CHARACTERIZATION OF LONG-TERM POLYMER MATERIALS MECHANICAL CHARACTERISTICS – FROM THE TEST SPECIMEN TO THE STRUCTURE

ARM, Annual Meeting.

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- **P' Institute – CNRS/ISAE-Ensma/University of Poitiers in France together with Total Research and Technology Feluy in Belgium worked together for the last 15 years in the field of mechanical properties assessment of Rotomolded parts.**

- **One of the main goal was to develop a method to characterize static and creep properties of rotomolded parts that is:**
  - **FAST**
  - **ACCURATE**
  - **And ALLOW LONG TERM FEA's**

Our Approach

Characterization
Tensile tests
Tensile creep tests

Materials
Behavior Laws

Numerical Simulations

Correlation
Tests/Simulations

Structural Testing
Complex,
under environment

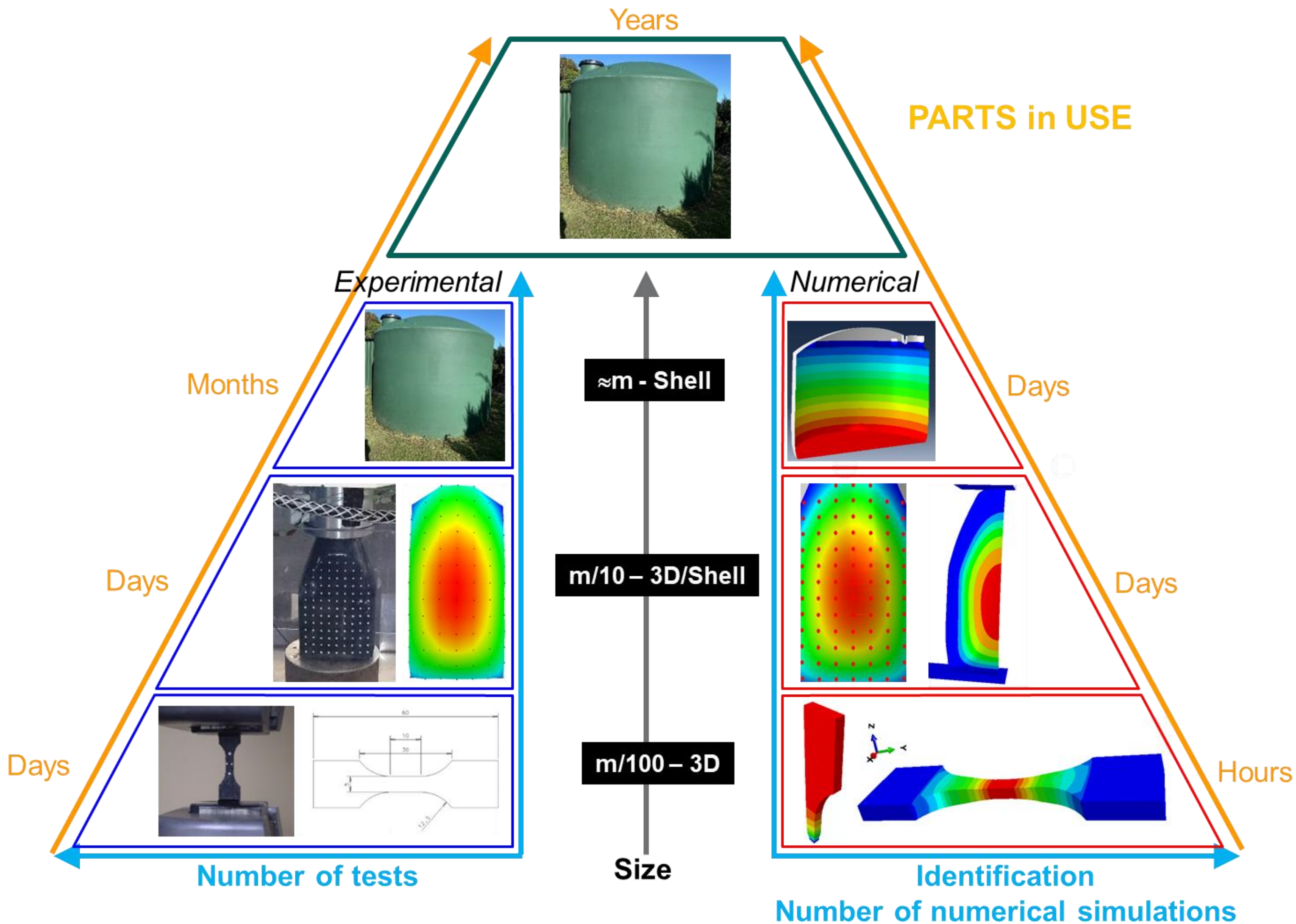
Sizing

Predictive Design

(Constitutive Laws, Criteria)

Objective: to reduce "design factor"

LONG-TERM PREDICTION OF ROTOMOLDED PARTS = CHARACTERIZATION, EXPERIMENTAL AND VIRTUAL TESTING

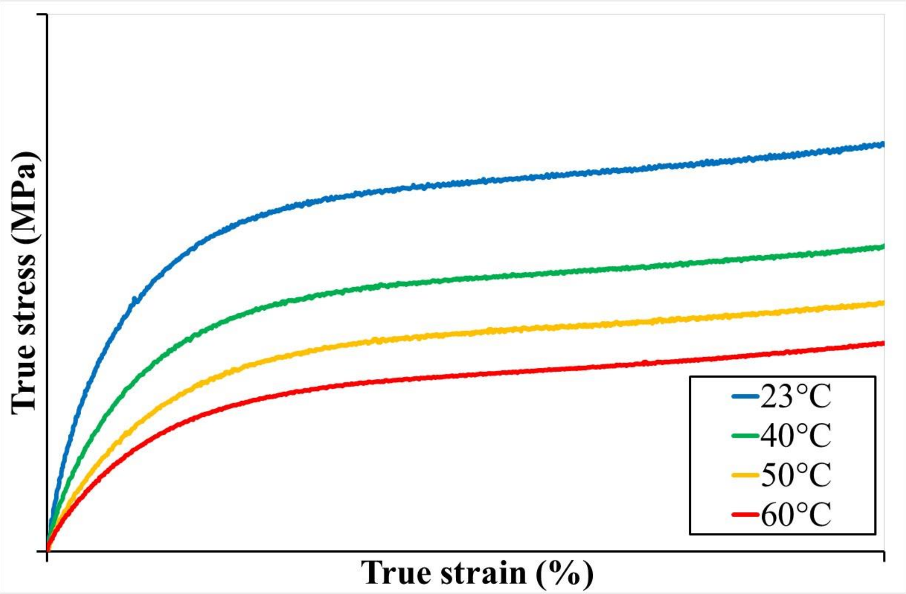


NEW METHOD FOR TENSILE AND CREEP CHARACTERIZATION OF ROTOMOLDING MATERIALS.

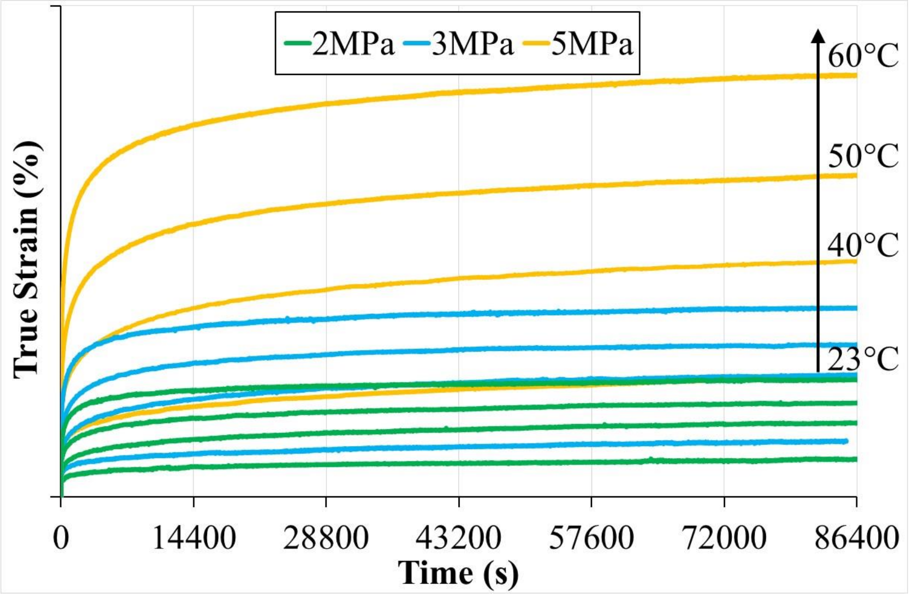
The method is based on true stress / true strain testing at different temperatures of <u>rotomolded</u> samples.

- **Tensile tests at constant true strain rate**
- **Tensile Creep tests during 24 or 48 hours at constant true stress**

Tensile tests at $10^{-3}s^{-1}$



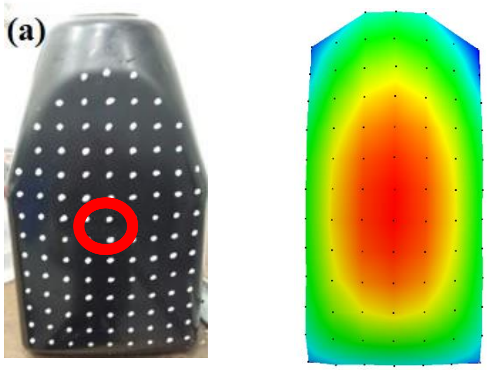
Tensile Creep tests

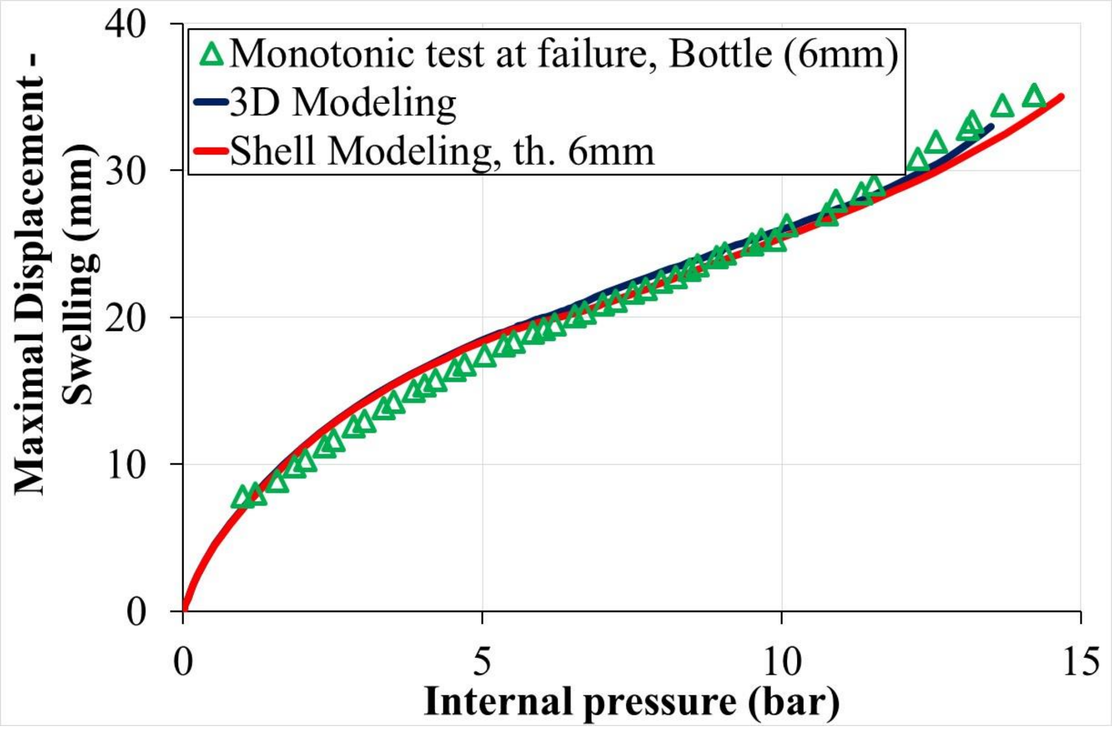


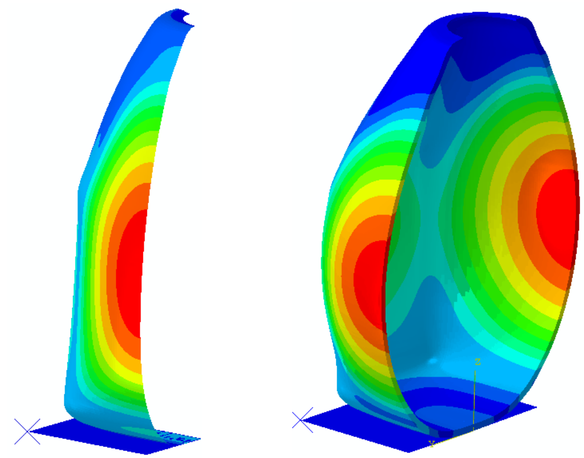
➔**Development of a complete database of static and creep behavior laws for rotomolding materials.**

CORRELATION BETWEEN STRUCTURAL TESTING *AND* NUMERICAL SIMULATION OF ROTOMOLDED PARTS.

- **STATIC test under internal pressure (at room temperature)**
- **HDPE rotomolded Total test bottle**
- **Nominal thickness of 6mm (single layer)**



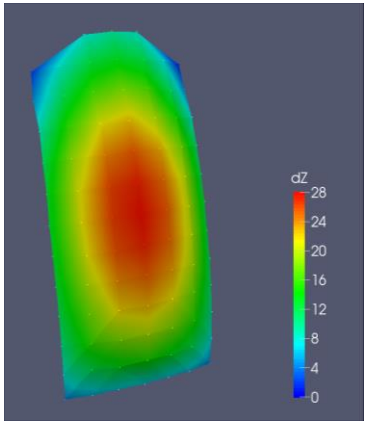


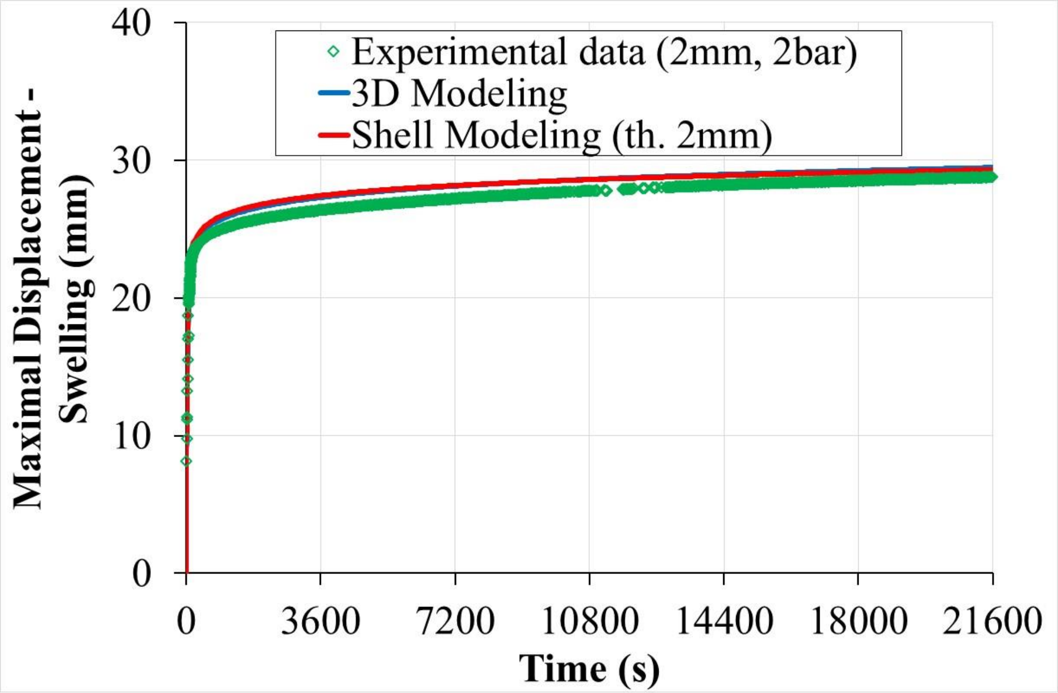


Shell Modeling 3D Modeling

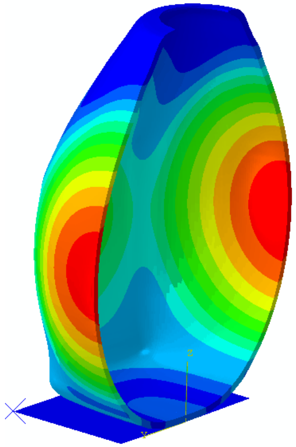
CORRELATION BETWEEN STRUCTURAL TESTING *AND* NUMERICAL SIMULATION OF ROTOMOLDED PARTS.

- **CREEP testing under internal pressure of 2 bars / 29 PSI (at room temperature)**
- **HDPE rotomolded Total test bottle**
- **Nominal thickness of 2mm (single layer)**





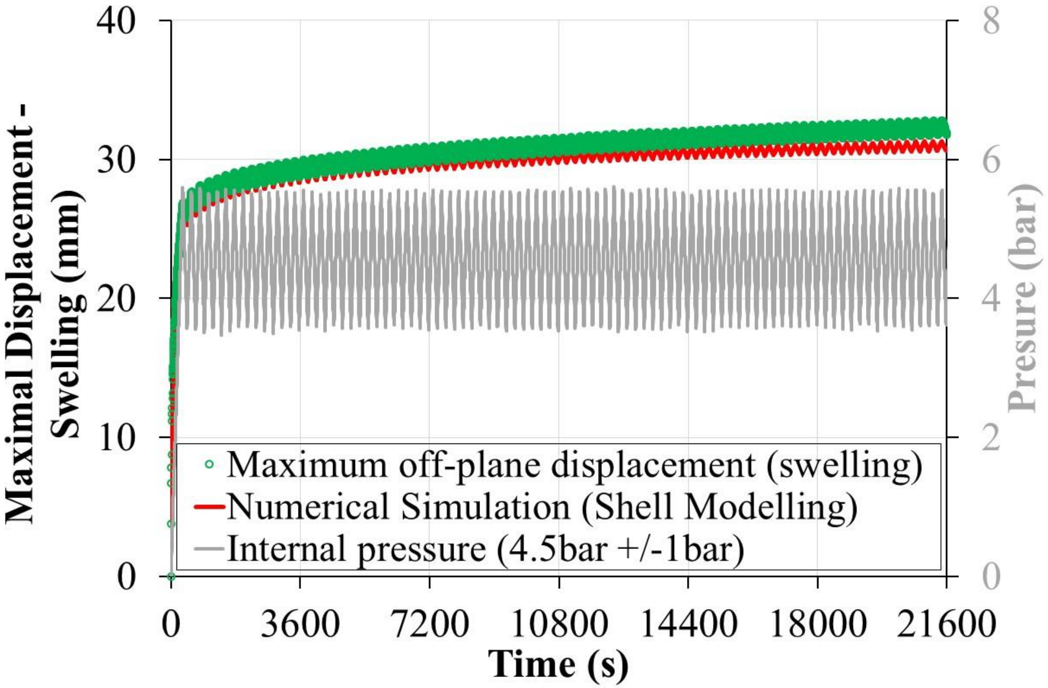
Shell Modeling



3D Modeling

CORRELATION BETWEEN STRUCTURAL TESTING *AND* NUMERICAL SIMULATION OF ROTOMOLDED PARTS.

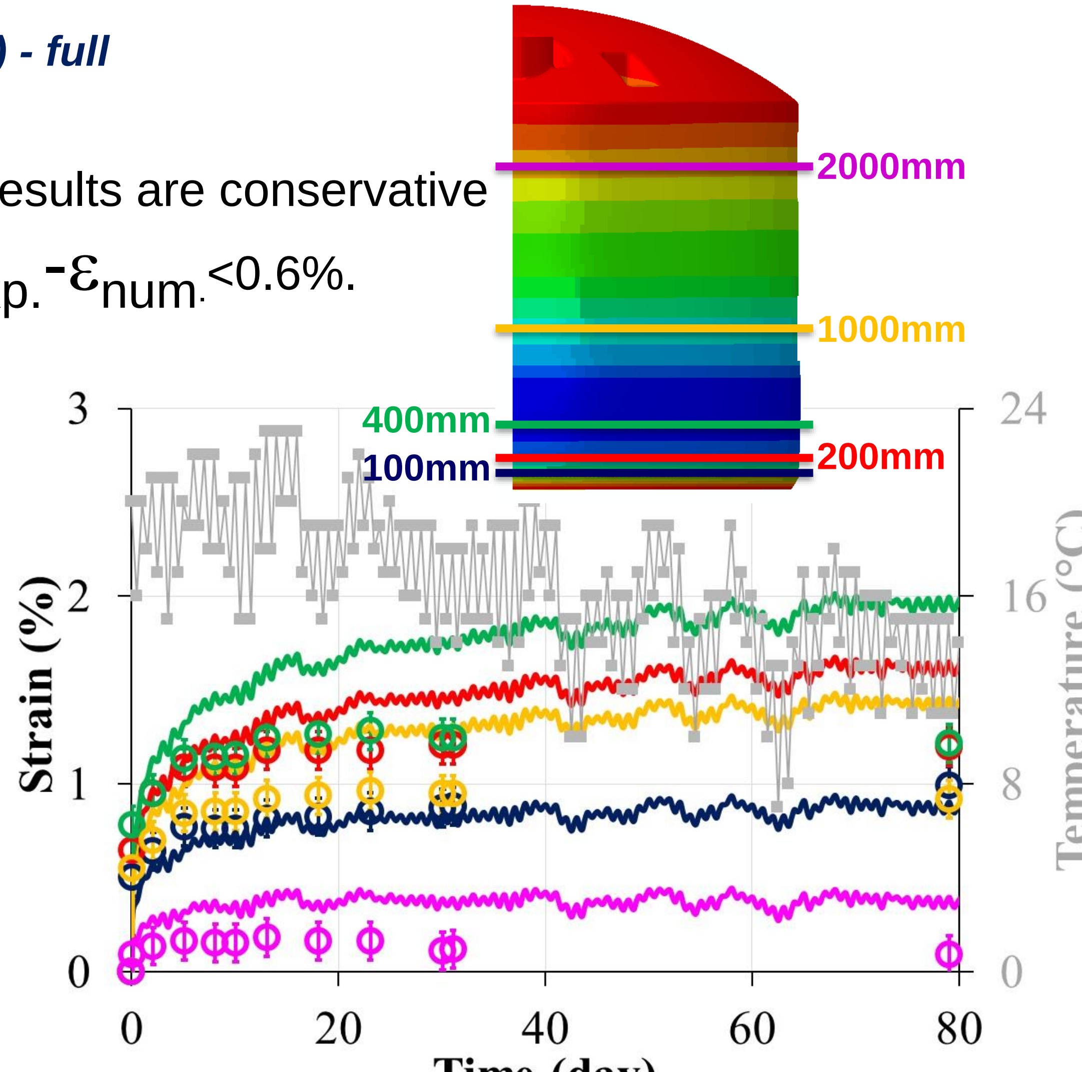
- **Cyclic test from 3,5 bars (50,7 PSI) to 5,5 bars (79,8 PSI) at room temperature**
- **HDPE rotomolded Total test bottle**
- **Nominal thickness of 4mm (single layer)**

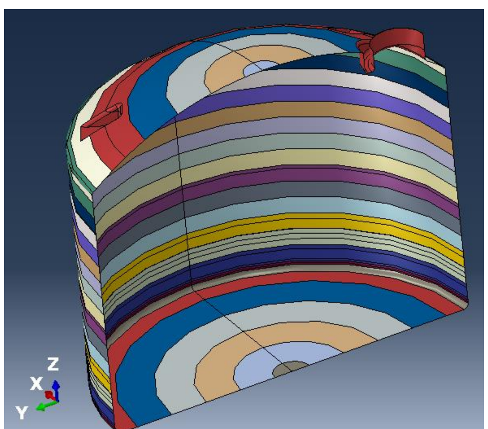


CORRELATION BETWEEN STRUCTURAL TESTING *AND* NUMERICAL SIMULATION OF ROTOMOLDED PARTS.

25,000 liter water tank – single layer (*) - full

- Numerical results are conservative
- $0.05\% < \varepsilon_{exp.} - \varepsilon_{num.} < 0.6\%$.





Thickness distribution

Taking into account the air temperature in Auckland

(*) Courtesy of DEVAN Tank and VPLAS in New-Zealand

What's is done for the moment ?

AS/NZS 4766 – Polyethylene storage tanks for water and chemicals

- **Material test data (tensile properties)**
  - **As per AS 1145 series, or ASTM D638 or ISO527**

- **Hydrostatic Design Stress**
  - **As per ASTM D2837** *(Standard test method for obtaining hydrostatic design basis for thermoplastic pipe materials)*

ASTM D2990-09 – Standard Test Methods for Tensile, Compressive and Flexural Creep and Creep Rupture of Plastics

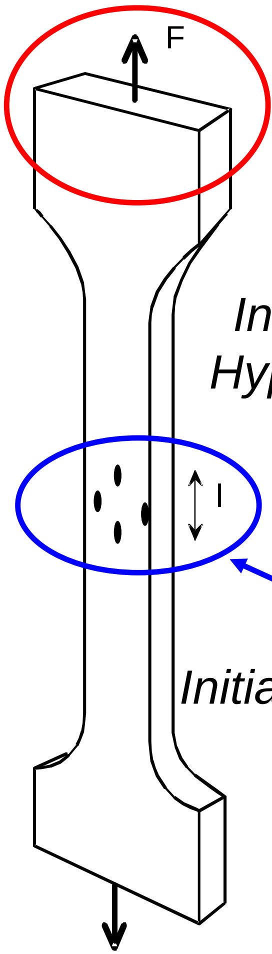
- **Material test data (creep properties, Modulus)**

	Remarks	Outputs
ISO 527	***Tensile test***	
	Nominal stress – Nominal strain **No effect of volume variation**	**Modulus E**
ASTM 2837	***hydrostatic design basis for thermoplastic pipe materials***	
	•**Based on the break** •Extruded tube •Difficult repeatability (many tests) •**Extrapolation for stress at 10, 20 and 50 years by linear regression** •Long and costly tests •1 temperature (23°C)	**Material Class** **Ex: 8.62MPa**
AS/NZS 4766	***Hydrostatic Design Stress***	
	“design factor” ≥2	**Design stress** **Ex: 4.1MPa (≥9.5mm)**
ASTM D2990-09	***Tensile creep test***	
	•**Constant Load (the stress increases)** •Long tests (5000h) •**Extrapolation for Creep Modulus to design limit at 10, 20 and 50 years by linear regression**	***Creep Modulus at 10 years***

The new way for tensile and creep tests

Behavior Law
σ_n- ε_n global

Measured **GLOBAL** data : (ISO527)
- Force,
- Crosshead displacement



Initial section, gauge length
Hyp : Conservation of volume

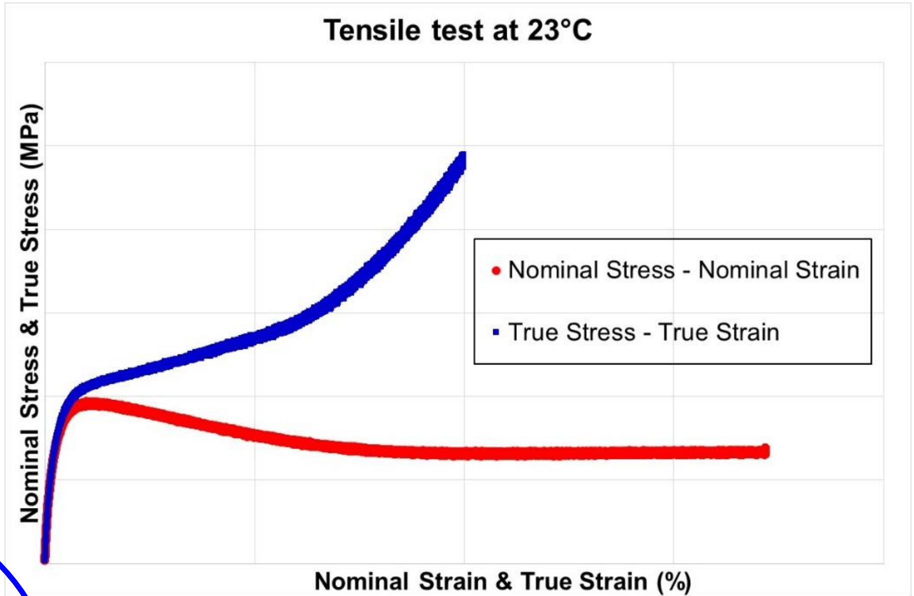
Behavior Law
σ_V- ε_V local

Initial section

Measured **LOCAL** data :
- Longitudinal true strain
- Transverse true strain

+

Measured **GLOBAL** data :
- Force

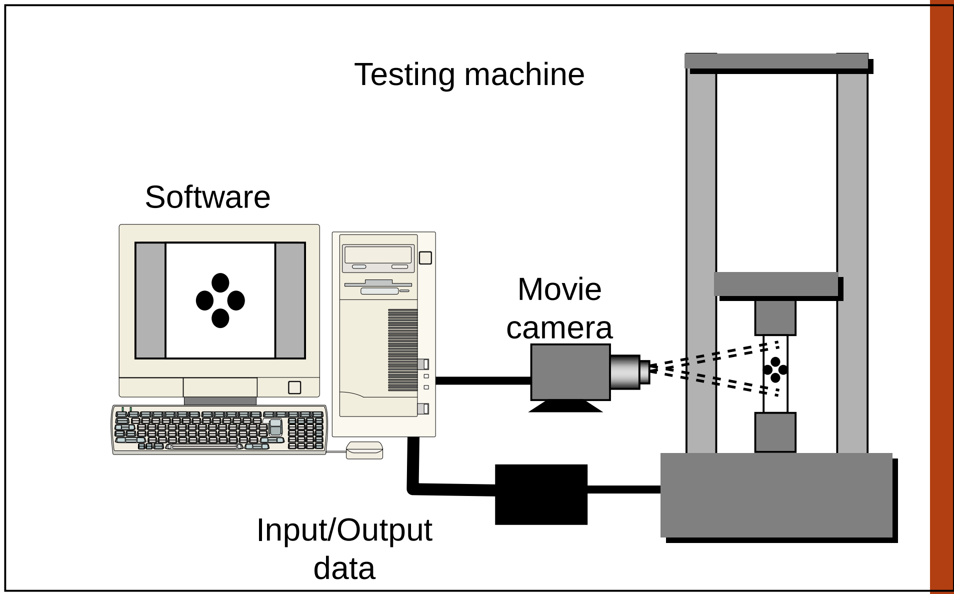


The new way for tensile and creep tests

System VideoTraction© *(1980, Pr. G'Sell)*

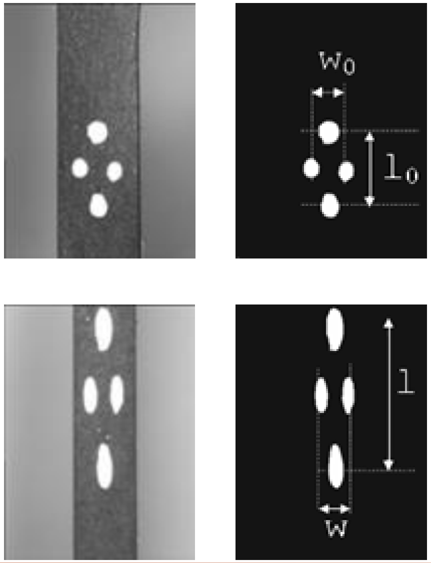
Possible conditions:

- **Constant true strain rate (tensile tests)**
- **Constant true stress (creep tests)**



The four markers system allows obtaining at any moment, the measurement of the longitudinal and transverse true strains

$$\varepsilon_L = \ln\left(\frac{l}{l_0}\right) \quad \text{and} \quad \varepsilon_T = \ln\left(\frac{w}{w_0}\right)$$

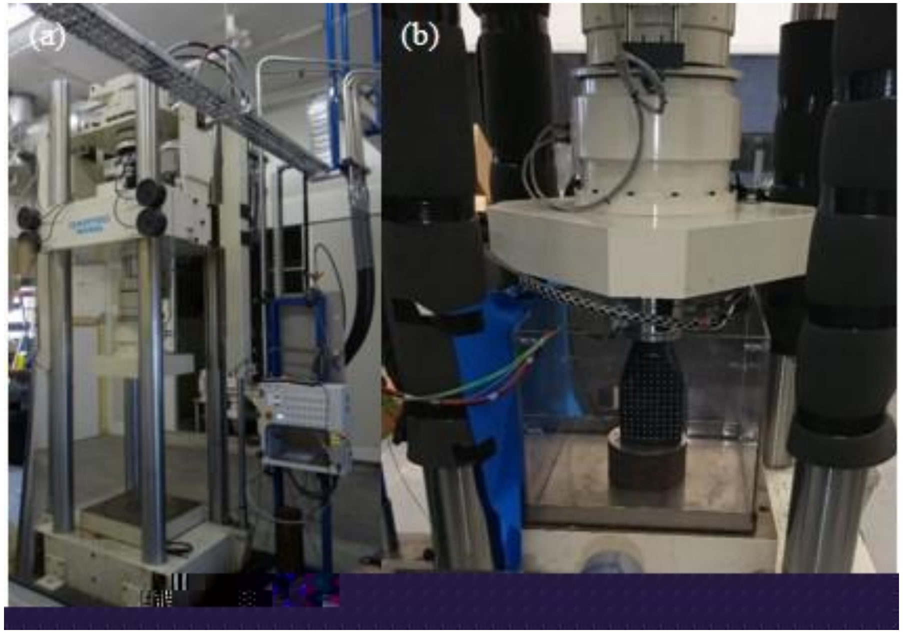


Thus, according to the assumption of transverse isotropy (homogeneous deformation), the true stress is obtained from the following expression :

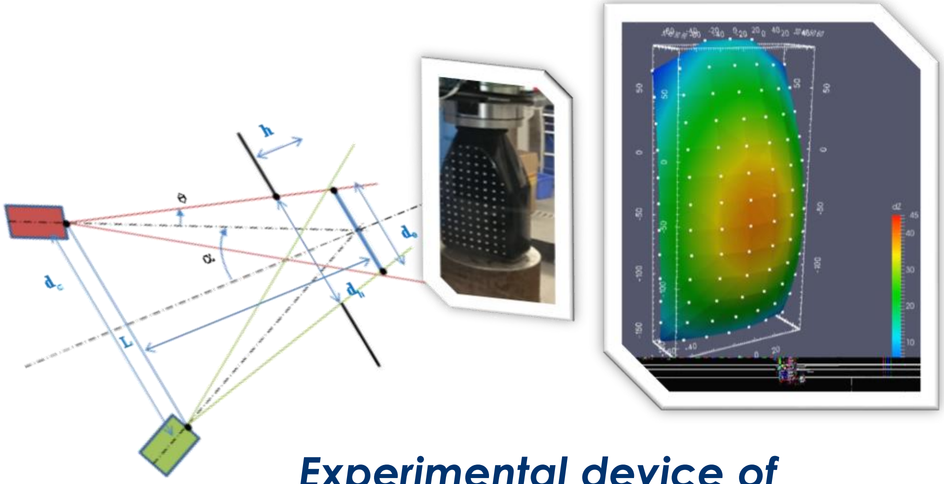
$$\sigma = \frac{\sigma_n}{\exp(2\varepsilon_T)} = \frac{F}{S_0}\exp(-2\varepsilon_T)$$

TESTING ROTOMOLDED PARTS UNDER STRESS:

The Bench Test (Developed by P'/DPMM/ENDO and Total)



Stereoscopic tracking of markers (P'/DGMSC/PEM)



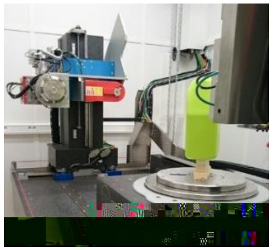
Experimental device of the stereoscopic

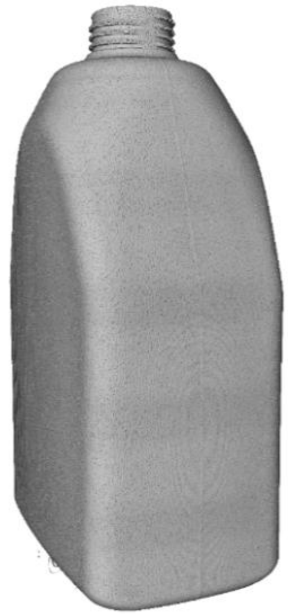
- Tensile / Compression : 1200kN
- Torsion : 50kN.m
- Pressure : 1200 bars
- Combination of efforts

Follow-up of the 3D deformed by markers :
→ Acquisition of images by two cameras
→ Stereoscopic tracking of markers

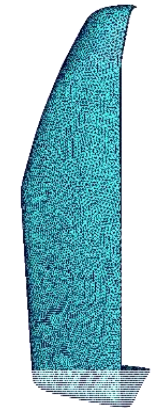
ROTOMOULDED STRUCTURE - TEST MOLD: DIFFERENT STEPS.

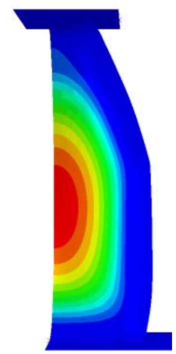
Tomography





CAO (Hypermesh©, Catia©)





Constitutive laws (Tensile and creep tests)

Tests on structures
(Internal Pressure, Compression)
with non-contact measurement methods

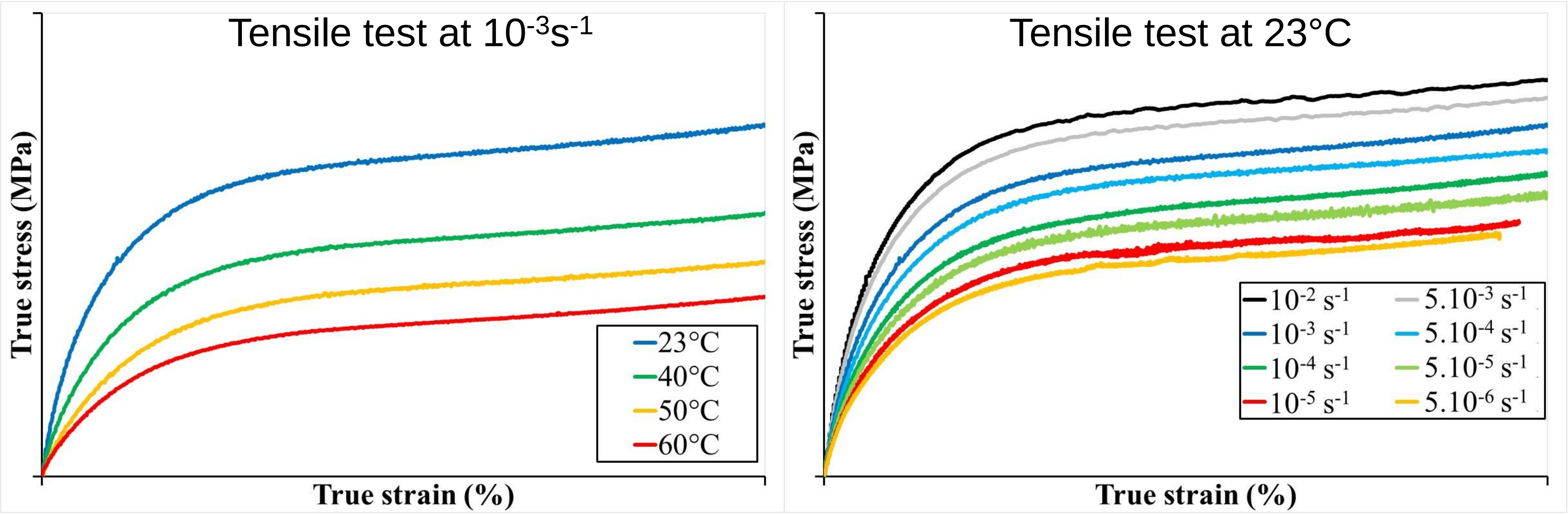
Correlation

Numerical Simulations (Abaqus©)

The importance of Polymers testing at different conditions

Polymers (PE, PP, ..) are complex materials, the behavior is a function e.g. of:

- Temperature
- Strain rate



LONG-TERM CHARACTERIZATION PROTOCOL

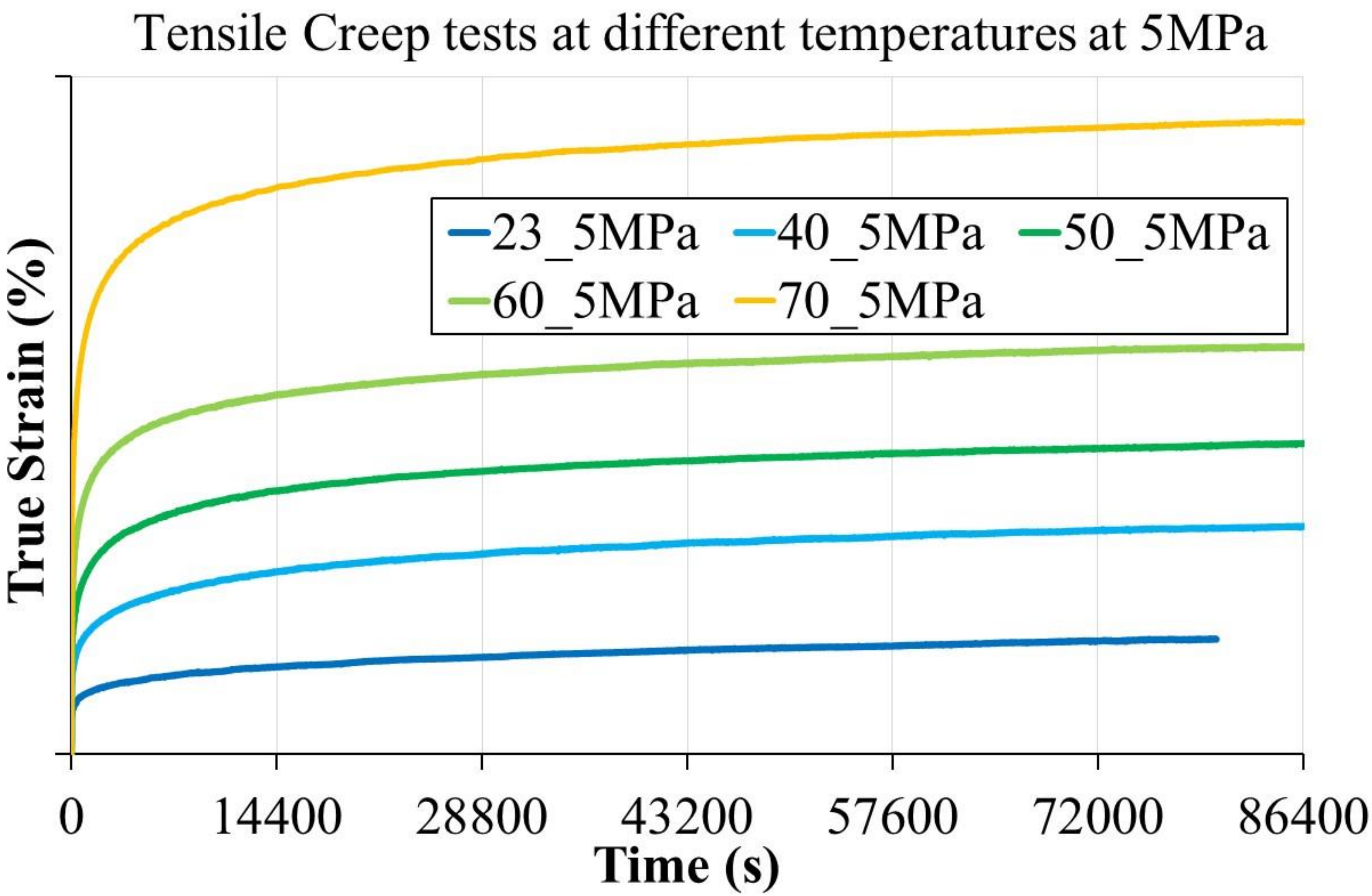
- **Principle of time-temperature superposition**

With some conditions, mechanical parameters (relaxation modulus, complex modulus, compliance,…) of a polymer obtained in the same range of time or frequencies at various temperatures. Curves can be superimposed on the condition of multiplying the time scale by a **shift factor** depending on temperature (or to carry out a translation along the logt axis). The curve obtained starting from the superposition is called ***master curve***.

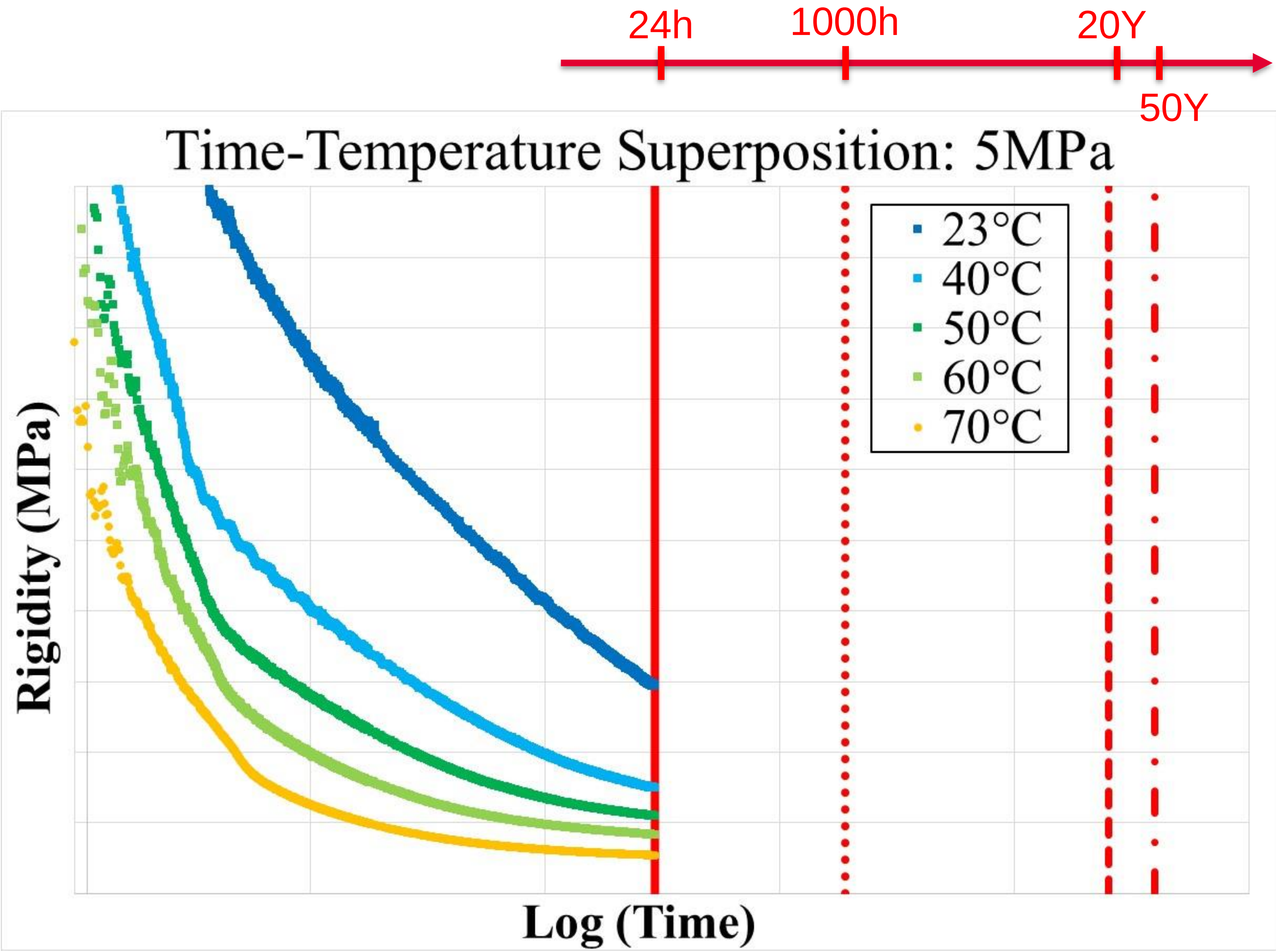
The Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-forming Liquids
Malcolm L. Williams, Robert F. Landel, John D. Ferry
J. Am. Chem. Soc., 1955, 77 (14), pp. 3701–3707

Long-term Characterization Protocol

- **Principle of time-temperature superposition (Williams-Landel-Ferry, 1955)**

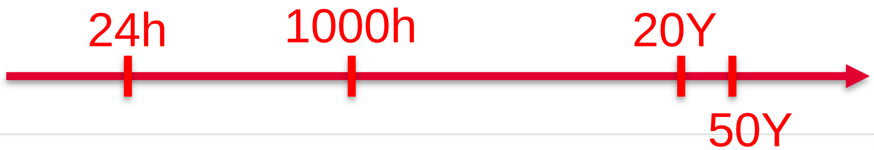


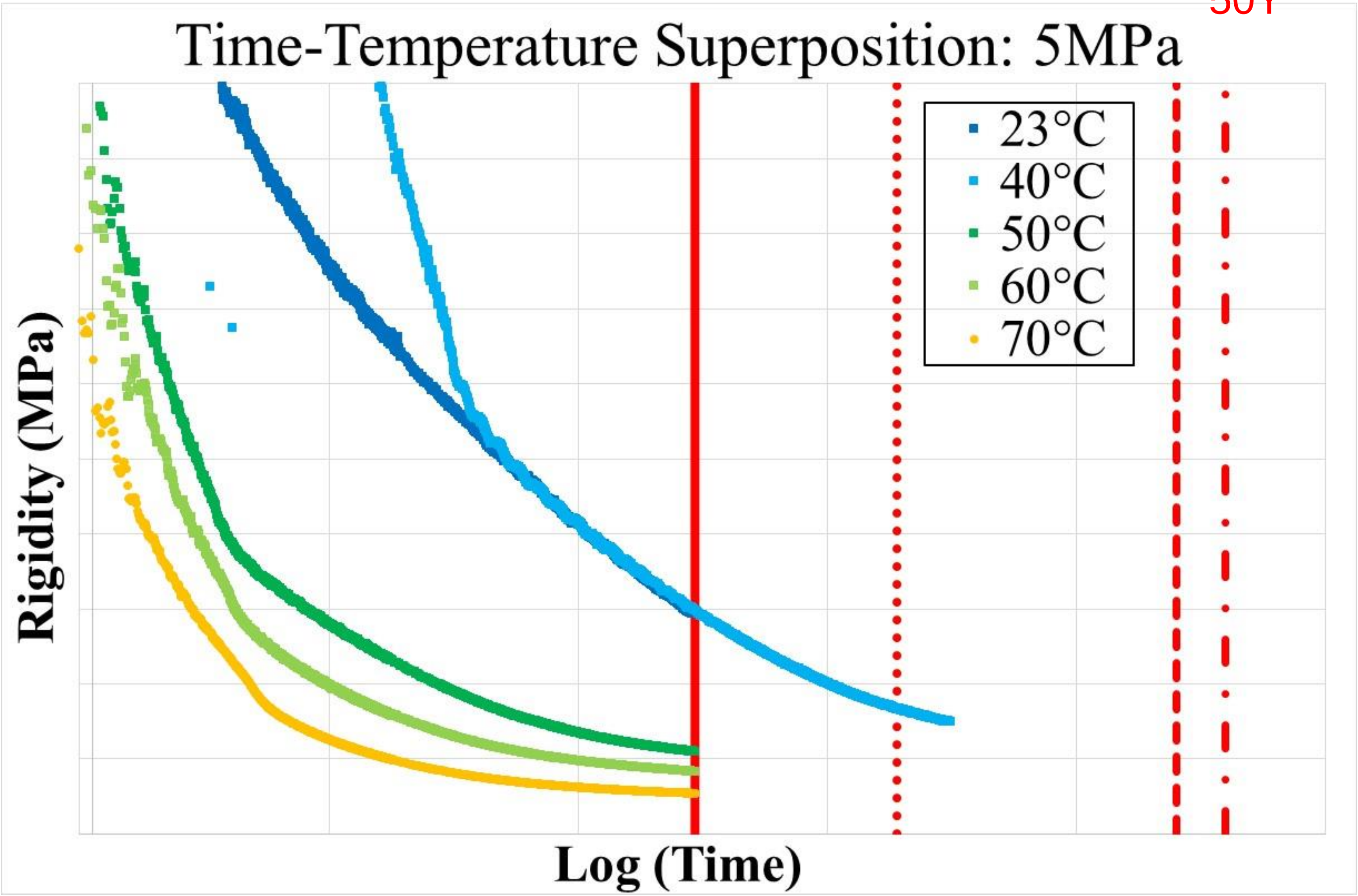
Long-term Characterization Protocol



Long-term Characterization Protocol

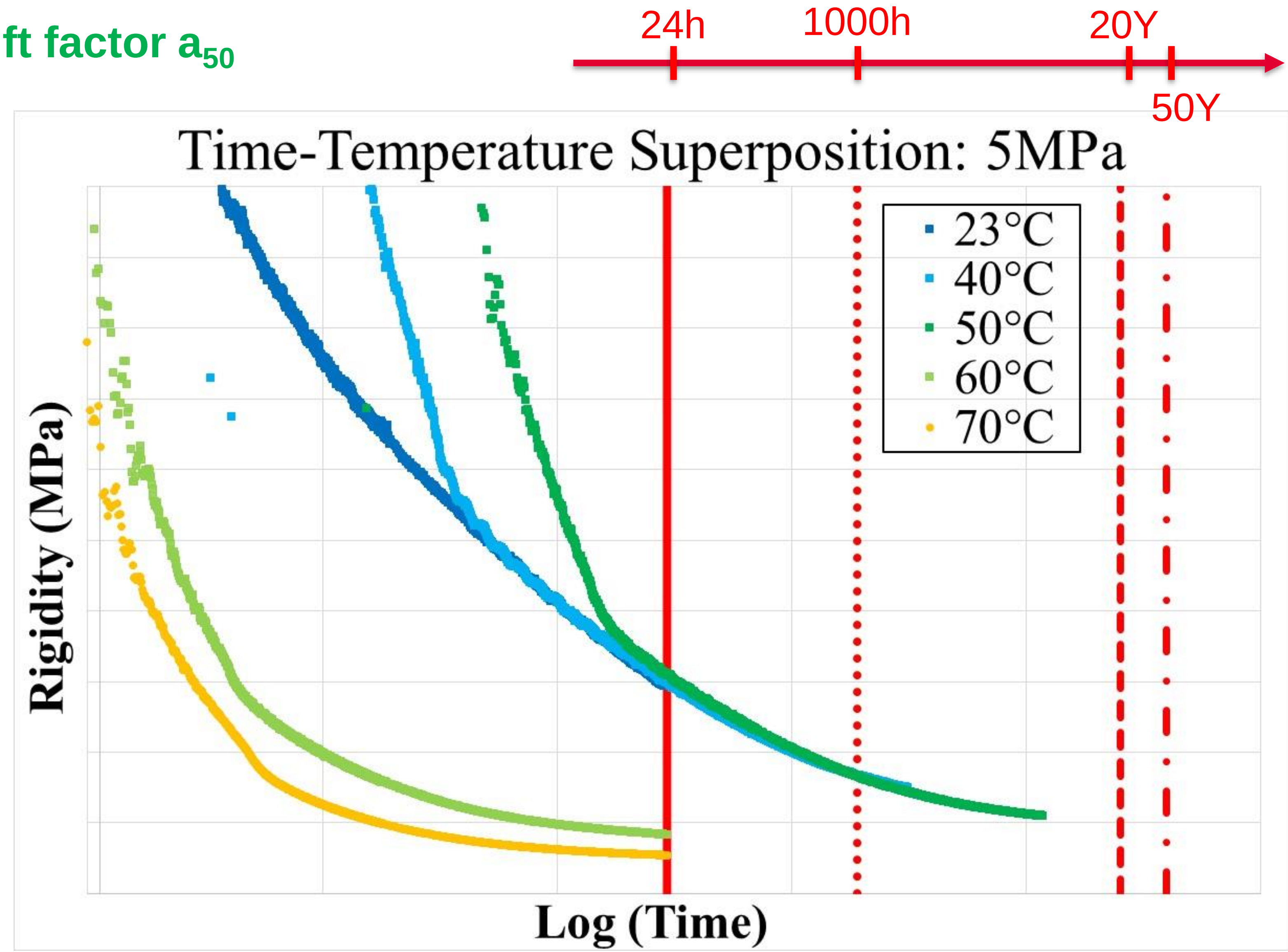
Shift factor a_{40}





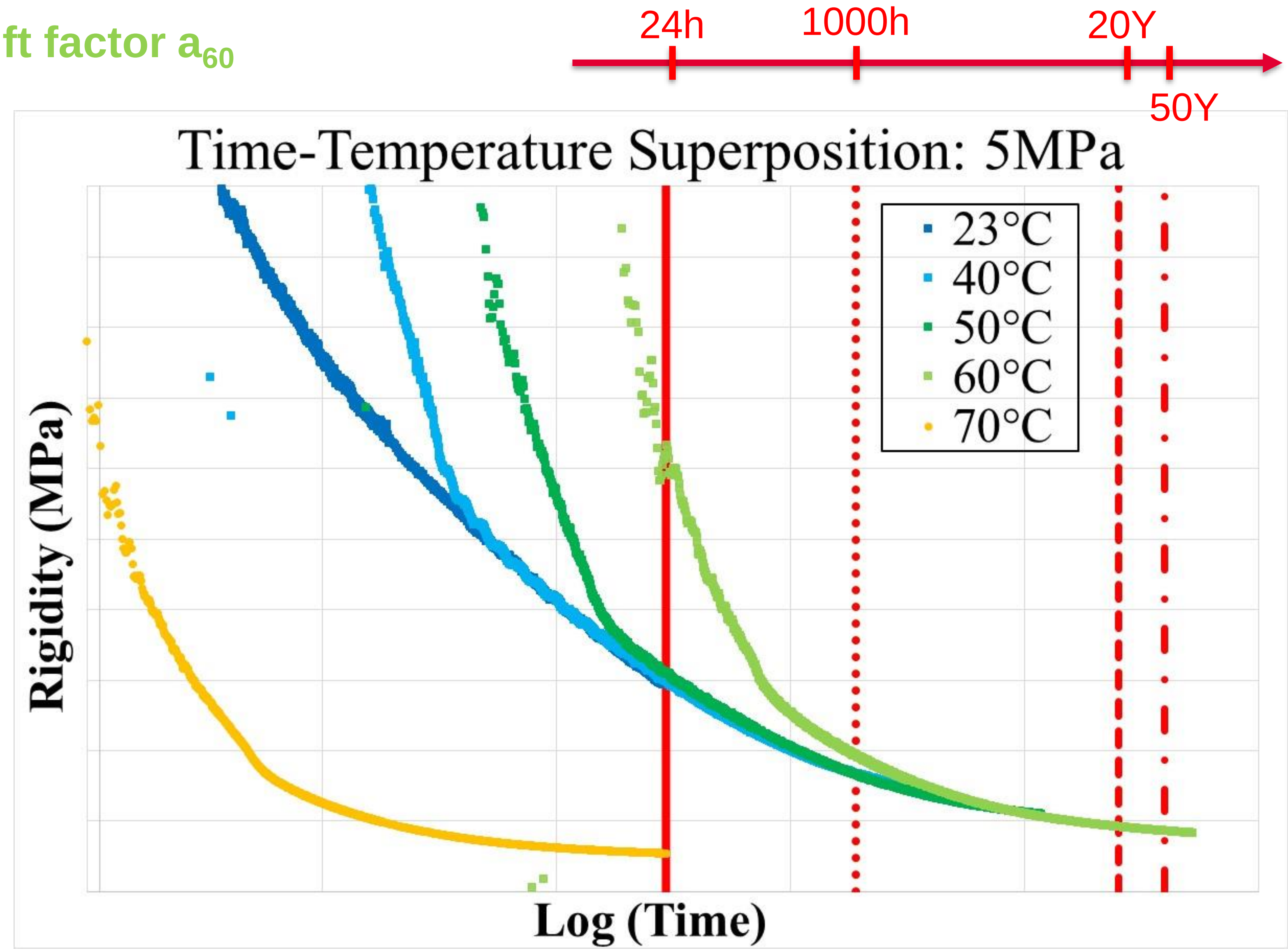
Long-term Characterization Protocol

Shift factor a_{50}



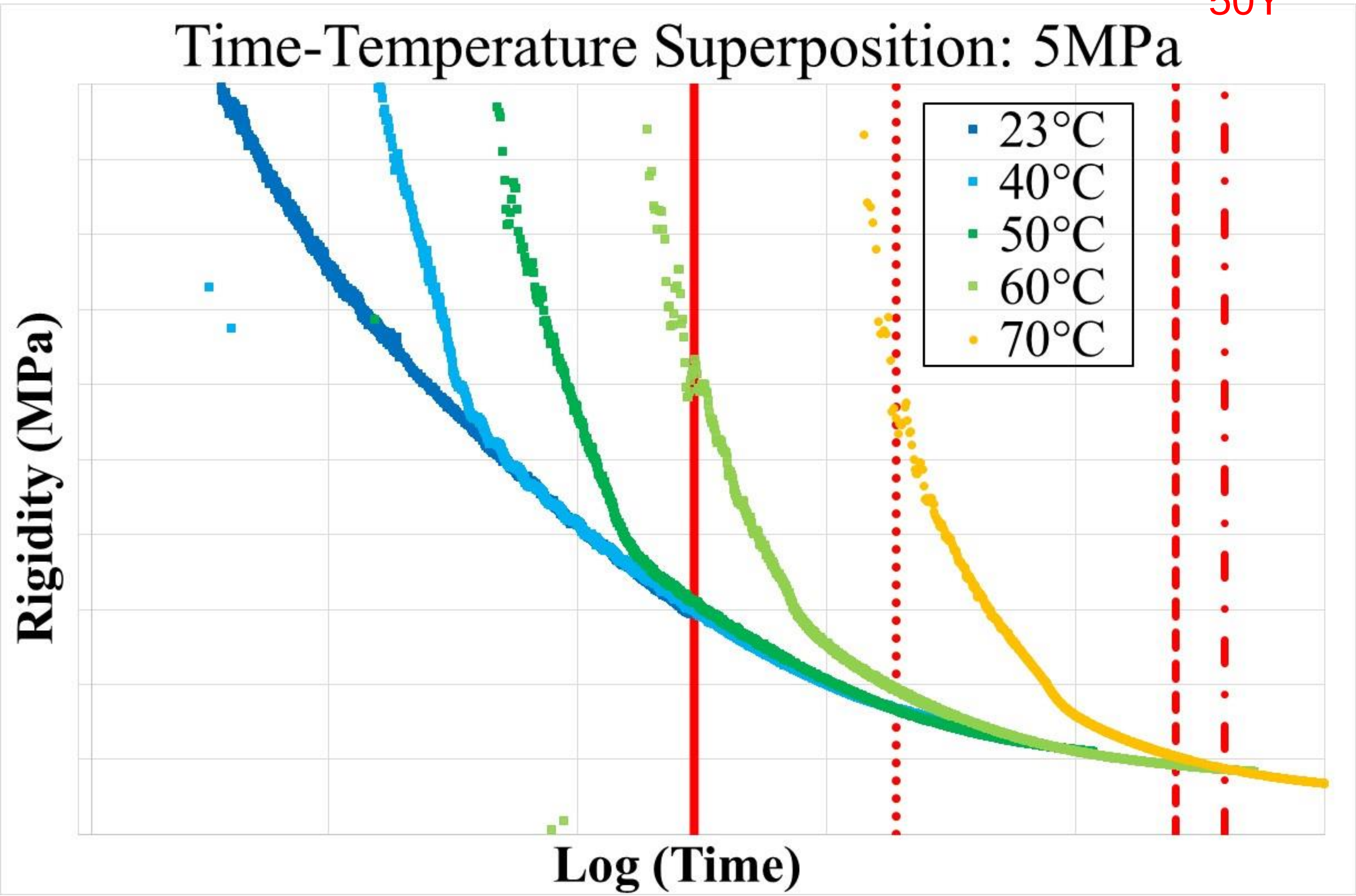
Long-term Characterization Protocol

Shift factor a_{60}



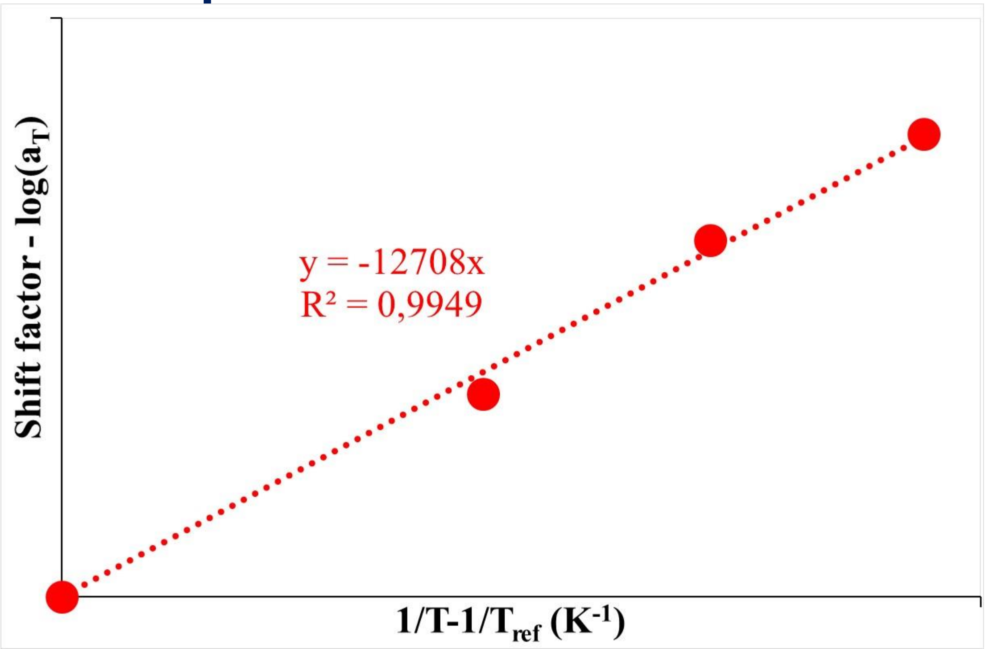
Long-term Characterization Protocol

Shift factor a_{70}



LONG-TERM CHARACTERIZATION PROTOCOL

- **Based on this method, the shift factor is defined, afterwards the master curves at any temperature can be established.**
- **The next, is the reconstruction of the true strain-time curves**
- **Finally the Long-term creep behaviour law is established.**



WHAT'S NEXT ?

- More detailed information will be published in future Rotoworld papers.
- A working group should be created to make a standard based on this approach.

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