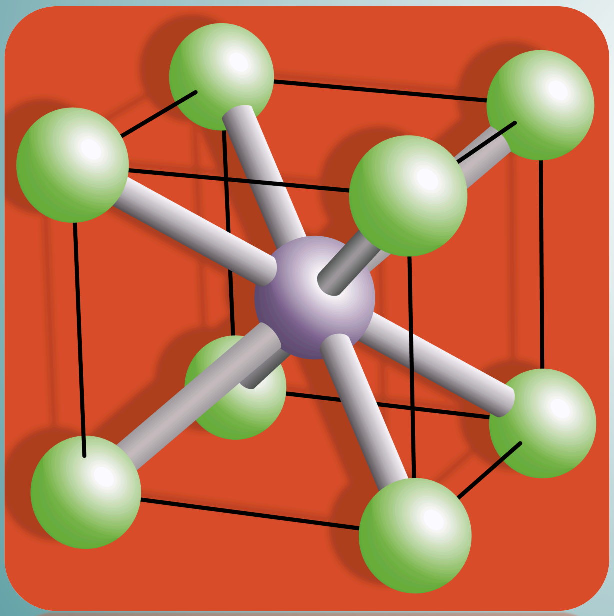
Materials

Topic 8. Creep and relaxation

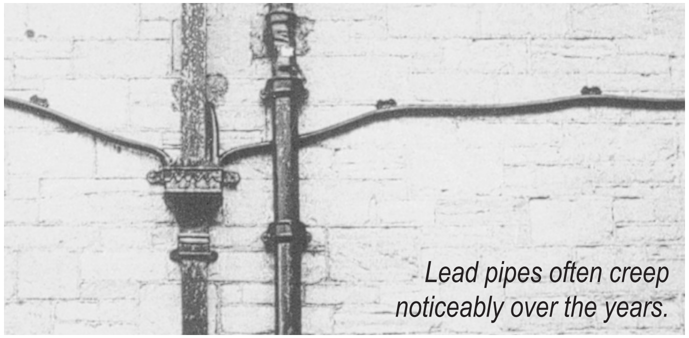


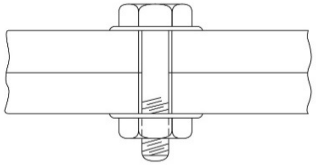
José Antonio Casado del Prado
Borja Arroyo Martínez
Diego Ferreño Blanco

Department of Science And Engineering of Land and Materials

8.1. INTRODUCTION

- The mechanical behavior dependent on time is analyzed according to 2 aspects:
  - Creep: variation of the deformation over time to constant load.
  - Relaxation: loss of stress over time to constant deformation.





8.2. CREEP

- **Strain depends on temperatura (T). The temperature at which materials start to creep depends on their melting point. As a general rule, it is found that creep starts when:**
  - **$T > 0.3$ to $0.4\ T_M$ for metals.**
  - **$T > 0.4$ to $0.5\ T_M$ for ceramics.**

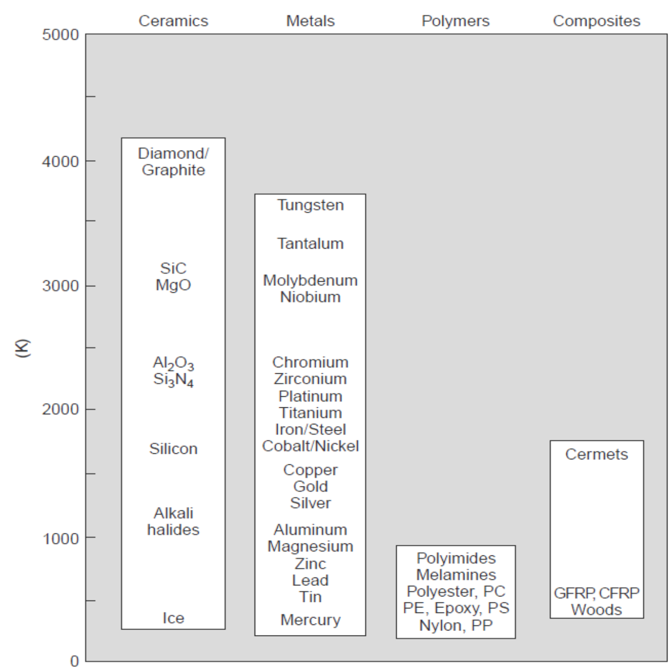
At Room Temperature = 300 K

- Tungsten, W (T_M = 3500 K) dosen´t creep.
- Lead, Pb (T_M = 600 K) creeps.
- Ice (T_M = 273 K, 0ºC) melts.

Melting or softening$^{(S)}$ temperature

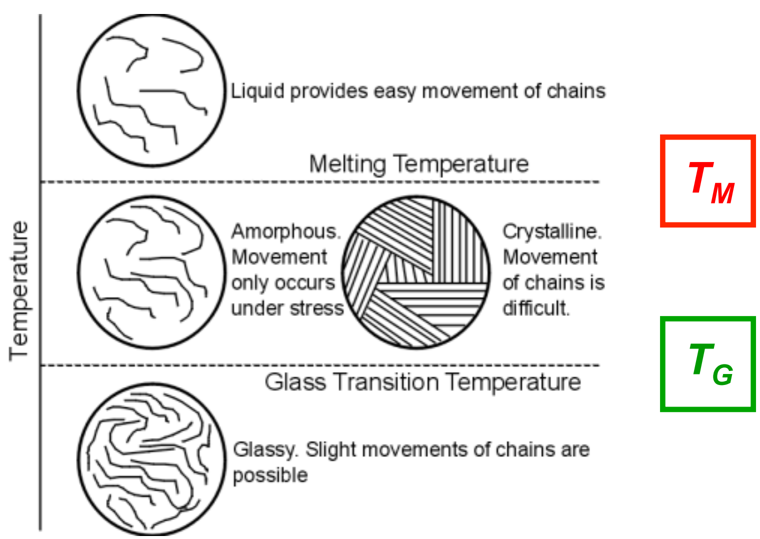
Material	T(K)	*Material*	T(K)
Diamond, graphite	4000	Gold	1336
Tungsten alloys	3500–3683	Silver	1234
Tantalum alloys	2950–3269	Silica glass	1100$^{(S)}$
Silicon carbide, SiC	3110	Aluminum alloys	750–933
Magnesia, MgO	3073	Magnesium alloys	730–923
Molybdenum alloys	2750–2890	Soda glass	700–900$^{(S)}$
Niobium alloys	2650–2741	Zinc alloys	620–692
Beryllia, BeO	2700	Polyimides	580–630$^{(S)}$
Iridium	2682–2684	Lead alloys	450–601
Alumina, Al_2O_3	2323	Tin alloys	400–504
Silicon nitride, Si_3N_4	2173	Melamines	400–480$^{(S)}$
Chromium	2148	Polyesters	450–480$^{(S)}$
Zirconium alloys	2050–2125	Polycarbonates	400$^{(S)}$
Platinum	2042	Polyethylene, high-density	300$^{(S)}$
Titanium alloys	1770–1935	Polyethylene, low-density	360$^{(S)}$
Iron	1809	Foamed plastics, rigid	300–380$^{(S)}$
Carbon steels	1570–1800	Epoxy, general purpose	340–380$^{(S)}$
Cobalt alloys	1650–1768	Polystyrenes	370–380$^{(S)}$
Nickel alloys	1550–1726	Nylons	340–380$^{(S)}$
Cermets	1700	Polyurethane	365$^{(S)}$
Stainless steels	1660–1690	Acrylic	350$^{(S)}$
Silicon	1683	GFRP	340$^{(S)}$
Alkali halides	800–1600	CFRP	340$^{(S)}$
Beryllium alloys	1540–1551	Polypropylene	330$^{(S)}$
Uranium	1405	Ice	273
Copper alloys	1120–1356	Mercury	235

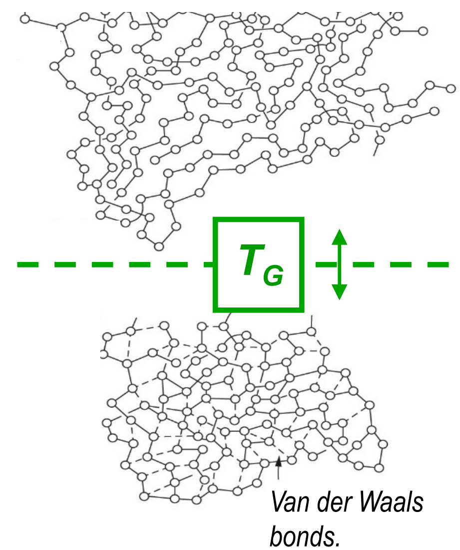
Melting or softening temperature



- **Most common polymers are not crystalline, and have no well-defined melting point. For them, the important temperature is the glass transition temperature, T_G, at which the Van der Waals bonds solidify:**
  - **$T > T_G$ Polymer is in a leathery or rubbery state, and creeps rapidly under load. (Molecular chains slide).**
  - **$T < T_G$ Polymer becomes hard (sometimes brittle) and there isn´t creep. (Strengthening secondary bonds of chains).**

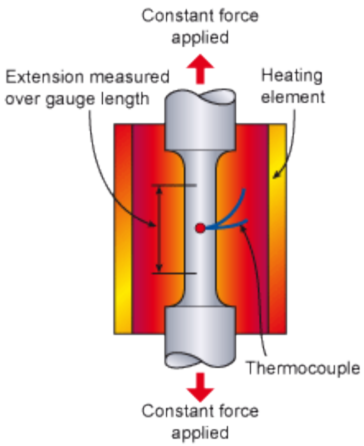
Polymer	PE	NR	PP	PA 6	PET	PVC	PS	PMMA
T_G (ºC)	–115	–73	–20	53	69	81	100	105
T_M (ºC)	137	128	176	265	212	240		

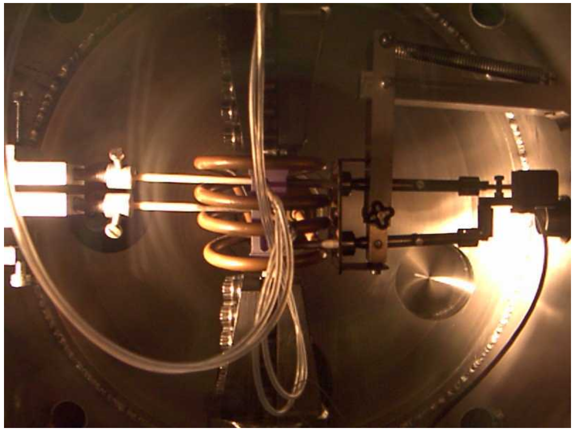




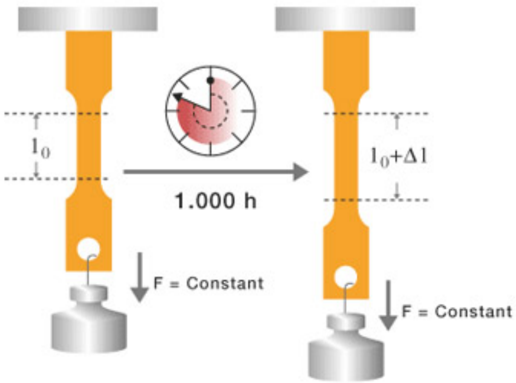
8.3. CREEP TESTS

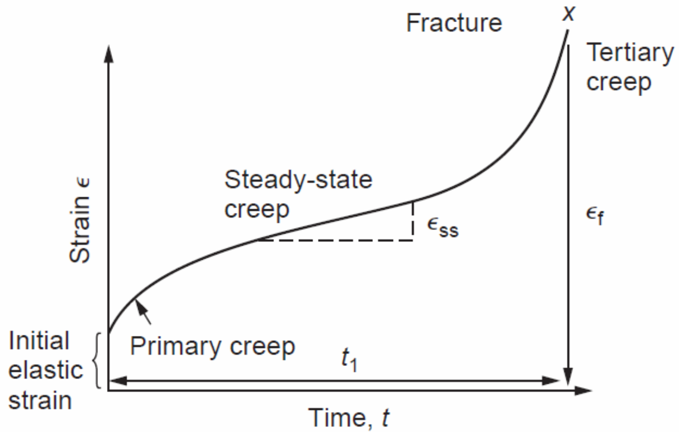
- **Creep tests require careful temperature control. A specimen is loaded in tension or compression, at constant load, inside a furnace at a constant temperature, T. The extension, ε, is measured and represented as a function of time, t –creep curve–.**

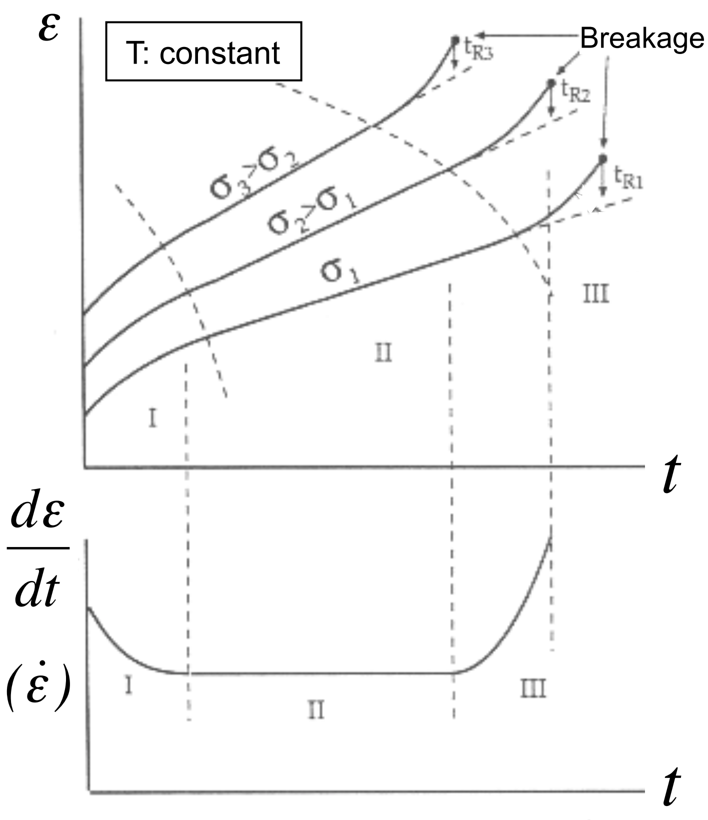




- Strict control of temperature.
- Adequate extensometry (strain gauges…).
- Insulation (environmental chamber).
- Coupling to machine tests.







I. Primary creep (transient) $\quad \dot{\varepsilon}$ *decreases*

II. Secundary creep (steady state) $\quad \dot{\varepsilon} = constant = \dot{\varepsilon}_{ss}$

III. Tertiary creep (accelerated) $\quad \dot{\varepsilon}$ *increases*

$$\varepsilon = \varepsilon_0 + B \cdot t^n + K \cdot t$$

Andrade´s equation

Inicial elastic strain

Term of Región II

$$K = C \cdot \sigma^m \cdot e^{-Q/R \cdot T}$$

(m = 3,0 – 5,5)

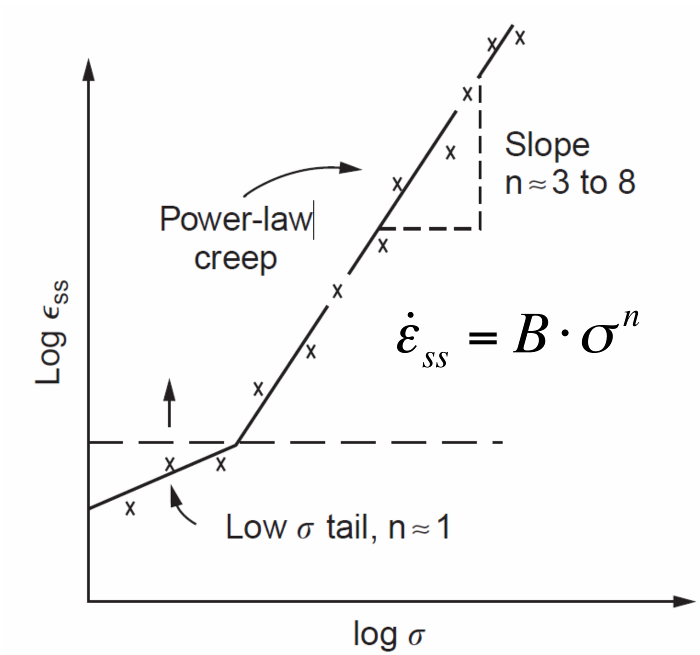
Term of Region I

(n = 1/4 – 2/3)

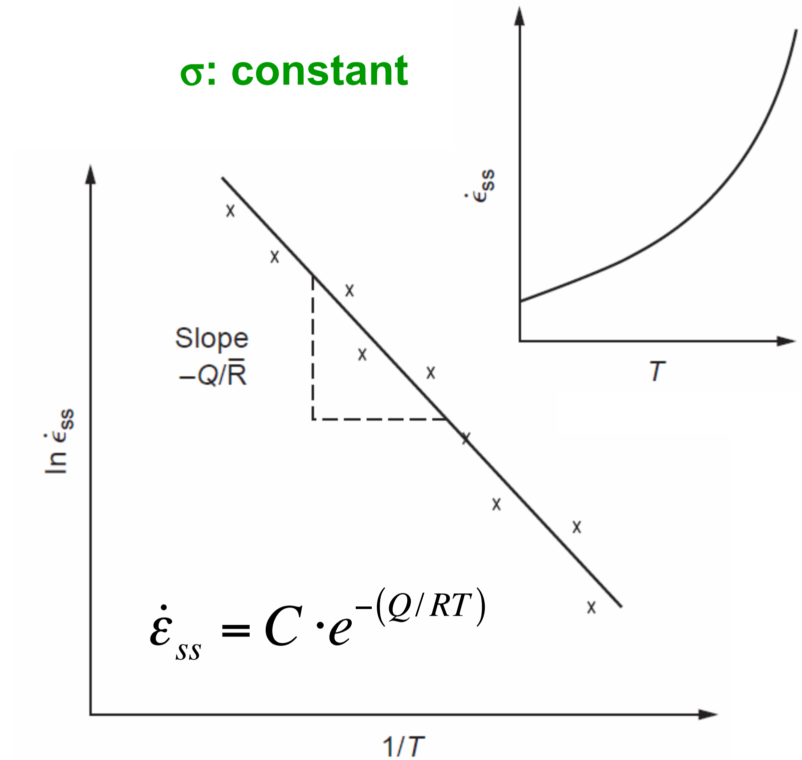
8.4. INFLUENCE OF STRESS AND TEMPERATURE

- **Empirical relationships:**

T: constant



σ: constant



- **Combining both expressions:**

$$\dot{\varepsilon}_{ss} = A \cdot \sigma^n \cdot e^{-(Q/RT)}$$

Weertman´s equation

R: Universal Gas Constant (8.31 J/mol · K).

Q: Activation Energy for Creep (J/mol).

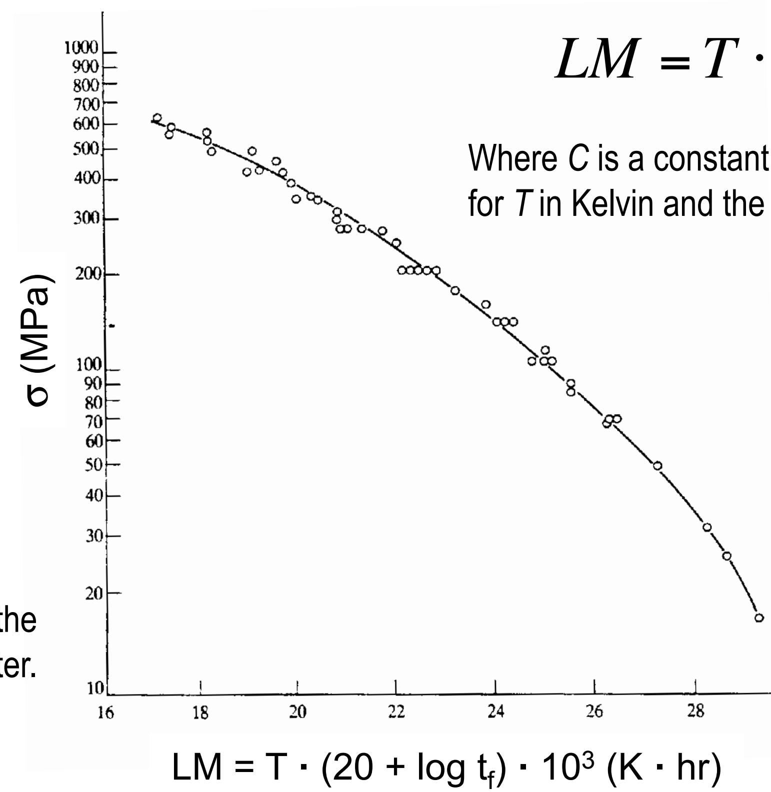
A, n: constants of the material.

8.5. DATA EXTRAPOLATION METHODS

- **Sometimes engineering creep data are impractical to collect from normal laboratory tests (on the order of years). One solution is performing creep tests at temperatures in excess of those required, for shorter time periods, and at a comparable stress level, and then making an extrapolation to the in-service condition. A commonly used extrapolation procedure employs the Larson–Miller parameter, defined as:**

$$LM = T \cdot \left(C + \log\ t_f \right)$$

Where C is a constant (usually on the order of 20), for T in Kelvin and the rupture lifetime in hours.



Logarithm stress versus the Larson–Miller parameter.

8.6. RELAXATION

- **Loss of stress of the material under constant strain.**
- **In relaxation, mechanisms analogous to those exhibited for creep are presented in the material, all responding to the same basic equations.**
- **Relaxation time, arbitrarily defined as the time taken for the stress to relax to half its original value.**