Mold Erosion

If we resolve the force exerted by metal stream, parallel and perpendicular to the mold bottom surface we get two forces (1) tangential force and (2) normal force. Tangential force induces shear stress in the mold material and normal force induces the compressive stress in the mold material. So we can define the constraint on mold erosion as follows:

(a) "Shear stress induced by melt jet should be less than the shear strength of the mold material."

(b) "Compressive stress induced by the melt jet should be less than compressive strength of the mold material."

Derivation of forces exerted by the melt jet

According to the Newton's second law

Force $F =$ rate of change of momentum

$$= \left(\frac{\text{mass} \times \text{change in velocity}}{\text{time}} \right)$$

$$= \dot{m} \times \text{change in velocity} \qquad \text{where } \dot{m} = \text{mass flow rate in kg/sec}$$

$$= \dot{m} \times (\text{final velocity - initial velocity})$$

So, for the molten metal striking the bottom of the mold

force exerted by jet on the mold bottom surface = mass flow rate × change in velocity

$$\Rightarrow F = \dot{m} \times \left(\begin{array}{l} \text{Velocity just before impingement of melt jet} \\ \text{- Velocity just at the time of impingement of melt jet} \end{array} \right)$$

$$\Rightarrow F = \dot{m} \times \left(V_{impinge} - 0 \right)$$

$$\Rightarrow F = \rho_m \times Q \times V_{impinge}$$

where $V_{impinge}$ = resultant impingement velocity of melt-jet at the mold bottom surface

Q = volume flow rate of molten metal

ρ_m = density of moltem metal

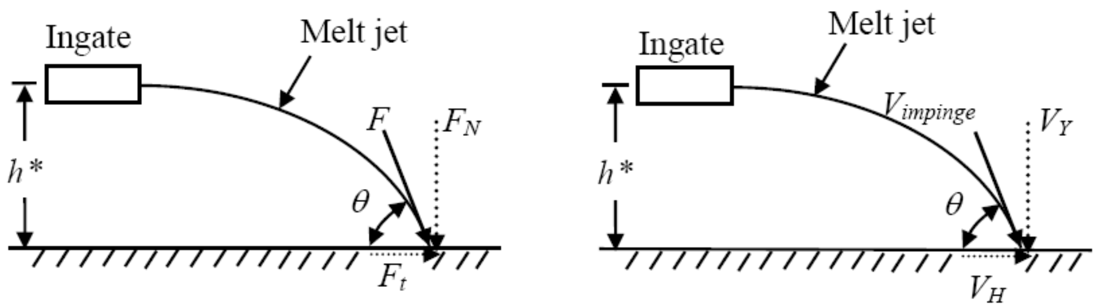


Figure (a) Representation of resolved forces of melt jet and (b) Representation of resolved impingement velocity of melt jet

Normal force exerted by the melt-jet

Normal force $F_N = F \sin\theta$ (F = resultant force exerted by melt jet)

$$\Rightarrow F_N = \rho_m \times Q \times V_{impinge} \sin\theta$$

$$\Rightarrow F_N = \rho_m \times \left(A_g \times V_g\right) \times V_{impinge} \sin\theta \qquad \left(\because \text{Q} = A_g \times V_g = \text{Volume flow rate of molten metal}\right)$$

Assuming that melt jet area at the point of impingement is same as melt jet area at ingate

$$\Rightarrow A_{impinge} = A_g$$

After substututing this value in the previous equation, we have

$$\Rightarrow F_N = \rho_m \times \left(A_{impinge} \times V_g\right) \times V_{impinge} \sin\theta$$

$$\Rightarrow \frac{F_N}{A_{impinge}} = \rho_m \times V_g \times V_{impinge} \sin\theta$$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times V_{impinge} \sin\theta \qquad \left(\because \frac{F_N}{A_{impinge}} = \text{induced compressive stress } = \sigma_Y\right)$$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times V_Y \qquad (\because V_Y = \text{vertical component of impingement velocity} = V_{impinge} \sin\theta\ )$$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times (V_{Y0} + a_Y \times t_{flight}) \qquad (V_{Y0}\ = \ \text{initial vertical component of velocity})$$

For projectile motion $a_Y = \ -\text{g}$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times (V_{Y0} - g \times t_{flight})$$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times \left(V_{Y0} - g \times \frac{1}{g}\left[V_{Y0} + \sqrt{V_{Y0}^2 + 2 \times g \times h^*} \right] \right) \quad \text{..}(4.9)$$

To avoid mold erosion,

compressive stress $\le$ compressive strength of mold

$$\Rightarrow \sigma_Y \le \ S_Y \qquad (4.10)$$

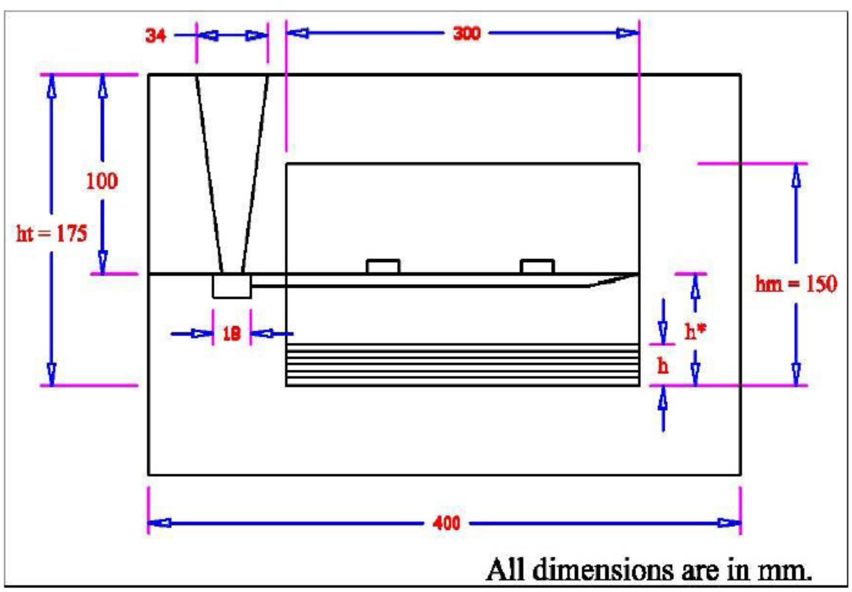
substituting equation 4.10 in 4.9, we get

$$\Rightarrow \rho_m \times V_g \times \left(\sqrt{V_{Y0}^2 + 2 \times g \times h^*} \right) \le \ S_Y$$

In the case of parting line or top gating system, we have

Initial projection angle, $\theta = 0$

As $\theta = 0 \Rightarrow V_{Y0} = V_g \sin\theta \ = 0$



From the figure 4.3 , $h^* = h_t - 0.1$

substituting the value of V_{Y0} and h^* in the equation 4.10, we have

From the figure 4.3 , $h^* = h_t - 0.1$

substituting the value of V_{Y0} and h^* in the equation 4.10, we have

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times \left(0 - g \times \frac{1}{g}\left[0 + \sqrt{0 + 2 \times g \times (h_t - 0.1)} \right] \right)$$

$$\Rightarrow \sigma_Y = \rho_m \times V_g \times \sqrt{2 \times g \times (h_t - 0.1)} \text{ .... } (compressive) \tag{4.11}$$

Now compressive stress induced by the melt jet should be less than compressive strength of the mold material.

That is,

$$\sigma_Y \le S_Y \tag{4.12}$$

Substituting equation 4.11 in 4.12, we have

$$\rho_m \times V_g \times \sqrt{2 \times g \times (h_t - 0.1)} \le S_Y \tag{4.13}$$

For aluminium

S_Y = mold compressive strength =117.19 kPa

S_H = mold shear strength = 68.94 kPa

Substituting these values in equation 4.13, we have

$$2380 \times V_g \times \sqrt{2 \times 9.81 \times (0.175 - 0.1)} \le 117198$$

$$\Rightarrow V_g \le 40.59 \ m/\text{sec} \tag{4.14}$$

Tangential force exerted by the melt-jet

$$F_T = F\cos\theta$$
$$= \rho_m \times Q \times V_{impinge} \times \cos\theta$$
$$= \rho_m \times \left(A_g \times V_g\right) \times V_{impinge} \times \cos\theta$$

substituting $A_{impinge} = A_g$, we get

$$F_T = \rho_m \times A_{impinge} \times V_g \times V_{impinge} \times \cos\theta$$
$$\Rightarrow \frac{F_T}{A_{impinge}} = \rho_m \times V_g \times V_{impinge} \times \cos\theta \qquad \left(\frac{F_T}{A_{impinge}} = \textit{induced compressive stress} = \sigma_H\right)$$
$$\Rightarrow \sigma_H = \rho_m \times V_g \times V_{impinge} \times \cos\theta$$

As we know during projectile motion, horizontal component of velocity remains constant only vertical component of velocity changes.

Hence $V_H = V_g = V_{impinge} \times \cos\theta$

$$\Rightarrow \sigma_H = \rho_m \times V_g \times V_g$$
$$\Rightarrow \sigma_H = \rho_m \times V_g^{\,2}$$

To avoid mold erosion ,
Shear stress $\leq$ Shear strength of mold

$$\Rightarrow \sigma_H \leq S_H$$
$$\Rightarrow \rho_m \times V_g^{\,2} \leq S_H \qquad (4.15)$$
$$\Rightarrow 2380 \times V_g^2 \leq 68.94 \times 10^3$$

$$\Rightarrow V_g \leq 5.382 \;\; m/\sec$$

From equations 4.14 and 4.15, it is clear that this constraint gives maximum limit of velocity of molten metal at the ingate. Beyond that velocity mold erosion takes place.