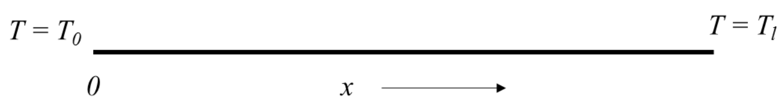
# PhD Qualifying Exam – 2015
# Manufacturing Processes-I

- Full marks 100
- No books or notes allowed
- Please make (and clearly state) any suitable assumption if required

1. In direct chill castings, the mold is filled with liquid metal and then brought in contact with a chill which is kept at a temperature lower than the melting point. Consider a one-dimensional, semi-infinite region $0 < x < \infty$ filled with a pure liquid metal, having a melting point $T_m$. The initial temperature of the liquid is $T_l$ at $t = 0$.




The temperature of the boundary surface x = 0 is suddenly brought in contact with a chill which is maintained at a temperature $t = T_0$, $T_0 < T_m$. This initiates the phase-change process from liquid to solid. Let $k_l$ and $k_s$ be the conductivities of liquid and solid phases respectively. Assume the densities and specific heats to be identical and constant in both the phases. Let $L$ be the latent heat of fusion.

   a. Write the heat conduction equation in liquid and solid phases
   b. How would you locate the solid-liquid interface? Describe the interface heat balance.
   c. Draw an approximate temperature profile (distance x vs. temperature T) in both the phases at time $t > t_0$, clearly showing the solid-liquid interface.
   d. If the length of the domain is L, and the location of the interface is $x = s(t)$, $0<s(t)<L$, write the expressions for calculating mass fractions of solid and liquid phases.

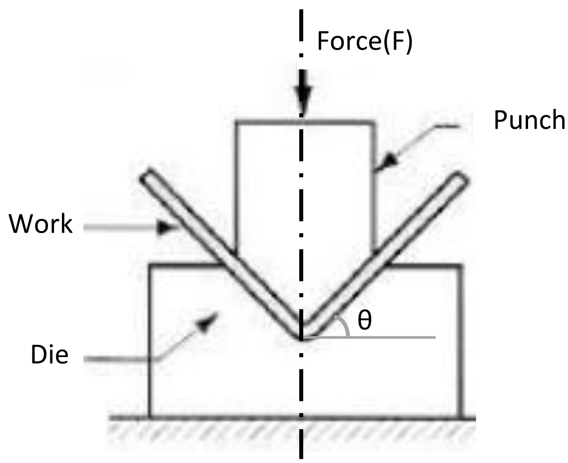
[20]

2. Shrinkage is a common problem in weld components. Consider the solidification process during the welding of a pure metal in one-dimension $0 < x < L$. Let $v_x$ be the speed at which solid-liquid interface is moving towards the weld pool. Consider that there is a density difference between the solid and liquid phases, for e.g., $\rho_s > \rho_l$.
   a. Will there be any difference in the phase change process compared to **Question 1**?
   b. If yes, what would you expect to happen at the solid-liquid interface? Write the mass conservation equation at the interface.
   c. What do you understand by the term 'solidification shrinkage'? Show how shrinkage velocity can be determined.
   d. Derive the expressions for volumetric and percentage relations for solidification shrinkage for a one-dimensional rod of length L.
   e. How does density difference affect calculation of mass and volume fraction values of solid and liquid phases?
   f. Give an example of a pure substance, for the following cases: (i) $\rho_s > \rho_l$ and (ii) $\rho_s < \rho_l$

[20]

3. In the wire drawing process, a wire of initial diameter of 50 mm is reduced to its final diameter 30 mm in two ways: (i) 50mm →40mm followed by 40mm →30mm (ii) 50mm →30mm in a single shot. In which case, plastic work is more? Material follows $\overline{\sigma} = 450\,\overline{\epsilon}^{0.5}$ strain hardening law. [10]

4. In a frictionless sheet bending operation, what should be the critical bending angle at which the punch force is maximum? Justify your answer by deriving necessary equation based on your assumptions. [15]




5. Estimate (with derivation) the longitudinal and transverse elastic modulus of a composite in which fiber and matrix have elastic modulus as 1234MPa and 567MPa respectively and fiber occupies 40% volume in the composite. Draw upper and lower bound of effective elastic modulus as a function of fiber volume fraction based on the derived equations. [5]

6. A hollow cylinder with ID=5 cm, OD=25 cm, and height=20 cm has to be cast with its hole in vertical direction. The cast metal is steel, which has a volumetric shrinkage of 5%. Estimate the volume of shrinkage defect, and show in a sketch where it will occur. Then design a top cylindrical feeder with H/D=2, considering two principles: (i) feeder must contain sufficient feed metal, and (ii) feeder should solidify later than the casting. Assume that solidification time of a simple shape depends on the square of its geometric modulus (that is, ratio of volume to cooling surface area). Check which of the two principles results in a larger size of feeder. Assuming that the first principle is critical, list the circumstances when the second principle will underestimate the feeder size. [15]

7. A hollow cylinder with ID=5 cm, OD=25 cm, and height=20 cm has to be produced in cast iron (assume zero overall volumetric shrinkage). The casting cavity is placed centrally in a sand mold of height 40 cm, with the core (for producing the hole) oriented vertically. Metal is poured in a cup at the top of mold, flows through a vertical sprue that reaches up to the (vertical) middle of the mold, and enters the casting cavity through a horizontal gate. Assuming that the pouring cup is kept full by the pouring system, and there are no flow losses, calculate the cross-section area of gate to ensure that the casting fills in exactly 20 seconds. Then calculate the Reynolds number, assuming that the kinematic viscosity of molten iron at its pouring temperature is the same as that of water at room temperature. List at least two ways to reduce the turbulence for this casting. [15]