Manufacturing Processes 1

Duration: 3 hours. Max Marks: 100

Note: (i) Closed book. Closed Notes. Students may use a single (1) self-prepared A4 sheet (both sides may be used) for the examination. It must be in their own handwriting and must be submitted with the answer-book

(ii) Make assumption wherever necessary and state it clearly.

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1. A stress tensor is given by

$$\sigma = \begin{bmatrix} 1 & 5 & -5 \\ 5 & 2 & 0 \\ -5 & 0 & -1 \end{bmatrix}$$

Determine this stress tensor as represented in a new axes system defined by orthogonal vectors:

U= **a** + 2**b** + 3**c** ; **V** = **a** + **b** – **c** ; **W** = -5**a** + 4**b** – **c**

where **a**, **b** and **c** are vector fields defined in the former orthogonal axes system. **[3]**

2. The principal axes of orthotropic symmetry are given by x, y and z. Hill's yield function in this case is given by:

$$2f(\sigma_{ij}) = F(\sigma_{yy} - \sigma_{zz})^2 + G(\sigma_{xx} - \sigma_{zz})^2 + H(\sigma_{xx} - \sigma_{yy})^2 + 2L\tau_{yz}^2 + 2M\tau_{xz}^2 + 2N\tau_{xy}^2 = 1$$

where *F*, *G*, *H*, *L*, *M* and *N* coefficients define the orthotropic symmetry in the yield function. How the onset of yielding in an orthotropic sheet metal can be predicted when a direct stress σ is combined with a shear stress τ in case (i) when σ and τ are aligned with the in-plane orthotropic axes x and y and (ii) when they are inclined at θ to the x and y axes in the counterclockwise direction? Consider complimentary shear stress in each case. **[7]**

3. Consider an axes system in which the two axes X and Y are at an angle θ. If the stress tensor is given by $\sigma_{ij} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{pmatrix}$, determine the angle that the principal axes will make from the X and the Y axes. Also determine the values of principal stresses. **[10]**

4. A thin-walled cylinder, with inner and outer radii r_1 and r_2 mm respectively is strained to the tensile yield point. Then the cylinder is subjected to an increasing torque while the simultaneous tension is maintained so that tensile yield strain Y/E is constant. Determine the stress state in the cylinder by assuming a non-hardening material. **[10]**

5. Set up an equation to simulate deformation of a tailor welded blank across the weld in uniaxial tension (i.e., tensile axis is perpendicular to the weld). Sheet thickness being equal on either side of the weld, what should be the ratio of the *n* values so as to obtain 60% of the total strain in the gauge length on one side (say, side A) of the weld and the remaining 40% on the other side (say, side B) of the welded joint ?

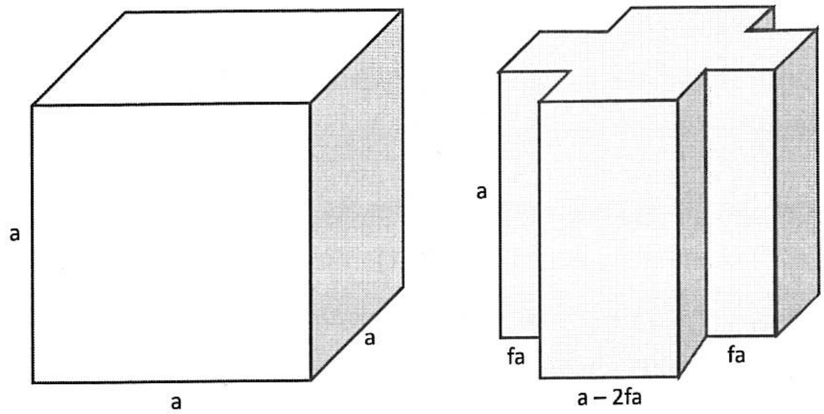
   What ratio of thickness would give the same result if material properties were the same across the weld (i.e., if the same value of *n* prevailed across the weld). Calculate the weld line movement. Assume the constitutive equation to be $\sigma = K\varepsilon^n$ and assume the weld to initially lie midway in the gauge length. Neglect the deformation in the weld.

6. Show using the Mohr's circle analysis the effect of plastic strain ratio, '*R*' on the orientation of the localised neck with reference to the tensile direction in uniaxial tension.

7. The stress strain curve of a rigid/plastic metal can be accurately fitted (except for very small strains) by the Ludwik equation $\sigma = C\varepsilon^n$. It is required to approximate this curve by the straight line $\sigma = Y + H\varepsilon$, giving the same plastic work over a total strain of $\varepsilon = \varepsilon_o$. Also, the stress difference in the stress values determined by the two equations at $\varepsilon = \varepsilon_o/2$ is half of that at true strain of ε_o. Show that $\frac{Y}{\sigma_o} = \frac{3-n}{1+n} - 2^{1-n}$; $\frac{H\varepsilon_o}{2\sigma_o} = 2^{1-n} - \frac{2-n}{1+n}$; where $\sigma_o = C\varepsilon_o^n$. Assuming n=0.3, and that at a true strain of ε_o the straight line prediction exceeds that of the Ludwik equation, estimate the maximum percentage error in the linear approximation where the straight line falls below the curve described by the Ludwik equation.

8. A foundry consultant claims to improve casting yield by placing a notch in feeders. You are concerned that casting quality will suffer (due to shrinkage cavities). To verify the claimed benefit, check how notch size (as a fraction of feeder size) affects: (i) ratio of notched feeder yield to plain feeder yield, and (ii) ratio of solidification time of notched feeder to that of plain feeder. Plot the two graphs to visualize the variations and discuss your conclusion. Assume casting volume is twice the volume of plain feeder (without notch). The feeder shape is cubic,

and is directly connected to casting top (without any neck). During solidification, take heat transfer coefficient at internal corners of notch as negligible compared to that at external faces.



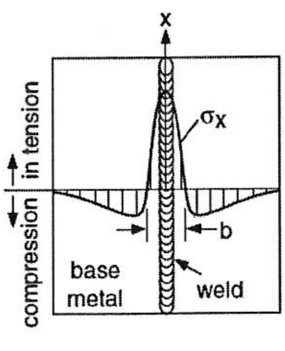
9. Al and Si form a binary eutectic at 13 wt% Si that solidifies at 577 °C. Thermodynamic data for the solidification of the pure phases are given in the table below. The solubility in both phases is very limited in the solid state.

Material	T_f(K)	C_{pl} (J/gK)	C_{ps} (J/gK)
Al	933	1.176	$0.7657 + 4.586 \times 10^{-4} T$
Si	1683	0.912	$0.8535 + 8.786 \times 10^{-5} T - 1.473 \times 10^{4} / T^2$

(a) Compute the latent heat of fusion of the pure phases (Al and Si) at eutectic temperature and at melting temperature (T_f) **[4]**

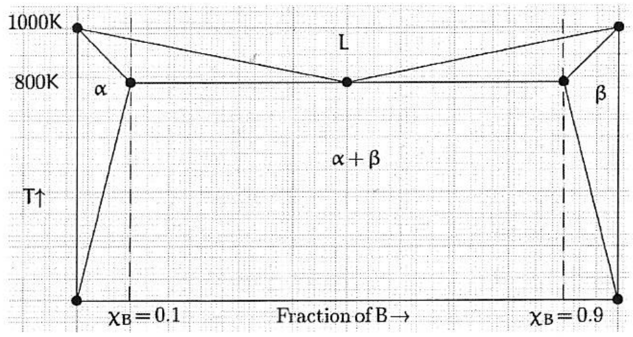
(b) Use simple rule of mixture to estimate the latent heat of fusion of the eutectic. **[2]**

10. Based on three bar analogy explain the residual stress development in fusion welding as shown in the figure. If this welding is diffusion welding (solid state) of aluminum and titanium sheet (where thermal coefficient $\alpha_{Al} > \alpha_{Ti}$) explain the residual stress development. **[10]**



11. During arc welding temperature distribution (in K) at the top surface of a thick sample (A_fB_{1-f} alloy) as a function of time (t) and the distance (r) from the weld centerline is given below:

$$T(r,t) = T_o + \frac{q}{2\pi\lambda v t}\exp\left(-\frac{r^2}{\alpha t}\right)$$



Phase diagram of the alloy A_fB_{1-f} is eutectic as shown here, in which all the phase separating curves are straight lines.

Material and process parameters are as follows: thermal conductivity (λ) = 50W/m/K, density(ρ) = 7850kg/m3, specific heat (C_P) =0.45kJ/kg-K, initial temperature (T_o) of the plate = 300K, weld current (I) = 150 A, voltage (V) = 20 volts, welding speed (v) = 2.5mm/s, weld efficiency= 0.6. Assume that the recrystallization temperature is 70% of the mean of eutectic and liquidus temperature.

Answer the following:

a) Explain the three zones of arc characteristic in arc-welding. **[6]**

b) Based on the equation above, derive an expression for the time it takes to reach maximum temperature at a given distance r from the weld centerline **[2]**

c) Width of fusion zone (FZ) at top surface of the welded $A_{0.25}B_{0.75}$ alloy sheet **[2]**

d) Which alloy will show wider HAZ, $A_{0.25}B_{0.75}$ or the one with eutectic composition **[2]**

e) Is it possible that two different alloy compositions after welding lead to the same width of FZ as well as HAZ? **[2]**