Manufacturing Processes

Short notes for B.Tech Mechanical · GATE ME

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1. Introduction

- **Manufacturing** = turning raw material into useful products with the required shape, size and finish.

Group	Idea	Examples
Casting	Pour molten metal into a mould	Engine blocks, pump bodies
Forming	Plastic deformation, no material removed	Rolling, forging, extrusion
Joining	Join two or more parts	Welding, brazing, riveting
Machining	Remove material as chips	Turning, drilling, milling
Non-traditional	Remove material by spark, chemical, laser, etc.	EDM, ECM, LBM
Additive	Build layer by layer	3D printing (FDM, SLS)

2. Casting

➤ Pattern and allowances

- **Pattern** = replica of the part used to make the mould cavity. Materials: wood, metal, plastic, wax.
- Pattern allowances:
  1. **Shrinkage** (pattern made bigger; for cast iron about 1%)
  2. **Draft** (taper on vertical faces for easy removal)
  3. **Machining** (extra metal for finishing)
  4. **Distortion** (camber for shapes that warp)
  5. **Shake / rapping** (pattern made slightly smaller; negative allowance)
- **Core**: sand shape that makes holes and hollow parts; held by core prints. Chaplets support long cores.

Moulding sand

- Main parts: silica sand + clay (binder, e.g. bentonite) + water + additives.
- Properties: permeability (lets gases escape), refractoriness, green strength, dry strength, collapsibility, flowability.

Gating and risering

- Gating system: pouring basin → sprue → sprue well → runner → ingates. Sprue is tapered to avoid **aspiration** (air suction).

FORMULA Sprue taper (continuity + free fall): A_top / A_bottom = sqrt(h_bottom / h_top) (h measured from the liquid level in the basin).

FORMULA Fill time, top gating: t = Am H / (Ag sqrt(2gH)). Bottom gating: t = (Am / (Ag sqrt(2g))) x 2 (sqrt(H) − sqrt(H − hm)).

- **Riser** (feeder) supplies liquid metal to make up for solidification shrinkage. It must solidify after the casting.

FORMULA Chvorinov's rule: solidification time t = B (V/A)^2 (B = mould constant). V/A is called the modulus.

- For a given volume, a sphere has the smallest surface area, so it is the best riser shape; a cylinder with H = D is the practical choice.

EXAMPLE A 60 mm cube solidifies in 2 min. Time for a 120 mm cube in the same mould: V/A = a/6, so the modulus doubles and t = 2 x 2^2 = 8 min.

Casting defects

Defect	Cause
Blow holes / gas porosity	Low permeability, high moisture
Shrinkage cavity	Poor feeding (riser too small)
Misrun / cold shut	Low pouring temperature, slow pouring
Hot tear	Hindered contraction (hard core / mould)
Scab, swell, fins	Weak mould, mould wall movement, gaps
Inclusions	Slag or sand pieces in metal

➤ Special casting methods

- **Die casting** (pressure; zinc, aluminium), **centrifugal casting** (pipes, no core needed), **investment casting** (lost wax; turbine blades, jewellery, very good finish), **shell moulding**, **continuous casting** (steel billets and slabs).

3. Welding and Joining

- **Welding** = joining metals by heat and/or pressure, with or without filler.

Process	Heat source	Key point
SMAW (manual arc)	Arc with flux-coated electrode	Cheap, all-position
GTAW (TIG)	Arc, non-consumable tungsten	Inert gas (argon), clean thin welds
GMAW (MIG)	Arc, consumable wire	Fast, semi-automatic
SAW	Arc under granular flux	High deposition, thick plates, flat position
Gas (oxy-acetylene)	Flame about 3200°C	Neutral, oxidising, carburising flames
Resistance (spot, seam)	I^2 R heat + pressure	Car bodies, sheet metal
Thermit	Chemical reaction (Al + iron oxide)	Rail joints

- Oxy-acetylene flames: **neutral** (most metals, steel), **oxidising** (brass, bronze), **carburising / reducing** (high-carbon steel, non-ferrous hard facing).
- In DC arc welding about 2/3 of heat is at the positive pole. **DCEN (straight polarity)**: work positive, deeper penetration. **DCEP (reverse polarity)**: electrode positive, used for thin sheets and with some coated electrodes.

FORMULA Heat input per length $H = \eta V I / v$ (J/mm, v = travel speed).
Resistance welding heat $H = I^2 R t$.

EXAMPLE V = 20 V, I = 200 A, v = 5 mm/s, η = 0.8. H = 0.8 x 20 x 200 / 5 = 640 J/mm.

- **Solid-state welding**: friction (and friction stir), forge, explosive, ultrasonic, diffusion welding (no melting).

- **Soldering**: filler melts below 450°C. **Brazing**: filler melts above 450°C but below the base metal. Base metal does not melt in either.
- **Heat affected zone (HAZ)**: base metal not melted but its structure changed by heat.
- Welding defects: porosity, slag inclusion, lack of fusion, incomplete penetration, undercut, cracks, distortion.

4. Metal Forming

- **Hot working**: above recrystallisation temperature; low forces, no strain hardening, poorer finish and tolerance.
- **Cold working**: below recrystallisation temperature; better finish and accuracy, strain hardening raises strength, needs more force.

➤ Bulk forming

Process	Idea	Products
Rolling	Squeeze between rotating rolls	Plates, sheets, rails, I-beams
Forging	Hammer or press between dies	Crankshafts, gears, connecting rods
Extrusion	Push through a die	Rods, tubes, window sections
Wire / bar drawing	Pull through a die	Wires, rods

FORMULA Rolling: max draft $\Delta h_{max} = \mu^2 R$. Angle of bite α with $\mu = \tan\alpha$ (for the strip to enter).

EXAMPLE Roll radius 300 mm, $\mu = 0.1$. Max draft = $0.1^2 \times 300 =$ 3 mm per pass.

FORMULA Extrusion force (ideal) $F = A0 \times Y \times \ln(A0/Af)$. Extrusion ratio $R = A0/Af$.

- Extrusion types: direct (forward), indirect (backward, lower friction), impact (toothpaste tubes), hydrostatic.
- Drawing: max reduction per pass is limited because the pulled wire itself carries the stress.

➤ Sheet metal working

- **Blanking**: the punched-out piece is the product. **Punching / piercing**: the hole is the product.
- **Clearance** goes on the punch in blanking and on the die in punching:
  - Blanking: die size = blank size; punch = blank size − 2c.
  - Punching: punch size = hole size; die = hole size + 2c.

FORMULA Shearing force $F = L\ t\ \tau u$ (L = cut perimeter; circle: $L = \pi d$). Shear on punch or die reduces this force.

EXAMPLE Punch a 50 mm hole in 2 mm sheet, τu = 300 MPa. $F = \pi \times 50 \times 2 \times 300 =$ 94.2 kN.

- Other operations: bending (springback), deep drawing (cups; limiting draw ratio about 2), spinning, stretch forming, coining, embossing.

5. Metal Cutting (Machining Theory)

- **Orthogonal cutting**: cutting edge normal to cutting velocity (2D). **Oblique cutting**: edge inclined (real turning).

➤ Chip types

Chip	Formed when
Continuous	Ductile material, high speed, large rake angle, good finish
Discontinuous	Brittle material (cast iron), low speed
Continuous with BUE	Ductile material, low speed, poor lubrication; built-up edge spoils finish

FORMULA Chip thickness ratio $r = t1/t2$ (< 1). Shear angle: $\tan\phi = r\cos\alpha / (1 - r\sin\alpha)$.

FORMULA Merchant's theory: $2\phi + \beta - \alpha = 90°$. Friction coefficient $\mu = \tan\beta = (Ft + Fc\tan\alpha) / (Fc - Ft\tan\alpha)$.

EXAMPLE $\alpha = 10°$, uncut thickness 0.5 mm, chip thickness 1.25 mm. Find ϕ.

- $r = 0.5/1.25 = 0.4$.

- $\tan\phi = 0.4 \times 0.985 / (1 - 0.4 \times 0.174) = 0.394 / 0.931 = 0.423$.
- $\phi = 22.9°$. By Merchant, $\beta = 90 + 10 - 2 \times 22.9 = 54.1°$.

➤ Tool life and tool materials

FORMULA Taylor's tool life equation: $V\,T^n = C$. Typical n: HSS 0.1–0.15, carbide 0.2–0.4, ceramic 0.5–0.7.

EXAMPLE $V\,T^{0.25} = 200$ (V in m/min, T in min). At $V = 100$ m/min: $T = (200/100)^4 = 16$ min.

- **Flank wear** (on the clearance face) is used as the tool life criterion. **Crater wear** (on the rake face) is due to diffusion at high temperature.
- Tool materials in order of hot hardness: carbon steel < HSS < cast alloys < cemented carbide < ceramics < CBN < diamond.
- Diamond is not used for machining steel (carbon diffuses into iron); CBN is used instead.
- Cutting fluids: cool, lubricate, wash away chips, prevent corrosion.
- **ASA tool signature**: back rake, side rake, end relief, side relief, end cutting edge angle, side cutting edge angle, nose radius.

6. Machine Tools

FORMULA Cutting speed $V = \pi D N / 1000$ (m/min). Turning time $t = L / (f N)$. MRR (turning) $\approx V f d$.

EXAMPLE Turn a 200 mm length at $f = 0.2$ mm/rev, $N = 500$ rpm. $t = 200 / (0.2 \times 500) = 2$ min.

Machine	Main operations
Lathe	Turning, facing, taper turning, threading, knurling, boring
Drilling	Drilling, reaming, boring, tapping, counterboring
Milling	Plain, face, slot, gear cutting (indexing head)
Shaper / planer	Flat surfaces; quick return mechanism
Grinding	Fine finish and accuracy; surface, cylindrical, centreless

- **Up milling** (conventional): cutter rotates against feed, chip thin to thick. **Down milling** (climb): with feed, better finish, needs backlash-free table.
- **Grinding wheel marking** (example A 46 K 5 V): abrasive (A = alumina, C = silicon carbide), grain size, grade (hardness of bond), structure, bond (V vitrified, B resinoid, R rubber, S silicate, E shellac, M metal).
- Use a soft wheel for hard materials, a hard wheel for soft materials.
- **CNC**: G-codes (motion, e.g. G00 rapid, G01 linear, G02/G03 arcs) and M-codes (machine functions, e.g. M03 spindle on clockwise, M05 spindle stop).

7. Non-Traditional Machining

Process	Mechanism	Best for
EDM	Spark erosion in dielectric (kerosene / deionised water)	Hard conductive materials, dies, moulds
Wire EDM	Moving wire electrode	Punches, complex profiles
ECM	Anodic dissolution (Faraday's law), reverse of electroplating	Hard conductive alloys, turbine blades; no tool wear
USM	Abrasive slurry hammered by a tool at about 20 kHz	Hard brittle non-conductors (glass, ceramics)
AJM	High-speed abrasive in gas jet	Brittle materials, deburring, cleaning
LBM	Focused laser melts / vaporises	Small holes, cutting sheets
EBM	Electron beam in vacuum	Very fine holes

- EDM and ECM need an electrically conductive workpiece. EDM leaves a thin recast (heat-affected) layer; ECM does not.

8. Powder Metallurgy and Additive Manufacturing (short)

- Powder metallurgy steps: powder making → blending → compacting → sintering → finishing. Products: self-lubricating bearings (porous), carbide tool tips, filters.
- Additive manufacturing (3D printing): FDM (melted plastic filament), SLA (UV-cured resin), SLS (laser-sintered powder). Good for prototypes and complex shapes.

9. Most Asked Questions (practice)

1. Explain pattern allowances. Why is shake allowance negative?
2. Derive the sprue taper relation and fill time for top gating.
3. State Chvorinov's rule and explain riser design.
4. List casting defects with causes and remedies.
5. Compare TIG, MIG and SAW. Explain the three oxy-acetylene flames.
6. Compare hot and cold working. Derive max draft in rolling.
7. Explain clearance in blanking and punching with a numerical.
8. Derive Merchant's shear angle relation and explain the force circle.
9. Explain Taylor's tool life equation and tool wear types.
10. Compare EDM, ECM and USM with applications.

TIP In GATE ME, numericals come from Chvorinov / gating, welding heat input, rolling draft, blanking force, Merchant's circle, Taylor's equation and machining time. Learn the units and the one-line formulas.