

ME 206 Manufacturing Processes I (S1)

Vishal Neeli

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1 Introduction

- The five M's of the manufacturing define the profitability of the manufacturing process
 - Men (women)
 - Machine
 - Materials
 - Money
 - Management
- Manufacturing processes can be classified into:
 - Shaping processes
 - alter the shape
 - * Solidification process
 - * Metal Removal process
 - * Deformation process
 - * Assembly process
 - Property enhancing processes
 - change the properties of the material
 - Ex: annealing, hardening
 - Surface enhancing processes
 - clean the surfaces or coat them
 - Ex: Surface oxidation
- Selection of manufacturing processes depends on various factors
 - Cost
 - Available infrastructure
 - Operating temperature
 - Required properties
 - Dimensions of required product

2 Casting Process

Pros:

- Complex forms, low cost
- Certain shapes cannot be machined
- One piece parts vs. multiple piece parts
- Design changes are easily incorporated
- High volume, low skilled labor
- Large, heavy parts can be made easily

Cons:

- Problems with internal porosity
- Dimensional variations due to shrinkage
- Trapped impurities, solids and gasses
- High-tolerance, smooth surfaces not possible
- More costly than stamping or extruding in some cases

2.1 Pattern

- It is the replica (usually a bit bigger) of the req product
- It should be cost efficient, easily machinable into common shapes.
Possible choices are:
 - Wood : more than 90% of the production happens with wood, absorbs moisture, relatively lower life
 - Metal: longer life, used in large quantity production, Al, cast iron and bronze are most used
 - Plastic : good corrosion resistance, smooth surfaces, do not absorb moisture, dimensionally stable, low weight
- Pattern types
 - Single piece pattern: Name says it all
 - Split pattern
 - Cope
 - split pattern: Same as split pattern except that parts are moulded separately
 - Gated pattern: Tree like structure with each branch holding the required shape

2.2 Allowances

- Shrinkage Allowance
When the metal changes from liquid to solid state and cools down in solid state, its volume reduces. So we make the pattern size more than the size required. This is called shrinkage allowance.
- Draft/ Taper Allowance
To avoid damage to the sand mould and casted metal on the internal walls while removing the metal after it cools, we need to provide extra material on the walls of the pattern. We typically use a tapering angle(angle at which pattern is bent outwards) of 1 deg to 3 deg.
- Machining/Finishing allowance
It is the extra material allowed to cut to smooth finish the product. The amount of machining depends on method of moulding method of molding and casting used, size and shape of casting, metal used in casting, required accuracy and finish
- Distortion / Camber allowance
Due to typical shape of some patterns (non symmetric) (T, U, V, W), after cooling down the shape will change due to uneven shrinkage, so we need to allow distortion allowance i.e, we need to bend the pattern in opp dir to the expected distortion to get correct shape. This varies between 2 to 20 mm.

2.3 Molds

- Expendable Molds: A new mold has to be produced for every cycle. Types: green sand, dry sand, shell, investment, plaster
- Permanent molds: Multiple usages, used in: die casting, centrifugal, pressure die, injection molding
- Required properties of moulding sand:
 - Refractoriness: Ability to withstand higher temperatures
 - Permeability: For the air to escape
 - Cohesiveness: Adhesive forces in sand
 - Flowability: It should flow uniformly to all the portions

2.4 Gates

Gate is the hole through which the molten metal flows into the mould cavity. Mainly 3 types of gates are used:

- Top gating: The gate is present at the topmost portion of the cavity. In this case, the metal poured through the gate hit the mould cavity floor with some force. This can cause the sand to erode and mix up with the molten metal. But this can be avoided by making the passage from runner to gate a bit above the runner floor. This will slow the metal.

- Bottom gating: In this case, gate is present at the lowest part of the mould cavity. After filling some part of the mould cavity, the process slows down as the pressure difference driving the flow of metal is getting reduced.
- Parting line gating: Gate is present at parting line or joining line of cope and drag.
- A top gating design is preferred over bottom gating design and parting gating design because in the case of top gating design, the gravity helps the molten metal to flow to intricate corners of the pattern.

2.5 Types of Casting

- Sand casting:
Advantages - This is cheap, this can be used for ferrous and non-ferrous materials. (Non-ferrous metals require high temp)
Disadvantages - Rough finish
- Investment casting
 - We first create a pattern out of wax (optimised for this process) and then dip it in slurry (silica). The slurry solidifies on the outer surface to required thickness. Then we heat the thing to melt wax and remove the wax completely to create an outer wall for the required shape. The liquid metal is poured into the solid slurry to create the required shape. After cooling down, outer shell can be removed
 - This has a smooth wall finish
 - It can be used to create complex shapes because wax can be easily bent
 - Also known as lost wax casting, precision casting
 - This is relatively expensive compared to sand casting
- Centrifugal casting
 - Molten metal is poured into a long cylinder and rotated, and it is cooled on the outer surface
 - The outer part cools faster and has smaller grain size
 - The lighter impurities present in the metal get accumulated at the inner surface. This can be removed by machining process in the inner surface
- Shell moulding
 - The required shape in metal is heated and some silica or sand made to stick to the metal and an outer shell is made.
 - Then liquid metal is poured into the mould.
 - Axial symmetry things can be made easily by this.
- Lost Foam/ Evaporation Pattern
 - A pattern is created using polystyrene and sand is used to support it.
 - The metal is directly poured into the polystyrene and the polymer evaporates and creating required shape
- Continuous casting
 - Partially solidified (outer surface) metal is sent through the roller and cooling liquid is sprayed
 - This creates uninterrupted long strands of metal
- (Pressure) Die casting
 - High cost
 - The dies are two shapes which lock into each other creating a cavity in between.
 - Before locking they are sprayed with some liquid to prevent sticking of molten metal to die
 - Metal is poured in cavity and pressure is applied to molten metal. Pressure ensures that metal reaches all the cavities and ensures that metal reaches everywhere before it starts solidifying. After removing ejector pins, dies get separated.
 - Cooling channels are present in the die which cool the metal. The whole can be completed as fast as 1 min.
 - In cold chamber die casting - higher melting point metals (preferred because it can cost higher to maintain metal in liquid state)
 - In hot chamber die casting - lower melting metal (can also be used for higher melting metal)

2.6 Casting Defects

- Misrun : metal solidified before reaching all places
- cold shut : meeting of two metal streams is not complete, i.e, metal flow was not able to reach parts of the mould cavity where two metal flows meets
- cold shot : Due to turbulence during the pouring of the metal, some solid globules form which become entrapped in the metal.
- Sand blow : The gas bubble in the cavity which entered the during pouring (or gases released by metal as it cools) stays in the cavity and create bubble shaped cavity.
- Pinholes : The small pores in the metal which are due to the gases which are released during solidification
- Blowholes : Blowholes are similar to pinholes but with larger holes.
- Shrinkage cavity: Depression or internal void created due to shrinkage of metal volume while cooling is called shrinkage cavity
- Hot tearing : when the casting is restrained from contraction by an unyielding mold during the final stages of solidification or early
- Sand wash : Irregularity in the surface of the casting that results from erosion of the sand mold during pouring

2.7 Trends

- Change in casting metal
 - Steel to ductile iron - lower material and conversion cost
 - Al to Al-Mg-Ti alloys - increase in strength to weight ratio
 - In alloy casting, we need to ensure that the composition remains the same throughout.
- Change in geometry
 - Wall thickness is reducing. This is because in casting of thick pieces, distortion happens and we want straight parts. In case, we have multiple thickness, then we can use chill to start solidification earlier at thicker points
 - Weight reduction and increasing shape complexity

3 Metal flow in typical casting

- Metal flow is turbulent. Turbulence causes mixing with air, sand erosion
- When metal flows against the mold wall erosion, vortex formation (air pocket/slag), splashing against the mold walls, air aspiration(due to reaction with mold material) and metal solidification.
- We can determine the reynold's numbers of molten metal.
- Velocity of the metal gets reduced due to loss by sudden change in cross section, etc.

$$v_{actual} = c_d \sqrt{2gh}$$

- Typical value of c_d is 0.6-0.8
- Friction can be ignored for considering loss in velocity of metal, losses due to change in cross section dominate the losses
- Sprue shape has to be shaped as a frustum pointing downwards because as the velocity of the metal increases (due to gravity), the area of cross section gets reduced ($A_1 v_1 = A_2 v_2$). If the shape is cylindrical or frustum pointing upwards, the flow separates from the mould walls and form a air cavity which can lead to defects.
- For multiple top gates, L gate (gate at the end of the sprue) has higher c_d compared to T gate. L gate has the highest flow rate (even if it is the farthest) due to inertia.
- To reduce defects in casting process due to erosion of sand mould, we need to ensure that Stress due to impact > Sand mould strength

- Velocity of the metal should not be very high, because high vel makes erosion and causes defects in metal product
- Desired $Re < 8000$

$$Re = \frac{\rho v D}{\mu}$$

- Surface turbulence (Jetting or fountaining effect) - Weber number (γ is the surface tension of the metal)

$$We = \frac{\rho v^2 d}{\gamma}$$

$We < 1$: No surface turbulence

$We < 10$: Mild

$We < 100$: High turbulence

- Bond number (Related to buoyancy)

$$B = \frac{\rho d^2 g}{\gamma}$$

$B < 1$: Surface tension dominate

$B > 1$: buoyancy force overcomes surface tension and leads to surface instability

3.1 Fluidity

- **Fluidity** in case of metal casting refers to the distance the metal can travel before solidifying. This is different from the physics definition (inverse of viscosity)
- Fluidity can be increased by increasing pressure and/or pouring temperature.
- No of gates has to be increased if the fluidity is low
- Pure metals have higher fluidity than alloys
- Spiral test / honeycomb test can be carried out to find the fluidity. This can also be simulated using finite element analysis software like Ansys etc.
- This also can be roughly estimated by doing some calculations:
Consider a metal at its melting point T_m poured into a channel of radius a with average flow velocity v . Let the metal solidify at a distance L_f in time t . The heat released by metal (latent heat) per unit time is equal to the heat conducted by the mold-metal interface. Let h be the heat transfer coefficient of mold-metal interface. Then

$$\rho_m \pi a^2 V \Delta H = (2\pi a L_f) h (T_m - T_0)$$

$$L_f = \frac{\rho_m v \Delta H a}{2h(T_m - T_0)}$$

- The above expression is valid only for pure metals since the melting point of alloys is not a single point but a range of temperatures
- Fluidity of alloys when solid grains are present can be expressed as

$$L_f = f_s^{cr} V t_s$$

where f_s^{cr} is the critical fraction of solid at which fluid stops

3.2 Aspiration effects in mold filling

- For a mold made up of permeable material (eg sand), the pressure of the metal stream should not be less than atmospheric pressure. Because if this happens gases from the baking of organic compounds in mold will enter the molten metal stream, producing porous casting. This is known as **aspiration effect**.
- Consider a sprue (part between pouring basin and gate) of uniform diameter of height h which lead to a mould cavity open to atmosphere (completely or partially through runner). Let the pressure at the start of the sprue be P and velocity v_1 . The pressure at the end of the sprue is P_{atm} (since it is open to atmosphere) and let the velocity be v_2 . Since the sprue diameter is uniform from continuity equation, we have $v_1 = v_2$. By applying Bernoulli principle,

$$P + \rho gh = P_{atm}$$

$$P = P_{atm} - \rho gh$$

Here, the pressure is less than the atmospheric pressure which causes aspiration.