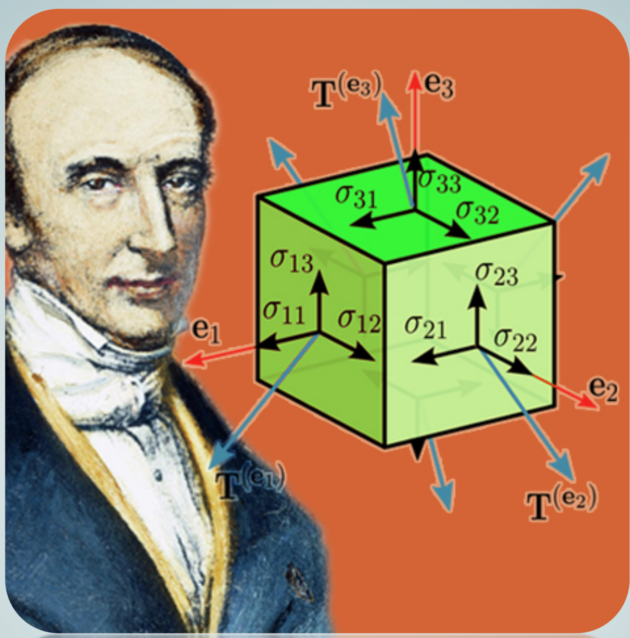
Mechanical Properties of Materials, Processing and Design

Exercises Lesson 3. Creep behavior



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MECHANICAL PROPERTIES OF MATERIALS **_2019-2020_**

3: Creep behavior

1. The table below includes the data obtained in a viscosity test performed on a clay:

τ (Pa).	$d\gamma/dt\ (s^{-1})$
20	4
25	10
32	20
36	30
40	50

Model its behavior as a Bingham perfect body based on the first three data, determining its apparent viscosity and critical shear stress. Compare it with the actual behavior and with that of a pseudo-plastic model, determining, for this last one, the values of K and n, and the viscosity for $d\gamma/dt = 1\ s^{-1}$.

2. The blades of a steam turbine work at a stress of 150 MPa and a temperature of 400ºC. In order to improve the turbine performance, new working conditions consisting on an a stress of 180 MPa and a temperature of 450ºC are proposed. Analyze the blade lifespan in case that the change of conditions is done knowing that after 2 years of performance, a strain of 1.3% is achieved and that the maximum admissible strain is 5.0%. Consider a creep behavior model of the blade material equivalent to:

$$\dot{\varepsilon} = A\sigma^3 e^{-E_a/RT}$$

where the first member of the equation represents the creep strain rate, A is a material constant, σ is the working stress and E_a is the activation energy, with a value of $40000\ cal{\cdot}mol^{-1}$ for this steel.

Given that the result is not economically feasible, it is decided to study the working conditions of the turbine that guarantee at least another three years of performance, taking into account the following working relationship table:

$T(^{o}C)$	400	410	420	430	440	450
$\sigma(MPa)$	150	154	159	165	172	180

3. The closing mechanism of a vessel of a nuclear power plant uses high strength bolts ($E = 200\ GPa$; $s_Y = 200\ MPa$) which working temperature and stress are, $300\ ^{o}C$ and $100\ MPa$, respectively, being their task to keep together two non-deformable rigid plates.

Due to the strict safety requirements, the tightening stress of the bolts can not decrease more than 10% over their lifetime (defining it as the time period between refueling outages). In order to know the creep properties of the material used, some laboratory tests have been performed with stresses of $50\,MPa$ obtaining, for temperatures similar to those of the working vessel, strain rates of $9.5{\cdot}10^{-15}\ s^{-1}$.

a) Assuming that the dominant creep mechanism follows a potential law (n=4), what is the maximum expected lifetime with the working conditions described?
b) If, due to an accident, the working temperature increased up to 1000ºC, will this event affect the remaining useful lifetime? Would it be possible to calculate it?
c) Represent on a creep map the conditions in which the bolt can be found during its service life as well as during the accident.

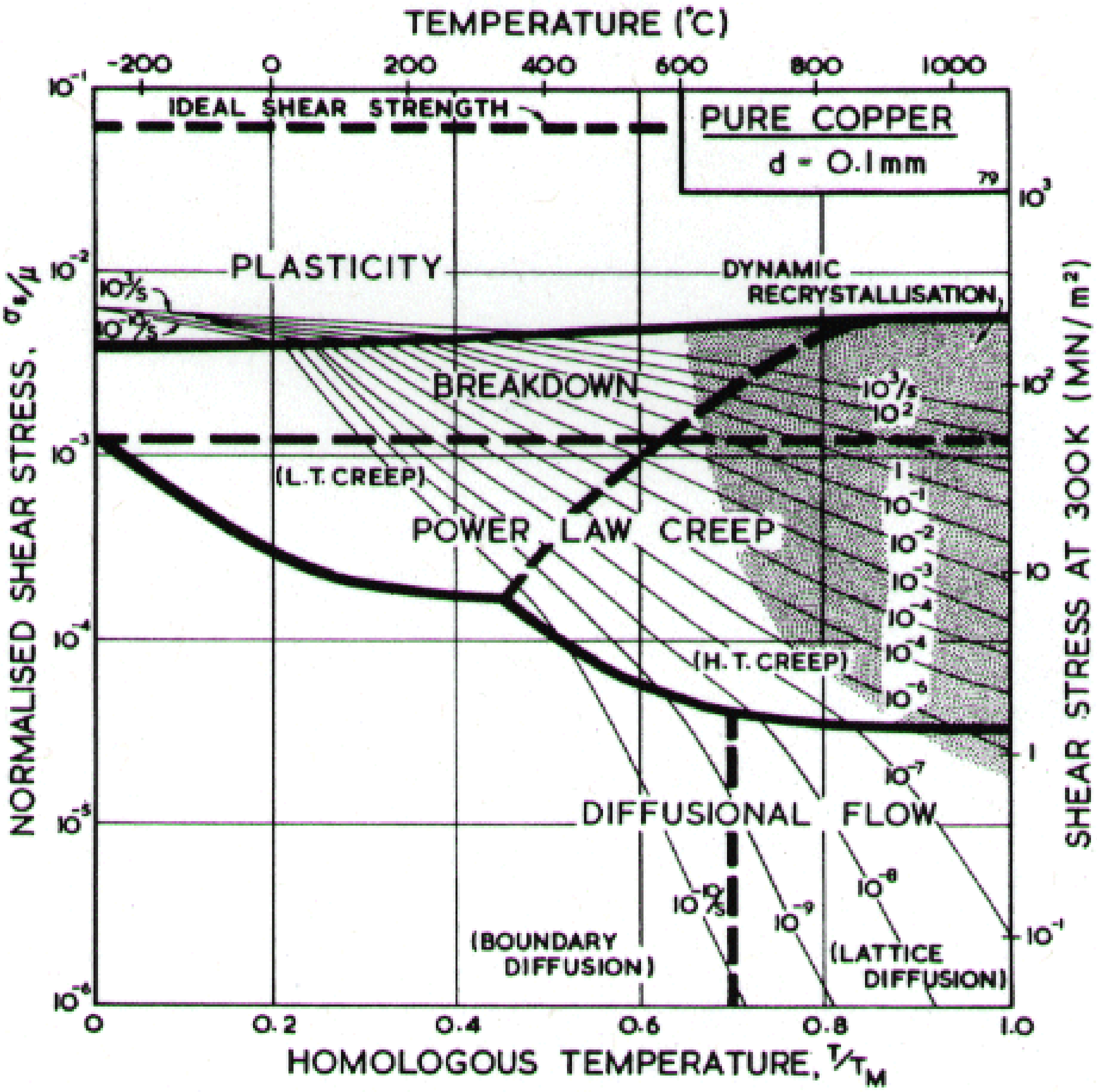
4. The Materials Lab at the Universidad de Cantabria has been asked to characterize the creep behavior of certain copper alloy for which there were designed some tensile tests at different stresses and temperatures, as shown in the following table:

	$\sigma(MPa)$	$\varepsilon(\%,s^{-1})$
T=629 ºC	79.43	$3.16\cdot10^{-3}$
	63.09	$6.03\cdot10^{-4}$
	50.12	$1.07\cdot10^{-4}$
	39.81	$3.98\cdot10^{-5}$
	31.62	$7.41\cdot10^{-6}$
	25.12	$1.74\cdot10^{-6}$
	19.95	$1.00\cdot10^{-6}$
	13.54	$6.31\cdot10^{-7}$
T=651 ºC	41.98	$1.51\cdot10^{-3}$
	37.58	$4.57\cdot10^{-4}$
	31.62	$2.00\cdot10^{-4}$
	25.13	$5.01\cdot10^{-5}$
	22.39	$2.51\cdot10^{-5}$
	18.24	$8.91\cdot10^{-6}$
	13.55	$5.01\cdot10^{-6}$
T=760 ºC	13.55	$2.51\cdot10^{-4}$
	9.33	$2.29\cdot10^{-5}$
	8.32	$9.55\cdot10^{-6}$
	5.79	$1.58\cdot10^{-6}$

With this information:

a) Represent in the creep map given below, that represents the normalized shear stress and the relative temperature, the tests performed. Discuss the expected creep mechanisms.
b) For each given temperature, obtain the value of the coefficient *n* in the creep rate equation for the tested material. Discuss the result obtained relating it to part a).
c) Determine the activation energy of the creep process for the stress and temperature range applied.
d) Obtain the constitutive equation of the creep process.
e) Considering that creep life ends for $\varepsilon_f = 20\,\%$, what kind of life can we expect if the material is subjected to a stress of $25.11\,MPa$ and a temperature of $820\,^{o}C$?
f) Calculate the Larson – Miller parameter for this material: $P_{LM} = T\cdot(\log t_r + C)$

Data: $T_M\,(Cu) = 1085\,^{o}C$; $E\,(Cu) = 110\,GPa$; $G = 3/8\,E$; $d = 100\ \mu m$;



5. Creep maps of metallic materials represent the dominant mechanisms for each combination of stress and temperature. From this point of view, there are two major regions: in the first one, the dominant factor is the motion of dislocations and it is characterized by a power law creep; the second region is controlled by the diffusion mechanisms and it is divided into two subregions, depending on where the diffusion takes place, either boundary diffusion (Coble creep mechanism) or lattice diffusion (Nabarro-Herring mechanisms).

The following table represents the characteristic equations for each region, described above, in an aluminum alloy, as well as the constants necessary to define them, expressing $\sigma(Pa)$, $T(K)$ and $d\varepsilon/dt\left(s^{-1}\right)$.

POWER LAW	$\frac{d\varepsilon}{dt} = 1.8*10^{-33}(\sigma^{5.8}/T)\exp(-14490/T)$
HERRING-NABARRO	$\frac{d\varepsilon}{dt} = 0.218*(\sigma/T)\exp(-14490/T)$
COBLE	$\frac{d\varepsilon}{dt} = 1.03*10^{-4}(\sigma/T)\exp(-8700/T)$

a) Draw the creep map of the material representing the dominant mechanism for each of the following combinations of stress and temperature.

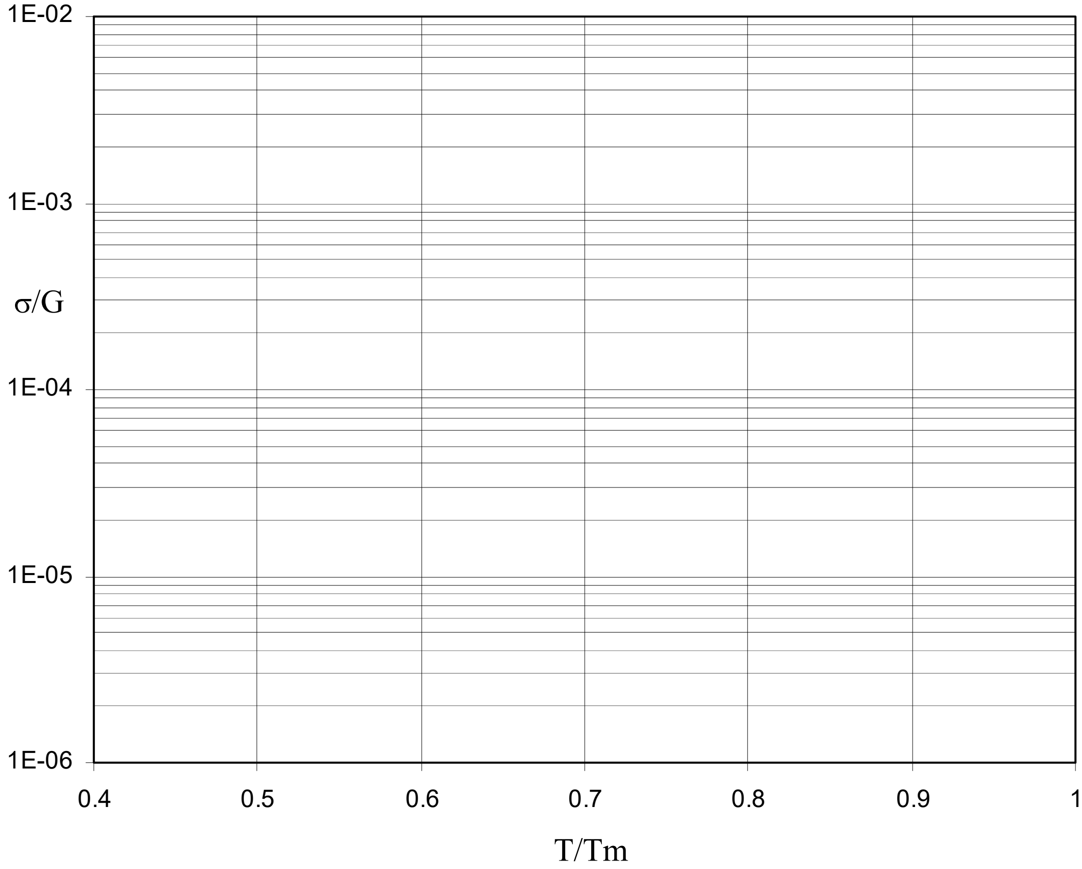
$T(K)$	600	700	800	900
$\sigma(MPa)$	1	3	10	100

b) Obtain the critical stress and temperature values between regions.

c) The possibility of using this alloy with a temperature of 475ºC considering that the maximum strain after 1000 h has to be less than 1% was proposed. Estimate the maximum admissible stress as well as the dominant mechanism.

d) Briefly suggest some modification in the material in order to improve the fulfillment of the specifications above.

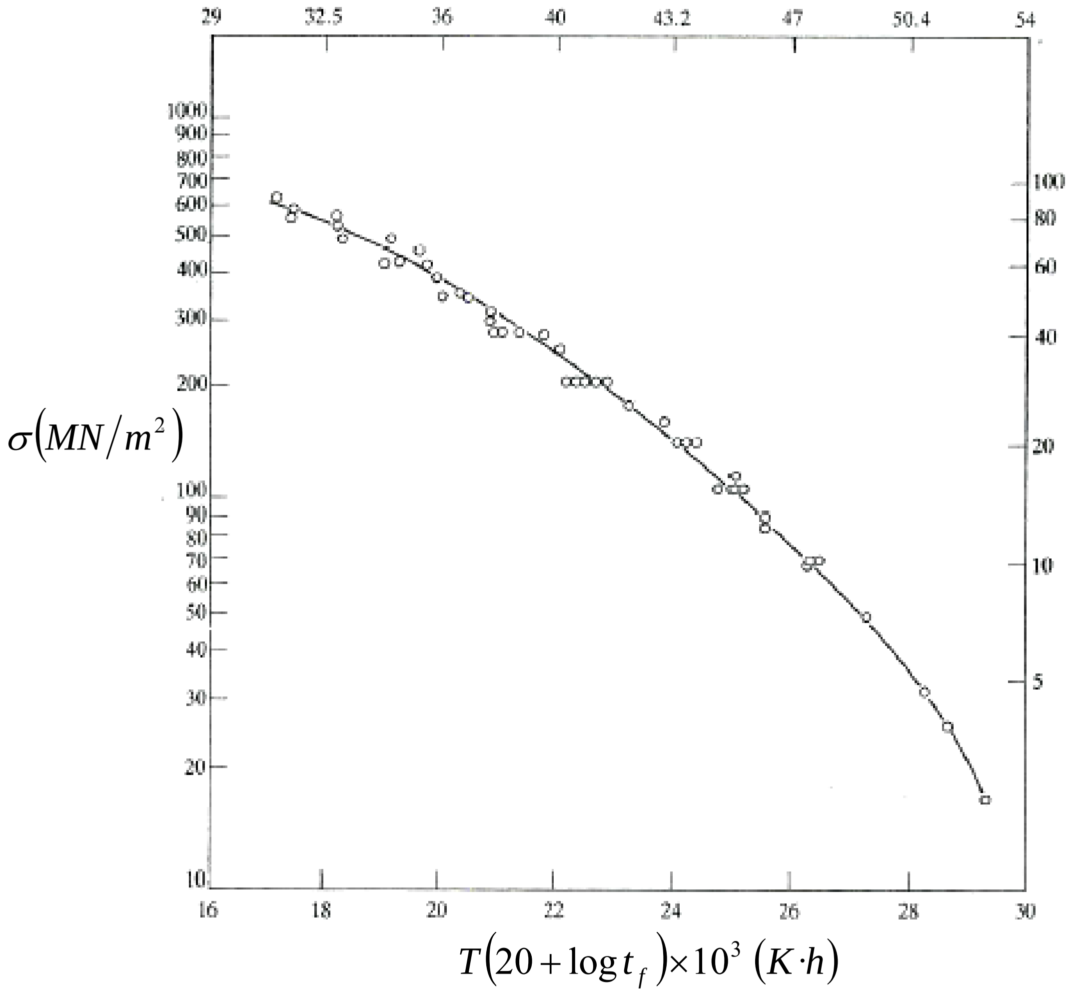
Data: $G = 2.5 \cdot 10^{10}\ Pa$, $T_M = 660^{\circ}C$.



6. Determine the maximum working stress of an alloy S590 at a temperature of $1100\,^{\circ}C$ in order to avoid its fracture during $10\,h$.

a) What would be the working stress if the maximum temperature was $500^{\circ}C$ and is lifespan was $10000\,h$?

b) Determine the lifetime of the alloy if the stress applied is $250\ MPa$ and the temperature is $870\,^{\circ}C$.



7. A sample of a cable elevator with a length of $5\,m$ length and a cross section of $150\,mm^2$ is subjected to a tensile test during $10000\,h$ at a constant temperature of $20\,^{\circ}C$, and a stress of $800\,MPa$. In parallel to this test and in an adjacent bench, another sample with the same length and cross section remains the same time subjected to a stress of $1000\,MPa$. With two extensometers, one on each sample and balanced immediately after the application of the stress, the following data were obtained:

$\sigma(MPa)$	Elongation (mm) elapsed:	
	10 minutes	100 hours
800	1.25	1.50
1000	1.45	

The behavior of the steel cables due to low temperature creep shows the following logarithmic law:

$$\varepsilon_c = A\cdot\log(1+\nu\cdot t)$$

where ν is a non-dimensional parameter ($\nu >> 1$) and A responds to the following second order function of stress (σ):

$$A = C_1\cdot\sigma^2 + C_2$$

being C_1 and C_2 two constants that depend on the material. Under these conditions:

a) Determine the elongation of the cable at $100\,h$ and $1000\,MPa$.

b) Determine the elongation of the cable at $10000\,h$ and $900\,MPa$.

c) Could we expect to get a 3% strain throughout the test?

d) Decide whether these cables are of quality R2, that is, if their maximum relaxation after $1000\,h$ is smaller than a 2% when they are subjected, according to standard, to a stress equal to the 70% of its ultimate stress in a test at $20\,^{o}C$, or not.

Data:
Breaking load of the cable: $285\,kN$.
Young's modulus: $E = 210\,GPa$.