QUIZ PE-MS

PE Practice Problems: Metallurgical and Materials

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Problem 1. Which of the following options is the best combination of steel type and quenching regime to avoid the formation of cracks?

A) Use a low-carbon steel and a fast rate of cooling.

B) Use a low-carbon steel and a slow rate of cooling.

C) Use a high-carbon steel and a fast rate of cooling.

D) Use a high-carbon steel and a slow rate of cooling.

Problem 2. Rank the following steel quenching media in **decreasing** order of quenching power.

X. Water quenching;

Y. Oil quenching;

Z. Brine quenching;

A) X > Z > Y

B) Z > X > Y

C) Z > Y > X

D) Y > X > Z

Problem 3. Four eutectoid steel samples W, X, Y and Z are austenitized and then subjected to normalizing, quenching, martempering and austempering treatments, respectively. Which of the following statements is **not** correct?

A) The microstructure of sample W will be fully pearlitic.

B) The microstructure of sample X will be untempered martensite.

C) The microstructure of sample Y will be tempered martensite.

D) The microstructure of sample Z will be bainitic.

Problem 4. Match the cast iron types in the left column with the microstructural features in the right column.

Cast Iron Types	Microstructure
P. Grey cast iron	**1.** Temper graphite
Q. Ductile cast iron	**2.** Pearlite
R. Malleable cast iron	**3.** Graphite flakes
S. White cast iron	**4.**Massive cementite
	5. Nodular graphite

A) P-3, Q-5, R-4, S-2;

B) P-1, Q-5, R-4, S-2;

C) P-2, Q-4, R-5, S-3;

D) P-3, Q-5, R-1, S-4;

Problem 5. The theoretical density (kg/m^3) of a FCC metal with atomic radius and molar mass of 0.180 nm and 120 g/mol, respectively, is most nearly:

A) 3960

B) 6040

C) 8550

D) 10,100

Problem 6. Identify the type of the following invariant reaction.

Solid 1 + Liquid 1 → Solid 2

A) Eutectic.
B) Eutectoid.
C) Peritectic.
D) Peritectoid.

Problem 7. Consider the gas carburization of type 1020 steel at 800°C. The steel has a nominal carbon content of 0.25% and the carbon content at the surface is 0.77%. The diffusion coefficient under these conditions is 1.3×10^{-11} m²/s. Refer to the following table for values of the Gaussian error function. The time (min) necessary to increase the carbon content to 0.4% at 0.5 mm below the surface is most nearly:

Z	erf Z
0.678	0.70
0.712	0.75
0.742	0.80

A) 137
B) 211
C) 306
D) 414

Problem 8. A specimen is made of steel with shear modulus of 60 GPa and Poisson's ratio of 0.35. A load of 200 kN is applied perpendicularly to a 5-cm wide, 10-cm deep face of the specimen. The normal strain (engineering) caused by this load is most nearly:
A) 2.47×10^{-4}
B) 4.94×10^{-4}
C) 2.47×10^{-3}
D) 4.94×10^{-3}

Problem 9. Two specimens, 1 and 2, of the same steel are subjected to the same tensile stress. The internal cracks caused by such a stress have lengths a_1 = 0.4 mm and a_2 = 1.2 mm. The ratio K_1/K_2 of the stress intensity factors in the two samples is most nearly:
A) 0.31
B) 0.58
C) 0.82
D) 1.2

Problem 10. Consider a flaw in a martensitic steel component subjected to tensile stress. The stress level is 100 MPa and leads to the formation of a penny-shaped flaw of 0.1 mm width. The geometric modification factor for use with the fracture equation $K = Y\sigma\sqrt{\pi c}$ is Y = 9.0. The crack propagation rate can be described with a Paris equation of the form

$$\frac{dc}{dt} = 1.36\times10^{-10} K^{3.0}$$

where K is given in MPa-m$^{1/2}$. The crack propagation rate (μm/s) attained after the application of the tensile stress is most nearly:
A) 11
B) 29
C) 56
D) 94

Problem 11. The fatigue life of a certain alloy at stress levels of σ_1, σ_2, and σ_3 is 10,000, 50,000, and 500,000 cycles, respectively. Assume Miner's rule to be valid. If a component of this material is subjected to 2500 cycles of σ_1 and 10,000 cycles of σ_2, the remaining lifetime in association with cyclic stresses at a level of σ_3 is most nearly:

A) 75,000 cycles

B) 125,000 cycles

C) 200,000 cycles

D) 275,000 cycles

Problem 12. A metal has a flow curve with strength coefficient of 850 MPa and strain-hardening exponent of 0.30. A tensile specimen of the metal with initial length of 100 mm is uniformly elongated to 160 mm. The average flow stress (MPa) that the metal has been subjected to during the deformation is most nearly:

A) 201

B) 362

C) 521

D) 680

(New!) Problem 13. Assuming that the kinetics of a steel's austenite-to-pearlite transformation obeys the Avrami equation, use the following data to determine the time *t* required for 95% transformation.

Fraction transformed	Time (t)
0.2	280
0.6	425

A) $t \approx 400$ s

B) $t \approx 600$ s

C) $t \approx 800$ s

D) $t \approx 1000$ s

(New!) Problem 14. Given that the resistivity of copper at 0°C is $1.67\times10^{-8}\ \Omega\cdot\mathrm{m}$ and the temperature coefficient of resistivity α is 6.8×10^{-3} °C^{-1}, the conductivity ($\Omega^{-1}\mathrm{m}^{-1}$) of this metal at −100°C is most nearly:

A) 8×10^{7}

B) 2×10^{8}

C) 4×10^{8}

D) 5×10^{8}

(New!) Problem 15. During electrolysis of a solution of silver nitrate ($AgNO_3$), 16,000 coulombs of charge pass through the electroplating bath. The mass of silver (g) deposited on the cathode will be, most nearly:

A) 12

B) 15

C) 18

D) 21

(New!) Problem 16. The structure of an as-cast Cu-Ni alloy has a dendrite arm spacing of 120 μm. If the activation energy for diffusion in this system is 140 kJ/mol and the pre-exponential factor is 6.5×10^{-9} m^{2}s^{-1}, the temperature (K) at which this alloy needs to be soaked to achieve homogenization in 24 h is, most nearly:

A) 950

B) 1410

C) 1700

D) 2150

(New!) Problem 17. A brittle material is mechanically tested in medium *P*, wherein it has surface energy γ_s = 0.9 J/m^2. The material has a fracture strength of 300 MPa for a given flaw size. The same solid containing the same flaws is then tested in medium *Q*, where γ_s = 0.1 J/m^2. Based on Griffith theory, the fracture strength (MPa) in medium *Q* is most nearly:

A) 33
B) 45
C) 100
D) 150

Problem 18. A metal cube with 10 cm dimension is solidifying after being cast. Assume Chvorinov's rule to be valid, with a mold constant of 4 min/cm^2 and an exponent of 2. The solidification time (min) is most nearly:

A) 5.2
B) 11
C) 19
D) 28

Problem 19. Consider the following engineering components.

P. Gas turbine blades
Q. Tungsten-based heavy alloy penetrators
R. Self-lubricating bearings
S. Engine block of an automobile

Two of these components are commonly made with powder metallurgy techniques. What are they?

A) P and R
B) P and S
C) Q and R
D) Q and S

Problem 20. A sintered metal powder has green density of 6.3 g/cm^3, theoretical density of 7.8 g/cm^3, and apparent density of 5.5 g/cm^3. The densification parameter is most nearly:

A) 0.15
B) 0.25
C) 0.35
D) 0.45

Problem 21. Consider the following welding processes.

X. Laser beam welding
Y. Submerged arc welding
Z. Metal inert gas welding

The width of the heat-affected zone in **decreasing** order is:

A) X > Y > Z
B) Y > Z > X
C) Z > X > Y
D) X > Z > Y

Problem 22. Match the welding processes in the left column to the corresponding sources of heat in the right column.

Welding Technique	Source of Heat
P. Ultrasonic welding	**1.** Thermochemical
Q. Spot welding	**2.** Electrical resistance
R. SMAW	**3.** Friction
S. Thermit welding	**4.** Electrical arc

A) P-3, Q-2, R-1, S-4;
B) P-4, Q-3, R-2, S-1;
C) P-1, Q-3, R-4, S-2;
D) P-3, Q-2, R-4, S-1;

Problem 23. An arc welding is performed at 400 amperes and 20 V with a traverse speed of 5 mm/s. If the heat transfer efficiency is 0.8, the energy input per unit length (kJ/mm) during the process is most nearly:

A) 1.04
B) 1.28
C) 1.51
D) 1.76

Problem 24. A 10 cm-thick metal sample is tested for thermal conductivity in a unidimensional setting. A heat flux of 80 W/m² flows across two ends of the specimen and the temperature difference between the two ends is measured to be 0.2 K. Previous tests revealed that the density and specific heat capacity of the sample are 7800 kg/m³ and 420 J/kg·K, respectively. The thermal diffusivity (m²/s) of the sample is most nearly:

A) 1.22×10^{-5}
B) 2.44×10^{-5}
C) 1.22×10^{-4}
D) 2.44×10^{-4}

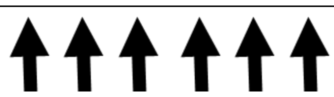
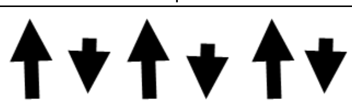
Problem 25. The heat transfer of a liquid metal in a constant-surface-temperature closed conduit can be modeled with the Shimazaki correlation

$$\mathrm{Nu}_D = 5.0 + 0.025\left(\mathrm{Re}_D\,\mathrm{Pr}\right)^{0.8}$$

where Nu_D is the Nusselt number, Re_D is the Reynolds number, and Pr is the Prandtl number. Consider the flow of liquid mercury in a circular duct of diameter 5 cm at a turbulent Reynolds number of 12,000. The mercury has a Prandtl number of 0.012 and thermal conductivity of 12 W/m·K. The heat transfer coefficient (W/m²·K) for this system is most nearly:

A) 530
B) 1020
C) 1520
D) 2040

Problem 26. Match the magnetic material type on the left column to the correct designation on the right column.

Magnetic Moment Arrangement	Material Type
 **P.** Random	**1.** Antiferromagnetic
 **Q.** Parallel	**2.** Ferrimagnetic
 **R.** Antiparallel	**3.** Paramagnetic
 **S.** Antiparallel and unequal	**4.** Ferromagnetic

A) P-4, Q-1, R-3, S-2;
B) P-2, Q-4, R-1, S-3;
C) P-3, Q-4, R-1, S-2;
D) P-1, Q-2, R-3, S-4;

Problem 27. From the standpoint of galvanic corrosion resistance, the most **unfavorable** combination is to have a:

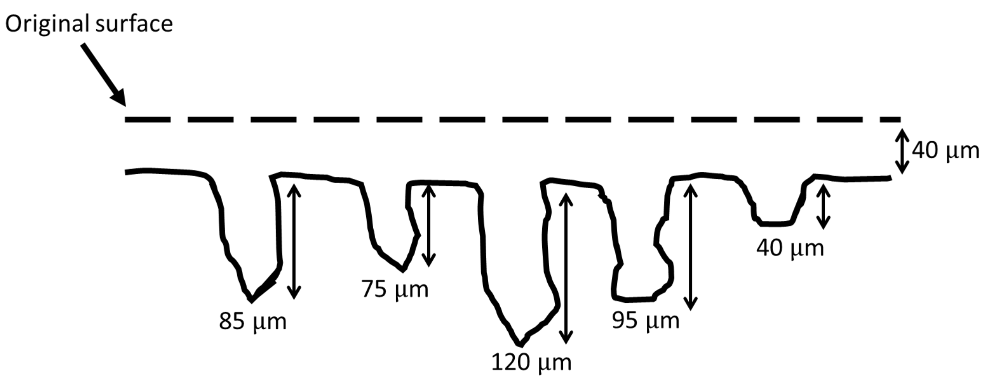
A) Very small cathode in contact with a very small anode.
B) Very small cathode in contact with a very large anode.
C) Very large cathode in contact with a very small anode.
D) Very large anode in contact with a very large anode.

Problem 28. Which of the following materials are protected by passivation (i.e., formation of a thin adherent film on the surface) from corrosion?

P. Aluminum
Q. Mild steel
R. Stainless steel
S. Cast iron

A) P and Q
B) P and R
C) Q and R
D) Q and S

Problem 29. One method to assess the intensity of pitting corrosion is to compute a so-called pitting factor. This parameter may be defined as the ratio of the average penetration of the five deepest pits to the average metal penetration by uniform corrosion. The surface of a corroded martensitic steel pipe is illustrated below. The pitting factor for this surface is most nearly:



A) 2.5
B) 3
C) 3.5
D) 4

Problem 30. Match the nondestructive testing type in the left column to the pertaining characteristic in the right column.

NDT Method	Characteristic
P. Liquid penetrant method	**1.** Usually provides no permanent record of the test
Q. Ultrasonic method	**2.** Based on capillary action
R. Radiographic method	**3.** Works on ferromagnetic materials only
S. Magnetic particle method	**4.** Instrumentation associated with safety hazard

A) P-2, Q-1, R-4, S-3;
B) P-2, Q-4, R-1, S-3;
C) P-2, Q-3, R-4, S-1;
D) P-3, Q-1, R-4, S-2;

Problem 31. Most ceramics and glasses fracture
A) in ductile mode after some plastic deformation.
B) in ductile mode with no plastic deformation.
C) in brittle mode after some plastic deformation.
D) in brittle mode with no plastic deformation.

Problem 32. Analysis of a sample of specimens for a certain ceramic revealed a two-parameter Weibull distribution with Weibull modulus of 15 and scale parameter of 200 MPa. The probability of survival at a stress level of 190 MPa is most nearly:
A) 0.63
B) 0.74
C) 0.82
D) 0.91

Problem 33. Rank the following ceramics in order of **decreasing** hardness at room temperature.

W. Cubic boron nitride
X. Diamond
Y. Silicon carbide
Z. Boron carbide

A) W > X > Y > Z
B) X > W > Z > Y
C) X > Z > W > Y
D) X > Y > W > Z

Problem 34. Which of the following techniques are **not** applicable for detecting flaws in a porous ceramic material?

P. Liquid penetration method
Q. Radiography
R. Ultrasonic testing
S. Eddy current method

A) P and Q
B) P and S
C) Q and R
D) Q and S

Problem 35. Match the glass structure point in the left column with the correct characteristic in the right column.

Point	Characteristic
P. Working Point	**1.** At this viscosity, stresses that form in the glass object are relieved in a matter of hours;
Q. Softening Point	**2.** Viscosity at which a machine is able to work on glass without losing control;
R. Annealing Point	**3.** At this viscosity, stresses that form in the glass object can be relieved in a matter of minutes;
S. Strain Point	**4.** Viscosity at which glass will deform under its own weight on the time scale of manufacturing operations;

A) P-2, Q-4, R-3, S-1;
B) P-2, Q-4, R-1, S-3;
C) P-4, Q-2, R-1, S-3;
D) P-3, Q-2, R-4, S-1;

Problem 36. The following data were obtained in the determination of the molar mass of a polymer. The number-average molar mass of the polymer is most nearly:

Molar mass	Mass (g)
72,000	1.4
54,000	2.0
25,000	3.7

A) 20,800
B) 34,700
C) 45,200
D) 50,500

Problem 37. The following is a list of structural modifications in a polymer chain.

P. Increased molecular weight
Q. Increased symmetry
R. Addition of polar groups
S. Increased crosslink density

What are the effects of each of these structural changes in the glass transition temperature (T_g) of an amorphous polymer?

A) P: increases T_g; Q: decreases T_g; R: increases T_g; S: decreases T_g
B) P: decreases T_g; Q: increases T_g; R: decreases T_g; S: increases T_g
C) P: decreases T_g; Q: decreases T_g; R: increases T_g; S: increases T_g
D) P: increases T_g; Q: increases T_g; R: increases T_g; S: increases T_g

Problem 38. Rank the following types of polymer structure in **decreasing** ability to crystallize.

X. Atactic polymers
Y. Isotactic polymers
Z. Syndiotactic polymers

A) Y > X > Z
B) X > Z > Y
C) Y > Z > X
D) Z > Y > X

Problem 39. A polypropylene specimen had its shear storage modulus determined as 120 kPa and shear loss modulus established as 150 kPa. The phase angle (degrees) of the deformation delay between stress and strain is most nearly:
A) 41
B) 46
C) 51
D) 56

Problem 40. The ratio of elongational viscosity to shear viscosity for a Troutonian polymer is:
A) 1/3
B) 1/2
C) 2
D) 3

▸ SOLUTIONS

P.1 ■ Solution

The susceptibility of a steel to develop cracks, distortion, and warpage is directly proportional to the steel's carbon content and rate of cooling.

▸ The correct answer is **B**.

P.2 ■ Solution

Caustic soda and brine have the greatest quenching power, and are followed by water, oil, and air, in that order. The quenching power of a medium can be represented by the Grossmann quench severity factor. Some typical values, listed in terms of degree of agitation, are given in the following table.

Agitation	Grossmann H-Factor		
	Oil	Water	Caustic soda or brine
None	0.25 – 0.3	0.9 – 1.0	2
Mild	0.3 – 0.35	1.0 – 1.1	2 – 2.2
Strong	0.5 – 0.8	1.6 – 2.0	–

▸ The correct answer is **B**.

P.3 ■ Solution

Once a material is quenched, its structure becomes (untempered) martensite. After martempering, the resulting structure is tempered martensite, so named because it is slightly less hard, strong, and brittle than common martensite. In austempering, the material is gently cooled and maintained at a temperature between 500°F and 600°F for a period of time long enough for a structural transformation in the bainite region to take place. Lastly, we should mention that, although fine pearlite is indeed one of the main products of normalization, a normalized steel will not necessarily be fully pearlitic. The normalized microstructure depends on the composition of the steel.

▸ The false answer is **A**.

P.4 ■ Solution

Grey cast iron is characterized by a microstructure in which carbon mainly occurs in the form of graphite flakes. Ductile cast iron contains nodular graphite; indeed, "nodular cast iron" is another term attributed to it. Malleable cast iron contains temper graphite, so named because such a carbon content is formed in the solid state during heat treatment. The microstructure of white cast iron contains both massive cementite and pearlite. The correct sequence is P-3, Q-5, R-1, S-4.

▶ The correct answer is **D**.

P.5 ■ Solution

The mass of an unit of FCC crystal is

$$m = \frac{4M}{N_A} = \frac{4\times 120}{6.02\times 10^{23}} \Big/ 1000 = 7.97\times 10^{-25} \text{ kg}$$

while the volume is

$$V = 8\times 2^{3/2} R^3 = 8\times 2^{3/2} \times \left(0.180\times 10^{-9}\right)^3 = 1.32\times 10^{-28} \text{ m}^3$$

so that

$$\rho = \frac{m}{V} = \frac{7.97\times 10^{-25}}{1.32\times 10^{-28}} = \boxed{6040 \text{ kg/m}^3}$$

▶ The correct answer is **B**.

P.6 ■ Solution

A peritectic reaction is a reaction where a solid phase and a liquid phase form a second solid phase at the same temperature and composition. Peritectics are not as common as eutectics and eutectoids, but do occur in some alloy systems. For instance, there is one in the iron-carbon system.

▶ The correct answer is **C**.

P.7 ■ Solution

The time required can be computed with the relation

$$\frac{c_s - c_x}{c_s - c_o} = \text{erf}\left[\frac{x}{2\sqrt{Dt}}\right]$$

In the left-hand side, c_s = 0.77 is the carbon content at the surface, c_x = 0.40 is the carbon content at a distance x from the surface, and c_0 = 0.25 is the initial carbon content; in the right-hand side, x = 0.5 mm is the distance from the surface, $D = 1.3\times10^{-11}$ m²/s is diffusivity, and t is time. Substituting the available data, we obtain

$$\frac{0.77-0.40}{0.77-0.25} = \text{erf}\left[\frac{0.5\times 10^{-3}}{2\sqrt{1.3\times 10^{-11} t}}\right] \rightarrow 0.712 = \text{erf}\left[\frac{69.3}{\sqrt{t}}\right]$$

That is, erf Z = 0.712. With reference to the table, we read Z = 0.75. Accordingly,

$$\frac{69.3}{\sqrt{t}} = 0.75 \rightarrow t = \left(\frac{69.3}{0.75}\right)^2 = 8540 \text{ s}$$

$$\therefore \boxed{t = 137 \text{ min}}$$

▶ The correct answer is **A**.

P.8 ■ Solution

We first compute Young's modulus for this steel,

$$G = \frac{E}{2(1+\mu)} \rightarrow E = 2G(1+\mu)$$

$$\therefore E = 2\times 60\times (1+0.35) = 162 \text{ GPa}$$

The normal stress due to the load is

$$\sigma = \frac{F}{A} = \frac{200,000}{0.05 \times 0.1} = 40 \text{ MPa}$$

The corresponding strain follows from Hooke's law,

$$\sigma = E\varepsilon \rightarrow \varepsilon = \frac{\sigma}{E}$$

$$\therefore \varepsilon = \frac{40}{162 \times 10^3} = \boxed{2.47 \times 10^{-4}}$$

▶ The correct answer is **A**.

P.9 ■ Solution

For specimen 1, we have

$$K_1 = Y\sigma\sqrt{\pi a_1} = Y\sigma\sqrt{\pi \times 0.4}$$

For specimen 2, in turn,

$$K_2 = Y\sigma\sqrt{\pi a_2} = Y\sigma\sqrt{\pi \times 1.2}$$

The ratio K_1/K_2 is then

$$\frac{K_1}{K_2} = \frac{Y\sigma\sqrt{\pi \times 0.4}}{Y\sigma\sqrt{\pi \times 1.2}} = \boxed{0.577}$$

▶ The correct answer is **B**.

P.10 ■ Solution

Substituting in the fracture equation, we obtain

$$K = Y\sigma\sqrt{\pi c} = 9.0 \times 100 \times \sqrt{\pi \times \left(0.1 \times 10^{-3}\right)} = 16.0 \text{ MPa-m}^{1/2}$$

Appealing to the Paris equation, we ultimately find

$$\frac{dc}{dt} = 1.36 \times 10^{-10} \times 16.0^{3.0} = 5.57 \times 10^{-7} \text{ m/s}$$

$$\therefore \boxed{dc/dt = 55.7 \ \mu\text{m/s}}$$

▶ The correct answer is **C**.

P.11 ■ Solution

This is a straightforward application of the Miner rule,

$$\Sigma \frac{N}{N_f} = 1 \rightarrow \frac{2500}{10,000} + \frac{10,000}{50,000} + \frac{N}{500,000} = 1.0$$

$$\therefore 0.25 + 0.2 + 2 \times 10^{-6} N = 1.0$$

$$\therefore 0.45 + 2 \times 10^{-6} N = 1.0$$

$$\therefore 2 \times 10^{-6} N = 0.55$$

$$\therefore N = 0.55 / \left(2 \times 10^{-6}\right) = \boxed{275,000 \text{ cycles}}$$

▶ The correct answer is **D**.

P.12 ■ Solution

The true strain is

$$\varepsilon = \ln\frac{160}{100} = 0.470$$

The average flow stress follows as

$$\bar{\sigma} = \frac{C\varepsilon^n}{n+1} = \frac{850 \times 0.47^{0.30}}{0.30+1} = \boxed{521 \text{ MPa}}$$

► The correct answer is **C**.

P.13 ■ Solution

The Avrami equation reads $f = 1 - exp(-Kt^n)$, where K and n are constants to be determined. Substituting the first data point, we have

$$0.2 = 1 - \exp\left(-K \times 280^n\right)$$

$$\therefore \exp\left(-K \times 280^n\right) = 0.8$$

$$\therefore K \times 280^n = -\ln\left(0.8\right) \quad \text{(I)}$$

Proceeding similarly with the second data point,

$$0.6 = 1 - \exp\left(-K \times 425^n\right)$$

$$\therefore \exp\left(-K \times 425^n\right) = 0.4$$

$$\therefore K \times 425^n = -\ln\left(0.4\right) \quad \text{(II)}$$

Dividing (II) by (I) and solving for n,

$$\frac{\cancel{K} \times 425^n}{\cancel{K} \times 280^n} = \frac{\ln\left(0.4\right)}{\ln\left(0.8\right)}$$

$$\therefore \left(\frac{425}{280}\right)^n = 4.11$$

$$\therefore n \times \ln\left(\frac{425}{280}\right) = \ln\left(4.11\right)$$

$$\therefore n \times 0.417 = 1.41$$

$$\therefore n = \frac{1.41}{0.417} = 3.38$$

Substituting in (I),

$$K \times 280^{3.38} = -\ln\left(0.8\right)$$

$$\therefore K = -\frac{\ln\left(0.8\right)}{280^{3.38}} = 1.19 \times 10^{-9}$$

Thus, the austenite-to-pearlite transition can be modelled by the Avrami-kinetic relationship

$$f = 1 - \exp\left[-\left(1.19 \times 10^{-9}\right) \times t^{3.38}\right]$$

To find the time required for 95% transformation, we write

$$0.95 = 1 - \exp\left[-\left(1.19 \times 10^{-9}\right) \times t^{3.38}\right]$$

$$\therefore \exp\left[-\left(1.19 \times 10^{-9}\right) \times t^{3.38}\right] = 0.05$$

$$\therefore \left(1.19 \times 10^{-9}\right) \times t^{3.38} = -\ln\left(0.05\right)$$

$$\therefore t^{3.38} = -\frac{\ln\left(0.05\right)}{1.19 \times 10^{-9}}$$

$$\therefore t = \left[-\frac{\ln\left(0.05\right)}{1.19 \times 10^{-9}}\right]^{\frac{1}{3.38}} = \boxed{604 \text{ s}}$$

▶ The correct answer is **B**.

P.14 ■ Solution

The resistivity can be assumed to vary with temperature according to the relationship

$$\rho_T = \rho_0\left(1+\alpha\Delta T\right)$$

Using the resistivity at 0°C as the base value, we may write

$$\rho_T = \left(1.67\times10^{-8}\right)\times\left[1+\left(6.8\times10^{-3}\right)\times\left(-100-0\right)\right] = 5.34\times10^{-9}\ \Omega\cdot\mathrm{m}$$

Since conductivity is the reciprocal of resistivity,

$$\kappa = \frac{1}{5.34\times10^{-9}} = \boxed{1.87\times10^{8}\ (\Omega\cdot\mathrm{m})^{-1}}$$

▶ The correct answer is **B**.

P.15 ■ Solution

In accordance with the cathodic reaction

$$\mathrm{Ag}^{+}_{(\mathrm{aq})} + e^{-} \rightarrow \mathrm{Ag}_{(s)}$$

one mole of electrons, or 96,500 C, is required to produce one mole of metallic silver. With 16,000 C, the mass of silver deposited will be

$$\frac{108\ \mathrm{g\ Ag}_{(s)}}{96{,}500\ \mathrm{C}} = \frac{m}{16{,}000\ \mathrm{C}}$$

$$\therefore m = \frac{16{,}000}{96{,}500}\times108 = \boxed{17.9\ \mathrm{g\ Ag}}$$

▶ The correct answer is **C**.

P.16 ■ Solution

The soaking temperature can be estimated from the diffusion coefficient, which in turn can be determined by means of the diffusion length equation $x = \sqrt{Dt}$. For a dendrite arm spacing of 120 μm, the diffusion distance will be 120/2 = 60 μm, so that

$$x = \sqrt{Dt} \quad\rightarrow\quad D = \frac{x^2}{t}$$

$$\therefore D = \frac{\left(60\times10^{-6}\right)^2}{24\times3600} = 4.17\times10^{-14}\ \mathrm{m^2s^{-1}}$$

In turn,

$$D = D_0\exp\left(-\frac{Q}{RT}\right) \quad\rightarrow\quad T = \frac{Q/R}{\ln\left(D/D_0\right)}$$

$$\therefore T = \frac{140{,}000/8.314}{\ln\left(\dfrac{4.17\times10^{-14}}{6.5\times10^{-9}}\right)} = \boxed{1410\ \mathrm{K}}$$

▶ The correct answer is **B**.

P.17 ■ Solution

On the basis of Griffith theory, the fracture strength is given by

$$F_s = \left(\frac{2E\gamma_s}{\pi c}\right)^{\frac{1}{2}}$$

where *E* is Young's modulus, γ_s is surface energy, and *c* is crack/flaw size. Applying this expressions to media *P* and *Q*, we have the ratio

$$\frac{F_{s,Q}}{F_{s,P}} = \sqrt{\frac{\gamma_{s,Q}}{\gamma_{s,P}}} \rightarrow F_{s,Q} = \sqrt{\frac{\gamma_{s,Q}}{\gamma_{s,P}}} F_{s,P}$$

$$\therefore F_{s,Q} = \sqrt{\frac{0.1}{0.9}} \times 300 = \frac{1}{3} \times 300 = \boxed{100 \text{ MPa}}$$

▶ The correct answer is **C**.

P.18 ■ Solution

The volume of the cube is V = 10³ = 1000 cm³ and the surface area is A = 6×10² = 600 cm². With n = 2 and C_m = 4 min/cm², the total solidification time can be estimated with Chvorinov's rule, namely

$$T_s = C_m \left(\frac{V}{A} \right)^n \rightarrow T_s = 4 \times \left(\frac{1000}{600} \right)^2$$

$$\therefore \boxed{T_s = 11.1 \text{ min}}$$

▶ The correct answer is **B**.

P.19 ■ Solution

Tungsten-based heavy alloy penetrators and self-lubricating bearings are commonly produced with powder metallurgy techniques. Gas turbine blades and engine blocks are not commonly manufactured with powder metallurgy technology.

▶ The correct answer is **C**.

P.20 ■ Solution

The densification parameter is given by

$$DP = \frac{\text{Green density} - \text{Apparent density}}{\text{Theoretical density} - \text{Apparent density}} = \frac{6.3 - 5.5}{7.8 - 5.5} = \boxed{0.348}$$

▶ The correct answer is **C**.

P.21 ■ Solution

Submerged arc welding yields the largest HAZ. It is followed by MIG, which is generally associated with an intermediate size HAZ. Laser welding, with its inherent precision, produces a very small HAZ.

▶ The correct answer is **B**.

P.22 ■ Solution

Ultrasonic welding is based on frictional transfer of heat between the materials being welded. Resistance spot welding is a process in which contacting metal surface points are joined by the heat obtained from resistance to electric current. Shielded metal arc welding relies on the formation of an electrical arc between the electrode and the metal to be welded. Lastly, thermit welding is made possible by an exothermic chemical reaction between the compounds of the thermit, a mixture of a metal oxide and aluminum powder. The correct sequence is P-3, Q-2, R-4, S-1.

▶ The correct answer is **D**.

P.23 ■ Solution

We appeal to the formula

$$Q = f \frac{EI}{V} = \frac{0.8 \times 20 \times 400}{5} = 1280 \text{ J/mm} = \boxed{1.28 \text{ kJ/mm}}$$

▶ The correct answer is **B**.

P.24 ■ Solution

We first require the thermal conductivity, which can be determined with Fourier's law.

$$\dot{q}'' = k\frac{\Delta T}{\Delta x} \rightarrow k = \frac{\dot{q}''\Delta x}{\Delta T}$$

$$\therefore k = \frac{80 \times 0.1}{0.2} = 40\ \text{W/m}\cdot\text{K}$$

Then, the thermal diffusivity is given by the ratio

$$\alpha = \frac{k}{\rho c_p} = \frac{40}{7800 \times 420} = \boxed{1.22 \times 10^{-5}\ \text{m}^2/\text{s}}$$

▶ The correct answer is **A**.

P.25 ■ Solution

Substituting Re_D = 8500 and Pr = 0.012, the Nusselt number is computed as

$$\text{Nu}_D = 5.0 + 0.025(12{,}000 \times 0.012)^{0.8} = 6.33$$

Given D = 0.05 m and k = 12 W/m·K, the heat transfer coefficient can be obtained with the definition of Nu,

$$\text{Nu}_D = \frac{h \times D}{k} \rightarrow h = \frac{\text{Nu}_D \times k}{D}$$

$$\therefore h = \frac{6.33 \times 12}{0.05} = \boxed{1520\ \text{W/m}^2\text{K}}$$

▶ The correct answer is **C**.

P.26 ■ Solution

Ferromagnetism occurs when the magnetic moments are all aligned in the same direction. Ferrimagnetism is the effect observed when the magnetic moments are aligned in parallel and anti-parallel directions in unequal numbers; in the special case where the opposing moments balance completely, antiferromagnetism is observed. Lastly, the material is said to be paramagnetic if the magnetic moments are randomly distributed. The correct sequence is P-3, Q-4, R-1, S-2.

▶ The correct answer is **C**.

P.27 ■ Solution

The greatest galvanic corrosion rate is achieved by connecting a very large cathode to a very small anode. One important aspect of galvanic corrosion is the so-called area effect, according to which the larger the cathode compared with the anode, the more oxygen reduction, or other cathodic reaction, can occur, and hence the greater the galvanic current. Accordingly, a valuable rule to avoid galvanic corrosion is to have a large anode-to-cathode area ratio.

▶ The correct answer is **C**.

P.28 ■ Solution

Pure aluminum and stainless steel are the most common examples of materials that undergo passivation. In the case of aluminum, reaction of the metal with oxygen leads to the formation of a thin aluminum oxide layer that protects the material from further oxidation. In the case of stainless steel, the protective layer comes in the form of chromium oxide.

▶ The correct answer is **B**.

P.29 ■ Solution

As mentioned in the problem statement, we first require the average penetration of the five pits, $\bar{d}$, which is given by

$$\bar{d} = \frac{(40+85)+(40+75)+(40+120)+(40+95)+(40+40)}{5} = 123\ \mu\text{m}$$

The penetration by uniform corrosion is h = 40 μm. Accordingly, the pitting factor is calculated to be

$$PF = \frac{\bar{d}}{h} = \frac{123}{40} = \boxed{3.08}$$

▶ The correct answer is **B**.

P.30 ■ Solution

The liquid penetrant test is based on the principle of capillary action. Production of permanent records is not typical of the ultrasonic method. The instrumentation employed in the radiographic method is obviously associated with a potential safety hazard. The magnetic particle method works only with ferromagnetic materials. The correct sequence is then P-2, Q-1, R-4, S-3.

▶ The correct answer is **A**.

P.31 ■ Solution

Most ceramics and glasses are brittle and fracture with no plastic deformation.

▶ The correct answer is **D**.

P.32 ■ Solution

Given σ_0 = 200 MPa and m = 15, the probability of survival is calculated as

$$p = e^{-(\sigma/\sigma_o)^m} = \exp\left[-\left(\frac{190}{200}\right)^{15}\right] = \boxed{0.629}$$

▶ The correct answer is **A**.

P.33 ■ Solution

Diamond, the hardest material known to man, is followed by cubic boron nitride. Boron carbide comes next. Silicon carbide, a moderately hard ceramic, is the least hard material on the list. Some typical values are listed below.

Material	Vickers Hardness (kg/mm^2)
Diamond	8600
Cubic boron nitride	5000
Boron carbide	3800
Silicon carbide	2800

▶ The correct answer is **B**.

P.34 ■ Solution

The liquid penetration method is inherently not suitable for evaluation of porous materials. The eddy current method in general requires materials with average or high electrical conductivity, and most porous ceramics are poor conductors.

▶ The correct answer is **B**.

P.35 ■ Solution

The correct sequence is P-2, Q-4, R-3, S-1. Some notes on each point are provided below.

Point	Note
Working Point	This point defines the viscosity at which a machine can work on a glass without losing control. At this point, molten glass can be formed and manipulated; viscosity is low enough for some shear processing (pressing, blowing) but high enough to retain shape after shear stress is removed.

Softening Point	This is the viscosity at which glass will deform under its own weight in the time scale of manufacturing operations. More specifically, it may be regarded as the temperature at which a filament of 23.5 cm length and 0.55 – 0.77 mm diameter elongates by 1 mm/min under its own weight.
Annealing Point	This is the temperature to which the glass must be heated to relieve any internal stresses that arose as a result of the forming process. It can be said that, at the annealing point, an artificially strained glass is relaxed to 10% in 15 minutes.
Strain Point	Stresses that form in the glass object are relieved in a matter of hours, not minutes. It can be said that an artificially strained glass is relaxed to 10% of the strain in 15 hours. In addition, the strain point defines the maximum temperature at which a glass can be used for structural applications without undergoing creep.

► The correct answer is **A**.

P.36 ■ Solution

The number-average molar mass is given by

$$\bar{M}_n = \frac{\Sigma W_i}{\Sigma\left(W_i/M_i\right)} = \frac{1.4+2.0+3.7}{\dfrac{1.4}{72,000}+\dfrac{2.0}{54,000}+\dfrac{3.7}{25,000}} = \boxed{34,700}$$

► The correct answer is **B**.

P.37 ■ Solution

All molecular modifications increase the glass transition temperature of a polymer chain. The modifications in question all reduce the freedom of movement or reduce backbone flexibility, thereby increasing T_g. Polyethylene, a polymer with very flexible backbone, has a T_g of about -20°C, whereas PTFE, a polymer with an exceptionally rigid backbone, has a T_g of 115°C.

► The correct answer is **D**.

P.38 ■ Solution

Due to their regular nature, isotactic polymers will readily crystallize from the molten state when thermodynamic conditions are favorable. Syndiotactic polymers can crystallize, but do so fairly slowly due to steric interference and the fact that repeat units comprising two monomers are required to organize into repeating arrays. Lastly, the nearly random placement of side groups in atactic polymers prevents them from developing regular structures. The correct order is then Y > Z > X.

► The correct answer is **C**.

P.39 ■ Solution

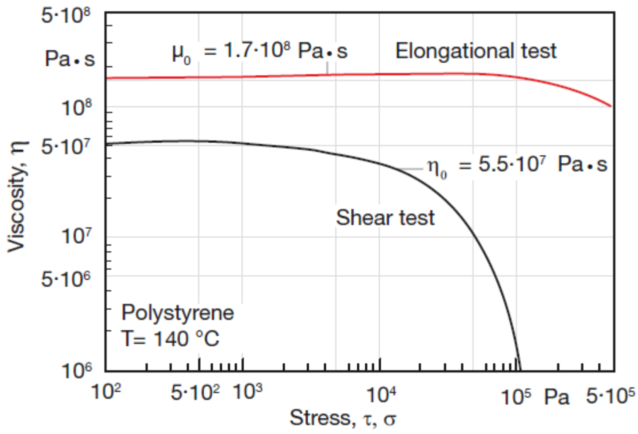
The loss tangent is the ratio of the loss modulus to the storage modulus; that is,

$$\tan\delta = \frac{G''}{G'} = \frac{150}{120} = 1.25 \rightarrow \boxed{\delta = 51.3^{\circ}}$$

► The correct answer is **C**.

P.40 ■ Solution

The elongational viscosity of a Troutonian polymer is three times the shear viscosity. The figure on the next page shows the shear and elongational viscosities of polystyrene. In the region of the Newtonian plateau, the limit of 3 is quite clear.



▶ The correct answer is **D**.

▶ ANSWER SUMMARY

1	B	21	B
2	B	22	D
3	A	23	B
4	D	24	A
5	B	25	C
6	C	26	C
7	A	27	C
8	A	28	B
9	B	29	B
10	C	30	A
11	D	31	D
12	C	32	A
13	B	33	B
14	B	34	B
15	C	35	A
16	B	36	B
17	C	37	D
18	B	38	C
19	C	39	C
20	C	40	D

▶ APPENDIX – Problems excluded from 2023 version

Five problems from the 2020 version of this quiz didn't make it to the 2023 version. The problems are mostly related to manufacturing processes; I chose to exclude these problems in order to make room for additional ones on physical metallurgy and materials' properties. The deleted problems are listed and solved below.

~~**Problem 13.**~~ A 42-mm thick plate made of low carbon steel is to be reduced to 34 mm in one pass in a rolling operation. As the thickness is reduced, the plate widens by 6%. The entrance speed of the plate is 15.0 m/min. The exit velocity (m/min) of the plate is most nearly:

A) 7.2
B) 12.5
C) 17.5
D) 21.2

Solution. The product of thickness, width, and plate velocity should be constant. Accordingly,

$$t_o w_o v_o = t_f w_f v_f \rightarrow v_f = \frac{t_o w_o v_o}{t_f w_f}$$

$$\therefore v_f = \frac{42 \times w_o \times 15.0}{34 \times (1.06 w_o)} = \boxed{17.5 \text{ m/min}}$$

▶ The correct answer is **C**.

~~Problem 14.~~ A 120-mm long billet with diameter of 55 mm is direct extruded to a diameter of 25 mm. The die angle is 90°. The extrusion strain is given by a Johnson equation of the form $\varepsilon_x = 0.6 + 1.3\ln r_x$, where r_x is true strain. Under homogeneous deformation, the extrusion strain is most nearly:

A) 0.44
B) 1.21
C) 2.65
D) 3.91

Solution. The extrusion ratio is given by

$$r_x = \frac{A_o}{A_f} = \frac{D_o^2}{D_f^2} = \frac{55^2}{25^2} = 4.84$$

The true strain follows as

$$\varepsilon = \ln r_x = \ln 4.84 = 1.58$$

Appealing to the Johnson equation, we can determine the extrusion strain,

$$\varepsilon_x = 0.6 + 1.3\ln r_x = 0.6 + 1.3 \times 1.58 = \boxed{2.65}$$

▶ The correct answer is **C**.

~~Problem 15.~~ The material of the billet described in Problem 14 has a flow curve represented by a strength coefficient of 750 MPa and a strain hardening exponent of 0.15. The average ram pressure (MPa) is most nearly:

A) 781
B) 845
C) 1300
D) 1850

Solution. The average stress is given by

$$\bar{\sigma} = \frac{C\varepsilon_x^n}{n+1} = \frac{750 \times 1.58^{0.15}}{0.15+1} = 698 \text{ MPa}$$

The ram pressure follows as

$$p = \varepsilon_x \bar{\sigma} = 2.65 \times 698 = \boxed{1850 \text{ MPa}}$$

▶ The correct answer is **D**.

~~Problem 16.~~ In an orthogonal cutting operation, the tool has rake angle of 18°. The chip thickness before the cut is 0.32 mm and the cut yields a deformed chip thickness of 0.67 mm. The shear plane angle (degrees) and the shear strain for the operation are, most nearly:

A) 28.1, 1.03
B) 28.1, 2.05
C) 40.4, 1.03
D) 40.4, 2.05

Solution. The chip thickness ratio is given by

$$r = \frac{t_o}{t_c} = \frac{0.32}{0.67} = 0.478$$

The shear plane angle follows as

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} = \frac{0.478 \times \cos 18^\circ}{1 - 0.478 \times \sin 18^\circ} = 0.533$$

$$\therefore \boxed{\phi = 28.1^\circ}$$

The shear strain in metal cutting, in turn, is expressed as

$$\gamma = \tan(\phi - \alpha) + \cot\phi = \tan(28.1^\circ - 18^\circ) + \cot 28.1^\circ = \boxed{2.05}$$

▶ The correct answer is **B**.

~~**Problem 17.**~~ Suppose the rake angle of the operation in Problem 16 were reduced to 0°. Assuming the friction angle remains the same, the shear plane angle (degrees) and the shear strain for the operation are, most nearly:

A) 19.1, 3.23

B) 19.1, 5.11

C) 25.2, 3.23

D) 25.2, 5.11

Solution. From the previous problem, α = 18° and ϕ = 28.1°. The friction angle can be obtained with the Merchant equation,

$$\phi = 45^\circ + \frac{\alpha}{2} - \frac{\beta}{2} \rightarrow 28.1^\circ = 45^\circ + \frac{18^\circ}{2} - \frac{\beta}{2}$$

$$\therefore 28.1^\circ = 45^\circ + 9^\circ - 0.5\beta$$

$$\therefore \beta = \frac{-25.9}{-0.5} = 51.8^\circ$$

Given the rake angle α = 0, with the friction angle unchanged, we find that

$$\phi = 45^\circ + \frac{\alpha}{2} - \frac{\beta}{2} = 45^\circ + 0 - \frac{51.8^\circ}{2} = \boxed{19.1^\circ}$$

The corresponding shear strain is then

$$\gamma = \tan(19.1^\circ - 0) + \cot 19.1^\circ = \boxed{3.23}$$

▶ The correct answer is **A**.

Got any questions related to this quiz? We can help!
Send a message to contact@montogue.com and we'll
answer your question as soon as possible.