ME5005/ME4002
DESIGN FOR MANUFACTURE
PRODUCTION ENGINEERING

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Lecture 4: Mechanical Properties and Casting

Stress and strain (review)

- Stress is an ________ force within a material which balances an ________ applied force or load

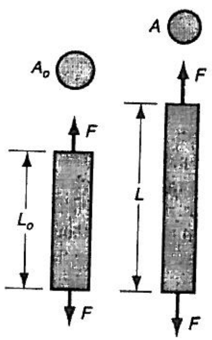
$$\sigma = \frac{F}{A}$$

- Strain is a measure of the elongation produced by a stress

$$\varepsilon = \frac{\partial L}{L_0}$$

Direct stresses and strains

- Direct stresses act perpendicularly to the area A_0 over which the force F is applied
- Stresses and strains may be tensile (+) or compressive (−)



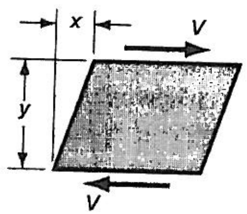
Shear stresses and strains

- Shear stresses act parallel to the area A_0 over which the shear force V is applied:

$$\tau = \frac{V}{A_0}$$

- Shear strain (for small values of γ):

$$\frac{x}{y} = \tan(\gamma) = \gamma$$

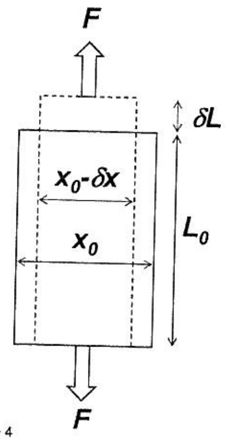


Poisson's ratio

- Poisson's ratio ν (nu) is defined as the ratio of Lateral strain to longitudinal strain for a direct stress:

$$\nu = \frac{\delta L / L_0}{\delta x / x_0}$$

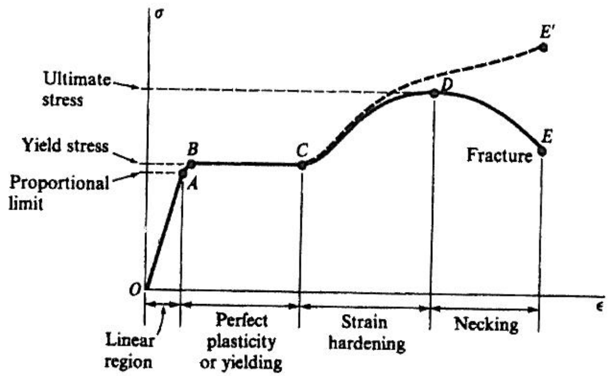
- Most materials have a Poisson's ratio between 0.3 -> 0.4



Elastic and plastic behaviour

- A material behaves ELASTICALLY when an applied stress produces a recoverable directly proportional amount of strain:
  - _
- A material behaves PLASTICALLY when an applied stress produces permanent deformation (________)
  - Force removal results in recovery of ________ deformation only
- Both important in materials processing

Stress-Strain curve

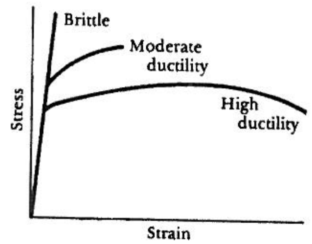


Key points and regions

- *OA* – Elastic region
  - Proportional relationship
- *AB* – non-linear region
  - still reversible
- *B* = Yield stress, σ_y
- *BC* – Perfect yielding
  - Significant twinning and slip occurs
  - B and C may coincide
- *D* = Ultimate tensile stress, σ_U or σ_{UTS}
- *CD* - Strain hardening occurs
  - Number of dislocations INCREASES (Frank-Read source)
  - Dislocations that interact are harder to move
- *DE* – Necking
  - cross-section reduces
- *E* – Fracture
- *DE'* – True behaviour
  - Instantaneous area used

Ductility

- A measure of how much deformation a material can withstand without breaking
  - %Elongation
  - %Reduction in area
- High ductility preferred for material processing
  - Lower forces
  - Smaller plant



Elastic constants

- Young's modulus

$$E = \frac{\sigma}{\varepsilon}$$

- Shear modulus

$$G = \frac{\tau}{\gamma}$$

- Bulk modulus

$$K = \frac{\sigma V_0}{\delta V}$$

- Inter-relationships

$$G = \frac{E}{2(1+\nu)}$$

$$K = \frac{E}{3(1-2\nu)}$$

Thermal stresses and strains

- When a material is heated or cooled by $\delta\theta$ its dimensions will change by δL:

$$\delta L = L_0 \alpha \delta\theta$$

- If the material is constrained, thermal stresses and strains exist:

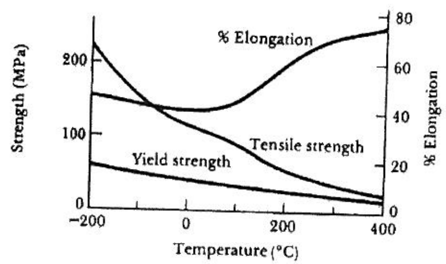
$$\varepsilon_{th} = \frac{\delta L}{L_0} = \frac{L_0 \alpha \delta\theta}{L_0} = \alpha\delta\theta$$

- If E is known:

$$\sigma_{th} = E\varepsilon_{th} = E\alpha\delta\theta$$

Processing temperature

- Many material properties vary significantly with temperature
  - Ductility
  - σ_y, σ_{UTS}
- Often advantageous to raise material temperature to simplify processing



Dimensional accuracy

- Both thermal and mechanical effects can make dimensional accuracy in the final component difficult to achieve
- Processes that are both high temperature and require high loads for deformation are particularly problematic
  - e.g.: _
- Both forms of shrinkage must be accounted for in the component design

Mechanical effects

- Applied stress must be greater than or equal to the yield stress for material to deform
- Only plastic strain is permanent
- When stress is removed after mechanical deformation, material experiences elastic recovery

$$\varepsilon = \frac{\sigma_y}{E}$$

- Therefore final component geometry will be smaller or distorted

Thermal effects

- Final geometry will be reduced by:
  - _
    - Solid occupies less volume than liquid
  - Thermal Contraction

$$\varepsilon = \alpha\delta\theta$$

  - Solid phase changes during cooling
    - FCC to BCC
- Initial component geometry must be Oversized to compensate

Casting processes

- Casting involves filling a die or mould with molten metal and allowing it to solidify
- May be broadly classified into two types:
  - Consumable moulds
  - Permanent moulds/dies
- Different casting processes are required depending on:
  - Size/weight of component
  - Material to be cast (melting point)
  - Complexity of geometry
  - Number of items to be manufactured

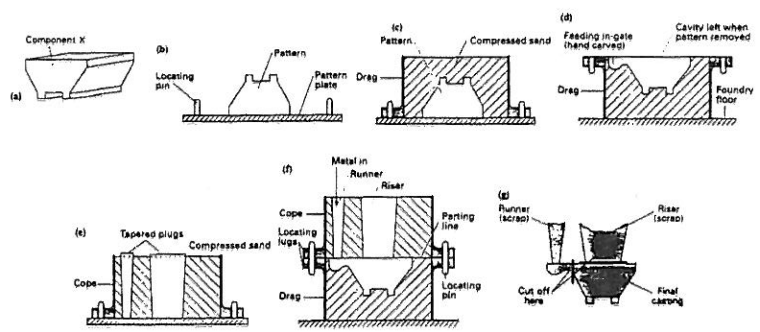
Sand casting process

- Mould is made by compacting sand around a pattern of the final component
  - Sand used is usually a mixture of silica (90%) with other minerals such as clay or resins (7%) to act as binders, and a carefully controlled moisture content (3 % typically)
- Pattern is removed to leave correctly shaped impression in compacted sand
  - Pattern may be re-used
- Cores may be added to create holes or hollow sections in the finished components
- Mould filled with molten metal and then allowed to cool

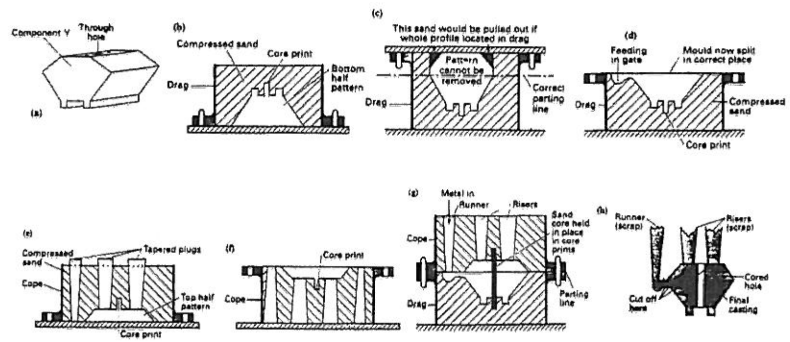
Sand casting details

- Mould broken away from finished component
  - Most of the sand may be re-used
- Labour intensive process
  - high mould preparation time
- Only practical casting process for high melting point materials, and large heavy products
- Surface finish may be poor
  - Sand grain size, compromise between required surface finish, mould permeability and mould strength
- Buoyancy of the molten metal may displace the sand mould or cores

Sand casting – simple mould

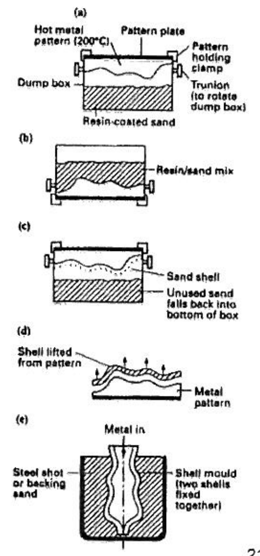


Sand casting – cored mould



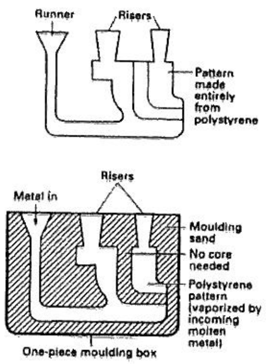
Shell casting

- Sand is held together by a thermosetting resin binder
- Heated metal pattern forms thin cured shell
- Surface finish better than in traditional sand casting
- Sand more expensive, less of it can be re-used



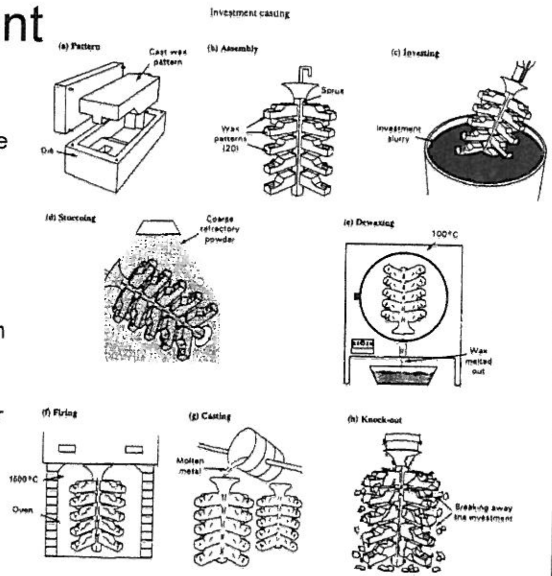
Full-mould casting

- Parting lines are eliminated
- Complex components may be cast
- Pattern is consumed each time
- Faster set-up than sand casting
  - New patterns required
- Patterns easily damaged



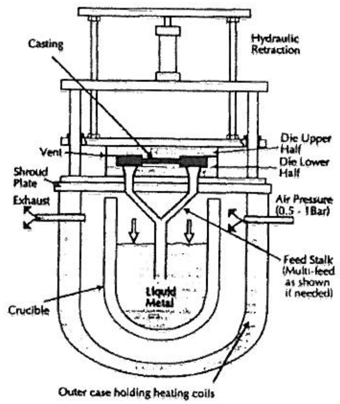
Investment casting

- Wax patterns made in separate permanent die
- Complex process limited to small components
- Very precise
- Good surface finish
- Suitable for metals difficult to machine
- Highly skilled labour



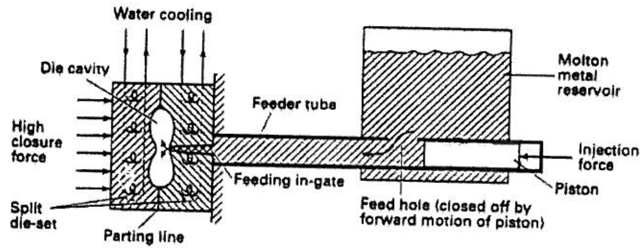
Low-pressure die casting

- Molten metal forced into dies using low pressure air
- Pressure is maintained until casting solidifies
- Clean molten metal from centre of crucible is used
  - Reduces gas porosity and oxidation defects



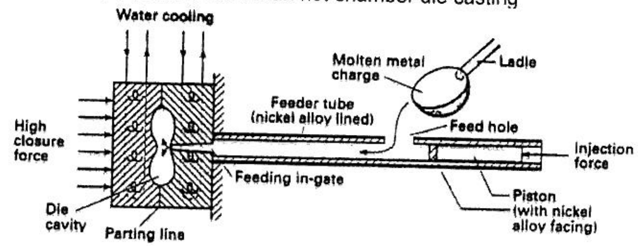
Hot-chamber die casting

- Used to cast non-ferrous alloys except AL
- Typical injection pressures are 7 to 35 MPa
- Production rates up to 500 parts/hour common
- Robust injection system required – submersed in molten metal



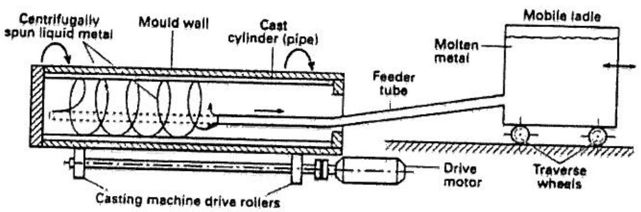
Cold chamber die casting

- Molten aluminium alloys react with iron in the die steels
  - Surface pitting in component, damage to dies
  - Nickel alloy linings required
  - High injection pressures 14 to 140 MPa
  - Slower production rates than hot chamber die casting



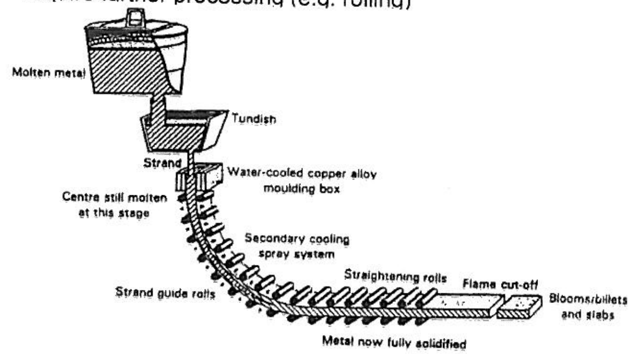
Centrifugal casting

- Used to make _______ components
- Outside shape may be non-circular
  - Inside surface will _______ be circular
- May also be used to increase metal density at the radial extremities of solid components
  - Semi-centrifugal casting



Continuous casting process

- Due to limited shape production, mainly limited to _______ that require further processing (e.g. rolling)



Common casting defects