Indian Institute of Technology, Bombay / Department of Mechanical Engineering
ME 206 - Mid Semester Examination - 2023

Time : 120 mins Max. Marks : 40

Answer briefly and precisely. One reason is needed for the selection of your choice for Question No. #2, #3

1. Chvorinov's law states that the time to solidification (t_s) of a cast can be written as: $t_s = \beta(V/A)^2$, where β is a constant, and V and A are the volume and surface area of the cast, respectively. Considering the above relation, find out the relative time to solidification for castings of the following different shapes (a to e), which are of identical volume and same material.

   (a) a sphere of diameter d

   (b) a cylinder with h/d = 1, where h and d are height and diameter, respectively

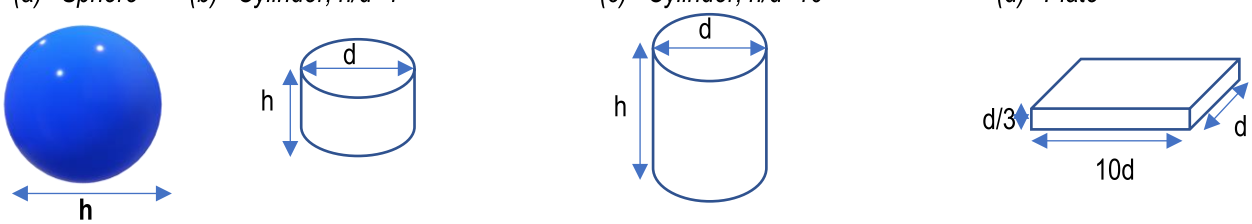
   (c) a cylinder with h/d = 10, where h and d are height and diameter, respectively

   (d) a flat plate with length = 10d; width = d and thickness = d/3

   Plot in your answer book the time to solidification (t_s) of the above shapes as a function of the corresponding surface area and comment on the results. [4 X 2 + 2]

Ans-

(a) Sphere (b) Cylinder, h/d=1 (c) Cylinder, h/d=10 (d) Plate



Surface Area

$A_a = \pi d^2$

$$A_b = \pi dh + \frac{\pi d^2}{2} = \pi d^2\left(\frac{h}{d} + \frac{1}{2}\right) = \frac{3}{2}\pi d^2$$

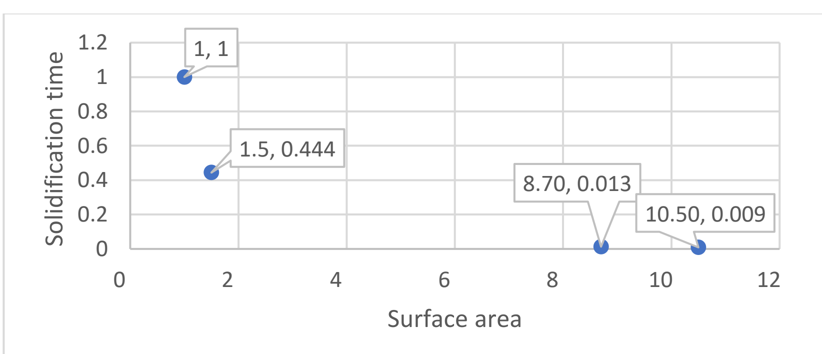
$$A_c = \pi dh + \frac{\pi d^2}{2} = \pi d^2\left(\frac{h}{d} + \frac{1}{2}\right) = \frac{21}{2}\pi d^2$$

$$A_d = 2\left(\frac{10d^2}{3} + \frac{d^2}{3} + 10d^2\right) = \frac{82d^2}{3}$$

Same material and identical volume so, Solidification time $t_s \; \alpha \; \frac{1}{A^2}$, Relative solidification time w.r.t sphere given below:

$$\frac{(t_s)_a}{(t_s)_a} = 1 \qquad \frac{(t_s)_b}{(t_s)_a} = \left(\frac{2}{3}\right)^2 = 0.444 \qquad \frac{(t_s)_c}{(t_s)_a} = \left(\frac{2}{21}\right)^2 = 0.009 \qquad \frac{(t_s)_d}{(t_s)_a} = \left(\frac{3\pi}{82}\right)^2 = 0.013$$

Let $A_a = 1$ *then* $A_b = 1.5, A_c = 10.5, A_b = 8.7$ *and* $(t_s)_a = 1,\ (t_s)_b = 0.444, (t_s)_c = 0.009, (t_s)_d = 0.013$



With increase in surface area, solidification time decreases. As seen by the decreasing order of solidification times $(t_s)_a > (t_s)_b > (t_s)_d > (t_s)_c$, the sphere will solidify last, followed by the cylinder with h/d=1, the plate, and finally the cylinder with h/d=10.

2. Which ONE of the following processes will result in the highest surface roughness of the cast? [2.5]
(i) sand casting (ii) lost foam casting (iii) die casting (iv) centrifugal casting

Reason: *Mold surface is not so smooth in sand casting because of sand particles. High temperature of the molten metal can lead to degradation of mold surface, which can produce conditions that lead to high surface roughness.*

3. Consider that an alloy is compressed at room temperature. As the amount of deformation increases, the ratio of the ultimate tensile strength of the alloy to its yield strength will approach to [2.5]
(i) 1 (ii) 0 (iii) ∞ (iv) 0.5

Reason: *When the material gets compressed, the yield strength of the material approaches the ultimate tensile strength. So, ratio of the ultimate tensile strength to yield strength will approach to 1.*

4. The forging force F to carry out an impression-die forging operation is given as: $F = kY_fA$, where k is a factor that is directly influenced by the volume of flash during forging, Y_f is the average flow stress of the material, and A is the projected area of the forging. State two points with reasons how the forging force can be reduced. [2.5]

Ans- *(a) Impression-die forging at elevated temperatures (hot forging): because of the high surface area to thickness ratio of the flash gap, the flash cools faster than the work piece. As the flash resists deformation more than bulk, filling of the die cavity takes place with low force. Flow stress, Y_f value decreases at elevated temperature.*

(b) Reducing the projected area of forging including the flash, A: High frictional resistance of the material in radial outward direction due to flash gap and land helps in reducing the forging force.

5. A solid cylindrical steel disc with an initial diameter of 150 mm and height of 100 mm is reduced in height by 50% at room temperature by open-die forging with flat dies. The coefficient of friction (μ) between the forging dies and disc is 0.2 and the average flow stress Y_f of the steel is 1000 MPa. It is given that the forging force at the end of the stroke for open die forging can be calculated as [5]

$F = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h}\right)$ where h is the final height and r is the final radius of the disc. Please calculate the – (a) absolute true strain experienced by the disc, and (b) forging force F.

Ans- *(a) Let initial height h_0 = 100 mm, 50% height reduction, so final height h = 50 mm.*

$$True\ strain = ln(\frac{h_0}{h}) = ln\frac{100}{50} = 0.693$$

(b) Volume consistency: $\frac{\pi}{4}d_0{}^2h_0 = \frac{\pi}{4}d^2h$, so $d = d_0\sqrt{\frac{h_0}{h}}$ =212.132 mm, r = 106.066 mm

Forging force $F = 1000\pi(106.066)^2\left(1 + \frac{(2)(0.2)(106.066)}{(3)(50)}\right)$ =45.339 MN

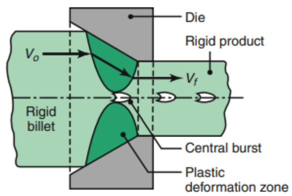
6. What are the four most important factors, which influence the force required during direct extrusion process? [5]

Ans- *The force required for extrusion depends on*
(a) the strength of the billet material,
(b) the extrusion ratio,
(c) the friction between the billet and the chamber and die surfaces, and
(d) process variables, such as the temperature of the billet and the speed of extrusion.

7. ***Center-burst*** (or *arrowhead fracture* or *chevron cracking*) and ***pipe-defect*** (or *tailpipe* or *fishtailing*) are two major defects, which are faced during extrusion of metallic materials. With a schematic sketch, state two likely reasons and two possible remedies for each of those two defects. Please answer in bulleted points only. [5]

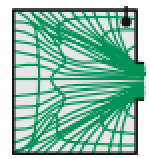
Ans-

Center-burst *(arrowhead fracture or chevron cracking)*



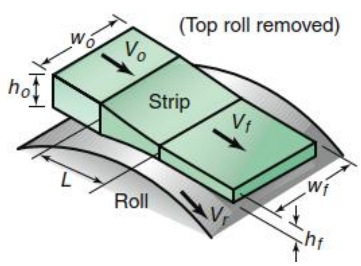
- *Hydrostatic tensile stress at the centerline*
- *Two plastic zones do not meet*
- ✓ *Decrease in die angle*
- ✓ *Increasing extrusion ratio and friction*
- ✓ *Decreasing amount of impurities*

Pipe-defect *(or tailpipe or fishtailing)*



- *Surface oxides at the center of the billet*
- *Impurities at the center of the billet*
- ✓ *More uniform flow pattern modification*
- ✓ *Billet's surface machining prior to extrusion*

8. In a flat rolling process of a strip (as shown in the figure below), [2.5 x 3]



the length (L) of contact between the roll and strip is usually estimated as: **L = [R×(h_0 - h_f)]**$^{0.5}$, where $\mathbf{h_0}$ is initial strip height, $\mathbf{h_f}$ is final strip height, **R** is roll radius, and **(h_0 - h_f)** is referred to as the maximum possible draft. If a 250 mm wide (**w_o**) copper strip of initial height (**h_0**) 25 mm is rolled to a final height (**h_f**) 20 mm in one pass by a roll of radius 300 mm, what will be the

(a) roll-strip contact length (**L**)?, and,

(b) absolute true strain experienced by the strip?

[It is given that the initial and final width of the strip remains the same].

(c) Since you know **(a)** and **(b)**, can you get roll force – please comment.

Ans- *Given w_0=250 mm, h_0=25 mm, h_f=20 mm,, R =300 mm, No of pass = 1*

(a) $L = \sqrt{R(h_0 - h_f)} = \sqrt{300(25-20)} = 38.73mm$

(b) $\epsilon = \ln\left(\frac{h_0}{h_f}\right) = \ln\left(\frac{25}{20}\right) = 0.223$

(c) Roll force is estimated as $F = Lw\tau_{avg}$; where τ_{avg}= average true stress. The roll force can not be calculated with the known values of L and w only. The value of τ_{avg} for a certain material is needed. Exact calculation of the force in rolling is difficult because of the uncertainties involved in (a) determining the exact contact geometry between the roll and the strip and (b) accurately estimating both the coefficient of friction and the strength of the material in the roll gap.