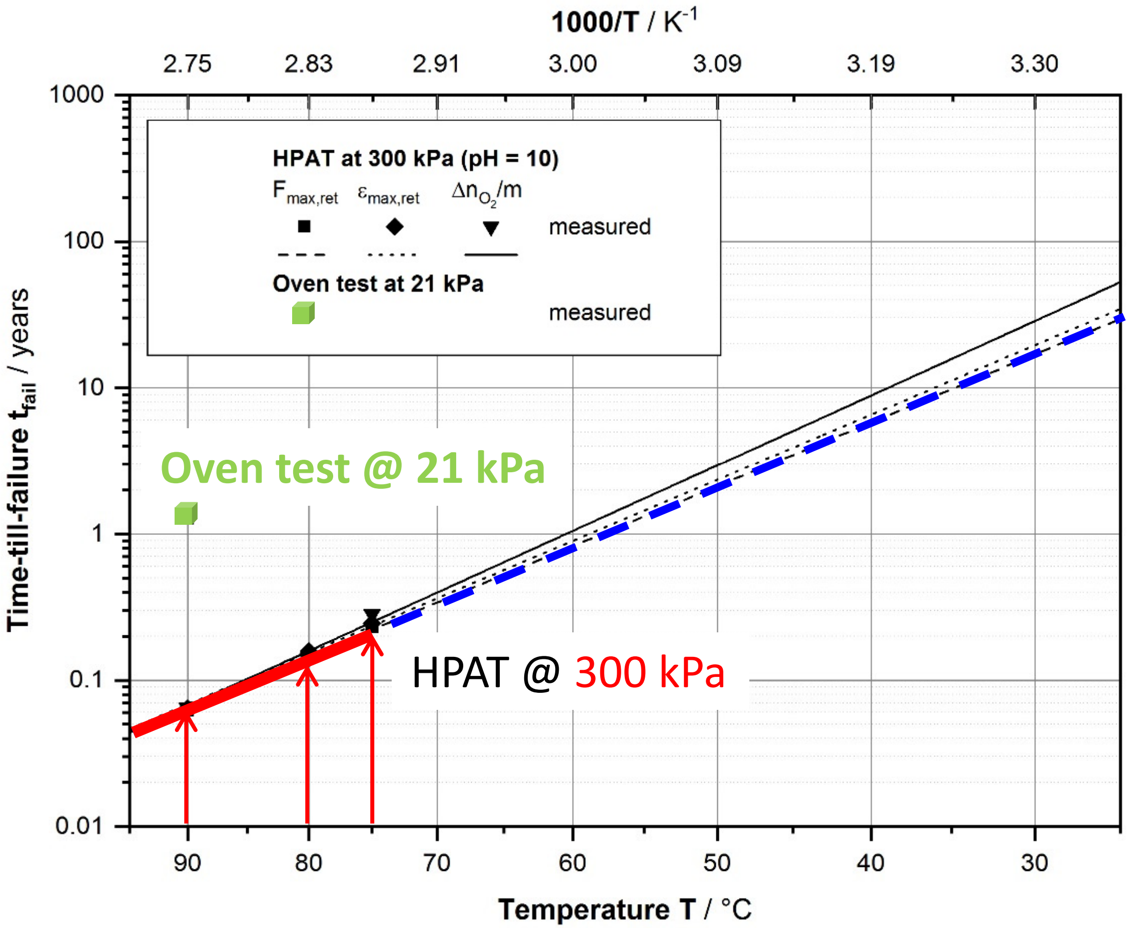
Autoclave test results at different T



at 300 kPa

Woven PP-geotextile

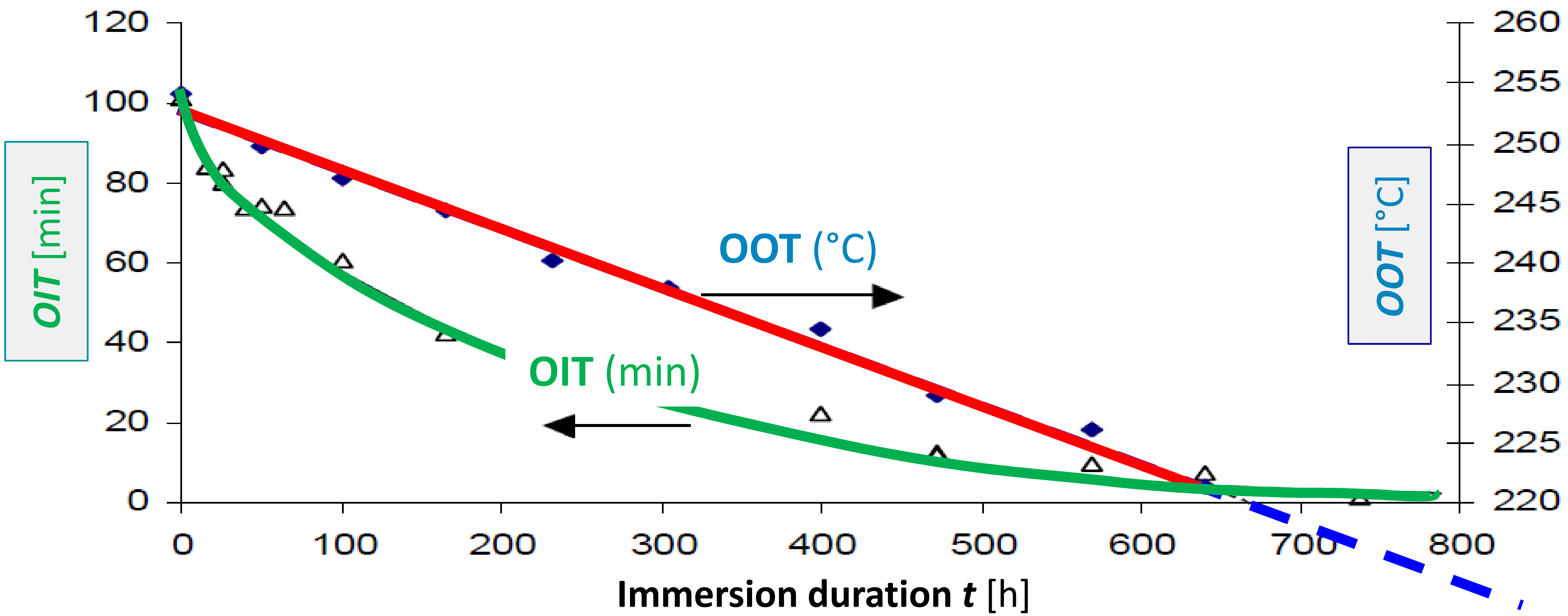
Arrhenius-Extrapolation regarding temperature



Factor

pH value

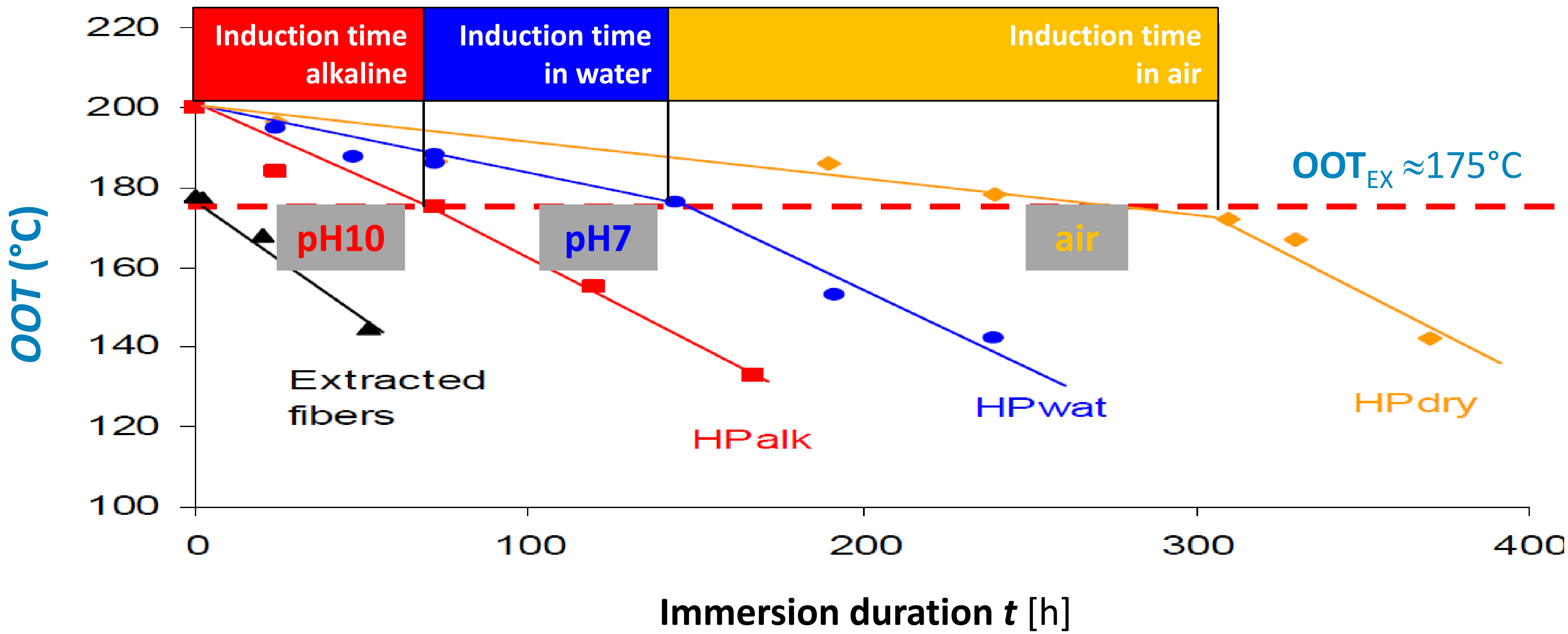
Geosynthetics stabilized with phenolic additives



Bartolomeo, Astruc, Massieu, Barberis, Lavaud & Benneton (2004).
Thermo-oxidative ageing of polypropylene geosynthetics monitored by thermal analysis and mechanical tensile test.
EuroGeo3, Munich, Germany

HPAT

Geosynthetics stabilized with phenolic additives



Bartolomeo et al. (2004)

Suggestion

- **Study of influence on Antioxidant (AO) depletion by:**
  - Variation of pH-values (pH3, pH7 and pH10)
  - Effect of salt water

→ Evaluation of depletion time of AO with the use of OOT

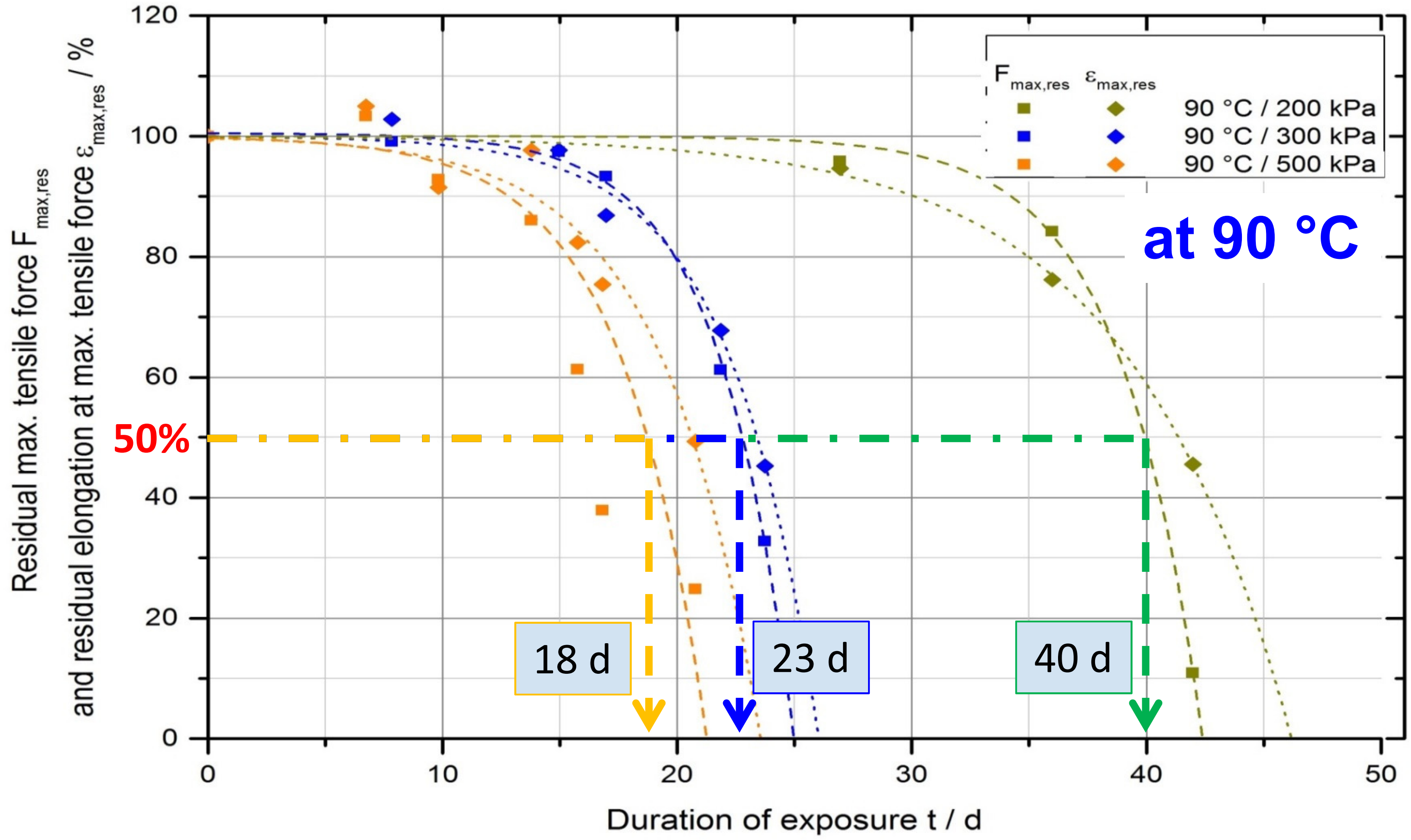
EN ISO 11357-6
Differential scanning calorimetry (DSC) -
Determination of ***Oxidation Induction Temperature (OOT)***

Factor

OXYGEN PRESSURE

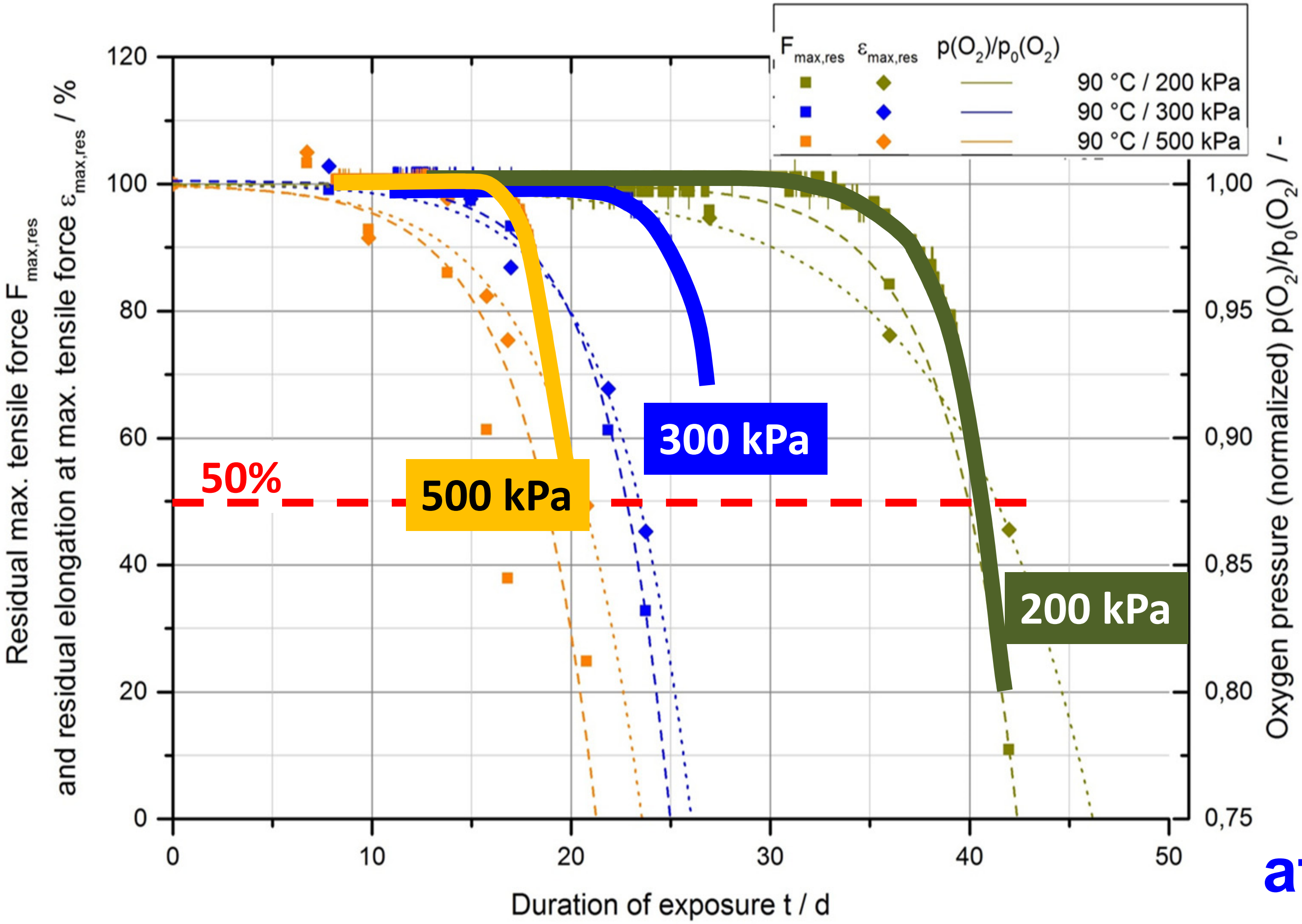
Woven geotextile

Autoclave test results at different O_2-pressure



Woven PP-geotextile

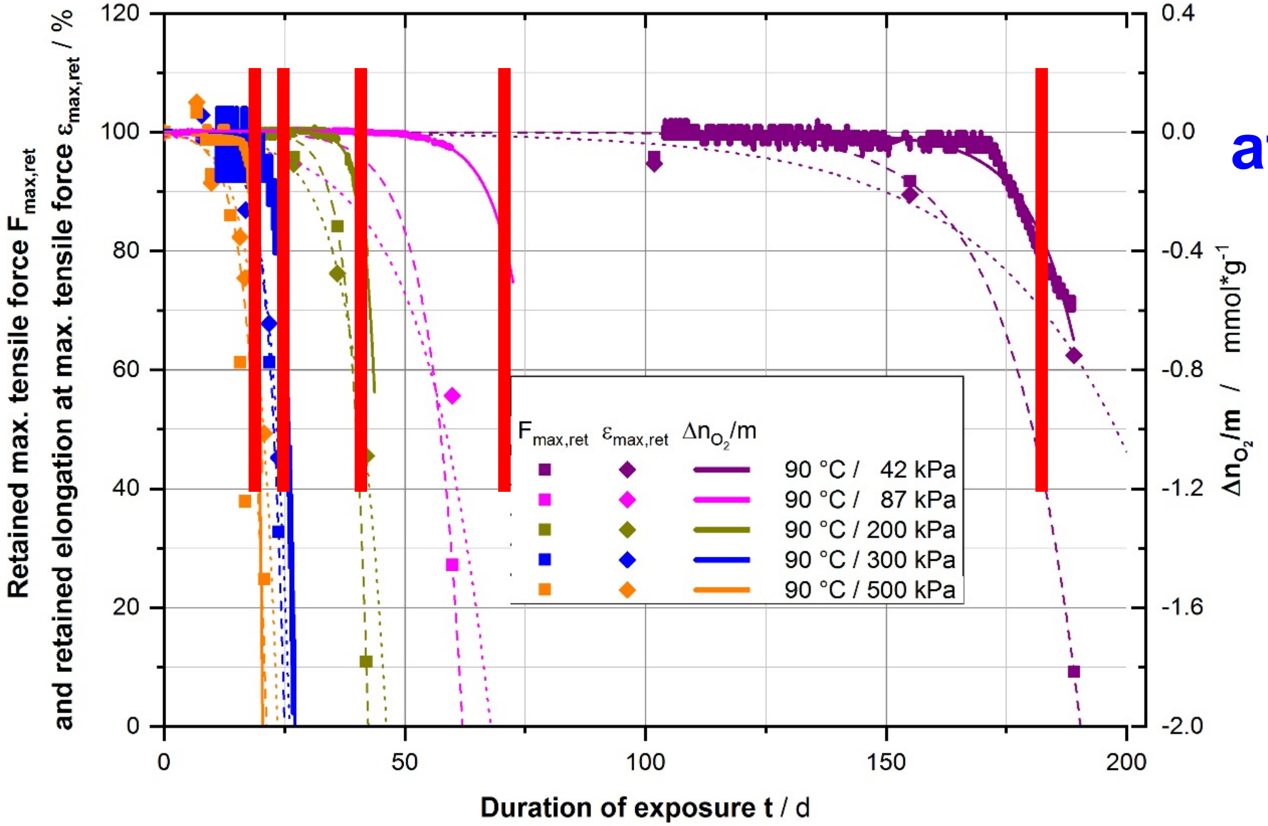
Mechanical properties + oxygen consumption



at 90 °C

Woven PP-geotextile

Mechanical properties + oxygen consumption



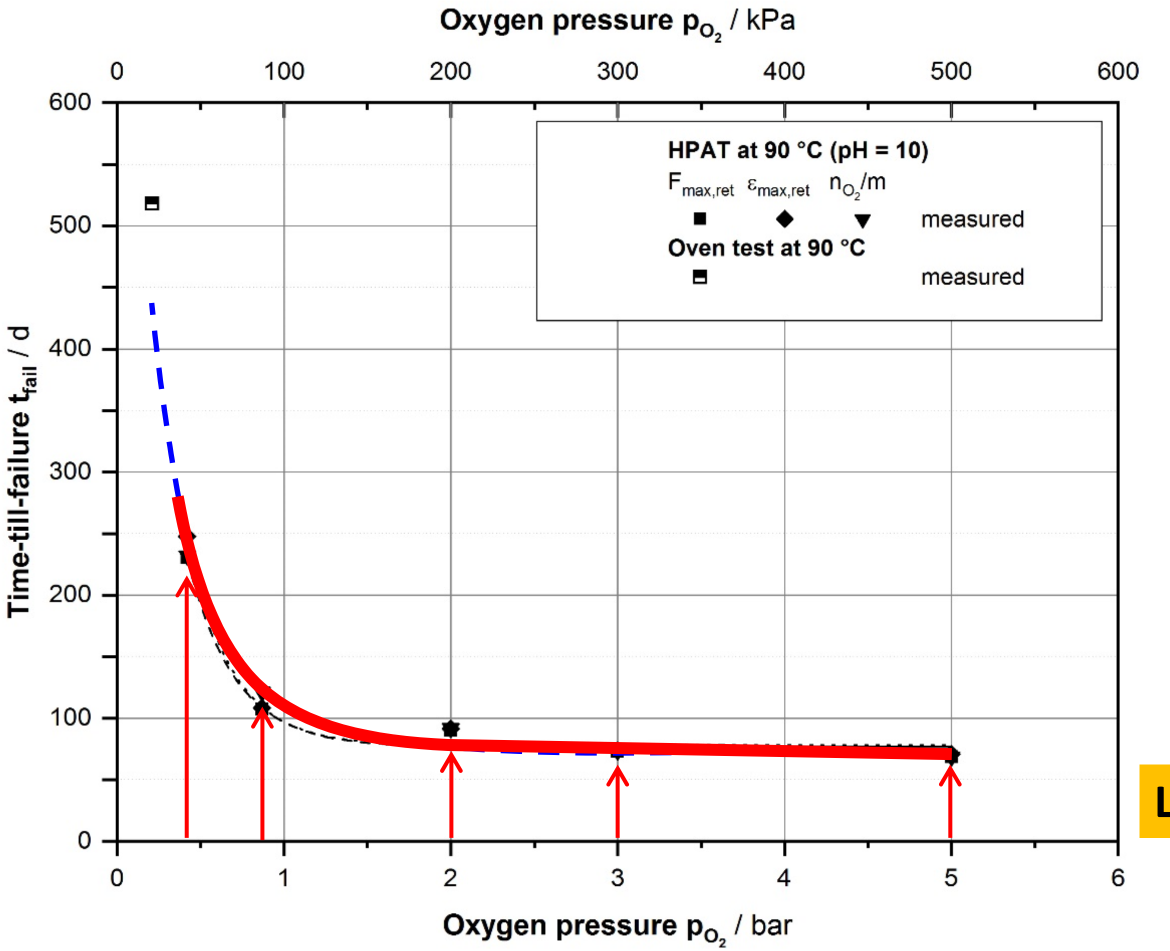
at 90 °C

Hausmann et al. (2019).

Oxidative lifetime prediction of a polypropylene woven geotextile by applying high temperature and moderately increased oxygen pressure. (offered for publication to Geotextiles & Geomembranes)

Woven PP-geotextile

Extrapolation regarding O_2-pressure

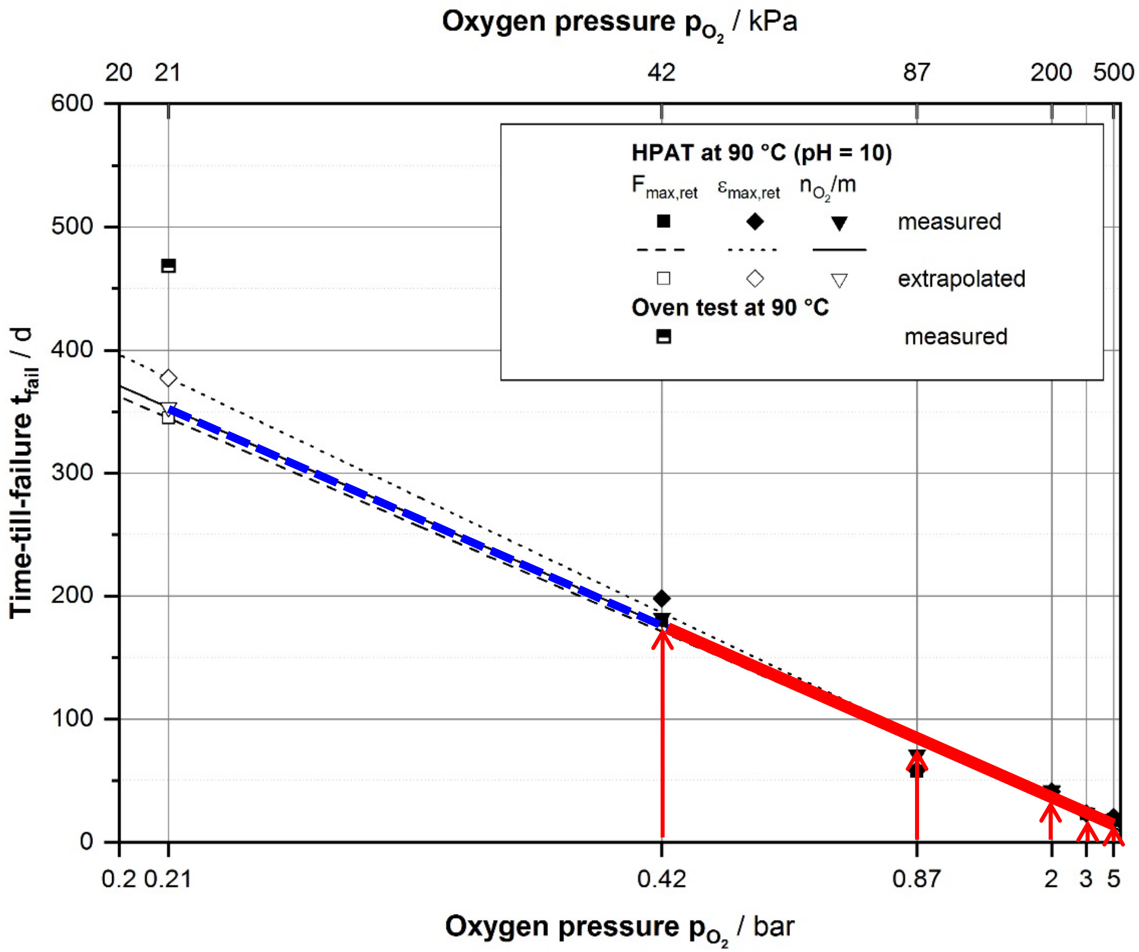


at 90 °C

Linear scale

Woven PP-geotextile

Extrapolation regarding O_2-pressure



at 90 °C

Log scale

Modified Arrhenius models by Schröder et al. (2008)

Model I:

$$1/t_{50\%} = A \cdot \exp\left(\frac{B + C \cdot p_{O2}}{T}\right)$$

Model II:

$$1/t_{50\%} = A \cdot \left(\frac{p_{O2}}{1 + D \cdot p_{O2}}\right) \cdot \exp\left(\frac{B}{T}\right)$$

Model III:

$$1/t_{50\%} = A \cdot \left(\frac{p_{O2}}{1 + D \cdot p_{O2}}\right) \cdot \exp\left(\frac{B + C \cdot p_{O2}}{T}\right)$$

$t_{50\%}$: half-life period, T: temperature, p_{O2}: oxygen pressure, A, B, C, D: constants

Schröder, H., Böhning, M., Munz, M. (2008).
A new method for testing and evaluating the long-time resistance of oxidation of polyolefinic products, Polymers and Polymer Composites 16 (1), pp. 71 – 79.

SKZ-model by Hausmann et al. (2019)

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The following Eq. 9 refers to Schröder's Modell II which merely is a multiplication of both previously mentioned relationships on temperature and pressure with the restriction that oxidation is not limited by diffusion.

$$t_{fail} = \alpha'' \cdot \left(\frac{1 + \beta \cdot p_{O2}}{p_{O2}}\right) \cdot \exp\left(-\frac{E_A}{R \cdot T}\right) \qquad (9)$$

α'': fit parameter based on Arrhenius equation and α' (cf. Eq. 5), E_A: activation energy, R: universal gas constant, β: fit parameter (cf. Eq. 5)

Hausmann et al. (2019).
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3D-Extrapolation

regarding T and c(O_2) to service conditions

Activation Energy E_A

E_A = 84 – 93 kJ/mol

and

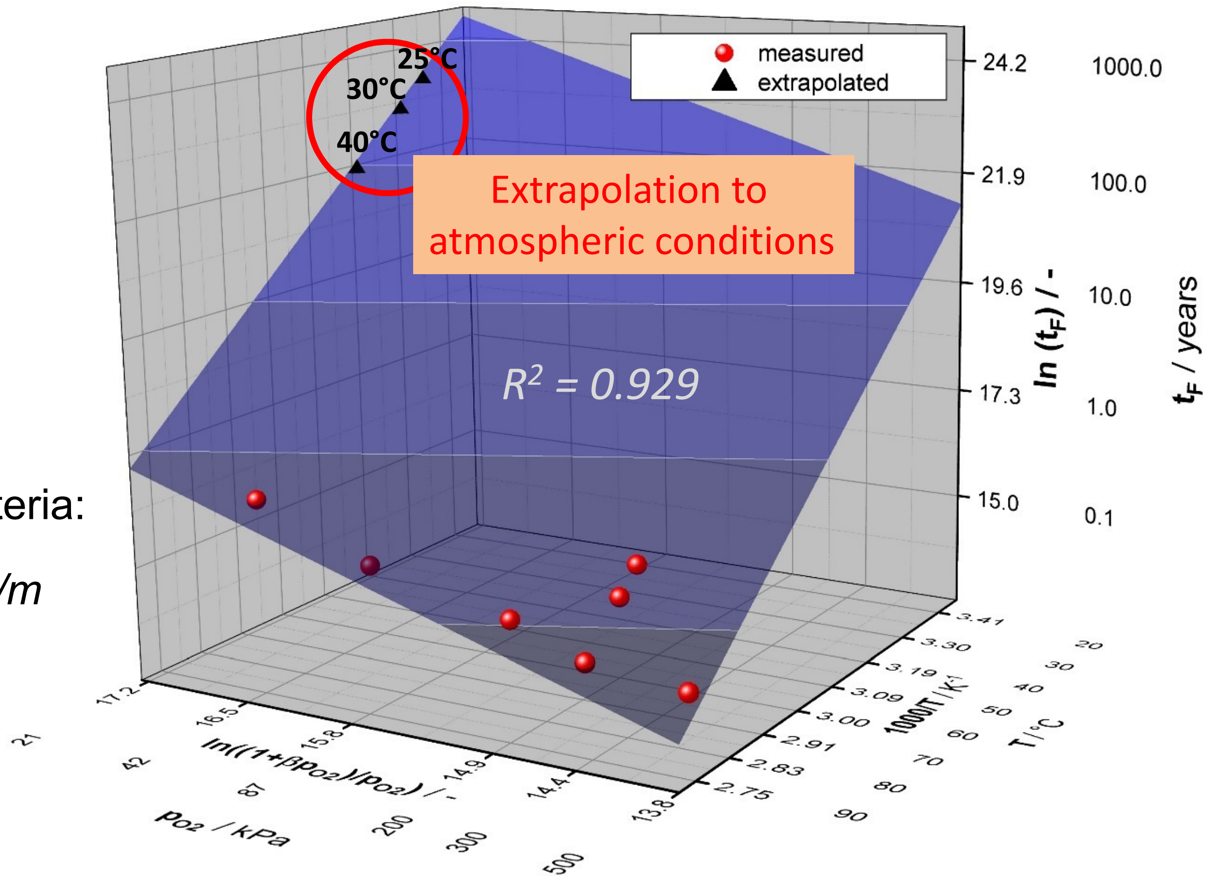
Service Life t

at atmospheric pressure

t = 100 – ~1000 years

depend on the chosen failure criteria:

$F_{max,res} \,|\, \varepsilon_{max,res} \,|\, p(O_2) \,|\, n(O_2)/m$



Service life

at atmospheric O_2-partial pressure and various temperatures

Temperature °C	Service life based on failure criteria … years		
	$F_{max,res}$ = 50%	$\varepsilon_{max,res}$ = 50%	$\Delta n_{O2}/m$ = -0.4 mmol/g
20	863	1091	1502
25	483	602	795
30	275	339	430
35	160	195	237
40	94	114	133

Hausmann et al. (2019).
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Summary

- Time-till-failure at **oven testing** @ 90 °C: ~ 500 d
- Time-till-failure at **HPAT** @ 90 °C: < 50 d *(depending on O_2-pressure applied)*
- Time of abrupt **oxygen pressure** drop *(= significant consumption of O_2)*

  correlates with time-till-failure based on mechanical properties.
- "Temperature dependency" of HPAT results: **Arrhenius typical**
- "Pressure dependency" of HPAT results: **Double logarithmic**
- Activation energy E_A = 85 – 93 kJ/mol
- **Service life estimation** based on HPAT results: ~200 years @ e.g. 35 °C

Questions are welcome.

Thank you for your interest.

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Marine Aging of Polymers