



Nylon Accelerated Aging: Thermal-oxidative versus Humidity

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Robert Bernstein, Dora K. Derzon, and Ken Gillen

Sandia National Laboratories P.O. Box 5800 M.S. 0888
Albuquerque, NM 87185-0888 (505) 284-3690 FAX (505) 844-9624

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Organic Materials Aging and Degradation



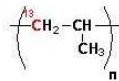
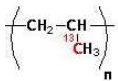
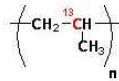
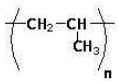
O-rings



Nuclear Power Plant Cable Insulation



Aircraft Wire Insulation



Labeled Polypropylene



Textiles

Long term aging programs: years

Different types of polymers

Specialized instrumentation

Approach/Goals

Macroscopic level

Physical property

Tensile Property

Permeation

Elongation

Dimensional changes

Molecular Level

Chemical Property

UV-VIS Spectroscopy

Surface Analysis

Differential Scanning Calorimetry

Additives

Molecular Weight Analysis

Density

Nuclear Magnetic Resonance

GPC

Infra-red Spectroscopy

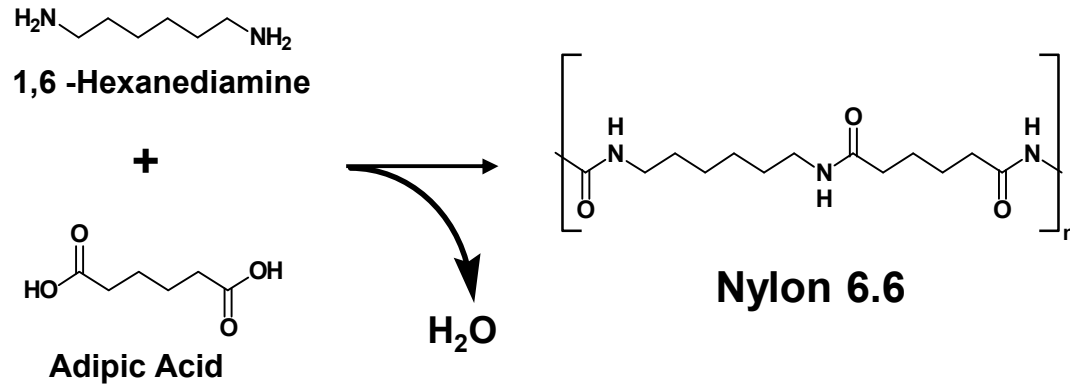
X-Ray Analysis

Goals

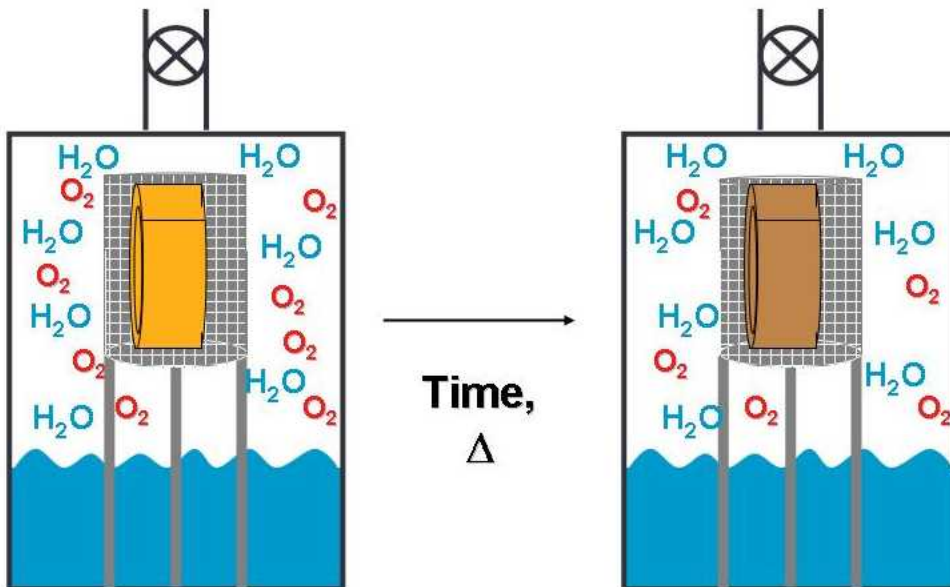
- Prediction of physical properties vs. time
 - Predict remaining lifetime of field materials
- Develop condition monitoring method

Humidity

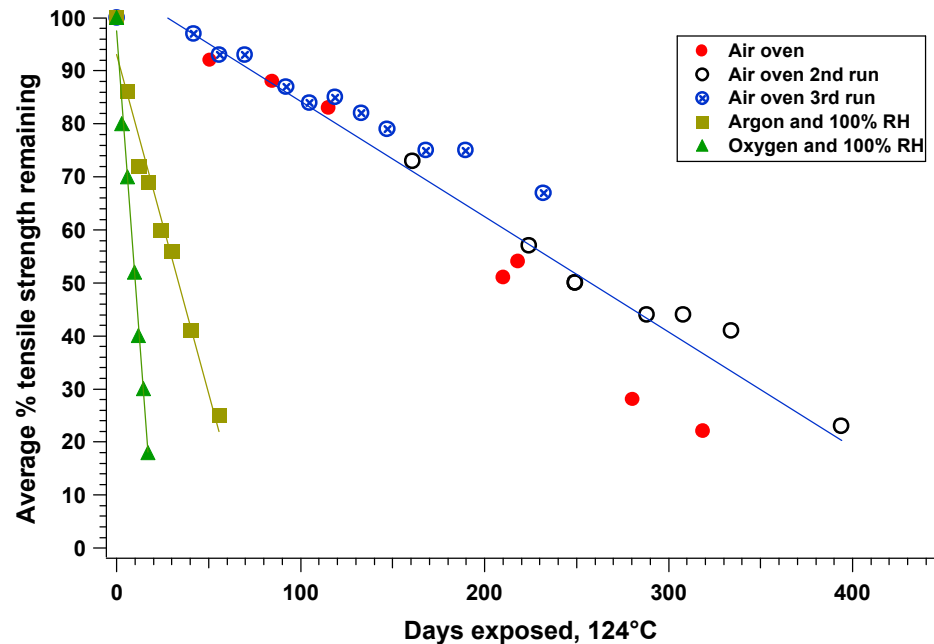
Simplified Nylon synthesis



Amide bonds susceptible to hydrolysis



Nylon Tensile Comparison



Conditions

Normalized Slope

124 °C

109 °C

Rate for Thermal and Oxygen

1.0

1.0

8.4

15.6

Rate for Thermal, **Argon**, and 100% R_H

7.4

14.6

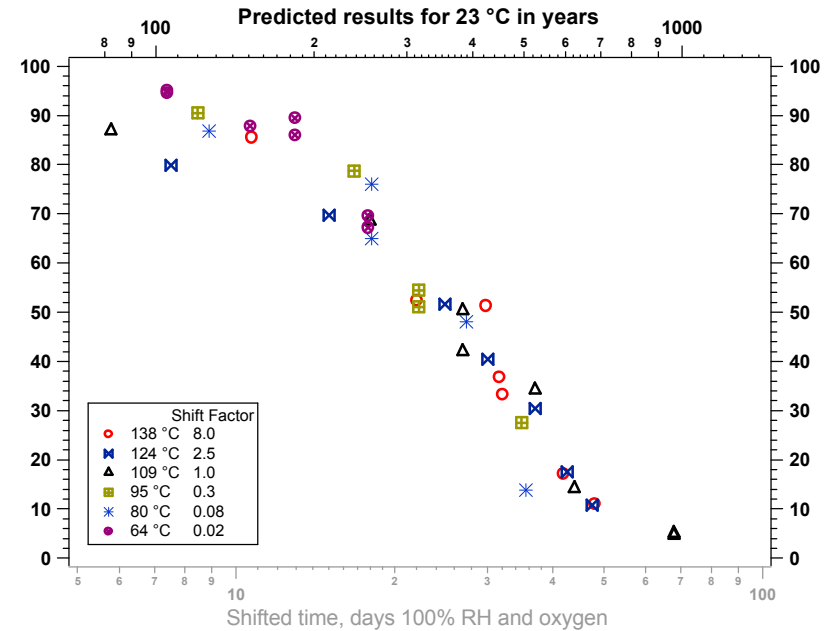
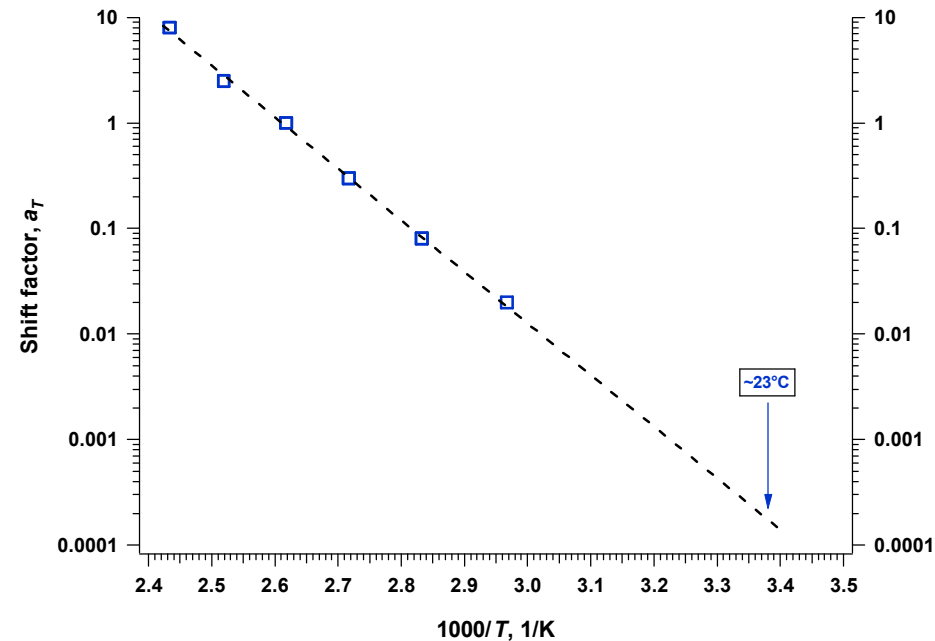
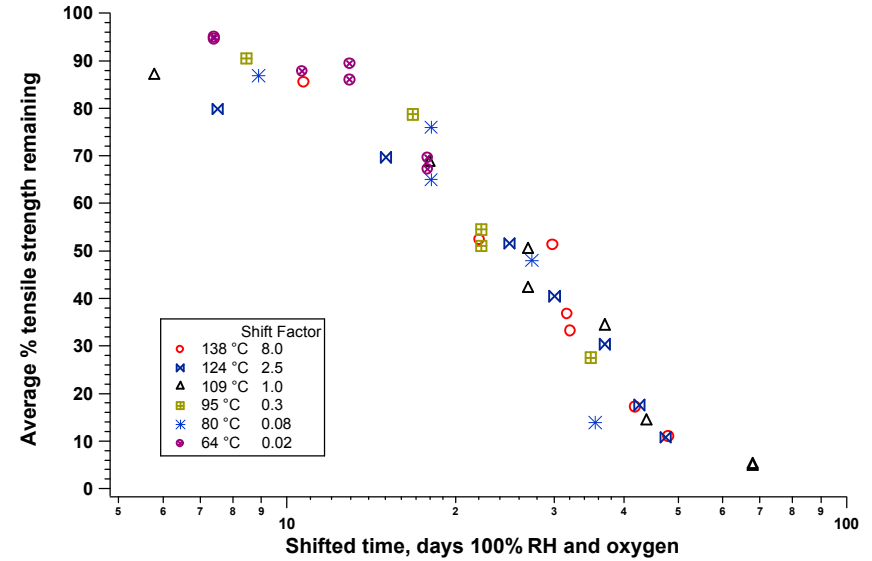
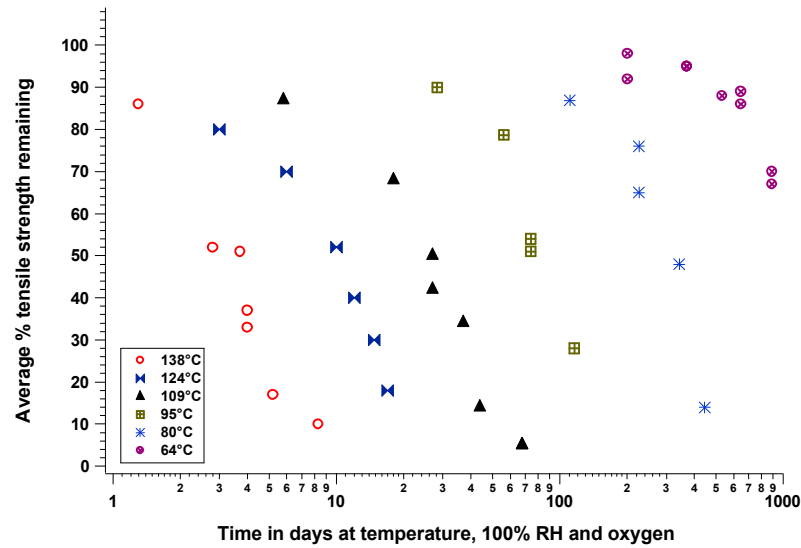
Rate for Thermal, **Oxygen**, and 100% R_H

22.9

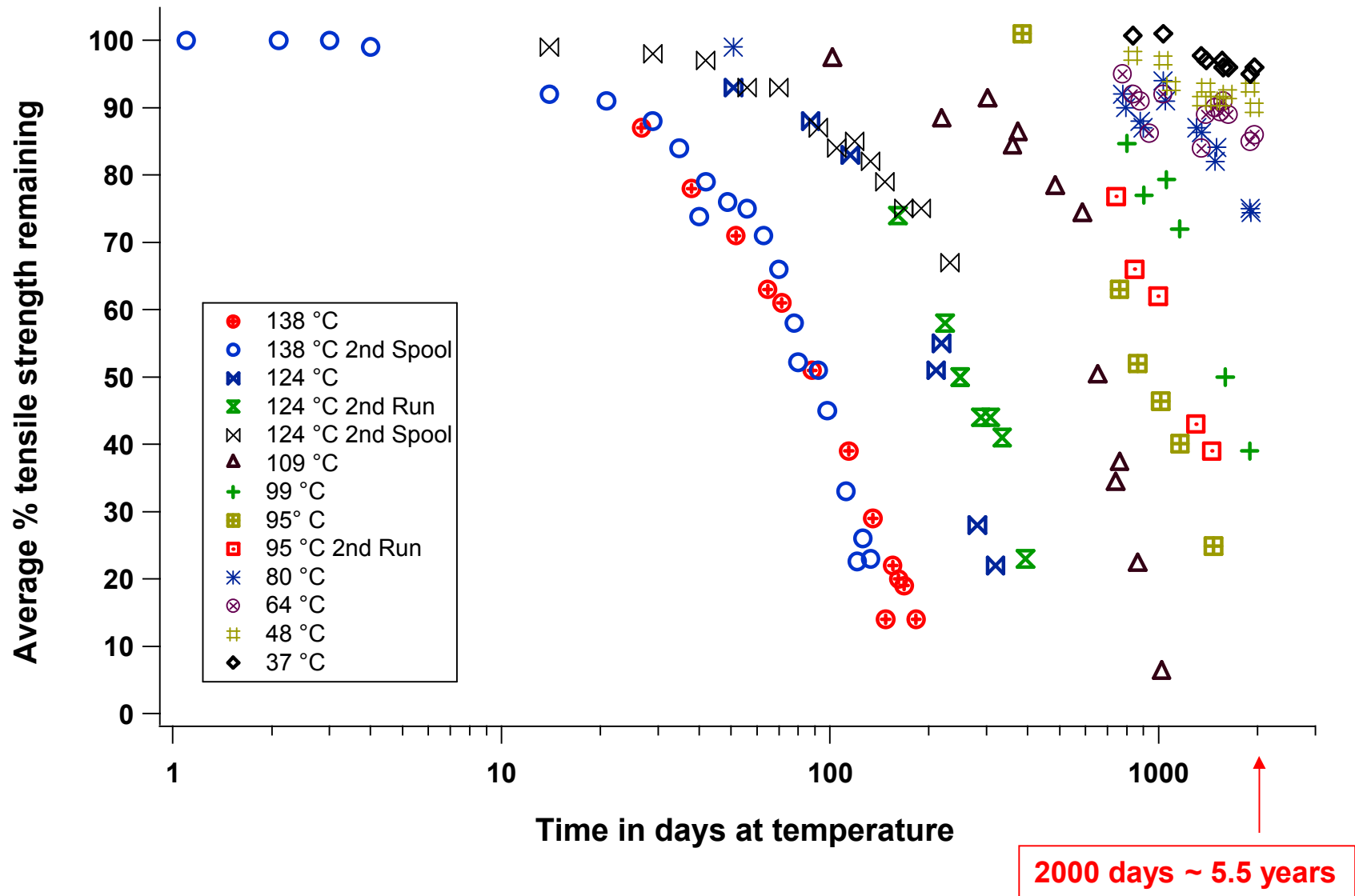
45.0

Combined rate ca. 3 times sum of individual rates

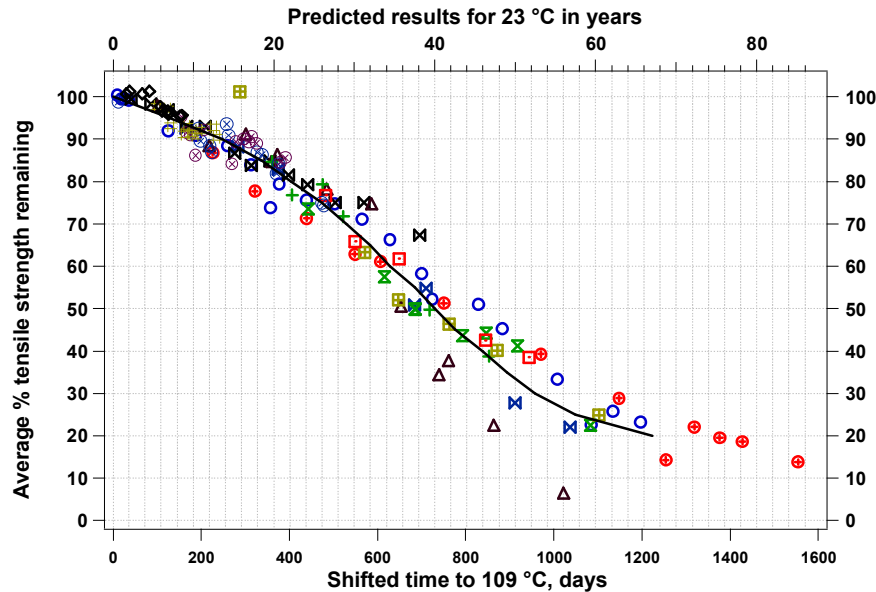
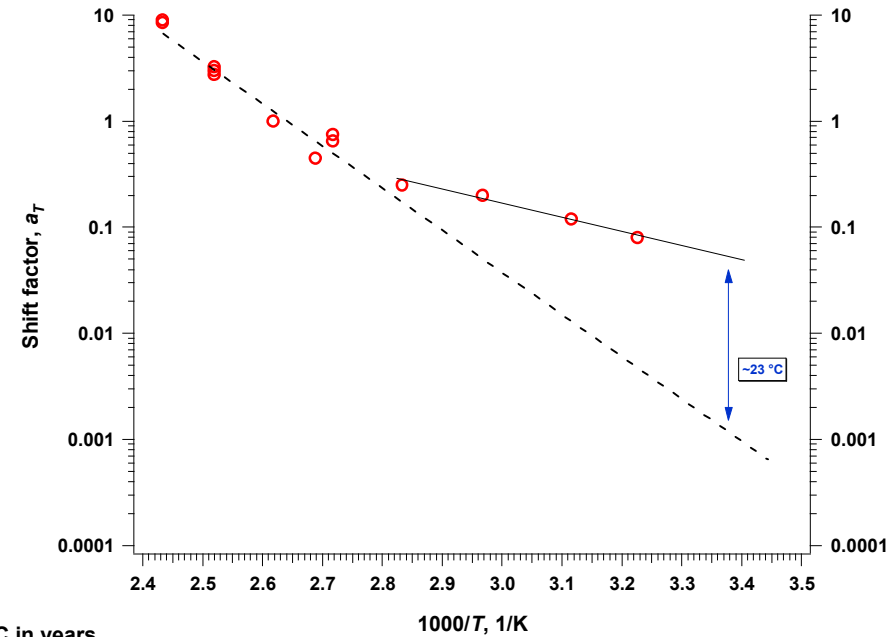
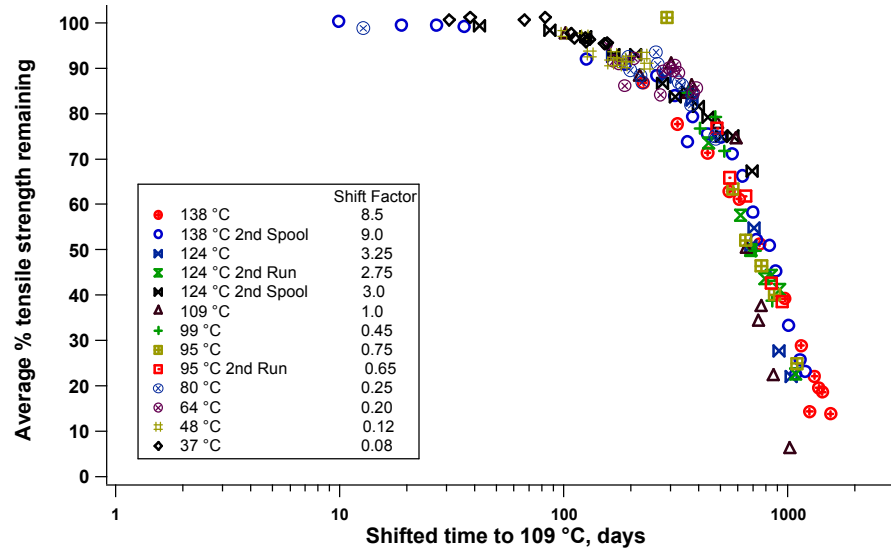
Nylon 100% RH O₂



Thermal-oxidative Aging: Nylon



Thermal-oxidative Aging



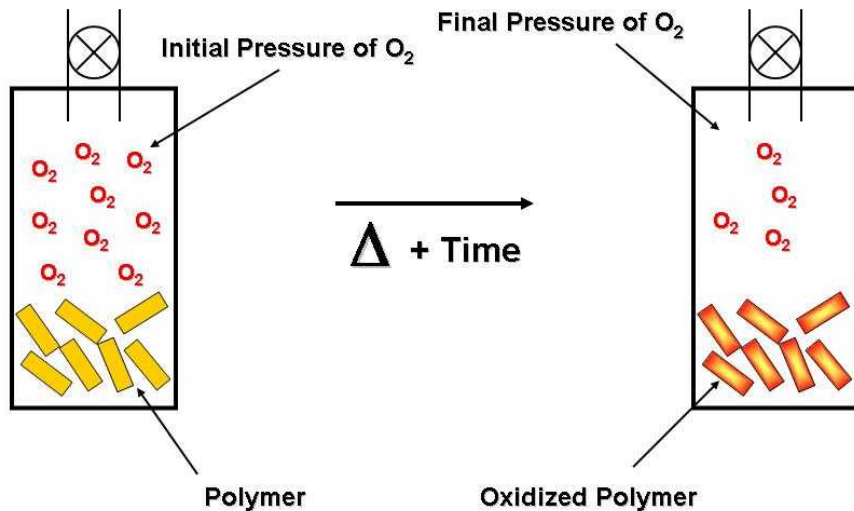
Thermal Exposure

Thermal-Oxidation



Quantify amount of oxygen consumed

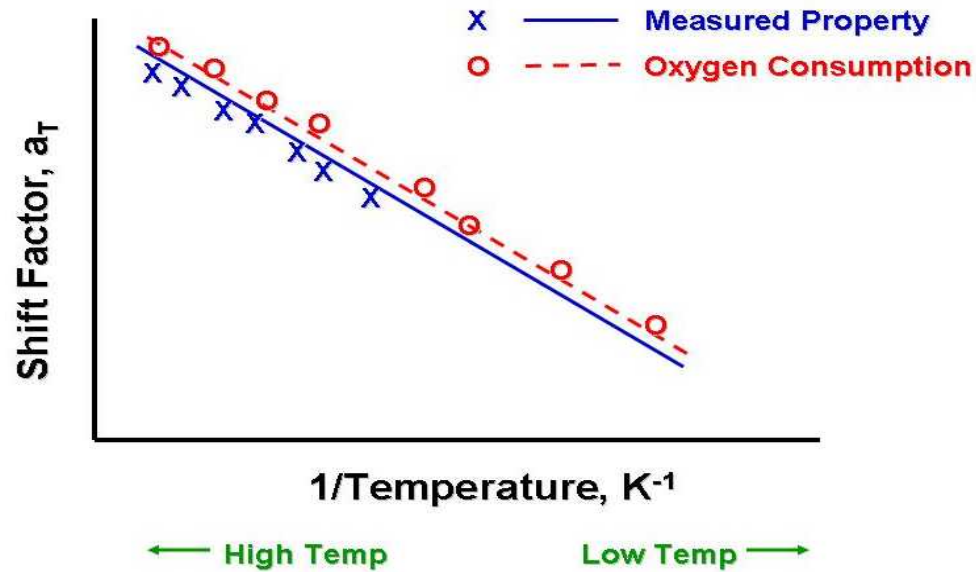
- Simple in theory
- Difficult in practice
- Amazingly sensitive



Extrapolation 'Validation'

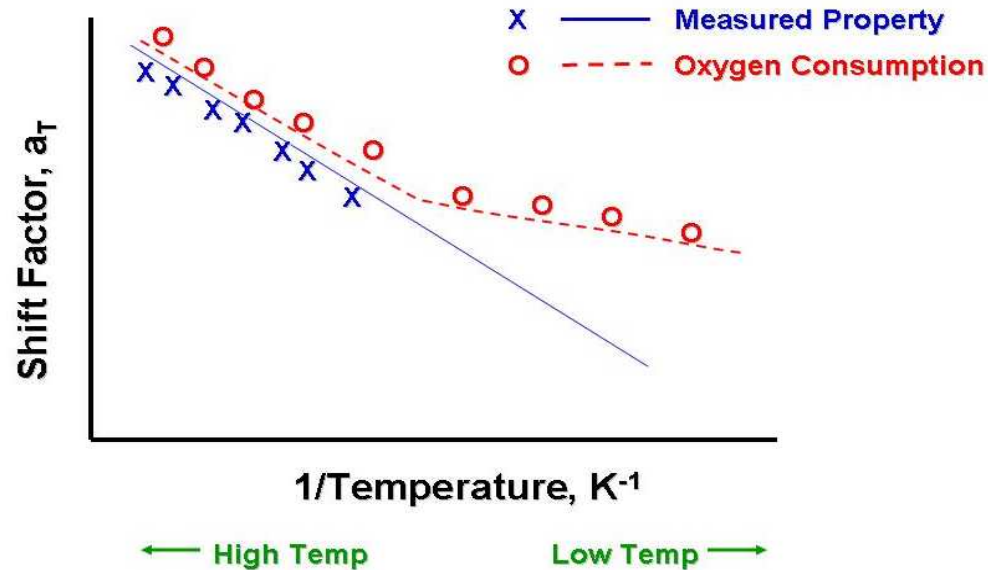
'Good'

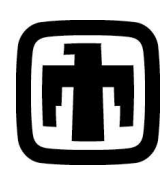
Normalized Measured Property



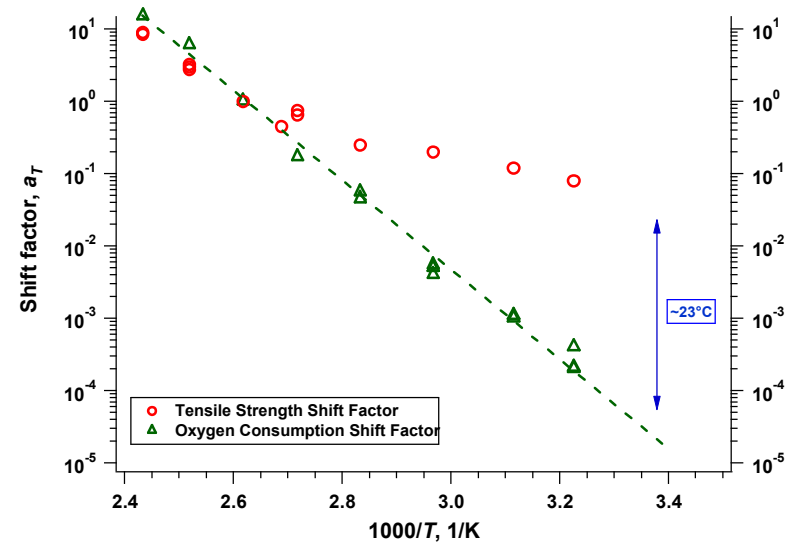
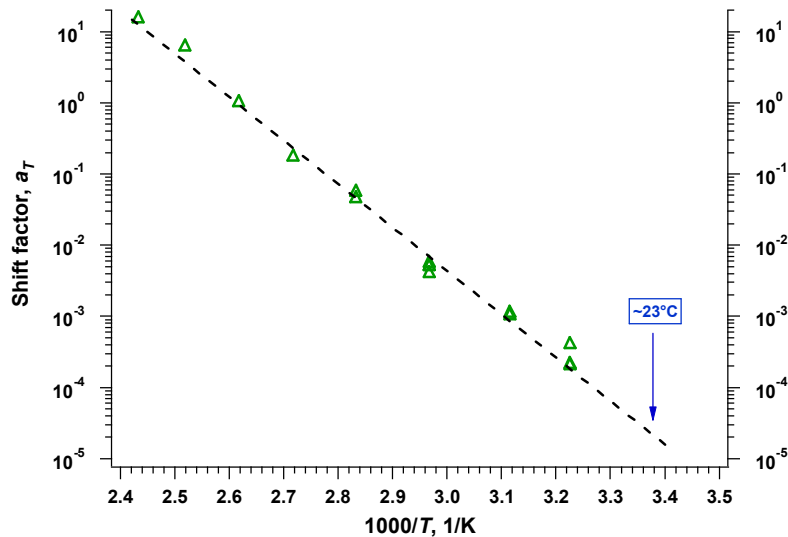
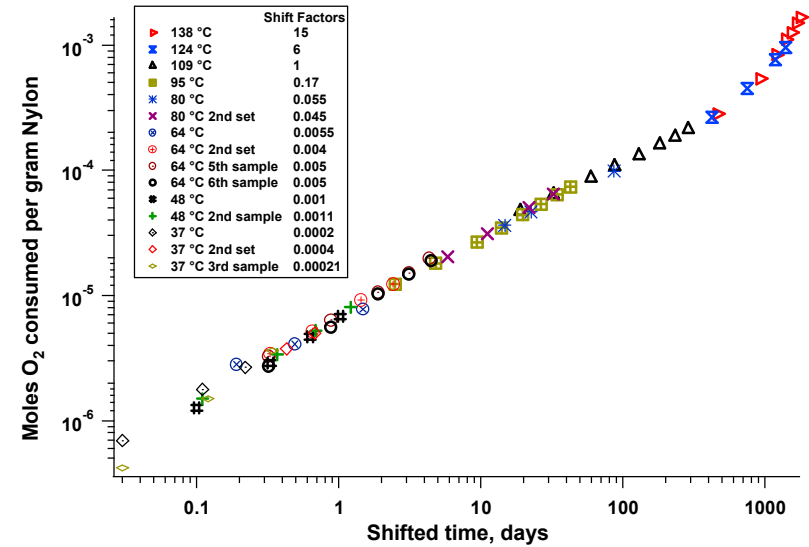
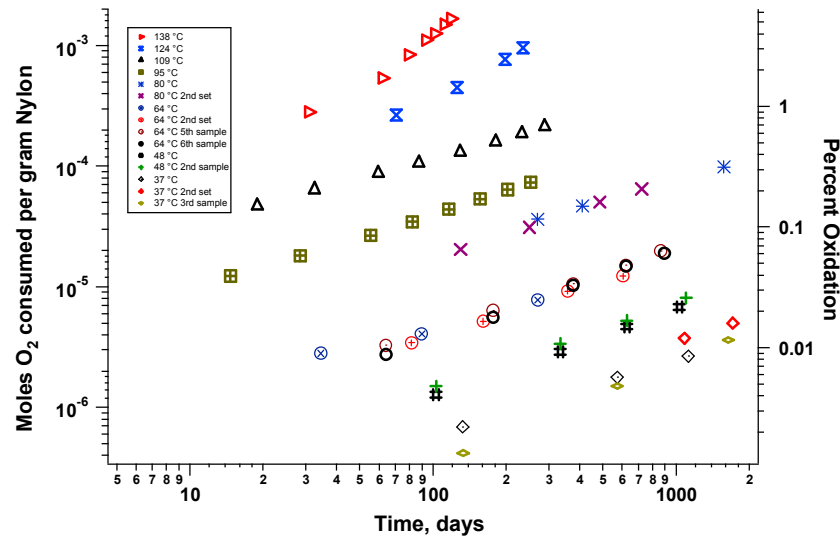
'Bad'

Normalized Measured Property



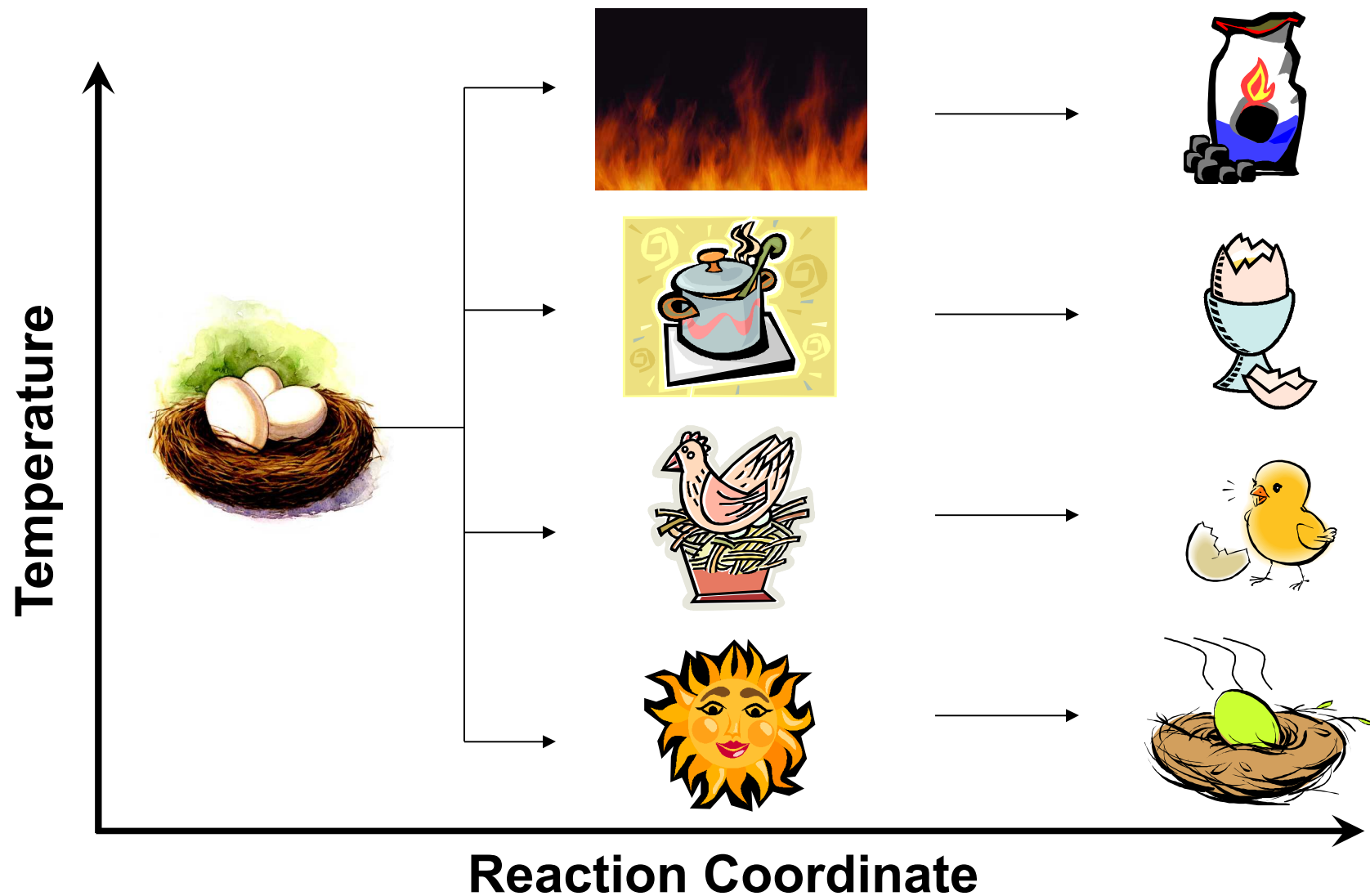


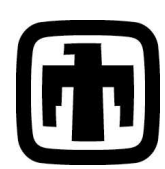
Nylon Oxygen Consumption



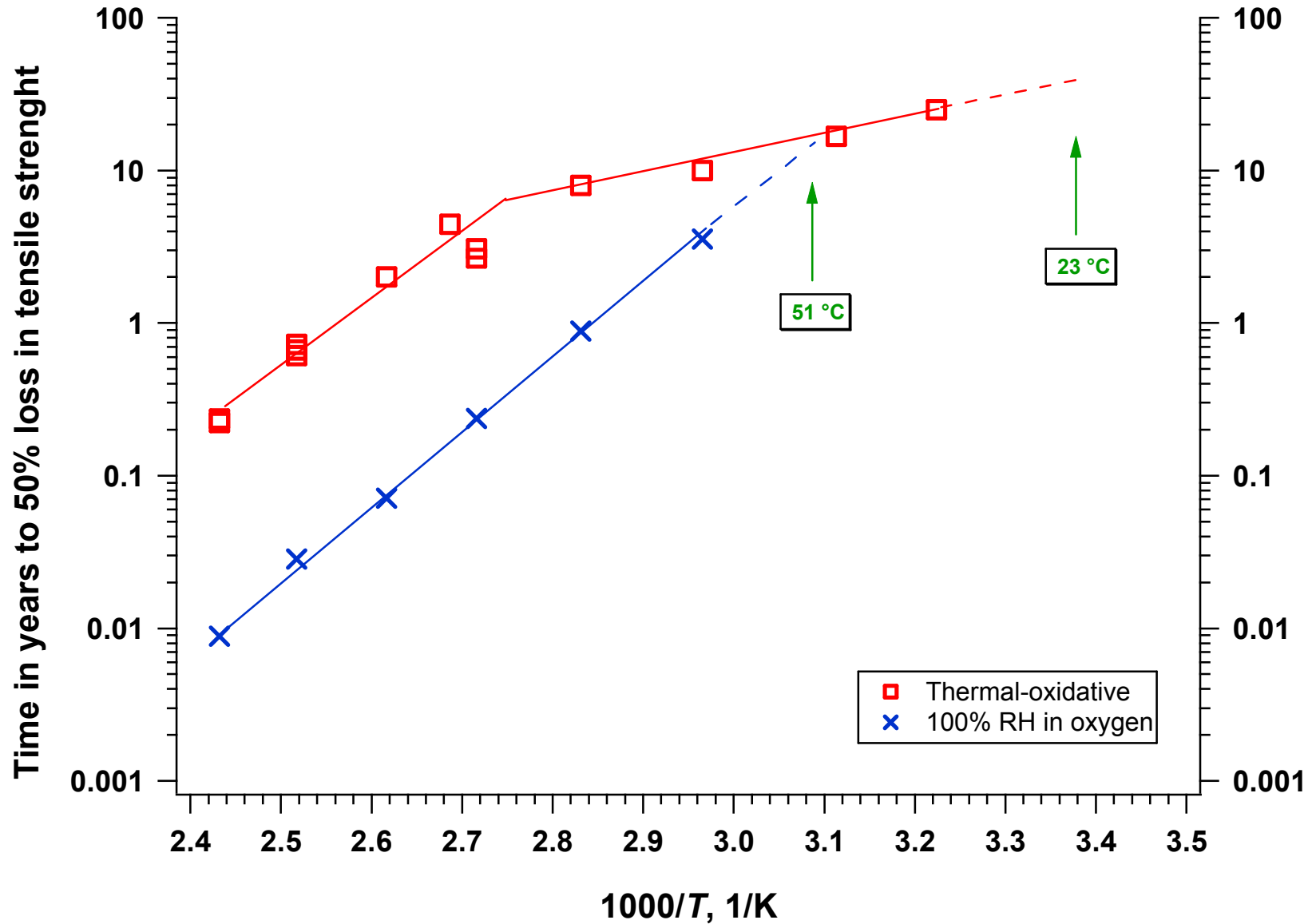


'Accelerated Aging'





Thermal-oxidative and Humidity Comparison





Conclusions

Nylon has linear oxygen consumption

Nylon thermal-oxidative degradation has significant curvature

Nylon humidity may not be relevant at lower temperatures

Future Work

Mechanistic studies...

^{13}C and ^{15}N labeled Nylon 6.6

Acknowledgements

Larry Whinery

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-DOE \$\$\$\$\$