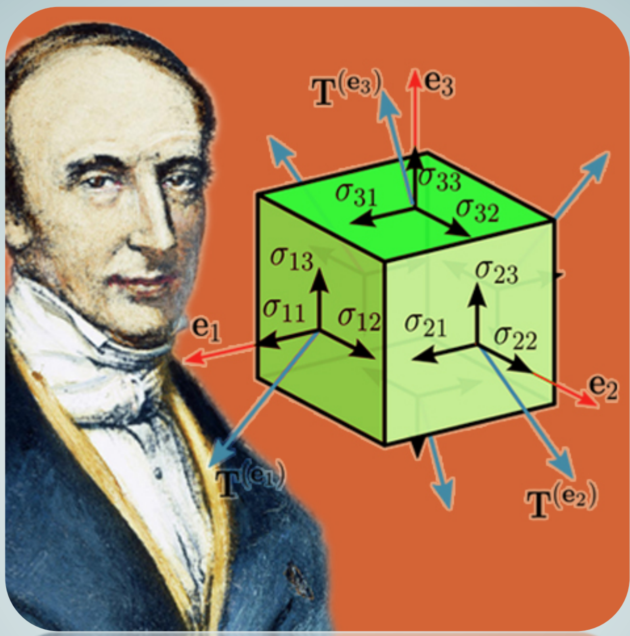
Mechanical Properties of Materials, Processing and Design

Exercises Lesson 2. Plastic behavior



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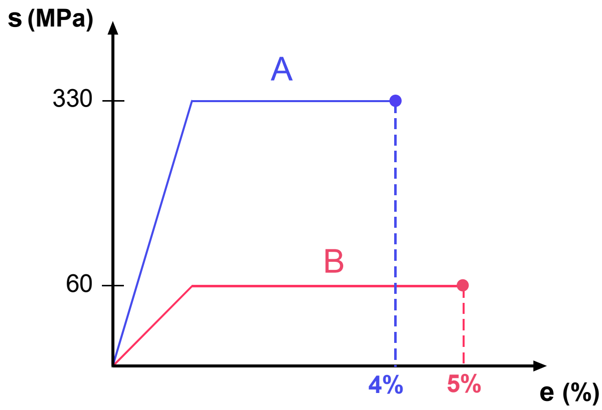
ETS de Ingenieros de Caminos, Canales y Puertos

MECHANICAL PROPERTIES OF MATERIALS **2019-2020**

2: Plasticity

1. In order to know the tensile behavior of a fiber-composite material, the attached graphs, corresponding to the matrix, B, and the fibers, A, idealized as perfect elasto-plastic solids, are provided. The Young's modulus of the fibers and the matrix are, respectively, $E_A = 30\,GPa$ and $E_B = 8\,GPa$. The cross section of the specimen is $3\,cm^2$, the total fiber area being $A_A = 0.6\,cm^2$ and the matrix $A_B = 2.4\,cm^2$. Answer the following questions about the composite material:

a) Determine the different regions according to the tensile response of both materials.
b) Obtain the equivalent Young's modulus and the proportionality limit.
c) Tensile strength and strain at that point.
d) Proof yield stress (0.1% and 0.2%).
e) Stress and strain state in the matrix and the fibers after unloading the specimen previously subjected to an average tensile stress of $104\,MPa$.



2. A steel wire with diameter$=1.25\,mm$ is coated with aluminum so that the composite cable has a diameter of $2.795\,mm$.

a) If this component is subjected to a tensile force, which is the material that yields firstly? Why?
b) What is the maximum load that the cable can bear without undergoing any plastic deformations?
c) Determine the equivalent Young's modulus of the compound cable.
d) What is the equivalent coefficient of thermal expansion of the system?
e) What change of temperature is necessary for the cable to yield? What is the material that yields firstly?
f) If none of the materials show any hardening, what is the maximum load that can be applied to the cable? What is the strain for that load?
g) Represent the complete □□□ curve of the compound cable.

	Steel	Aluminum
$E(GPa)$	210	70
$\sigma_Y(MPa)$	200	70
ν	0.3	0.3
$\alpha(K^{-1})$	$1.1{\cdot}10^{-5}$	$2.3{\cdot}10^{-5}$

3. The mechanical properties of a 304 steel to be used in high responsibility components of a nuclear power plant were determined. For this purpose, a tensile test was performed on a cylindrical specimen with a diameter of $12.7\ mm$, by using an extensometer with a nominal gauge length of $50\ mm$. The load vs. length results of test are included in the following table:

Load (N)	Measure (mm)
0	50.8000
4890	50.8102
9779	50.8203
14670	50.8305
19560	50.8406
24450	50.8508
27620	50.8610
29390	50.8711
32680	50.9016
33950	50.9270
34580	50.9524

Load (N)	Measure (mm)
35220	50.9778
35720	51.0032
40540	51.8160
48390	53.3400
59030	55.8800
65870	58.4200
69420	60.9600
69670	61.4680
68150	63.5000
60810 (Break)	66.0400

Determine:

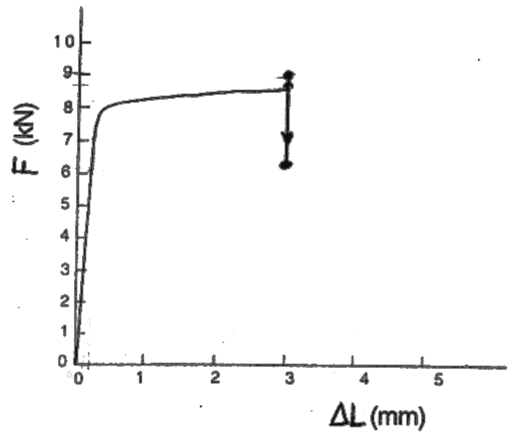
a) Young's modulus.
b) Proof yield stress.
c) Strain corresponding to the yield stress.
d) Tensile strength.
e) Strain under maximum load.
f) Elongation at fracture.
g) Establish the Ramberg-Osgood relationship in real variables; obtain the hardening coefficient and compare it with the strain under maximum load.

4. A tensile specimen with circular cross section and a diameter $D_0 = 6\ mm$ made out of an aluminum alloy presents the load-displacement curve shown below. The displacement data were obtained by using an extensometer with a gauge length of $54\ mm$; as can be seen, the extensometer stopped recording information when its elongation was $3\ mm$. However, as can also be seen, the load data acquisition continued operating normally. Before testing the specimen, two pairs of marks were impressed on the specimen, with a distance between them of $9{\cdot}D_0$ y $10{\cdot}D_0$, respectively.

Once the test was completed, the fracture cross section was measured, the final diameter being $D_f = 4\ mm$. Moreover, the final distance between marks was determined as well: The distance for those originally separated $9 \cdot D_0$ was $60\ mm$ whereas for the other pair was $66.6\ mm$.

With this information, calculate:

a) Young' s modulus.
b) Yield stress.
c) Tensile strength.
d) Strain at tensile strength.
e) Reduction of area.
f) Elongation in base 5Φ containing necking.
g) Stress-strain curve with real variables, including the final fracture point.



5. A tensile test is performed on a specimen with a circular cross section of $\Phi 12$ and a length of $50\ mm$, obtaining the load and displacement results shown in the table below. The final length, after fracture, was $72.8\ mm$ and the minimum diameter of the necking section is $6.8\ mm$. With this information, answer the following questions:

a) Represent the stress-strain curve in engineering variables.

- Determine the yield stress of the material.
- Young' s modulus.
- Tensile strength.
- Reduction of area and maximum deformation.

b) Draw the stress-strain curve in real variables.
c) Obtain the value of strain in base $5 \cdot \Phi$ containing the necking.

P (kN)	0	2	4	6	8	10	12	14	16
ΔL (mm)	0	0.0041	0.0082	0.0132	0.0183	0.0226	0.0267	0.031	0.0351
P (kN)	18	20	22	24	25.2	28	30	34	38.4
ΔL (mm)	0.0391	0.0445	0.0485	0.0518	0.51	1.52	2.03	3.05	4.57
P (kN)	40	40.4	40.8	40.2	38.6	36.4	32.4		
ΔL (mm)	6.6	7.62	12.7	14.7	15.7	17.8	19.3		

6. Figure 1 shows the stress-strain curves corresponding to the steel core (curve 1) and to the polymer coating (curve 2) that constitute an electric power cable. The figure itself shows the values of some physical and mechanical magnitudes of interest. The cable cross section with its significant geometrical dimensions are shown in Figure 2.

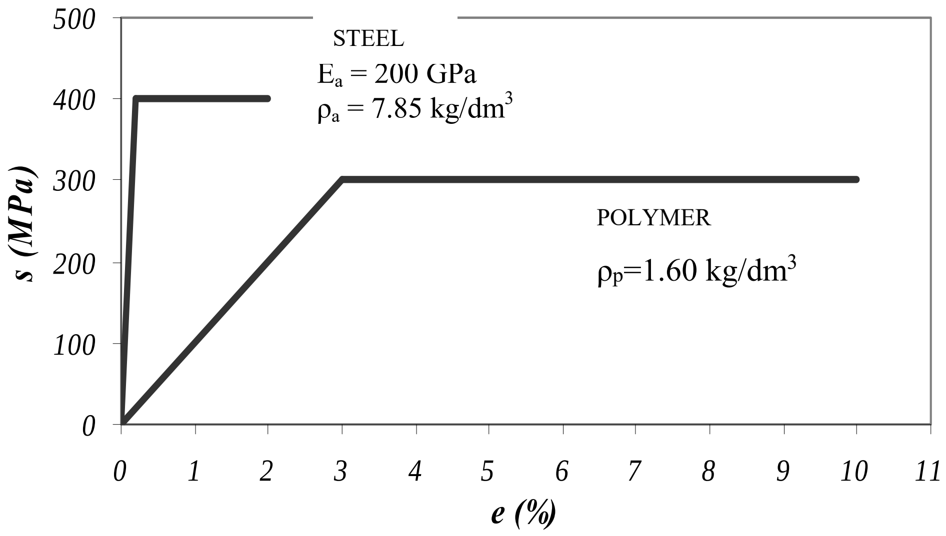


Figure 1

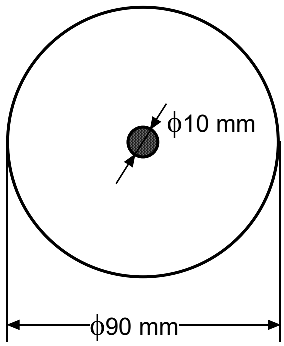


Figure 2

The UC Materials Laboratory has two of those specimens (L= 1 m) to be tested in tension with the possibility of performing the test under load or displacement control. Before testing them, some representative parameters must be determined in order to optimize the test. Assuming that the adherence between both materials is perfect, answer the following questions:

a) Calculate the equivalent Young' s modulus, E_{eq}. Determine the force ($F_{\lim}$) and elongation ($\delta_{\lim}$) values above which the modulus is not representative of the behavior of the component.

b) Obtain the stress state in both materials for an applied force of 100 kN. What does the ratio between both stresses represents? Justify the answer.

It was decided to test two specimens under load and displacement control, respectively, in order to appreciate the different appearance of the experimental curves. For this purpose, a test machine able to apply a maximum load of 1000 kN is used.

c) Will the total fracture of the specimen take place?

d) Will this test allow us to appreciate the differences we were looking for?

e) What is the value of the permanent deformation if it the specimen is unloaded after applying the maximum (1000 kN) load?

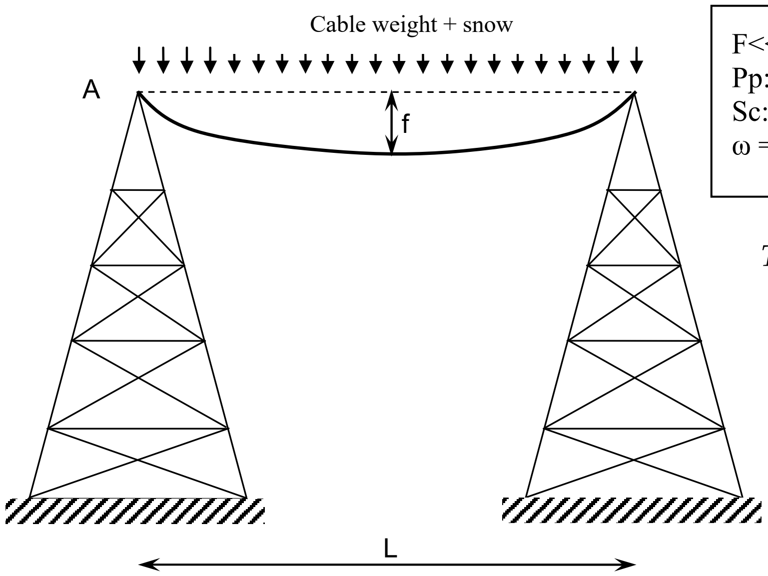
Given the results above, we decided to use a more powerful machine, between one able to provide $1900\ kN$ and another one with a loading capacity of $2500\ kN$.

f) Which one of them is strictly necessary to achieve the complete physical fracture of the component?

g) Represent the force-strain curves corresponding to the load and displacement control tests.

The electrical installation in which the cable is going to be used is shown, schematically, in Figure 3; as can be seen, it is a power line between two towers 20 m high. It is necessary to find out the maximum distance between towers, so that the electrical conduction is possible. Considering the geometrical constraints and the information in the figure itself:

h) Express what is the condition to be fulfilled.
i) Calculate the requested length knowing that the maximum allowable value of the parameter ‘f’, due to gauge conditions, is $2\ m$.



F<<L: Constant load law
Pp: 10.67 kg/m
Sc: 1kg/m
ω = 11.67 kg/m

$$T_A = \frac{\omega L}{2}\sqrt{1+\frac{L^2}{4f^2}}$$

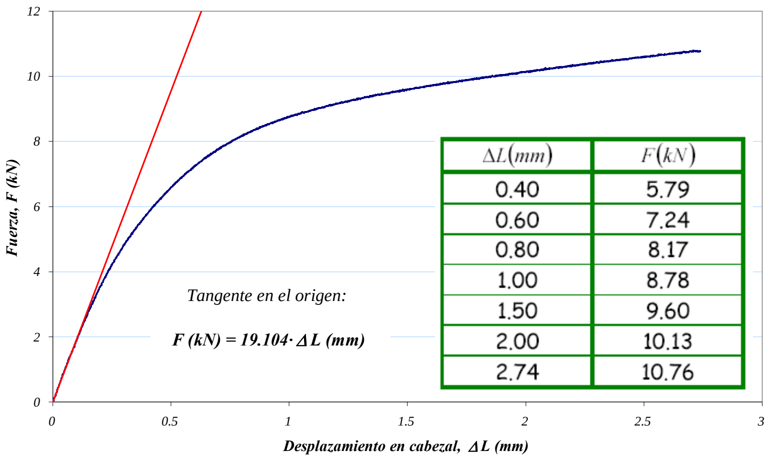
Figure 3

7. The following figure shows the force-displacement data recorded by the machine head, of a tensile test performed on a specimen made of magnesium alloy AZ91D. There is also a table attached, containing 7 points of the curve (including, among them, the last one that corresponds to fracture) as well as the curve equation in the linear elastic region of the test.

As mentioned above, the elongation was measured between the heads of the loading machine but, between the ends of the specimen and those heads a set of parts (bars, nuts, etc.) are interposed to connect the specimen to the machine. It is assumed that the deformation of the connecting parts respond in a linear elastic manner throughout the whole test. Furthermore, the Young's modulus of the aluminum alloy is known, $E = 40\ GPa$, as well as the dimensions of the specimen: cross section, $A = 64\ mm^2$, and length, $L = 120\ mm$.

With all this information:

a) Obtain the force-elongation curve at the ends of the specimen. Determine it for the 7 points given in the table. To get the answer, you should take into account that the elongation of the specimen plus the connecting parts equals the elongation between heads at all times (particularly in the elastic region of the test) and that the connecting system shows an elastic behavior throughout the whole process (that can be expressed as $F=K\cdot\Delta L_{PARTS}$).
b) From the answer above, obtain the stress-strain curve that an extensometer with a gauge length of $12.5\ mm$ would record.
c) Repeat section b) for another extensometer with a gauge length of $18.0\ mm$.
d) Obtain the Hollomon’s equation of the material.
e) Calculate the conventional yield stress, tensile strength and strain at maximum load of the AZ91D alloy.



8. Calculate the critical pressure that yields a spherical thin-walled container subjected to an increasing internal pressures. Knowing the thickness, t= 50 mm, the mean radius, R= 1 m, and the yield stress, σ_y= 200 MPa, perform the calculations according to the Tresca and Von Mises criteria, respectively.

9. A cylindrical body with the following initial dimensions: mean radius R_0= 1000 mm and thickness t_0= 10 mm, is used as a pressure vessel. The material has a yield stress σ_y= 240 MPa.

a) Determine the pressure for which the container yields.
b) Obtain the volume variation per unit length of the container at that moment.

Data: E=205000 MPa, ν=0.33.