Kafrelsheikh University
Faculty of Engineering
Mechanical Engineering Department
1st year –bylaw: 2007
Final Exam

نموذج الاجابه

Materials Engineering & Testing
June 3, 2018, 10: 00 AM
Time: 3 Hrs.
Full mark: 120

Question No. 1(40 Marks):

This question measures the following ILOs; a.8.1, a.8.2, b.2.1, b.2.2, c.3.1, c.3.2, c.3.3,

Put (√) or (×) in the front of each of the following sentence:

1	Close-packed planes are planes with the highest possible linear density.	(×)
2	The units of toughness and resilience are not same.	(×)
3	Ductility may be expressed quantitatively in elongation percent as $\%EL = 100(l_f - l_o)/l_f$	(√)
4	Plastic deformations are permanent deformations.	(√)
5	In creep test strain rate is equal zero.	(×)
6	Maxwell model can be used to evaluate material properties in tensile test	(×)
7	Dashpots have instantaneous response with respect to load.	(×)
8	Kelven and Voiget models are same viscoelastic models.	(√)
9	The true strain can be expressed as $\varepsilon_T = \ln(1+\varepsilon)]^n$	(×)
10	For Brinell hardness test three types of indenters are available.	(×)
11	Lattice parameter can be measured within 5 – 900 A^o.	(×)
12	All metals in elevated temperature are viscoelastic materials	(√)
13	Viscoelastic behavior is linear elastic behavior	(×)
14	Diffusion coefficient is dependent on material and temperature.	(√)
15	Conversations between hardness results of different scales are available	(√)
16	Superficial Rockwell are used for microhardness measurement	(√)
17	Loads used for Rockwell hardness test are 50 kg, 100kg and 150 kg.	(×)
18	Colombia space shuttle was lost due to failure of thermal protection system	(√)
19	FGMs are used in dental implant	(√)
20	FGMs are used in electric power transportations	(×)
21	Recently polymers are used in electric power transportations	(√)
22	Elastic modulus of ceramics are higher than that that of metals	(√)
23	Fracture toughness of ceramics are lower than that of metals	(√)
24	Generally, for metal HB and the tensile strength are related according to TS(MPa) = 3.45 x HB	(×)
25	X-ray diffraction method cannot be used to measure the inter atomic distance of polymers	(√)
26	Kelven model cannot be used to evaluate viscoelastic material properties in relaxation test	(√)
27	X-Ray diffraction method measures lattice parameter within 0.5 – 50 A^o.	(√)
28	Close-packed direction is a direction with the highest possible linear density.	(√)

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29	Noninear elastic behavior is a viscoelastic behavior.	(√)
30	In relaxation test strain rate is equal zero.	(√)
31	For anisotropic materials mechanical properties from tensile and compression tests are same	(×)
32	For most of metals values of yields stress in shear is twice it value in tension	(×)
33	Strain hardening exponent is equal to true tensile strain at ultimate points	(√)
34	Viscoelastic properties of material can be determine from relaxation test using Kelven model	(×)
35	FGM can be used in manufacturing of fuel cell	(√)
36	Resilience can be defined as the require energy per unit volume of material to induce yielding.	(√)
37	Corrective stress strain curve values are lower that of engineering one.	(×)
38	Most of metals are crystalline in the simple hexagonal structure due to its poor APF	(×)
39	Ashby charts are used in metal forming process	(×)
40	X-ray diffraction technique can measure lattice dimensions for metal.	(√)
41	ASTM is a material properties	(×)
42	Toughness of brittle materials are higher than that of ductile materials	(×)
43	RCC composites strength increases with increasing temperature	(√)
44	Mechanical properties can be determine from tensile or compression test for anisotropic materials	(×)
45	Bucking is a precaution that should be considered in compression test	(√)
46	Friction effect is an important parameter that should be eliminated during tensile test	(×)
47	Design of machine elements depends on their plastic properties	(×)
48	Spinning is a metal forming process that depends on plastic properties	(√)
49	Deep drawing process can be used in production of aluminum pans	(×)
50	Most of metals are crystalline materials	(×)
51	Most of polymers are crystalline materials	(×)
52	Gold electric resistivity is poor	(√)
53	Materials engineering is a recent approach	(×)
54	FGM is a non-homogenous composite materials	(√)
55	Elastic deformation is a non-reversible process	(×)
56	All metals are ductile in elevated temperature	(√)
57	The total number of atoms in the large HCP cell is six	(√)

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58	X-ray diffraction method can be used to measure the inter atomic distance of polymers	(×)
59	There are four atoms per BCC cell	(×)
60	For isotropic materials stress-strain curves from compression and tensile tests are different.	(×)
61	Toughness and resilience are different for brittle materials	(×)
62	For ductile materials resilience is greater than toughness.	(×)
63	For linear elastic deformation $\sigma = E\,\varepsilon$	(√)
64	Elastic recovery induced when removing loads during elastic deformation	(×)
65	FCC and HCC have the same packing factor	(√)
66	Vacancy diffusion induced only between the same materials atoms.	(√)
67	Diffusion flux is the mass diffused through and perpendicular to unite cross sectional area per unit time.	(√)
68	Nonlinear plastic behavior is a viscoelastic behavior	(×)
69	For onset yielding strain offset of 0.002 can be efficiently used to identify yield stress.	(×)
70	Creep test is used in determining viscoelastic properties.	(√)
71	Diffraction condition is $n\,\lambda = 2\,d \sin\theta$	(√)
72	Ashby chart relates more than two material properties	(×)
73	FGM material properties can be expressed in exponential function	(√)
74	Instantaneous response of spring is equal zero.	(×)
75	Necking occurs just after yield point	(×)
76	Unloading during plastic deformation is parallel to elastic behavior	(√)
77	Relating ultimate tensile strength and hardiness is possible	(√)
78	Stress concentrations are not excluded using standard tensile test specimen.	(×)
79	Buckling is excluded by using standard tensile test specimen.	(×)
80	Friction is a parameter that should be excluded during compression test.	(√)

Question No. 2 (`15 Marks):

This question measures the following ILOs; a.8.1, b.2.1, b.2.2,

In the following figure is shown a plot of the logarithm (to the base 10) of the diffusion coefficient versus reciprocal of absolute temperature, for the diffusion of copper in gold. Determine values for the activation energy and the pre-exponential. N.B. R=8.31 J/mol K

***Plot of the logarithm of the diffusion coefficient versus the reciprocal of absolute temperature for the diffusion of copper in gold*.**

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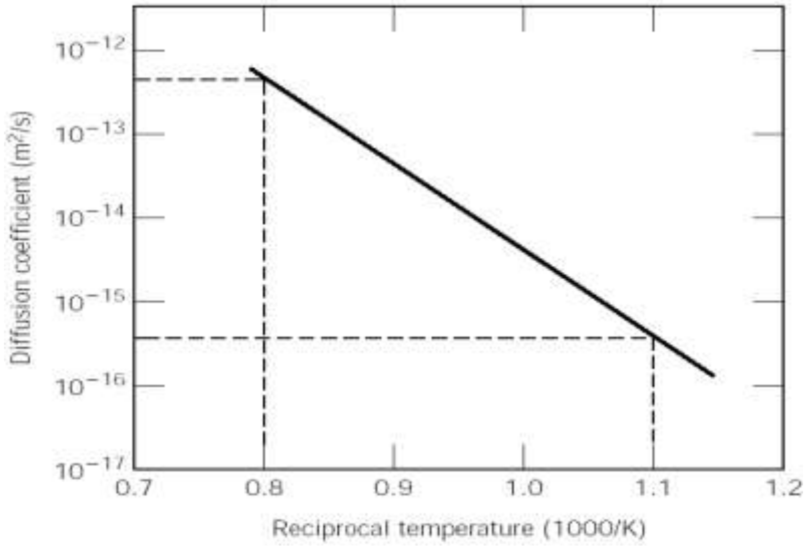
Solution:

From Equation the diffusion coefficient the slope of the line segment in logarithmic scale, in the given figure, is equal to $-Q_d/2.3R$, and the intercept at $1/T = 0$ gives the value of log D_0 . Thus, the activation energy may be determined as

$$Q_d = -2.3R(slope) = -2.3R\left[\frac{\Delta(\log D)}{\Delta(\frac{1}{T})}\right]$$

$$= -2.3R\left[\frac{\log D_1 - \log D_2}{\frac{1}{T_1} - \frac{1}{T_2}}\right]$$ **(5Marks)**



where D_1 and D_2 are the diffusion coefficient values at $1/T_1$ and $1/T_2$, respectively.

Let us arbitrarily take $1/T_1 = 0.8 \times 10^{-3}$ (K)$^{-1}$ and $1/T_2 = 1.1\times10^{-3}$(K)$^{-1}$.

We may now read the corresponding log D_1 and log D_2 values from the line segment in the following figure.

Before this is done, however, a parenthetic note of caution is offered. The vertical axis in the following figure is scaled logarithmically (to the base 10); however, the actual diffusion coefficient values are noted on this axis. For example, for $D=10^{-14}$ m^2/s, the logarithm of D is-14.0 *not* 10^{-14}. Furthermore, this logarithmic scaling affects the readings between decade values; for example, at a location midway between 10^{-14} and 10^{-15}, the value is not 5×10^{-15}, but rather, $10^{-14.5} = 3.2 \times 10^{-15}$].

Thus, from the above figure, at $1/T_1 = 0.8\times10^{-3}$ (K)$^{-1}$, log D_1 = -12.40, while for $1/T_2 = 1.1\times10^{-3}$ (K)$^{-1}$, log D_2 = -15.45, and the activation energy, as determined from the slope of the line segment in the above figure, is

$$Q_d = -2.3R\left[\frac{\log D_1 - \log D_2}{\frac{1}{T_1} - \frac{1}{T_2}}\right] = -2.3(8.31J/mol.K)\left[\frac{-12.4-(-15.45)}{0.8\times10^{-3}(K)^{-1} - 1.1\times10^{-3}(K)^{-1}}\right]$$

= 194,000 J/mol = 194 kJ/mol **(5 Marks)**

Now, rather than trying to make a graphical extrapolation to determine D_0, a more accurate value is obtained analytically using Equation 5.9b, and a specific value of D (or log D) and its corresponding T (or $1/T$) from the above figure. Since we know that log D = -15.45 at $1/T = 1.1\times10^{-3}$ (K)$^{-1}$, then

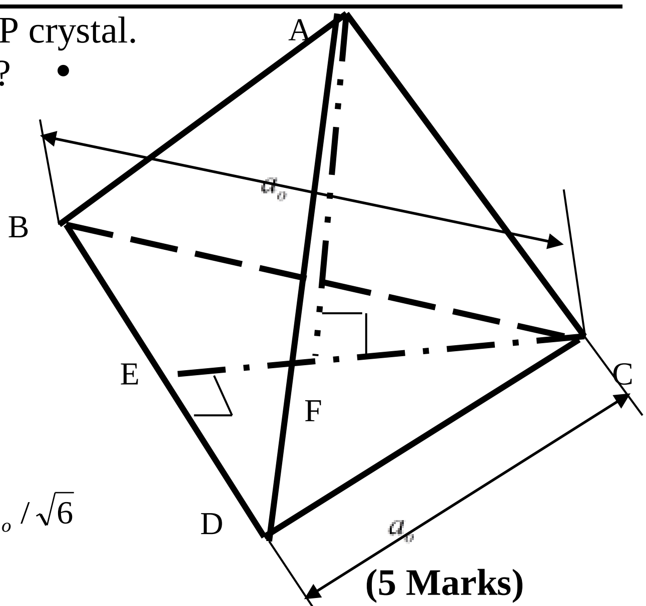
$$\log D_o = \log D + \frac{Q_d}{2.3R}\left(\frac{1}{T}\right) = -15.45 + \frac{(194{,}000 J/mol)(1.1\times10^{-3}[K^{-1}])}{(2.3)(8.31 J/mol.K)} = -4.28$$

Thus, $D_0 = 10^{-4.28}$ m^2/s = 5.2 $\times 10^{-5}$ m^2/s. **(5 Marks)**

Question No. 3 (15 Marks):

This question measures the following ILOs; a.8.2, b.2.1, b.2.2

Drive the expression for the height, c, for the HCP crystal.
Show why the c/a_0 ratio should be close to 1.633?
Why does c/a_0 in some metals differ from 1.63?



Solution:

$a_o = 2r$

The height of the cell is h where c= 2 AF

Since AB = BC =BD = AB=AD= AC = a_o

Then EC = $a_o\sqrt{3}/2$

FC = 2EC/3 = $a_o\sqrt{3}/3$ **(5 Marks)**

$(AF)^2 = (a_o)^2 - (a_o\sqrt{3}/3)^2 = (a_o\sqrt{6}/3)^2$

$c/2$ = AF = $a_o\sqrt{6}/3$ then c= 2 AF = $a_o 2\sqrt{6}/3 = 4a_o/\sqrt{6}$

$c/a_o = 4/\sqrt{6} = 1.63$ **(5 Marks)** **(5 Marks)**

This relationship assumes that the atoms are perfect rigid spheres. Since this assumption is not always satisfied, many real HCP metals display a c/a_o ratio different from 1.633

c/a_0 ratios for selected HCP metals at room temperature.

Metal	c/a_0 **ratio**
Cd	**1.886**
Zn	**1.856**
"Ideal" HCP	**1.633**
Mg	**1.624**
Co	**1.621**
Zr	**1.593**
Ti	**1.587**
Be	**1.568**

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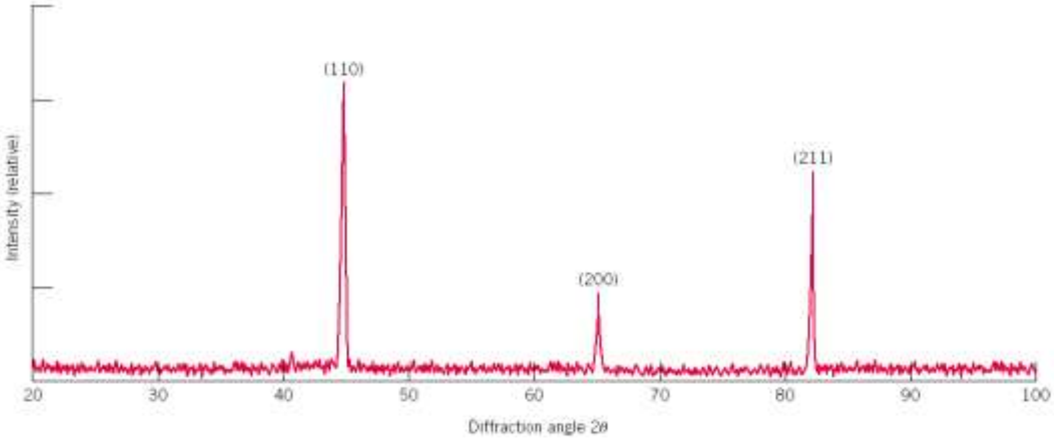
Question No. 4 (10 Marks):

This question measures the following ILOs; b.2.2, c.3.1, c.3.2, c.3.3,

The following figure shows an x-ray diffraction pattern for α-iron taken using a diffractometer and monochromatic x-radiation having a wavelength of 0.1542 nm; each diffraction peak on the pattern has been indexed. Compute the interplanar spacing for each set of planes indexed; also determine the lattice parameter of Fe for each of the peaks.



SOLUTION:

From the diffraction pattern for α-iron shown in the above figure, we are asked to compute the interplanar spacing for each set of planes that has been indexed; we are also to determine the lattice parameter of Fe for each peak. In order to compute the interplanar spacing and the lattice parameter for the first peak which occurs at 45.0.

$$d_{110} = \frac{n\lambda}{2\sin\theta} = \frac{(1)(0.1542\text{ nm})}{(2)\left(\sin\frac{45.0^\circ}{2}\right)} = 0.2015\text{ nm}$$

And

$$a = d_{hkl}\sqrt{(h)^2 + (k)^2 + (l)^2} = d_{110}\sqrt{(1)^2 + (1)^2 + (0)^2}$$

$$= (0.2015\text{ nm})\sqrt{2} = 0.2850\text{ nm}$$ **(5 Marks)**

Similar computations are made for the other peaks which results are tabulated below:

Peak Index	2θ	d_{hkl} (nm)	a (nm)
200	65.1	0.1433	0.2866
211	82.8	0.1166	0.2856

(5 Marks)

Question No. 5 (10 Marks):

This question measures the following ILOs; c.3.1, c.3.2, c.3.3,

a- What are the precautions that should be taken into consideration during preparing tensile test specimen. **(3 Marks)**

1- Using stander specimen configurations
2- Using high cutting speed and low depth of cut and coolant during specimen machining.
3- High surface finish for specimen.

b- Prove that for ductile materials the strain hardening exponent is equal to the true strain at tensile strength point.

Solution

For some metals and alloys the region of the true stress-strain curve from the onset of plastic deformation to the point at which necking begans may be approximated by

$$\sigma_T = K\, \varepsilon_T^n \qquad (1)$$

Where *K and* n are constants that vary from alloy to alloy and also depend on the condition of the material (i.e., whether it has been plastically deformed, heat treated, etc.). The parameter *n* is often termed the *strain hardening exponent* and has a value less than unity.

Also, using equation (1) with the help of the following equations

$$\sigma_T = \sigma(1+\varepsilon) \qquad (2)$$

$$\varepsilon_T = \ln(1+\varepsilon) \qquad (3)$$

it can be proved that the necking will occur when $\varepsilon_T = n$ as follows;

Substitute equations (2) and (3) into equation (1) to get

$$\sigma = \frac{K}{(1+\varepsilon)}\left[\ln(1+\varepsilon)\right]^n$$ **(2 Marks)**

Differentiation of the above equation with respect to ε will yields,

$$\frac{d\sigma}{d\varepsilon} = \frac{K}{(1+\varepsilon)^n}\left[\ln(1+\varepsilon)\right]^{n-1}\left[n - \ln(1+\varepsilon)\right]$$ **(2 Marks)**

for maximum values $\frac{d\sigma}{d\varepsilon}=0$. This will occur when n = ln (1+ ε)

using equation (3) it can be found that $n = \varepsilon_T$ at the start of the necking. This will leads to the value of the stress that induce necking to be of the following forms;

$$\sigma = \frac{Kn^n}{\exp(n)}$$

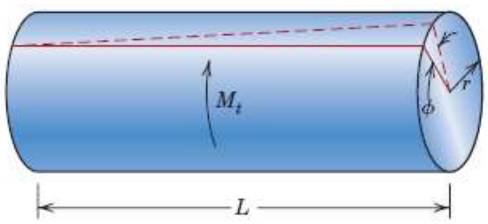
and $$\sigma_T = Kn^n$$ **(3 Marks)**

<u>Question No. 6 (15 Marks)</u>

This question measures the following ILOs b.2.2, c.3.1, c.3.2, c.3.3,

Design a light and strong cylindrical shaft of length L and radius r, as shown in Figure 6. The shaft is subjected to twisting moment (or torque) Mt that produces an angle of twist ϕ. Shear stress τ at radius r is defined by the equation $\tau = M_t r/J$. Where, J is the polar moment of inertia.

A solid cylindrical shaft that experiences an angle of twist ϕ in response to the application of a twisting moment M_t.



SOLUTION:

Consider the cylindrical shaft of length L and radius r, as shown in the given Figure.

The application of twisting moment (or torque), M_t produces an angle of twist ϕ. Shear stress τ at radius r is defined by the equation

$$\tau = \frac{M_t R}{J} \qquad (1)$$

Where, J is the polar moment of inertia, which for a solid cylinder is

$$J = \frac{\pi d^4}{32} \qquad (2)$$

Thus, $$\tau = \frac{2M_t}{\pi R^3} \qquad (3)$$ **(5 Marks)**

In order to establish a materials selection criterion for a light and strong material, we replace the shear stress in Equation (3) with the shear strength of the material τ_f divided by a factor of safety N, as

$$\frac{\tau_f}{N} = \frac{2M_t}{\pi R^3} \qquad (4)$$

It is now necessary to take into consideration material mass. The mass m of any given quantity of material is just the product of its density ρ and volume. Since the volume of a cylinder is just $\pi R^2 L$, then

$$m = \pi R^2 L \rho \qquad (5)$$

Or, the radius of the shaft in terms of its mass is just

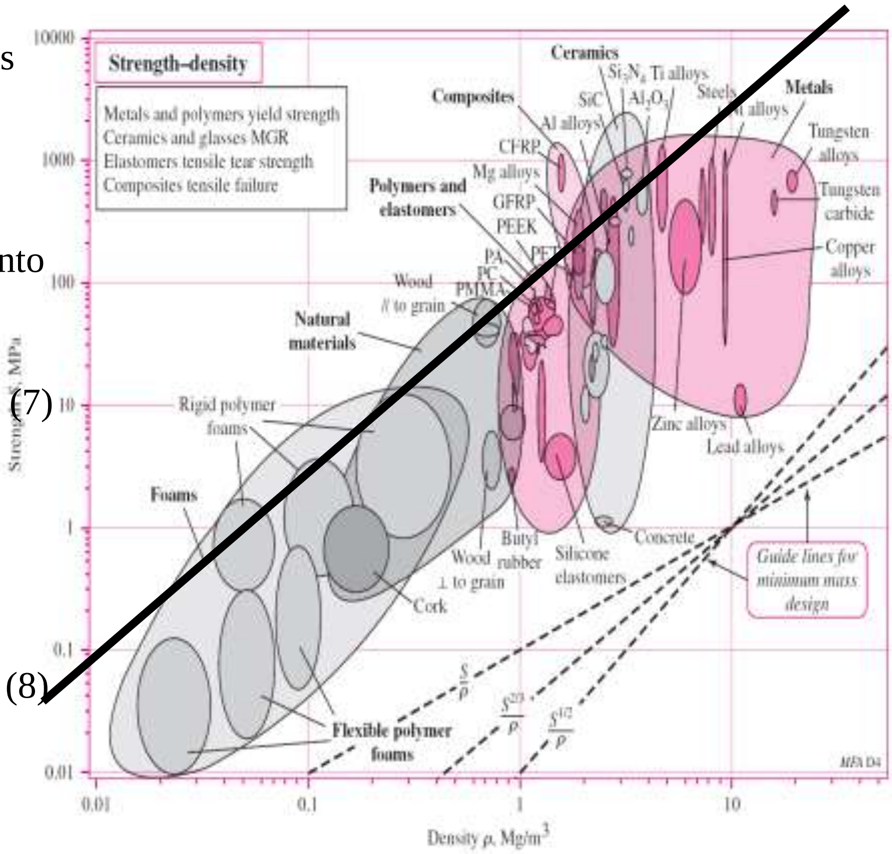
$$R = \sqrt{\frac{m}{\pi L \rho}} \qquad (6)$$

Substitution of this r expression into Equation (4) leads to

$$\frac{\tau_f}{N} = \frac{2M_t}{\pi\left(\sqrt{\frac{m}{\pi L\rho}}\right)^3} = 2M_t\sqrt{\frac{\pi L^3\rho^3}{m^3}} \qquad (7)$$

Solving this expression for the mass m yields

$$m = \left(2NM_t\right)^{2/3}\left(\pi^{1/3}L\right)\left(\frac{\rho}{\tau_f^{2/3}}\right) \qquad (8)$$



(5 Marks)

The parameters on the right-hand side of this equation are grouped into three sets of parentheses.

Those contained within the first set (i.e., N and Mt) relate to the safe functioning of the shaft. Within the second parentheses is L, a geometric parameter. And, finally, the material properties of density and strength are contained within the last set.

The upshot of Equation (8) is that the best materials to be used for a light shaft which can safely sustain a specified twisting moment are those having low $\frac{\rho}{\tau_f^{2/3}}$ f ratios. In terms of material suitability, it is sometimes preferable to work with what is termed a performance index, P, which is just the reciprocal of thisratio; that is

$$P = \left(\frac{\tau_f^{2/3}}{\rho}\right) \qquad (9)$$

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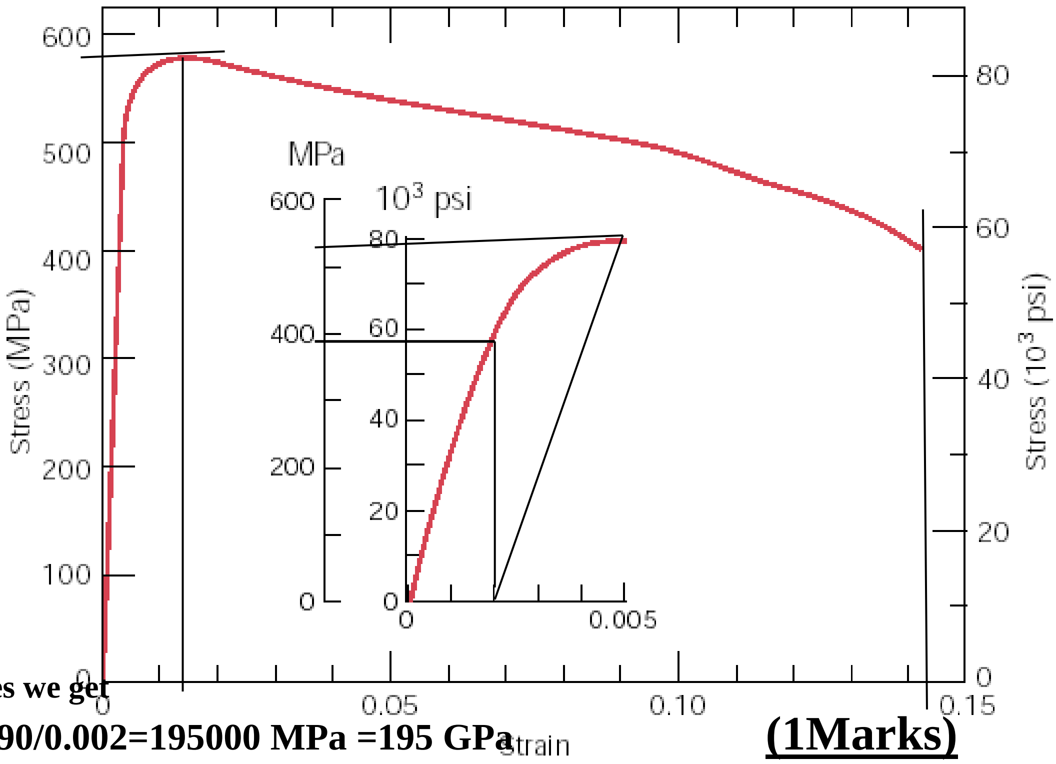
From the given charts and sited directions the following groups of materials can be selected
Composite (CFRP, GFRP, and PEEK)
Ceramics (Si_3N_4, $Al_2\,O_3$, and SiC)
Metals (Ti alloys, Steel,Ni alloys, and Al alloys) **(5 Marks)**

<u>Question No. 7 (10 Marks):</u>

This question measures the following ILOs; c.3.1, c.3.2, c.3.3,

The stress-strain curve for a steel alloy is shown in the given Figure. It is required to use it to find the following:-

1-Elastic modulus.
2-Yield stress.
3-Tensile strength.
4-Brinell hardness number.
5-Elongation percent.
6-strain hardening exponent.



Solution:

From the given Figure using the shown sketches we get

1- **E = sloop = 390/0.002=195000 MPa =195 GPa** **<u>(1Marks)</u>**

2- **σ_y = 530 Mpa** **<u>(2Marks)</u>**

3- **σ_u = 580 Mpa** **<u>(1Marks)</u>**

4- **Since** TS(MPa) = 3.45 x HB

Then HB = σ_u/3.45 = 580/ 3.45 =168.12 HB **<u>(2Marks)</u>**

5- $\%EL = 10\ 0(l_f - l_o)/l_o$ = ε_f % = **0.1425*100 =14.25%** **<u>(2Marks)</u>**

n= $\varepsilon_{T\ at\ Ultimate\ stress} = \ln(1+ \varepsilon_{Ultimate\ stress})$ **= ln (1+0.014) =0.0139** **<u>(2Marks)</u>**

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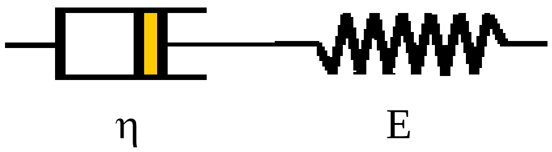
Question No. 8 (15 Marks):

This question measures the following ILOs; a.8.1, b.2.2, c.3.1,

Find the creep compliance and relaxation modulus for Maxwell model.

Solution

Maxwell model is a viscoelastic model that consists of a spring and dashpot that are connected in parallel position as shown in figure.



A representation of Maxwell.s model.

Let us assume that the Maxwell system is subjected to applied stress σ (t) that will induce a strain ε (t) therefore,

For spring $\sigma_s = E\ \varepsilon_s$

For dashpot $\sigma_d = \eta\ (d\varepsilon_d/dt)$

For Maxwell system $\sigma = \sigma_d = \sigma_s$

and $\varepsilon = \varepsilon_d + \varepsilon_s$

therefore $\frac{d\varepsilon}{dt} = \frac{d\varepsilon_s}{dt} + \frac{d\varepsilon_d}{dt}$

From the above equations the general deferential equation that represents Maxwell mode can be obtained as,

$$\frac{d\varepsilon}{dt} = \frac{1}{E}\frac{d\sigma}{dt} + \frac{\sigma}{\eta} \quad \text{(5Marks)} \quad (1)$$

Creep compliance for Maxwell model;

For creep

$$\frac{d\sigma}{dt} = 0 \qquad \sigma = \sigma_o \quad \text{(1Marks)}$$

Maxwell model general deferential equation for creep, equation (1), will be of the form $\frac{d\varepsilon}{dt} = \frac{\sigma_o}{\eta}$

The general solution of the above differential equation will be as;

$$\varepsilon(t) = \frac{\sigma_o}{\eta} t + c \qquad (2)$$

and the creep compliance of Maxwell model will be

$$J(t) = \frac{\varepsilon(t)}{\sigma_o} = \frac{1}{\eta} t + \frac{1}{E} \quad \text{(4Marks)} \quad (3)$$

from equations (2) and (3) one can see that the creep compliance for the Maxwell model has linear variation with time.

Relaxation modulus for Maxwell model;

For relaxation

$$\frac{d\varepsilon}{dt} = 0 \qquad \varepsilon = \varepsilon_o \quad \text{(1Marks)}$$

Maxwell model general deferential equation for creep, equation (1), will be of the form, $\frac{1}{E}\frac{d\sigma}{dt} + \frac{\sigma}{\eta} = 0$

The above equation can be rearranged as;

$$\frac{d\sigma}{\sigma} = -\frac{E}{\eta} dt$$

The general solution of the above differential equation will be as;

$$\sigma(t) = E\varepsilon_o \exp(-\frac{E_o}{\eta} t) \qquad (4)$$

and the creep compliance of Maxwell model will be

$$G(t) = \frac{\sigma(t)}{\varepsilon_o} = E \exp(-\frac{E_o}{\eta} t) \qquad (5)$$

(4Marks)

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