National Exams December 2014
10-Met-B5 Metal Fabrication
3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer page, a clear statement of any assumptions made
2. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book exam.
3. All questions should be answered or attempted.
4. There are four questions and they are all of equal value.
5. Some common formulae are given at the end of the examination as well as material property tables.

Question 1 (20 marks)

a. Why is high turbulence not desired in the liquid stream when gravity sand casting shapes? (2 marks)

b. Calculate the amount of each phase (solid and liquid) for a Pb-Sn alloy with a nominal composition of 20%Sn at 250°C. Use Figure 1 below. (2 marks)

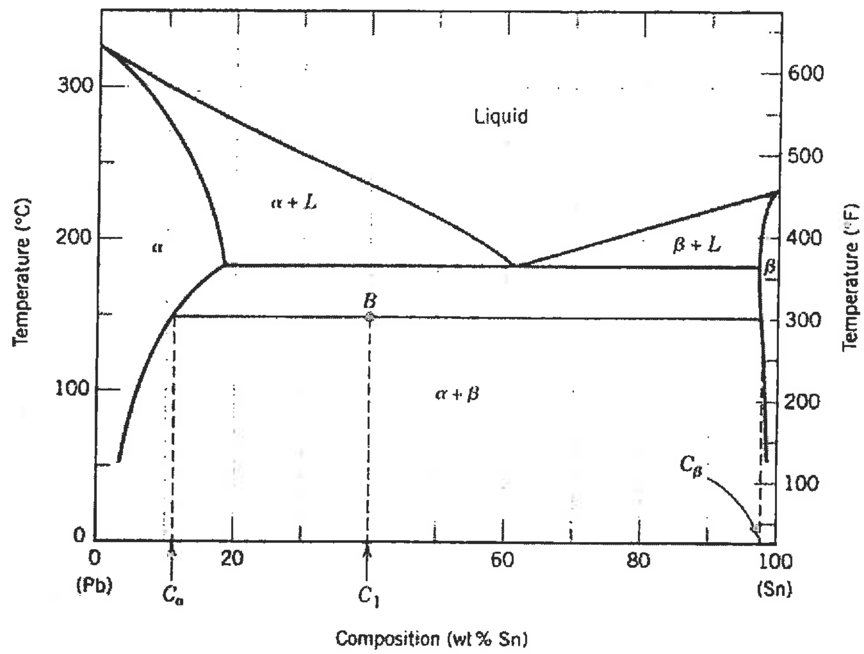

Figure 1 – Pb-Sn phase diagram.

c. Describe the role a riser plays in gravity sand casting and two things to consider in its design. (2 marks)

d. A cylinder with a height (h) to radius (h/a) ratio of 3 solidifies in five minutes in a sand-mold. Calculate the solidification time if the (h/a) ratio was changed to unity? Note: the top and bottom of the cylinder should be included in your analysis (2 marks). Hint: Use Chvorinov's rule with n = 2. (2 marks)

e. Define and differentiate between expendable and permanent patterns in casting and provide an example for each of these casting processes. (2 marks)

f. Estimate the engineering strain at which necking will occur for a 1008 steel alloy during uniaxial tension (2 marks)

g. Does the hardness of a sheet metal have any effect on the sheet springback in bending? Explain (2 marks)

h. Describe what causes hydrogen gas porosity to occur during both casting and fusion welding of aluminum alloys and how it can be prevented. (2 marks)

i. Calculate the strain experienced by an AA1100 aluminum alloy billet which is cold extruded from a diameter of 100 mm to a rod with a diameter of 25 mm. (2 marks):

j. Indicate two advantages of cold rolling relative to warm and hot rolling. (2 marks)

Question 2 (20 marks)

A coil of temper rolled mild steel strip (AISI 1015) is to be used to provide blanks for a deep drawing operation. The material properties for the 1015 steel include a yield strength of 245 MPa and a tensile strength of 345 MPa. Tensile test specimens are blanked from the strip and specimens were taken in three directions with respect to the rolling direction, i.e., 0°, 45° and 90°. The tensile tests were stopped at a strain of 0.2 which, in all cases, was prior to the onset of necking. The measured length and width strains are given in the Table below.

Specimen	Angle between long. Axis and R.D.	% Elongation in gauge length	% Change in gauge width
1	90°	16.2	8.9
2	0°	18.9	9.6
3	45°	14.7	7.2

(a) Calcualte the $\bar{R}$ and ΔR for this material. (5 points)
(b) What is the largest circular blank diameter that can be used to draw a cup with a diameter of 10 cm. (5 points)
(c) What will be the press force required to effect the draw if the sheet thickness is 1mm?. (5 points)
(d) At what locations if any are there likely to be ears formed at the top of the cup wall? (5 points).

Question 3 (20 marks)

You are spot welding two 2-mm thick aluminum sheets (AA5052) to make a Porsche. The electrodes are 6 mm in diameter. Each weld has a strength equal to the parent material (i.e., yield strength = 90 MPa). The total load including safety factor, that will be carried by the welds is 45,000 N. Room temperature is 25°C. The welding machine has a current of 5000 A. You may assume that 65% of the energy goes to welding the material.

You may assume that the resistivity for the material during welding is 4.0 $\mu\Omega$. The cost of electricity is \$0.09/kW-hr. (Note 1kW-hr = 3.6 MJ)

a) Determine the number of welds required to meet the load requirements (5 points).
b) Determine the time it takes to make all the welds (10 points).
c) Determine the electricity cost to make all the required welds (5 points).

Question 4 (20 marks)

You are open-die forging a right-circular cylinder made from AISI 1045 steel. The cylinder has an initial height of 20 cm and diameter 20 cm and is forged at 1000°C to a final height of 10cm. The dies are unlubricated and you can assume sticking friction applies during the deformation. The total deformation will occur over a 2 second interval at constant ram speed.

a) Sketch a pressure versus position curve across the specimen diameter at the end of forging. Indicate on the diagram the work required to overcome friction as well as the work required to deform the material (4 marks).
b) What minimum size of press is required in KW (10 marks)
c) What would be the effect on the answer to (b) if the ram speed were doubled (3 marks)
d) What is the overall efficiency of the operation? If you wanted to improve the forging press' efficiency what are some steps you could take? (3 marks)

Table 1a - Data for solid materials (room temperature):

Material	Specific heat (kJ/kg°C)	Density (kg/m^3)	Thermal conductivity (W/m°C)
Sand	1.16	1500	0.6
Aluminum	0.90	2700	222.0
Nickel	0.44	8910	92.1
Magnesium	1.03	1740	154.0
Copper	0.38	8960	394.0
Iron	0.46	7870	75.4
Steel	0.434	7832	59.0

Table 1b - Data for liquid materials:

Material	Melting point (°C)	Density (kg/m^3)	Latent heat of solidification (kj/kg)	Thermal conductivity (W/m°C)	Specific heat (kJ/kg°C)	Viscosity (mPa-s)
Aluminum	660	2390	396	94.1	1.05	4.5
Nickel	1453	7900	297	84.1	0.73	4.1
Magnesium	650	1585	384	139.0	1.38	1.24
Copper	1083	7960	220	49.4	0.52	3.36
Iron	1540	7150	211	65.0	0.34	2.2

Material Property Table of Steels and Copper Based Alloys*

* Data taken from Table 8-2 – Schey and also CES edupack database as required

Alloy	T_{Liq}/ T_{Sol} °C	Hot Working			Cold Working					
Steels		at °C	C (MPa)	m	K (MPa)	n	$\sigma_{0.2}$ (MPa)	TS (MPa)	Elong. %	RA (%)
1008	1530/ 1490	1000	100	0.1	600	0.25	180	320	40	70
1015	1530/ 1490	800	150	0.1	620	0.18	300	450	35	70
		1000	120	0.1						
		1200	50	0.17						
1045	1510/ 1430	800	180	0.07	950	0.12	410	700	22	45
		1000	120	0.10						
		1200	120	0.13						
8620	1520/ 1480	1000	190	0.13	1300	0.30	400	525	30	
D2 tool steel	1480/ 1430	1000	190	0.13	1300	0.30	2000	2300	14	
H13 tool steel	1500/ 1460	1000	80	0.26	1300	0.30	1600	2000		
302 SS		1000	170	0.1	1300	0.30	250	600	55	65
410 SS		1000	140	0.08	960	0.1	280	520	30	65
Copper based alloys										
Cu (99.94%)	1083/ 1065	600	139	0.06	450	0.33	70	220	50	78
		900	41	0.2						
Cartridge brass	955/ 915	600	130	0.06	500	0.41	100	310	65	75
		800	48	0.15						
Muntz metal	905/ 900	600	38	0.3	800	0.5	120	380	45	70
		800	20	0.24						
Leaded brass	900/ 855	600	58	0.14	800	0.33	130	340	50	55
		800	14	0.20						
Phosphor bronze	1050/ 950	700	160	0.35	720	0.46	150	340	57	
Aluminum bronze	1060/ 1050						170	400	65	

Material Property Table of Various Nonferrous Alloys*

* Data taken from Table 8-2 – Schey and also CES edupack database as required

Alloy	T_{Liq}/ T_{Sol} °C	Hot Working			Cold Working					
Light Metals		at °C	C (MPa)	m	K (MPa)	n	$\sigma_{0.2}$ (MPa)	TS (MPa)	Elong. %	RA (%)
1100 Al	657/ 643	300	60	0.08	140	0.25	35	90	35	
		500	14	0.22						
3003 Al	649/ 648	400	35	0.13			40	110	30	
2017 Al	635/ 510	400	90	0.12	380	0.15	70	180	20	
		500	36	0.12						
5052	650/ 590	480	35	0.13	210	0.13	90	190	25	
6061 – O	652/ 582	400	50	0.16	220	0.16	55	125	25	65
		500	37	0.17						
6061 – T6	652/ 582	400	50	0.16	450	0.03	275	310	8	45
		500	37	0.17						
7075	640/ 475	450	40	0.13	400	0.17	100	230	16	
Low-Melting Metals										
Sn	232							15	45	100
Pb	327	100	101	0.1				12	35	100
Zn	417	75	225	0.1				130/ 170	65/ 50	
		225	40	0.1						
High Temperature Alloys										
Ni	1446/ 1435						140	440	45	65
Hastelloy	1290	1150	140	0.2			360	770	42	
Ti (99%)	1660	600	200	0.11			480	620	20	
		900	38	0.25						
Ti-6Al-4V	1660/ 1600	600	550	0.08			900	950	12	
		900	140	0.4						
Zirconium	1852	900	50	0.25			210	340	35	
Uranium (99.8%)	1132	700	110	0.1			190	380	4	10

Formulae Sheet

1) Casting

$Energy = \rho V\left[C_{solid}(T_{melt} - T_{initial}) + \Delta H + C_{liquid}\left(T_{pour} - T_{melt}\right)\right]$		
$Q = A_1 v_1 = A_2 v_2$	$Re = \frac{vD\rho}{\eta}$	$t = C\left(\frac{V}{A}\right)^n$
$P_0 + \frac{\rho v_0^2}{2} + \rho g h_0 = P_1 + \frac{\rho v_1^2}{2} + \rho g h_1 + f$		

2) Mechanical Behaviour of materials

$\sigma_{eng} = \frac{F}{A_o}$	$e = \frac{\Delta l}{l_o}$	$\sigma = \frac{F}{A_i}$	$\varepsilon = ln\left(\frac{l_i}{l_o}\right)$
$\sigma = \sigma_{eng}(1 + e)$	$\varepsilon = \ln(1 + e)$	$\dot{\varepsilon} = \frac{v}{l} = \frac{v}{h}$	$\sigma = K\varepsilon^n$
$\sigma = C\dot{\varepsilon}^m$	$\Delta T = \frac{u_{Total}}{\rho C}$	$\bar{Y} = \frac{K\varepsilon^n}{n+1}$	$T_h = \frac{T}{T_{mp}}(K)$
$\sigma_{max} - \sigma_{min} = Y$	$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2Y^2$		

3) Bulk Deformation

Forging

$P = Y'e^{\left[\frac{2\mu}{h}(a-x)\right]}$	$P_{avg} \simeq Y'\left(1+\frac{\mu a}{h}\right)$	$P = Y'\left(1+\frac{a-x}{h}\right)$
$P_{avg} = Y'\left(1+\frac{a}{2h}\right)$	$P = Ye^{2\mu\frac{(r-x)}{h}}$	$P_{avg} \cong Y\left(1+\frac{2\mu r}{3h}\right)$
$P = Y\left(1+\frac{r-x}{h}\right)$	$P_{avg} \cong Y\left(1+\frac{r}{3h}\right)$	$F = P_{avg}Area$

Rolling

$L = \sqrt{R\Delta h}$	$\tan(\alpha) = \sqrt{\frac{\Delta h}{R}}$	$\mu \geq \tan(\alpha)$
$\Delta h_{max} = \mu^2 R$	$h_{min} = \frac{C\mu R}{E'}(\sigma_{flow} - \sigma_t)$	$E' = \frac{E}{1-v^2}$
$\dot{\varepsilon} = \frac{V_r}{L} ln\left(\frac{h_f}{h_o}\right)$	$\bar{Y} = \frac{K}{\varepsilon_1 - \varepsilon_0}\left[\frac{\varepsilon_1^{n+1} - \varepsilon_0^{n+1}}{n+1}\right]$	$h_{avg} = \frac{h_o + h_f}{2}$
$p_{avg} \cong 1.15\bar{Y}_{flow}\left(1+\frac{\mu L}{2h_{avg}}\right)$	$p_{avg} \cong 1.15\bar{Y}_{flow}\left(1+\frac{L}{4h_{avg}}\right)$	
$T = \frac{F_r L}{2}$	$\omega = 2\pi N$	$Power\ (P) = \omega T$

4) Sheet metal forming

Shearing

$F_{max} = 0.7(UTS)tL$		

Bending

$F_{max} = k\frac{(UTS)Lt^2}{W}$	$\frac{R_i}{R_f} = 4\left(\frac{R_iY}{Et}\right)^3 - 3\left(\frac{R_iY}{Et}\right) + 1$	$e_o = \frac{1}{\left(\frac{2R}{t}\right)+1} \leq e_u$
$Minimum\ \frac{R}{t} = \frac{50}{r} - 1$		

Drawing

$F_{max} = \pi D_p t_o (UTS)\left(\frac{D_o}{D_p} - 0.7\right)$	$DR = \frac{D_o}{D_p}$	$LDR = \frac{D_o(max)}{D_p}$

Anisotropy

$R = \frac{\varepsilon_w}{\varepsilon_t}$	$\bar{R} = \frac{R_0 + 2R_{45} + R_{90}}{4}$	$\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}$

5) Powder metallurgy, ceramics and polymers

$p_x = p_o e^{-4\mu k x/D}$	$V_{sint} = V_{green}\left(1 - \frac{\Delta L}{L_o}\right)^3$	$L_{sint} = L_{green}\left(1 - \frac{\Delta L}{L_o}\right)$
Polymer Extrusion		
$Q = Q_d - Q_p$	$Q_d = \frac{\pi^2 H D^2 N sin\theta cos\theta}{2}$	$Q_p = \frac{p\pi D H^3 sin^2\theta}{12\eta l}$
$Q_{die} = Kp$	$K = \frac{\pi D_d^4}{128\eta l_d}$	$P_{ext} = \rho Q C(T - T_{RT}) + \rho Q H + \Delta P Q$

6) Welding and Joining

$\frac{H}{l} = e\frac{VI}{v}$	$v = e\frac{VI}{uA}$	$H = I^2 Rt$