DEPARTMENT OF MECHANICAL ENGINEERING IIT BOMBAY

QUALIFIER EXAMINATION JANUARY 2020

Day & Date : Thursday, 16th January 2020 **Max marks : 100**
Duration : 3 hours
Notes : Open book, notes, handbooks, textbooks. All these may be used during the examination.

1. A flat steel plate of 5 mm thickness and width 2000mm has to be rolled from a slab of thickness 50mm and 2000mm width. The roll diameter is 800mm, and its length is 2400mm. The plate yields at 50 MPa and the Youngs Modulus for steel is 210 GPa. The material work hardens as $\sigma = 500*\varepsilon^{0.20}$. Neglecting roll flattening, determine the camber to be given on the rolls so as to achieve a reduction of 10mm in the thickness of the slab in a single pass. Rolling is to be performed at the temperature at which the properties have been specified here. The maximum roll deflection y_{bmax} may be estimated from the equation

   $y_{bmax} = P_c w^2/(6*3.1415*ED^4)*(5w + 24n)$

   where P_c is the Design load based on the nominal value of the safe working stress in the rolls; Roll length is given as $w + 2n$, where n (=200mm) is the length of the roll neck and w the length of the roll with a diameter 800mm.

   Assume yield strength of the roll material to be 1000 MPa, and the coefficient of friction to be 0.3. [8]

Why is it important to restrict the spread and roll under plane strain condition ? [1]

Is it possible to avoid camber on the rolls completely using front and back tension, if the tolerance on thickness variation is ±0.5mm ? [4]

2. A displacement field in a deforming body may be expressed as

$u = 0.01*x^2 (x^2+y^2)$

$v = 0.005*y^2(x^2 + y^2)$

Determine the nine components of the strain tensor at point P(2,3,4).

The flow stress at this state of deformation (as above) was found to be 350 MPa. With additional true strain of 0.20, the state of stress at that point may be given by the following stress tensor :

$$\sigma = \begin{bmatrix} 450 & 100 & 125 \\ 100 & 350 & 75 \\ 125 & 75 & 100 \end{bmatrix}$$

Determine the values of *K* and *n* if the material work hardens as $\sigma = K\varepsilon^n$

Determine the increments in the strain components and components of the total accumulated strain at the point P(2,3,4). [15]

3. A can (like a beverage can for instance) may be made from a flat sheet metal blank by various processing routes like (a) drawing followed by redrawing (b) Drawing followed by ironing (c) shear spinning (d) shear spinning followed by deep drawing.

Which of the manufacturing routes would you recommend to make the beverage can, and why ? [5]

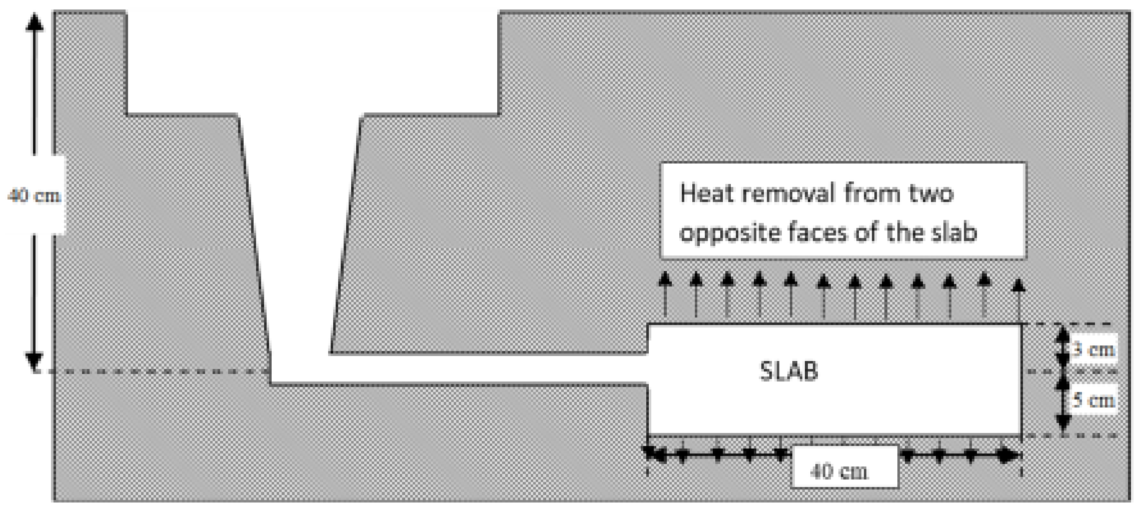
4. Which two factors are to be considered for deciding the location of risers in casting? Why? [3]

5. Which casting process would you choose for the following and why? [3]

a. Engine block b. Steel pipes c. Carburetor

6. A slab is to be produced via the sand-casting arrangement shown in the picture below. Calculate the total time of filling and solidification using the information given below. It is preferred that the following sub-questions are sequentially attempted, however, you may skip a sub-question or solve later if you really wish.

(a) Assume that superheat is sufficient to avoid freezing until the mould is full. Calculate the pouring time for the following square slab casting (assume the pouring cup is always full and the gate area is 3 cm^2). The width of the slab is 30 cm. $g = 10\ m/s^2$ [8]



(b) For solidification time calculation, consider heat loss through the upper and lower faces as indicated from the arrow. All other faces can be assumed to be insulated. Also assume that the melt is at a uniform temperature with 5 ºC superheat. The sand and metal properties are as follows: The mold is initially at a temperature of 100 ºC. The metal is poured at its melting point of 1100 ºC. The density, specific heat, latent heat of melting, and conductivity of metal are 7000 kg/m^3, 700 J/kg/K, 100 kJ/kg, and 80 W/m/K respectively. Similarly, the density, specific heat, and conductivity of the sand are 1600 kg/m^3, 1000 J/kg/K, and 1 W/m/K [7]

(c) Draw an approximate grain structure of the sand casting, considering it as an alloy. Also mark possible regions of eutectic microstructure formation.

[3]

(d) The average grain size is expected to be proportional (inverse) to the cooling rate $(\dot{T})^{-0.25}$ where $\dot{T} = G * V$, *G* being an *approximate* temperature gradient and *V* being *approximate* solidification velocity (solidification distance/time). For improving the yield strength, chills (made of metallic dies) are placed along the heat removal surfaces, which are maintained at 100 ºC. The heat transfer coefficient between the chill and solidified metal is 200 W/m^2/K. Estimate the percentage change in the grain size, upon enabling cooling through the chills.

[7]

(e) Draw an approximate compositional profile of the alloying element along the height (8 cm) of the slab, and briefly describe the trend.

[3]

6. As shown in figure 1 below, thicknesses of two steel workpieces vary from t1 to t2 over their lengths L. These workpieces are to be welded using an electric arc welding setup, on which the welding speed can be programed to vary as function of time, during the welding process. The voltage, E and current, I cannot be varied during the process. The welding process inputs are as following:

η = 0.9; f = 0.3; E = 25 V, I = 160 A, Q = 10 J/mm^3, t_1 = 5 mm, and $t = t_1\sqrt{e^{-Al}}$, where A = 0.01 mm^{-1}

a. Derive an expression of welding speed, V w.r.t thickness t. Assume cross-sectional welded area, Aw is semi-circular in shape. [3]
b. Express welding speed, V w.r.t. length l. [2]
c. Derive an expression for welding time w.r.t length l. [3]
d. Manipulate above to express welding speed as function of time. [2]
e. Calculate the total time required to perform the weld. [5]
f. For L = 100 mm, plot welding speed w.r.t. welding time, for values corresponding to 0 mm, 20 mm, 40 mm, 60 mm, 80 mm and 100 mm along the length of the workpieces. [5]

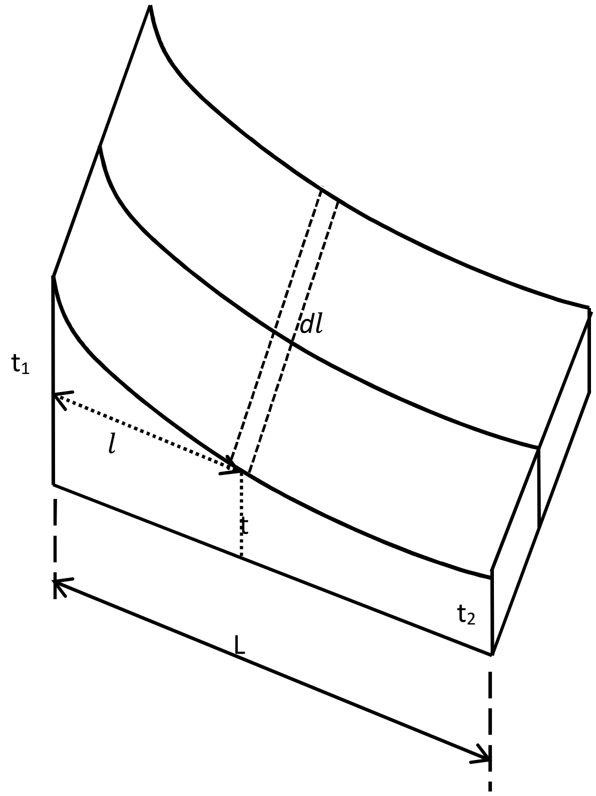


Figure 1. Two steel workpieces with varying cross-section

7. Based on the three bar arrangement/analogy in welding process as shown in figure:

   a. Justify the trend of each path AB, BC, CD and DE and the mode of deformation (elastic/plastic) for each segment. [4]
   b. What is the approximate yield stress (in MPa) of the material under tension and compression? [2]
   c. How this path (A→B→C→D→E) will change if the same material also undergoes phase transformation upon heating at 700°F leading to 20% dilation? Explain by drawing aschematic. [3]
   d. If the coefficient of thermal expansion of the middle bar is 10^{-5} ($^{o}C^{-1}$), how much percentage elongation of the middle bar (for point B) would have occurred if it were not constrained by the two side bars?

      [4]

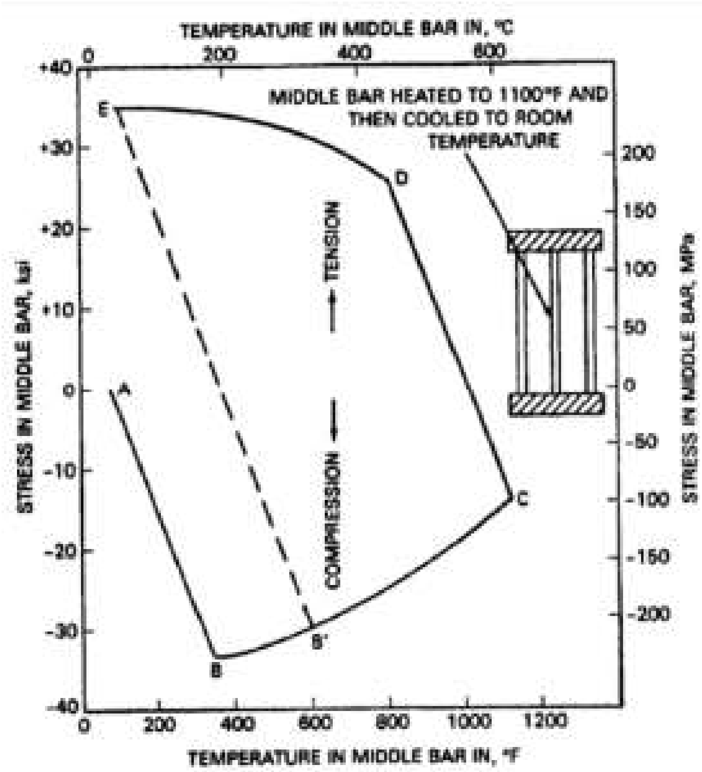


Figure 2. Three bar analogy for welding process