Institute of Refractories Engineers

Thermo-Mechanical Testing & Interpretation of Results

Kenwood Hall, Sheffield
27th September 2012

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Thermo-mechanical Testing & Interpretation of Results

Outline

- Overview of High Temperature Thermo-Mechanical Testing
- Refractoriness Under Load & Creep in Compression
  - Test Procedure & Set Up
  - Interpreting Plots
  - RUL Case Study – Relation to Chemistry/Mineralogy
  - Creep Case Study 1 – Test Duration
  - Creep Case Study 2 – Comparison of Mullite Products
  - Creep Case Study 3 – Factors Affecting Creep

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High Temperature Testing

- Hot Strength
  - Hot Modulus of Rupture (HMOR)
- Volume Stability
  - Permanent Linear Change (PLC)
- Thermal Expansion Under Load
  - Refractoriness Under Load (RUL)
- Thermal Expansion Under Load (Time Dependant)
  - Creep in Compression

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RUL & Creep Testing

RUL

- A measure of the resistance to subsidence when a refractory is subjected to a constant load and rising temperature
- The deformation of a test piece is recorded as it is under load and heated at a specified rate

Creep

- Relates to the deformation of a refractory under constant load as a function of time and temperature
- A test piece under load is heated to a given temperature and then held for a specified time while the deformation of the sample is recorded; the creep is obtained from the progression of the deformation curve from the point of maximum expansion until the end of the given hold time

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Test Procedure (ISO)

- Sample – Cylinder 50mm diameter x 50mm high with 12.5mm axial hole
- Applied Load – 0.2MPa (can be varied)
- Heat Rate - 5°C/min
- Creep hold time – 25h (can be varied..50h, 100h, 200h)

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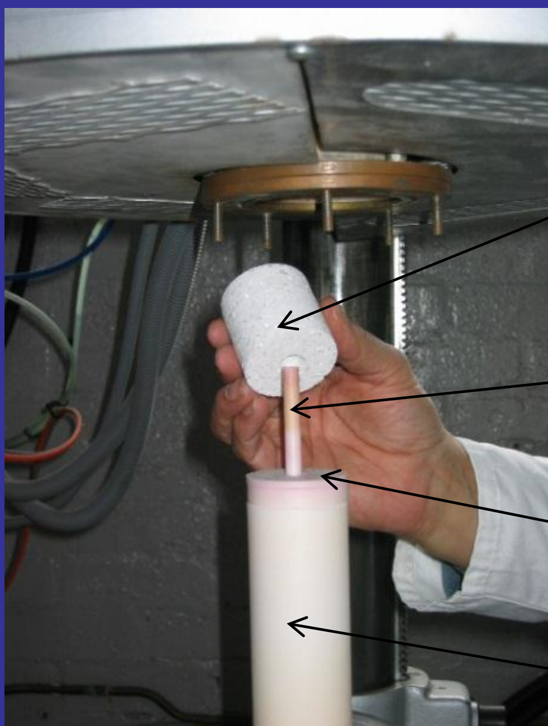
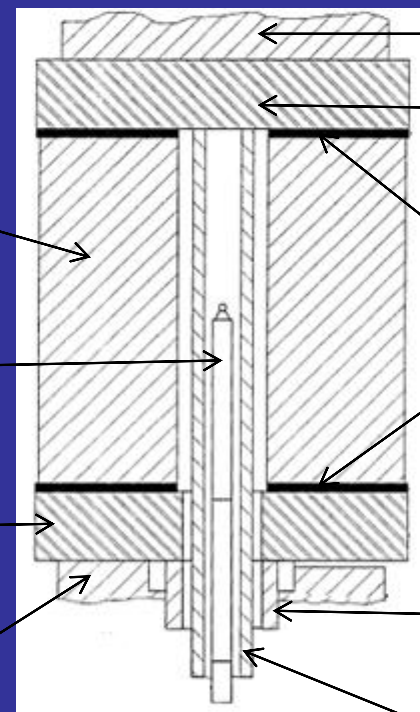
Test Apparatus





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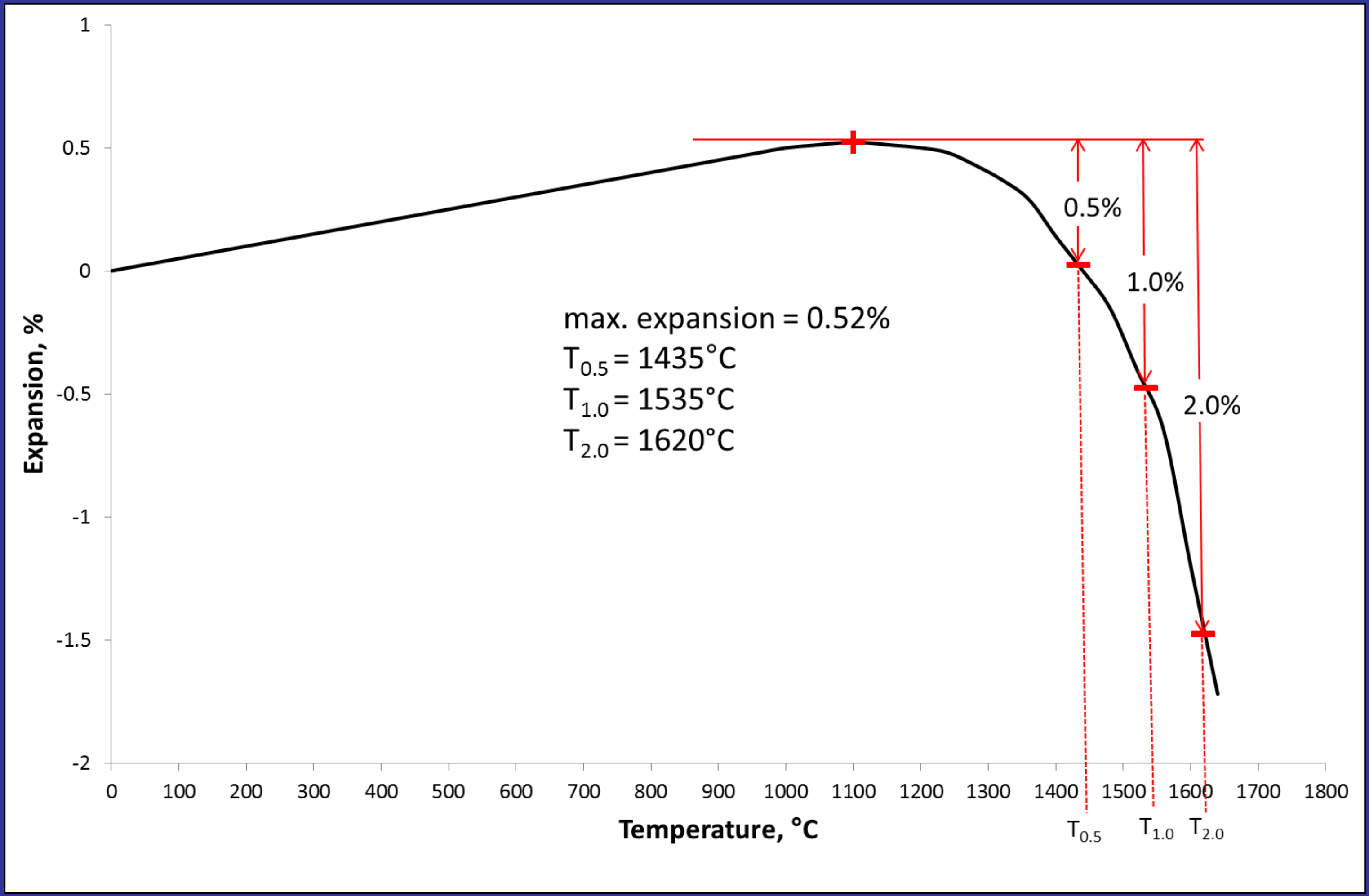
RUL Plot



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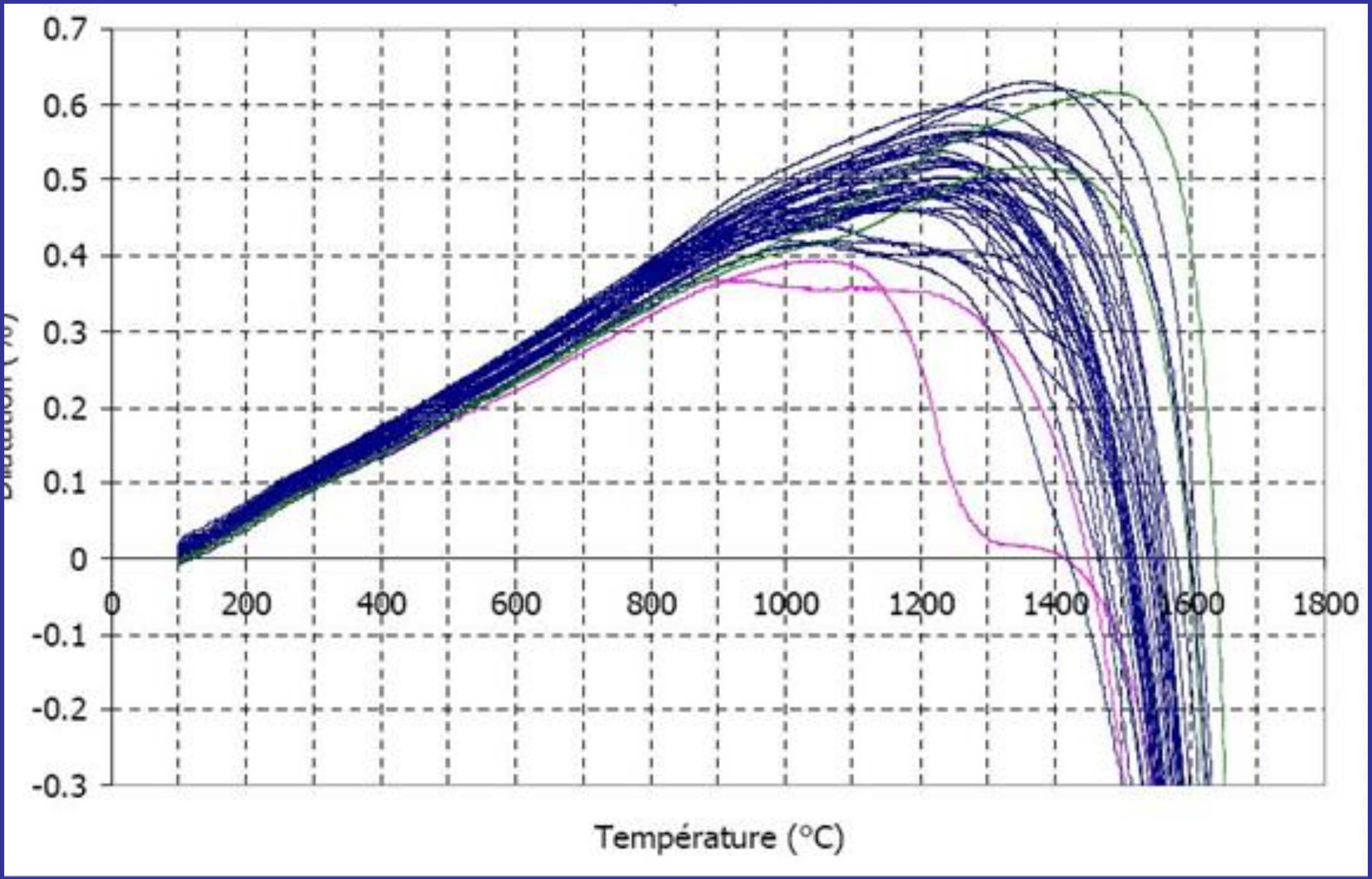
RUL as Quality Control Test



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RUL Case Study – Andalusite Based Products

The main performance criterion for alumino-silicate refractory products is the relative percentage of mullite present in the product

Mullite phase is associated with good hot properties and resistance to chemical corrosion and abrasion

Sillimanite minerals are used to produce mullite on firing; when andalusite is heated above ~1380°C it dissociates to form mullite and silica glass with an associated volume expansion of ~5%;-

$$3(Al_2O_3.SiO_2) \longrightarrow 3Al_2O_3.2SiO_2 + SiO_2$$

Andalusite	Mullite
SG = 3.20	SG = 3.05

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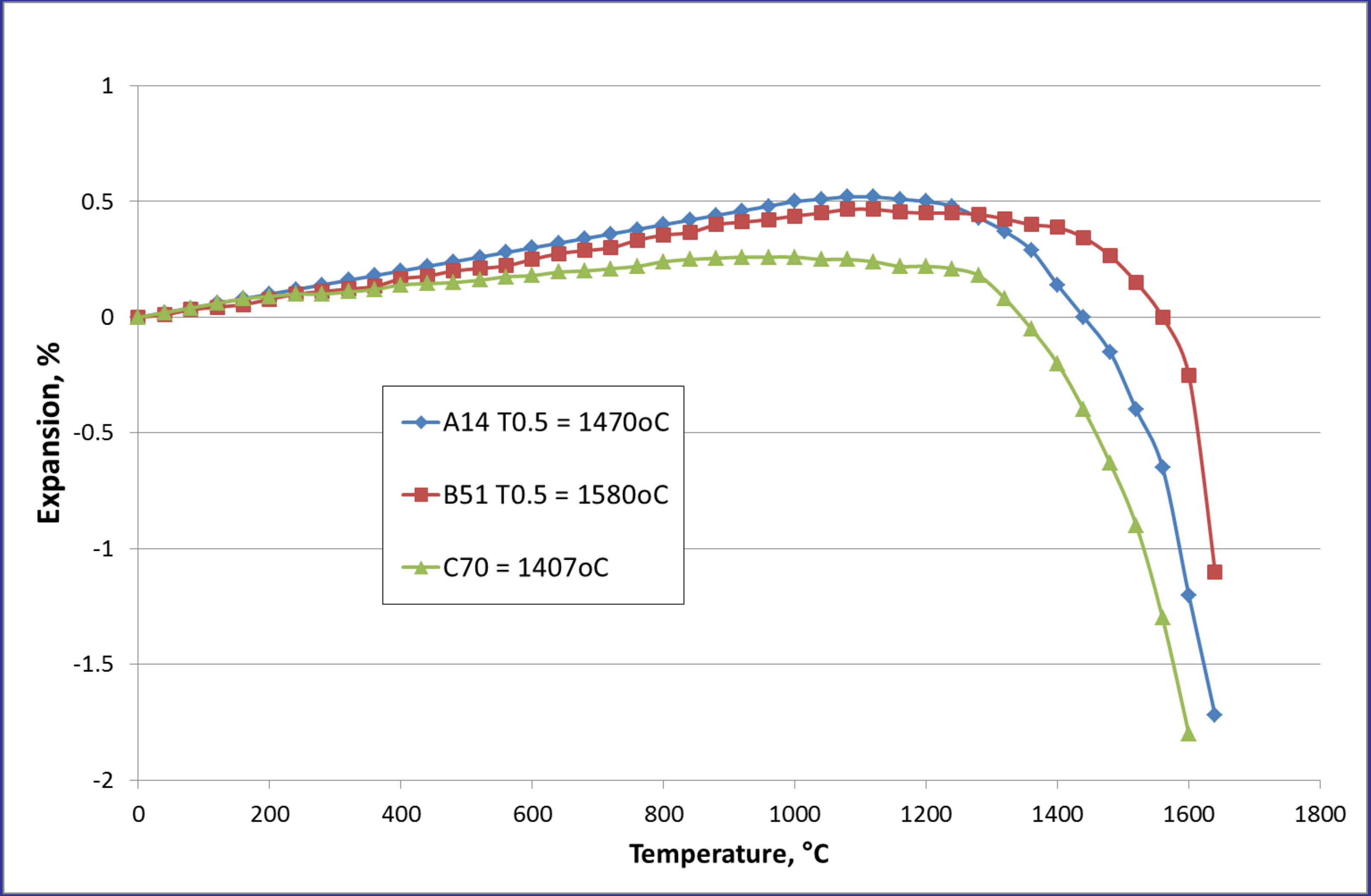
RUL Case Study – Andalusite Based Products



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RUL Case Study – Andalusite Based Products

Phase	A14	B51	C70	C70 refired
Mullite $Al_6Si_2O_{13}$	73	77	46	63
Cristobalite SiO_2	0.8	1.1	8.4	1.0
Quartz SiO_2	-	-	2.5	-
Andalusite Al_6SiO_5	-	-	24	-
Amorphous	26	22	17	36

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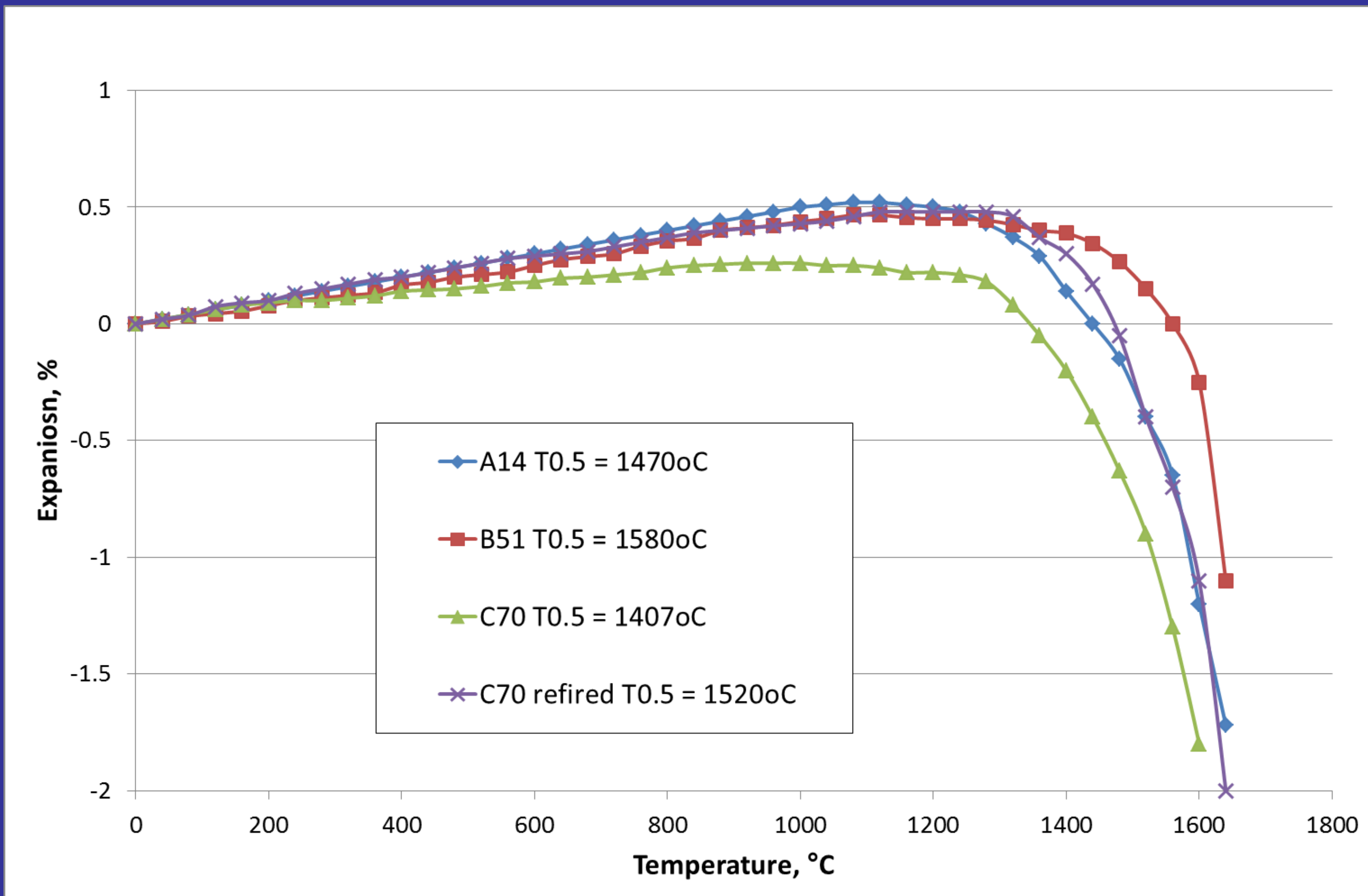
RUL Case Study – Andalusite Based Products



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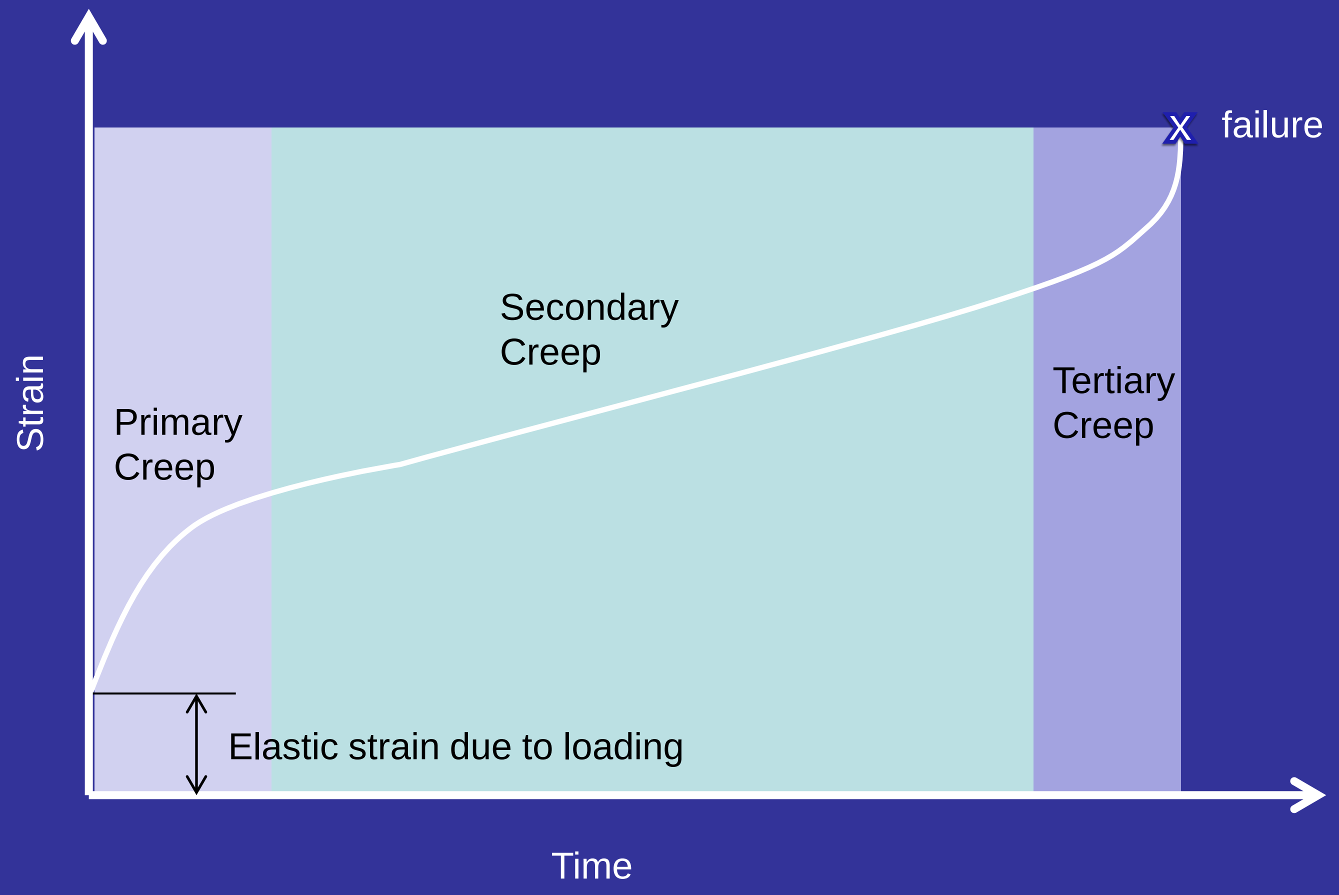
“Classical” Creep Curve



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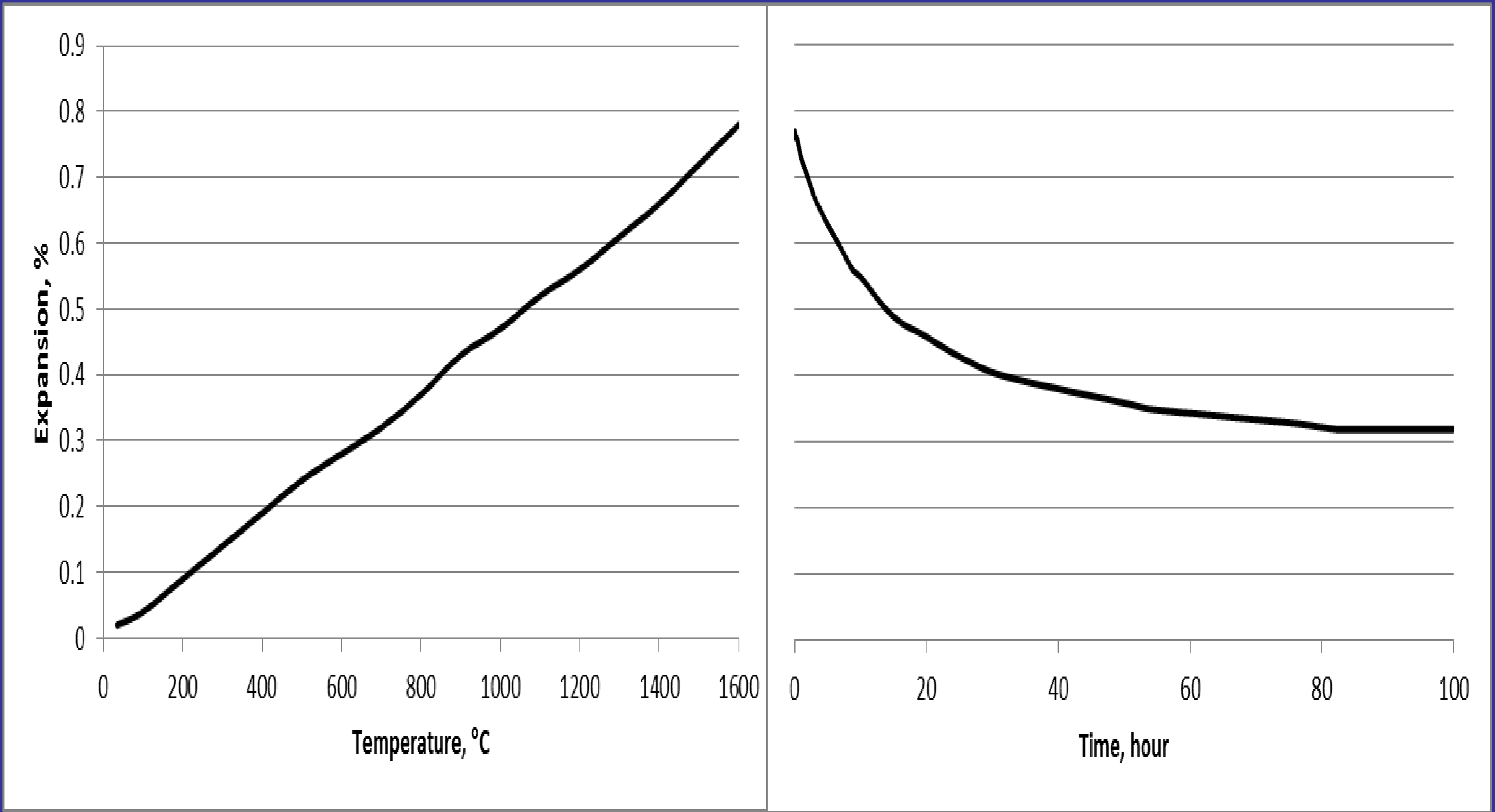
Compressive Creep Curve



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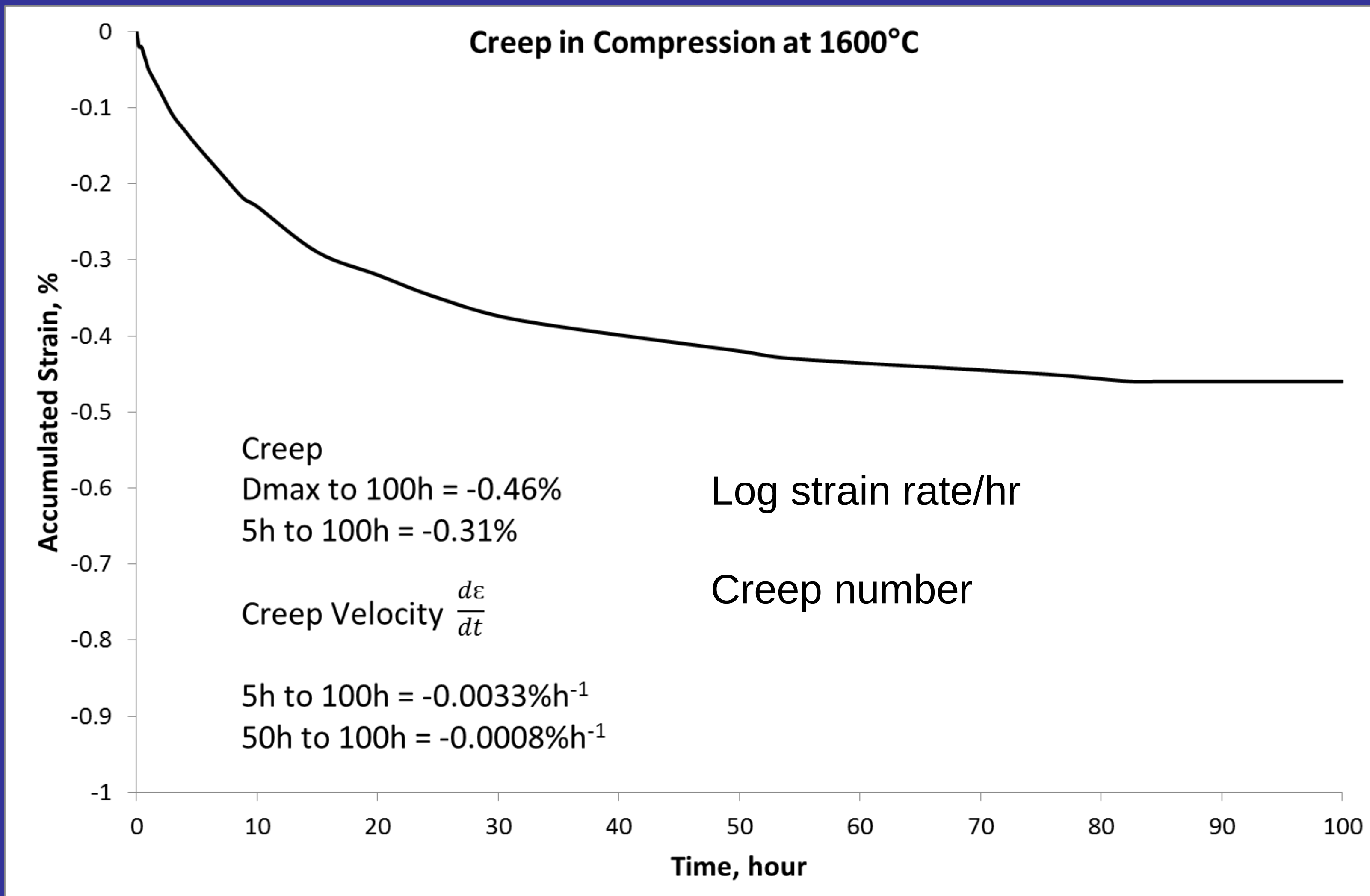
Compressive Creep Curve



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Compressive Creep Characteristics

Good Creep Properties

- Low total creep (<1%)
- ‘Steady state’ creep rate (secondary stage flat line)

Poor Creep Properties

- Large deformation
- Constant creep rate throughout (no flat-lining)

Factors affecting Creep

- Chemistry
- Mineralogy
- Manufacture Method
- Internal Flaws

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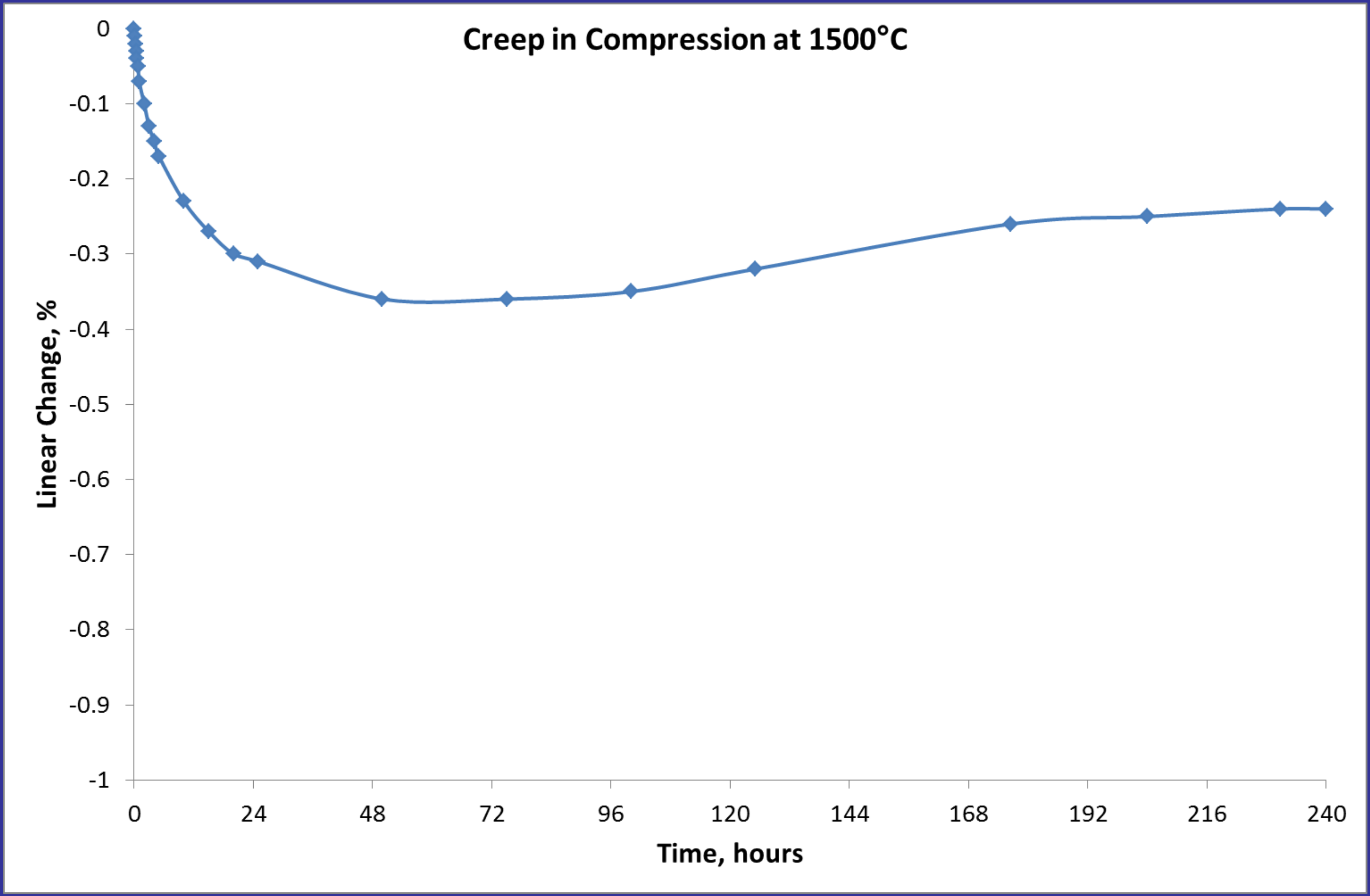
Creep Case Study 1 – Test Duration



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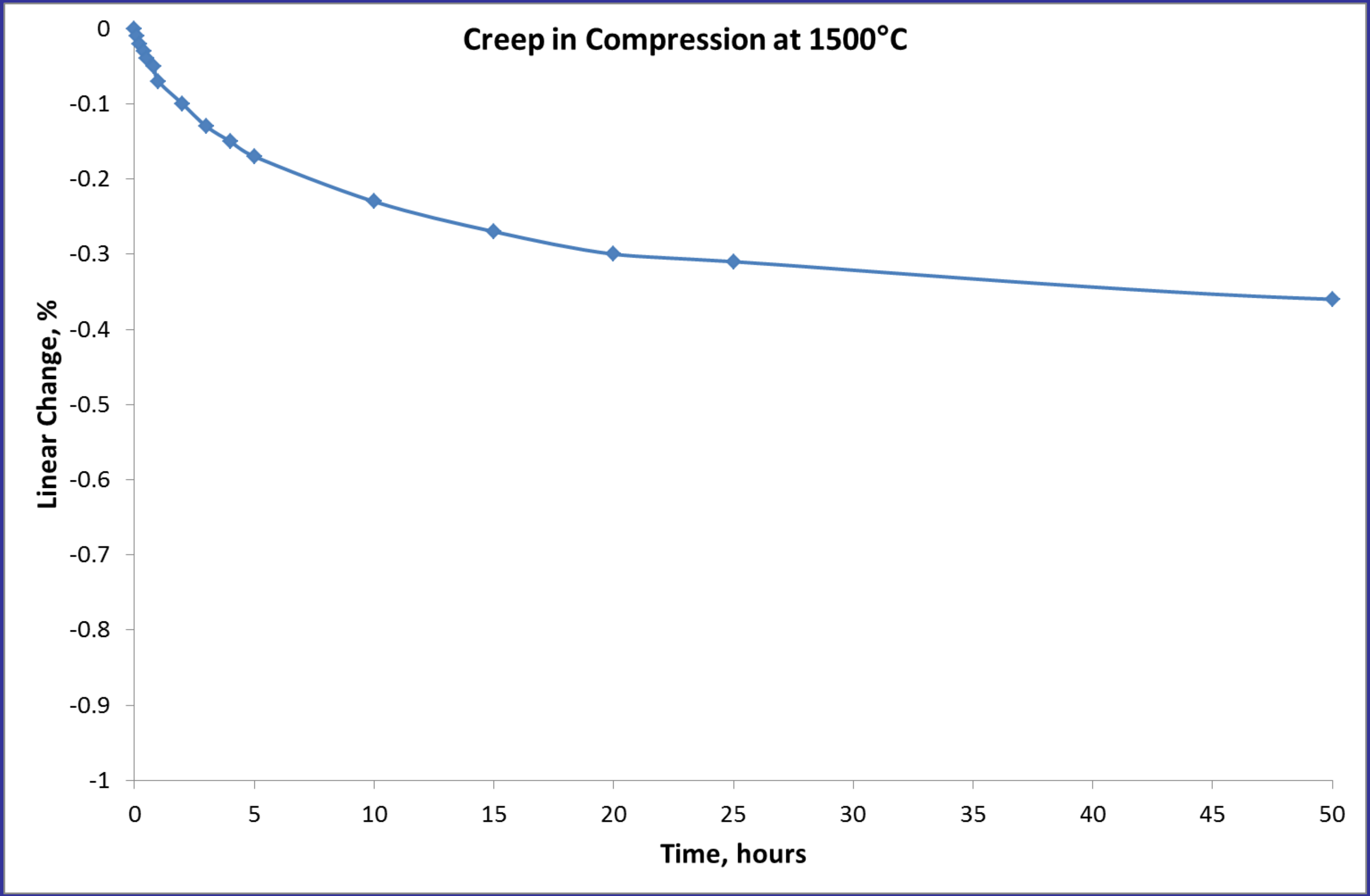

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Creep Case Study 2 – Comparison of Mullite Products

	Mullite A	Mullite B	Mullite C
Al2O3	76.4	70.4	76.9
SiO2	24.5	27.7	21.7
Fe2O3	0.08	0.79	0.55
TiO2	0.05	0.22	0.20
CaO	0.10	0.16	0.10
MgO	0.05	0.10	0.09
Na2O+K2O	0.26	0.53	0.43
Mullite $Al_6Si_2O_{13}$	98.1	94.7	47.9
Andalusite Al_6SiO_5	-	-	5.2
Corundum Al_2O_3	1.9	5.3	46.9

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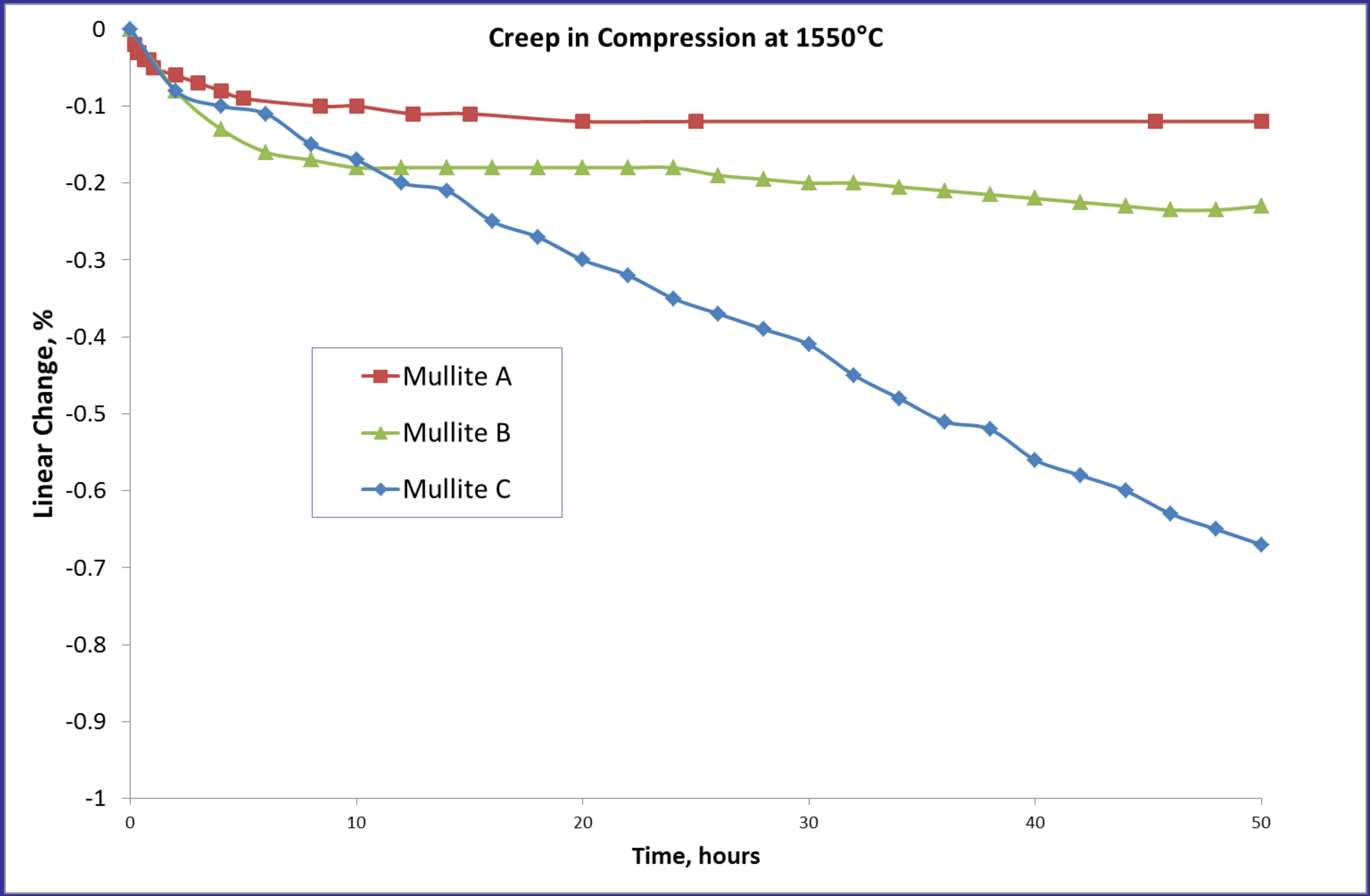

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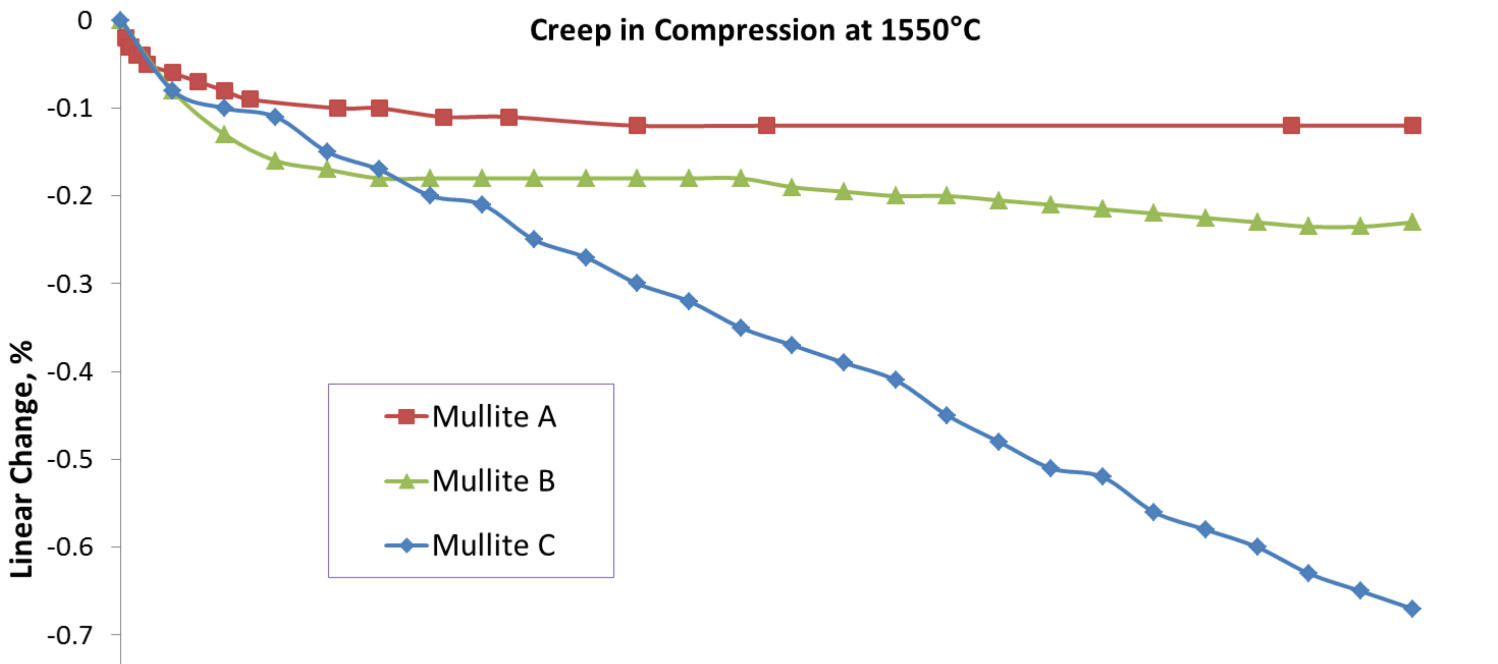

	Mullite A	Mullite B	Mullite C
Total Creep 0-50h, %	0.11	0.23	0.67
Creep Velocity 0-50h, %	0.0022	0.0040	0.013
Creep Velocity 25-50h, %	0	0.0018	0.012

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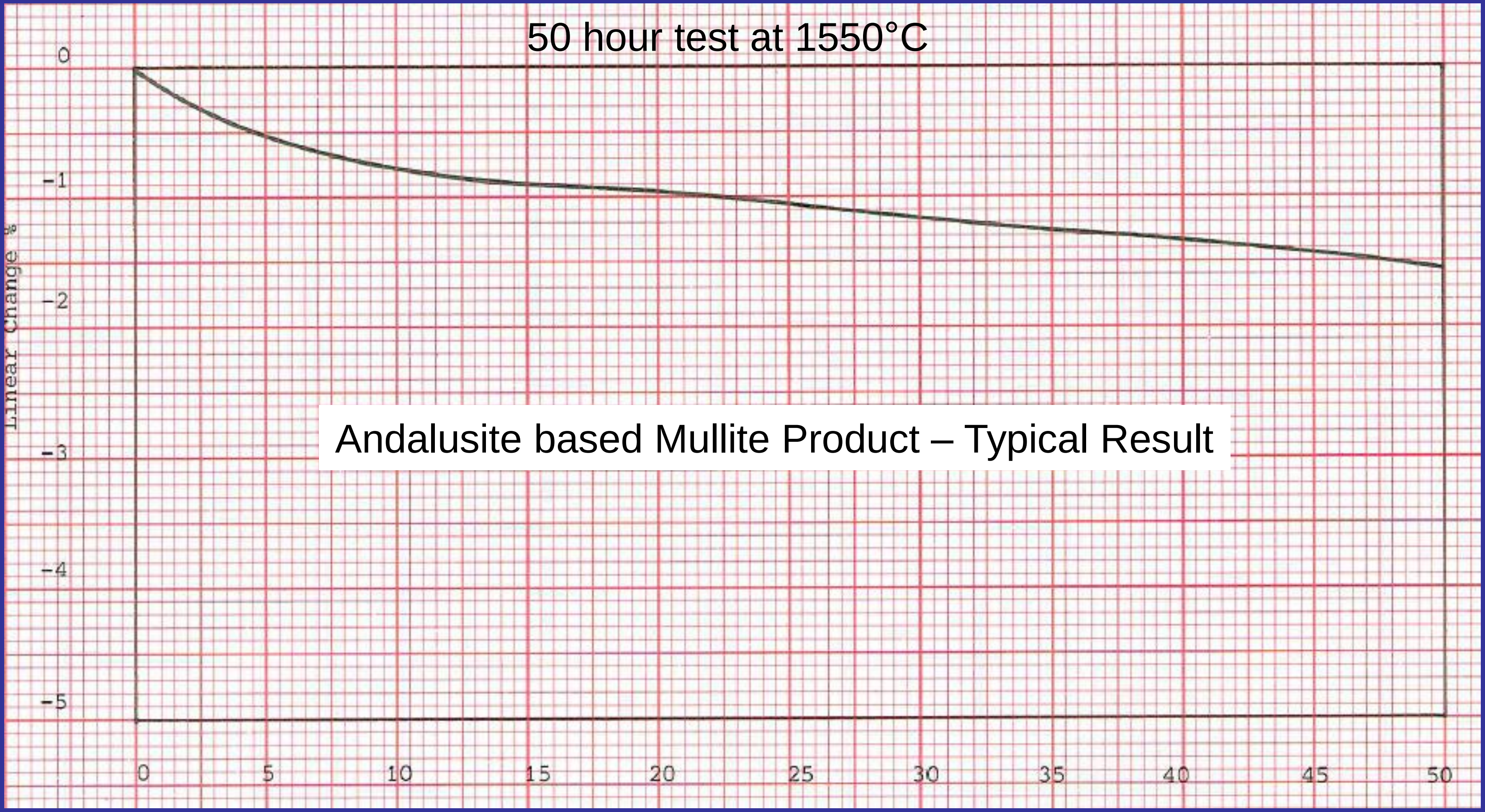
Creep Case Study 3 – Factors Affecting Creep



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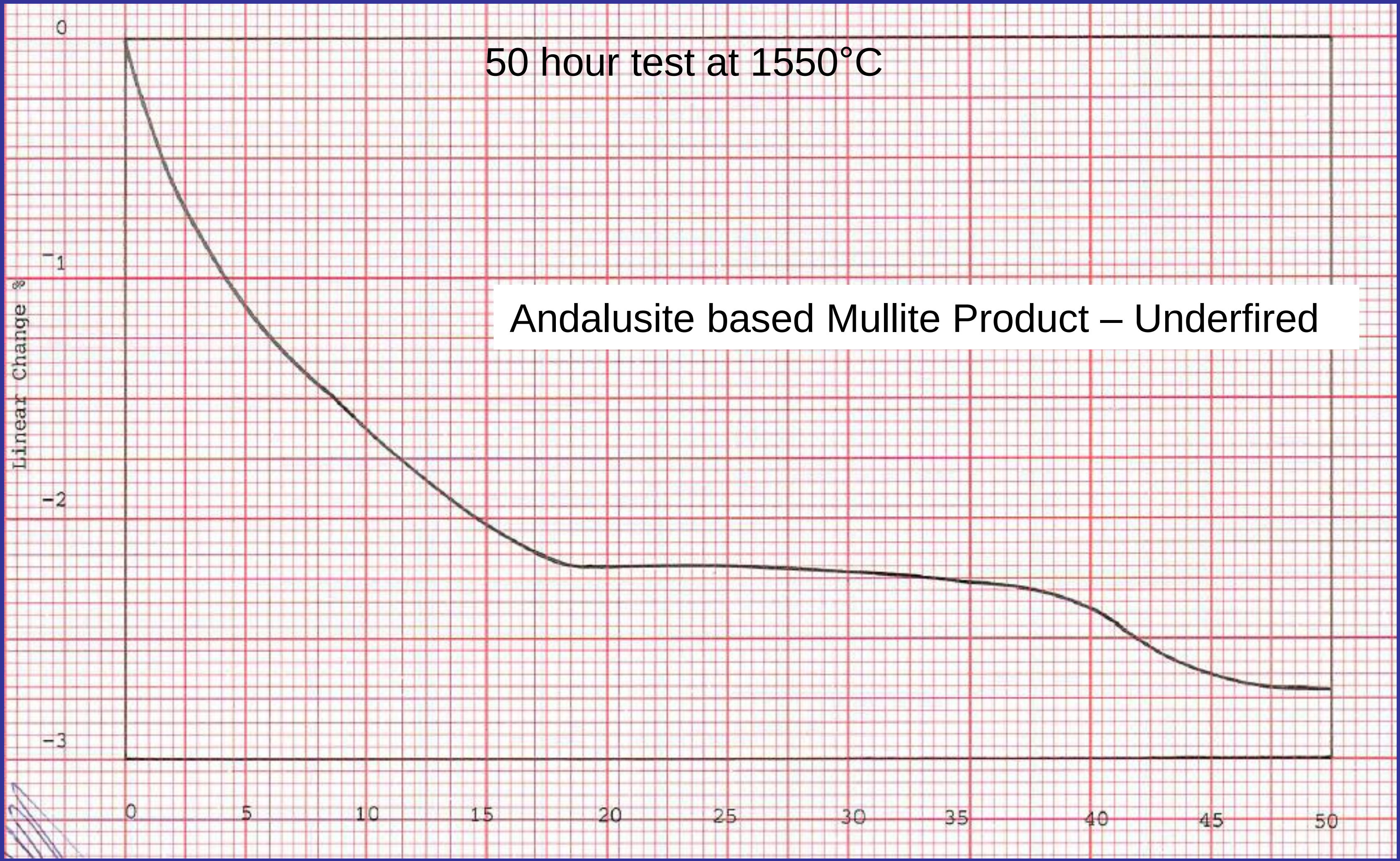
Creep Case Study 3 – Factors Affecting Creep



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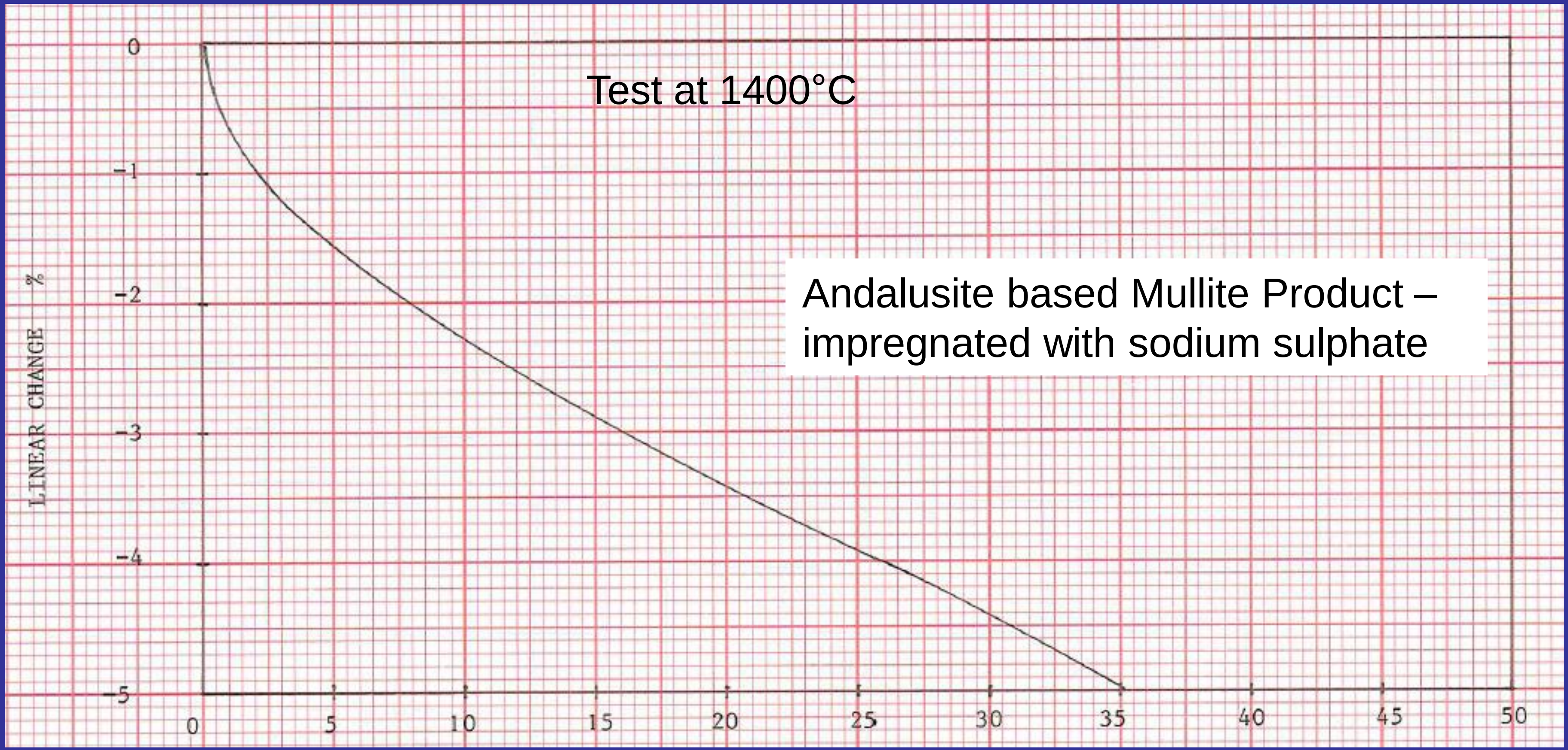

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Summary

- RUL & Creep – thermal expansion under load tests

- RUL
  - Constant load, increasing temperature
  - Softening point, $T_{0.5}$
  - Factors affecting RUL include chemistry and mineralogy

- Creep
  - Constant load and constant temperature
  - Creep velocity/rate
  - Duration of test critical
  - Factors affecting creep include chemistry, mineralogy and manufacture method

- Limitations of tests
  - Test atmosphere – difficult to replicate service conditions
  - Chemical interaction between sample and fixtures
  - Temperature fluctuations
  - Machining flaws on samples