# HSC Engineering Studies

Modelmat

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# CONTENT

# CHAPTER ONE

# CIVIL STRUCTURES

> Select one or more civil structures in this module. Some examples of civil structures include: bridges, roads, dams, buildings, cranes and lifting devices, parklands and children's playgrounds and equipment.
>
> –Engineering Studies Stage 6 Syllabus, NESA

## 1.1 Historical and societal influences

**Syllabus Excerpt**

- historical developments of civil structures
- engineering innovation in civil structures and their effect on people's lives
- construction and processing materials used in civil structures over time
- environmental implications from the use of materials in civil structures

–Engineering Studies Stage 6 Syllabus, NESA

## 1.2 Engineering mechanics

**Syllabus Excerpt**

- truss analysis
  - actions (loads)
  - reactions
  - pin jointed trusses only
  - method of joints
  - method of sections
- bending stress induced by point loads only
  - concept of shear force and bending moment
  - shear force and bending moment diagrams
  - concept of neutral axis and outer fibre stress

  - bending stress calculation (second moment of area given)
- uniformly distributed loads
- stress and strain
  - shear, compressive and tensile stress
  - engineering and true stress
  - yield stress, proof stress, toughness, Young's modulus, Hooke's law, engineering applications
  - factor of safety
  - stress/strain diagram

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### 1.2.1 Truss Analysis

### 1.2.2 Bending Stress Induced By Point Loads

### 1.2.3 Uniformly Distributed Loads

### 1.2.4 Stress and Strain

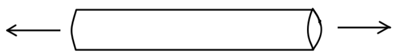
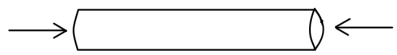
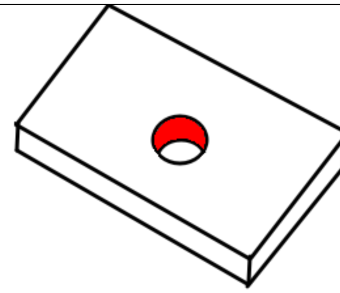
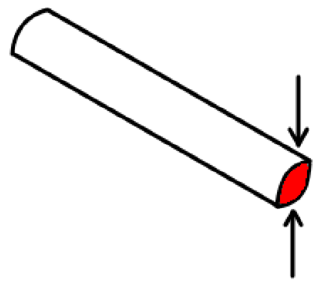
#### Shear, Compressive and Tensile Stress

Compressive forces are forces which squeeze an object, and will reduce the length. Tensile forces are forces which stretch and will lengthen the object. Shear forces are forces acting along the cross section of an object (highlighted in red).

Stress and strain are calculated with the following formulae:

$$\sigma = \frac{F}{A} \quad \varepsilon = \frac{e}{L}$$

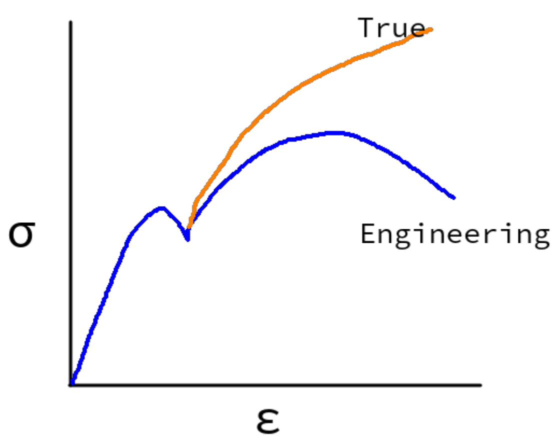
| | | | |
|---|---|---|---|
| $\sigma$ | stress (MPa) | $\varepsilon$ | Strain (unitless) |
| $F$ | Force (N) | $e$ | Elongation (mm) |
| $A$ | Area (mm$^2$) | $L$ | Original Length (mm) |

| Tensile | Compressive | Shear |
|---|---|---|
|  $A = \pi r^2$ |  $A = \pi r^2$ |  $A = \pi dh$  $A = \pi r^2$ |

### Engineering and True Stress

Engineering / nominal stress is the stress when the diameter of the material is assumed to be constant, i.e. the same size as it was before the beginning of uniform reduction in area of test specium or necking. This is easier to work with and is (mostly) the same in the elastic zone - which engineers try to stay within regardless.

True / Working stress is the actual stress the material experiences. As the material reduces in area, the stress increases.



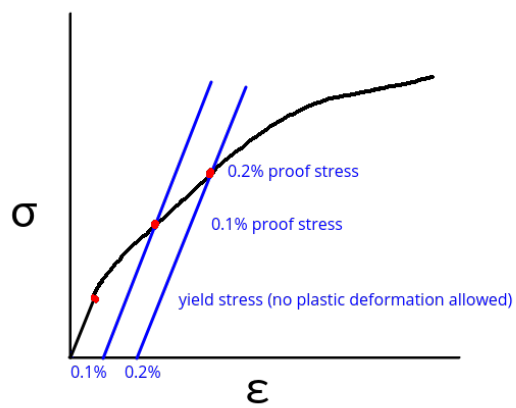

During plastic deformation, fatigue occurs and the material has weakened even after the force is removed.

### Stresses, Toughness, Young's Modulus, Hooke's Law, Engineering Applications

**Yield Stress** The point after which their is an increase in strain without increase in stress. Located just after the straight line line section on the graph.

**Proof Stress**

- A type of stress used when their is no definite yield point in a material e.g. aluminium / rubber.
- You allow some percentage of strain (e.g. 0.1% - 0.2%).
- Allows the materials to be "safely" used with a higher amount of stress
  - tradeoff is that they need to be replaced often due to creep.
  - Used for aluminium as it has low elastic limit; thus allows much higher safe loads with weight savings.




**Toughness** A measure of the impact resistance of a material. Represented as the area under the stress/strain graph. Is measured with an izod or charpy machine.

**Young's Modulus** Material stiffness. Measured as the gradient of the straight line section.

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

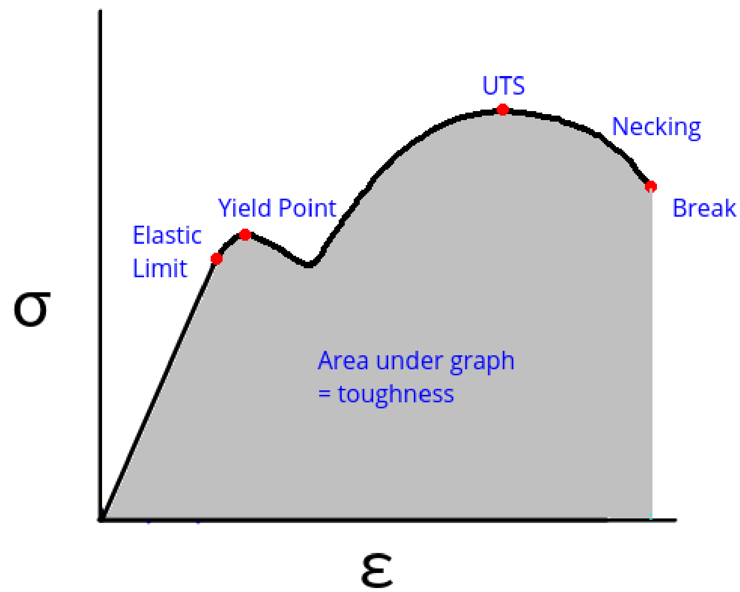
| | |
|---|---|
| $E$ | Young's Modulus (GPa) |
| $\sigma$ | Stress (MPa) |
| $\varepsilon$ | Strain (unitless/percentage) |

**Hooke's Law** $F = -kx$ It tells us that elastic deformation is a straight line gradient. $k$ would be Young's Modulus.

### Factor of Safety

- Materials are never entirely perfect and it is diffficult to accurately determine the working loads
- The factor of safety allows for defects in the materials or manufacturing
- The factor of safety changes with the relevant risk:
  - In bridges and planes, the risk is much higher: factory of safety is often 4-5x
  - In bikes, the risk is lower, and so the factory of safety maybe be only 2x.

### Stress/Strain Diagram




Tensomers measure force and elongation; not stress and strain. This creates a load-extension diagram, not a stress-strain diagram. Load-extension is specific to specimen, stress-strain is not.

## 1.3 Engineering materials

**Syllabus Excerpt**

- testing of materials
  - specialised testing of engineering materials and systems
  - X-ray
- testing of concrete
- crack theory
  - crack formation and growth
  - failure due to cracking
  - repair and/or elimination of failure due to cracking
- ceramics
  - structure/property relationships and their application to civil structures
  - glass
  - cement

- bricks
- composites
  - timber
  - concrete (reinforced, pre- and post- tensioned )
  - asphalt paved surface
  - laminates
  - geotextiles
- corrosion
  - corrosive environments
  - dry corrosion, wet corrosion, stress corrosion, galvanic corrosion
- recyclability of materials

–Engineering Studies Stage 6 Syllabus, NESA

## 1.4 Communication

**Syllabus Excerpt**

- Australian Standard (AS 1100)
- orthogonal assembly dimensioned drawings
- freehand pictorial drawings
- graphical mechanics
  - graphical solutions to engineering problems
- computer graphics
  - Computer Aided Drawing (CAD)
  - applications for solving problems
- collaborative work practices
- Engineering Report writing

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CHAPTER

TWO

# PERSONAL AND PUBLIC TRANSPORT

Select one or more forms of transport in this module. Some examples include: bicycles, motor cars, boats, motor cycles, buses, trucks, trains and trams

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## 2.1 Historical and societal influence

**Syllabus Excerpt**

- historical developments in transport systems
- effects of engineering innovation in transport on society
- construction and processing materials used over time
- environmental effects of transport systems
- environmental implications from the use of materials in transport

–Engineering Studies Stage 6 Syllabus, NESA

## 2.2 Engineering mechanics

**Syllabus Excerpt**

- simple machines
- static friction
  - concept of friction and its application in engineering
- coefficient of friction
  - normal force
  - friction force
  - angle of static friction
  - angle of repose
- basic calculations for work, energy and power

  - potential energy
  - kinetic energy

–Engineering Studies Stage 6 Syllabus, NESA

## 2.3 Engineering materials

**Syllabus Excerpt**

- testing of materials
  - hardness
  - impact
- heat treatment of ferrous metals
  - annealing
  - normalising
  - hardening and tempering
  - changes in macrostructure and microstructure
  - changes in properties
- manufacturing processes for ferrous metals
  - forging
  - rolling
  - casting
  - extrusion
  - powder forming
  - welding
- changes in macrostructure and microstructure of ferrous metals
- changes in properties of ferrous metals
- manufacturing processes for non-ferrous metals
  - alloying
  - annealing
  - solid solution hardening
- changes in macrostructure and microstructure of non-ferrous metals
- changes in properties of non-ferrous metals
- ceramics and glasses
  - as an insulation material
  - laminating and heat treatment of glass
  - structure/property relationship and their application

- thermo softening polymers
  - engineering textiles
  - manufacturing processes
    * extrusion
    * injection moulding
    * blow moulding
  - structure/property relationships and application

–Engineering Studies Stage 6 Syllabus, NESA

### 2.3.1 Testing of Materials

### 2.3.2 Heat Treatment of Ferrous Metals

### 2.3.3 Manufacturing Processes for Ferrous Metals

#### Forging

- Where metal is deformed due to compressive or high impact forces
- Forged objects are **stronger** than machined objects as it creates grainflow
- Functions that can be performed by forging are:
  - Upsetting
    * Flattening the metal
    * Increases cross-sectional area by reduces length
  - Drawing
    * Metal drawn out by hammering along sides
    * Increases length by reducing cross-sectional area

#### Hot Forging

- The metal is heated to above **recrystallisation** temperature and then worked at the temperature
- After working it is left to cool
- Much easier to change the shape of the metal as it becomes malleable
- (heating) will relieve internal stresses, increasing *toughness* and durability but decreases the *hardness*
  - prevents strain hardening
  - FCC not BCC is formed
  - due to heating, the material can warp due to thermal contraction/expansion -> low dimensional accuracy and poor surface finish

### Cold Forging

- **Large** amounts of force are applied to the metal at (mostly) room temperature
- usually for softer metals
- retains dimensional acccuracy and surface finish
- However, creates residual stresses which leads to lower ductility and toughness, but harder
- Can often be accompanied by later annealing to relieve stresses

### Rolling

Metal is passed through a set of rolls, which exert a compressive force on the sheet. This creates a reduction thickness an extension in length.

### Hot Rolling

- Done at temperatures above recrystallisation
- Produces fine, equiaxed, and unstressed grains
- Requires less force
- Not dimensionally accurate or good surface finish
- Can form an oxide layer

### Cold Rolling

- Produces elongated and **stressed** grains
- Harder and stronger final product
- Better surface finish
- Less ductile
- Elongated grains -> only strong in two dimensions
- Requires high amounts of form

### Casting

A general category involving **pouring molten metal into a mould**. Most of the difference comes in how the mould is made.

The solidification of pure metals has a defined temperature at which the metal transitions from liquid to solid. This causes a solidification front to move through the material, from the outer walls into the centre. Non-pure metals have a range of temperatures where the metal solidifies, this is the ‘mushy’ region.

At the mould walls, the metal cools rapidly and creates an outer shell of equiaxed grains. Grains will then grow opposite direction of heat transfer, forming columnar grains inwards on the material. Further away from the walls, the grains grow slower and are able to become equiaxed and course. The addition of nucleating agents (see (c)) creates course grains throughout. In alloys, dendrites form of the material with a higher freezing point.

Slower cooling creates coarser structures, and faster cooling creates finer dendritic structures.

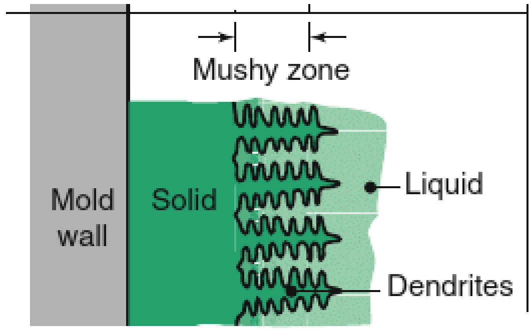


Fig. 1: From Manufacturing Engineering & Technology [6 ed], pg. 241

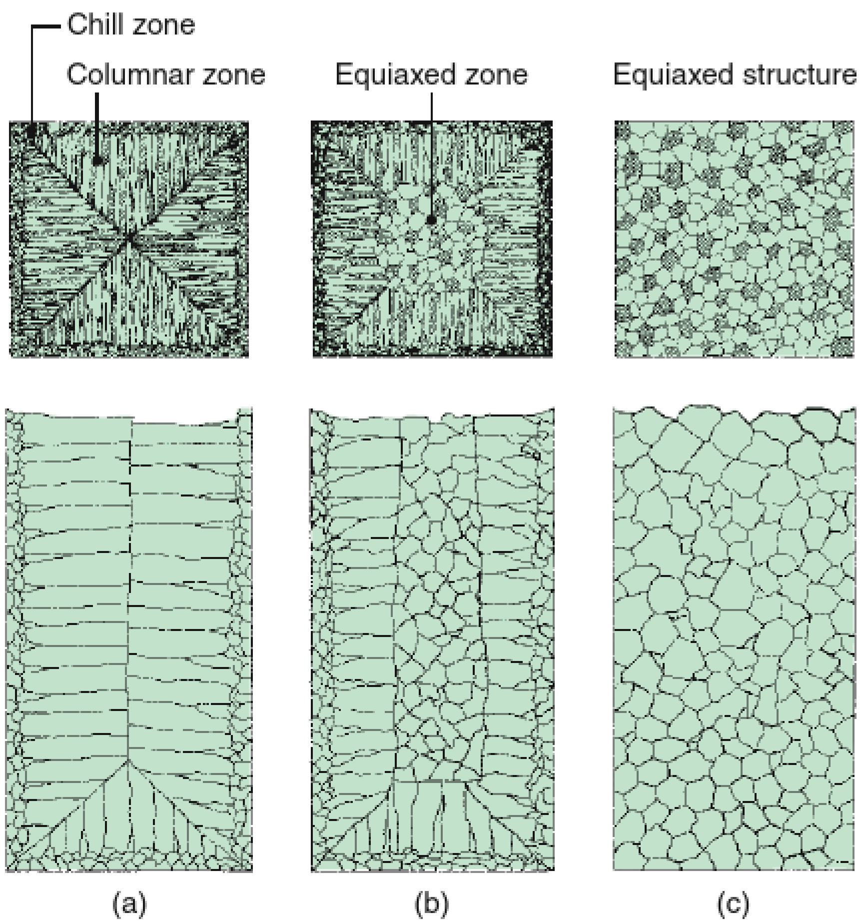


**FIGURE 10.2** Schematic illustration of three cast structures of metals solidified in a square mold: (a) pure metals; (b) solid–solution alloys; and (c) structure obtained by using nucleating agents.

Fig. 2: From Manufacturing Engineering & Technology [6 ed], pg. 239

Smaller grain size increases strength and ductility. Lack of uniform grain structures create anisotropic properties (not uniform in all directions).

Convection within the metal promotes the formation of the outer chill zone and the transition from columnar to equiaxed grains. Reducing convection creates more columnar structures.

### Sand Casting

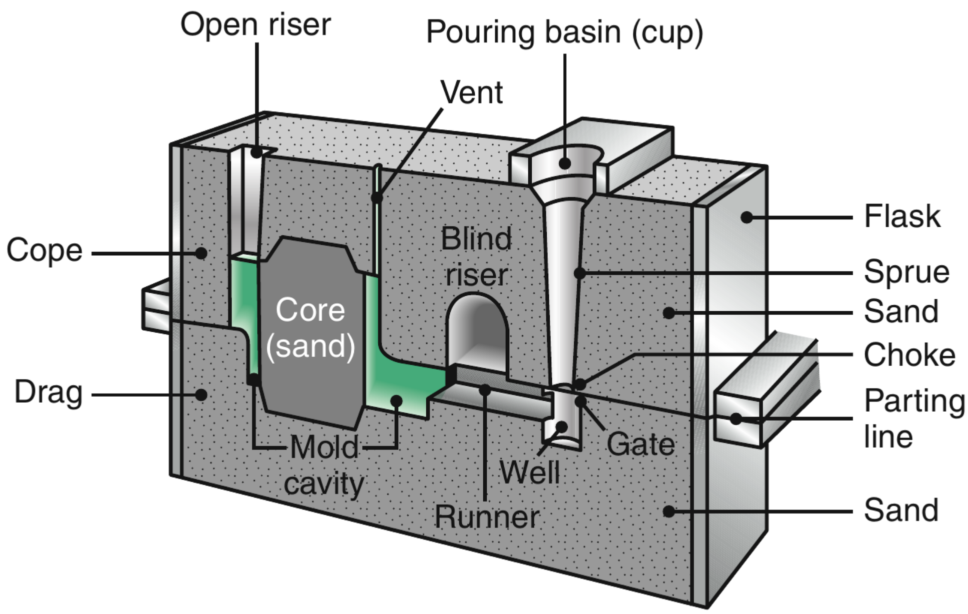


Fig. 3: From Manufacturing Engineering & Technology [6 ed], pg. 263

1. A pattern (made from wood or other material) is made from a design by a skilled pattern maker; in two parts, the cope and the drag [top and bottom] and mounted on plates
2. The cope pattern is placed within a flask, alongside a pattern for a sprue (for adding metal) and riser. It is then filled with sand that is then rammed to compact it.
3. This is repeated with the drag, except there is no sprue or riser.
4. The patterns are then removed.
5. The cope and drag are assembled together.
6. Metal is then poured into the sprue via the pouring basin
   - The pouring basin is used to ensure consistent flow of metal
7. The metal is then allowed to cool and then the cope and drag are separated. The excess parts created by the runner and riser are then machined off.
8. The sand can then be reused

**Advantages of sand casting:**

- Cost effective
- Relatively simple to do
- Suitable for small or large production runs

**Disadvantages:**

- Poor surface finish -> fatigue cracking
- Poor dimensional tolerance and stability
- Grains are often columnar
  - Properties become *anisotropic*
  - Large grains reduce ductility
  - Weakness where columnar grains meet equiaxed grains
  - Resolved with the addition of innoculants, which encourage nucleation (formulation of new crystals)

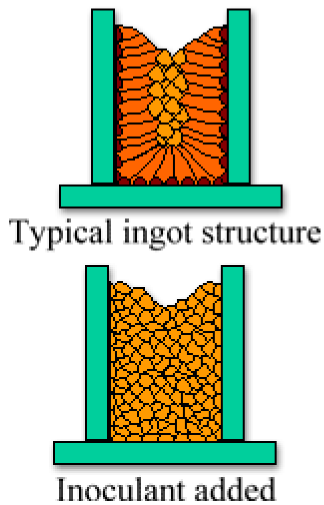


Fig. 4: From Materials Engineering Online Tutorials: Casting

### Shell Moulding

1. A metal (usually cast iron) pattern is made by hand and is then heated to ~200-300C
2. Fine silica sand combined with ~5% thermosetting phenotic resin is then dumped onto the metal pattern, and left to cure for a few minutes.
3. The pattern + sand are then inverted, allowign the excess (non-cured) sand to drop free. This leaves a 10-20mm shell.
4. The pattern + sand are then placed in an oven to finish curing.
5. The shell is then removed from the pattern via a removing pin, and combined with #. the other half of the shell by clamping/gluing/adhsive, forming a mold.
6. The shell is then placed in a flask filled with shot or sand.
7. Metal can then be poured into the shell and left to set.
8. The shell is then removed and **discarded**.

**Advantages:**

- can be completely automated
- law labour cost

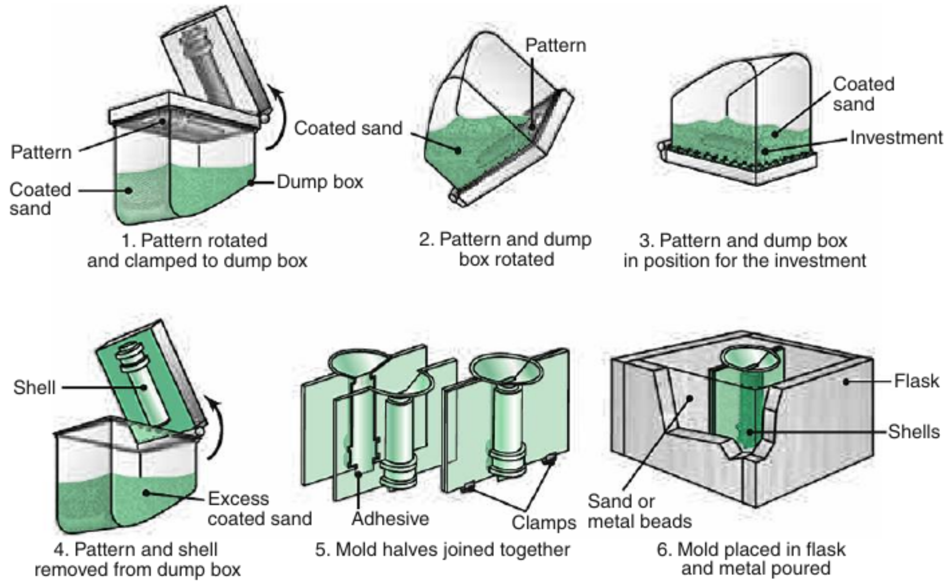


Fig. 5: From Manufacturing Engineering & Technology [6 ed], pg. 268

- efficient
- very good surface finish and dimensional tolerance
- relatively short lead time (~weeks)
- large and complex parts can be produce (similar to sand casting)

**Disadvantages:**

- the initial cast iron pattern is moderately expensive to make and hence requires long runs to be economical
- the dumping / shell moulding machine is expensive
- can be highly porous
- part size limited

### Permanent Metal Mould / Gravity Die Casting

1. A die is made from steel. This is **very expensive** and can take a while to make. It integrates the sprue and riser as part of the mould.
2. The die **must** be able to be separated along one plane
3. Metal can be poured into the mould, left to cool, then the mould is pulled apart

**Advantages:**

- good dimensional accuracy and surface finish
- high production rate

**Disadvantages:**

- high die cost
- limited part size

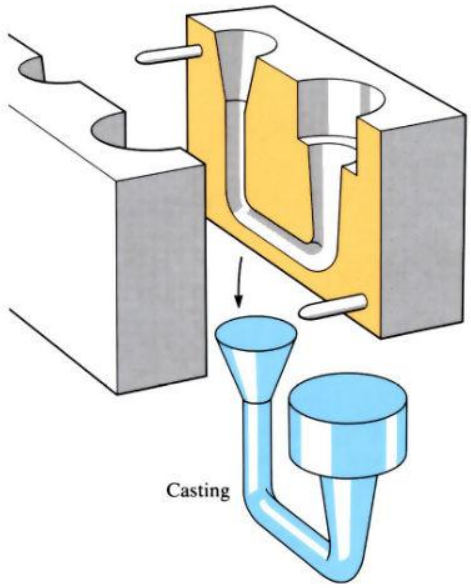


Fig. 6: From OpenLearn: Gravity die casting

- long lead time
- limited to nonferrous metals e.g. aluminium as the melting point needs to be lower than that of the die itself

### Pressure Die Casting

Similar to gravity die casting but is done under high pressure.

**Advantages:**

- excellent dimensional acuracy and surface finish (pressure forces into surface)
- high production rate

**Disadvantages:**

- lead time of up to a few months
- very expensive die cost

### Lost Foam Casting

1. A pattern is made from polystyrene by heating polystyrene beats containing pentane inside of an aluminium die, which is then separated
2. The polystyrene foam is then placed in a box with fine sand which is then compacted.
3. Molten metal is poured in and vapourises the foam pattern.

**Advantages:**

- simple process as no parting lines, risers, or cores
- minimal cleaning and finishing operations necessary

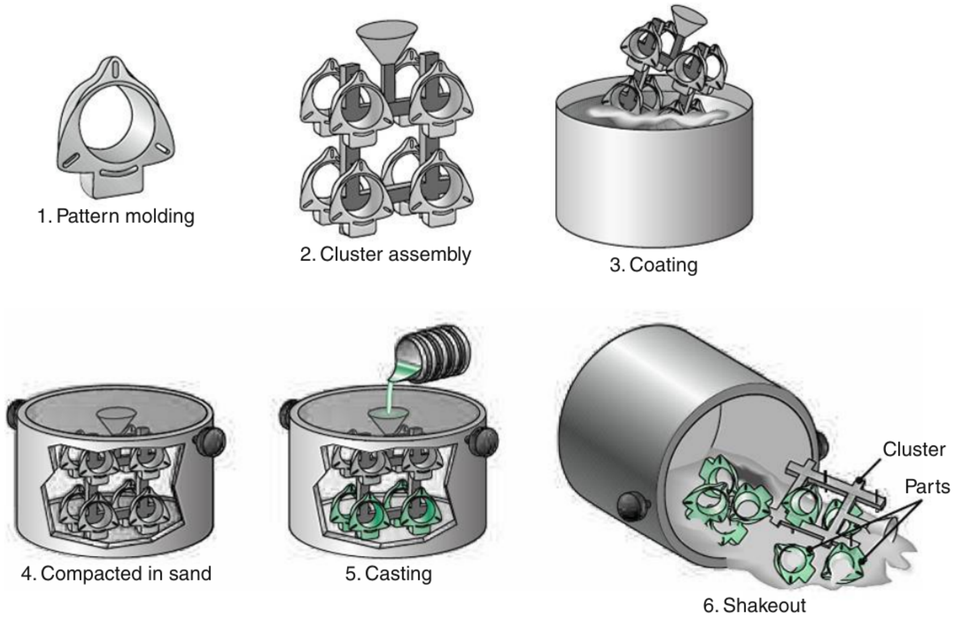


Fig. 7: From Manufacturing Engineering & Technology [6 ed], pg. 271

**Disadvantages:**

- die cost is expensive
- metal cools faster as energy is taken out through vapourisation of foam * formation of more columnar structures rather than equiaxed
- patterns low strength

### Investment Casting

1. A pattern is created of wax through moulding or other techniques
2. The wax patterns are often joined together in large trees, then covered in a fine silica and binders
3. Once dried, it is then repeatedly coated in more sand to increase the strength of the mould
4. The mould is then heated (~150C) to melt out the wax
5. It is then fired at 600-1000C to burn out any remaining wax or chemicals
6. Molten metal is then poured into the mould and then the mould is broken up to reveal castings

Can be used for manufacture of orthopedic replacements e.g. the knee. Suitable for use with titanium, chrome, or cobalt alloys.

**Advantages:**

- excellent surface finish and dimensional accuracy
- very high production rates
- can cast high melting point alloys
- removes the need for most finishing or machining processes, which can reduce cost
- creates equiaxed grains through the mould, leading to better properties

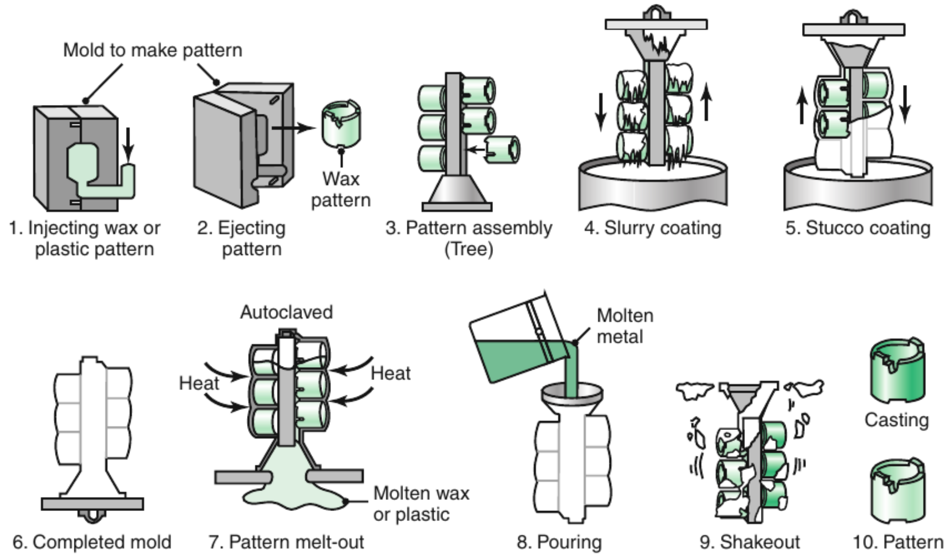


Fig. 8: From Manufacturing Engineering & Technology [6 ed], pg. 273

- thin walls (1.5mm) can be created

**Disadvantages:**

- expensive tooling cost, lead time of a few weeks * creation of both wax mould and then this secondary mould
- part size limited (up to ~35kg)

## 2.4 Engineering electricity/electronics

**Syllabus Excerpt**

- power generation/distribution
  - electrical energy and power
  - simple circuits
- electric motors used in transport systems
  - principles
  - applications
- control technology
- electrical safety

–Engineering Studies Stage 6 Syllabus, NESA

## 2.5 Communication

**Syllabus Excerpt**

- freehand sketching, design and orthogonal drawings
- sectional views
- Australian Standard (AS 1100)
- computer graphics, computer aided drawing for orthographic projection
- collaborative work practices
- Engineering Report writing

–Engineering Studies Stage 6 Syllabus, NESA

# CHAPTER THREE

# AERONAUTICAL ENGINEERING

One or more examples of aeronautical engineering must be used to develop an understanding of the scope and nature of this profession. Some examples include: design and construction of recreational aircraft, general aviation aircraft, military aircraft, space craft, agricultural aircraft, helicopters and home-built aircraft.

–Engineering Studies Stage 6 Syllabus, NESA

## 3.1 Scope of the profession

**Syllabus Excerpt**

- nature and scope of the aeronautical engineering profession
- current projects and innovations
- health and safety issues
- training for the profession
- career prospects
- unique technologies in the profession
- legal and ethical implications
- engineers as managers
- relations with the community

–Engineering Studies Stage 6 Syllabus, NESA

## 3.2 Historical and societal influences

**Syllabus Excerpt**

- historical developments in aeronautical engineering
- the effects of aeronautical innovation on people's lives and living standards
- environmental implications of flight

–Engineering Studies Stage 6 Syllabus, NESA

## 3.3 Engineering mechanics and hydraulics

**Syllabus Excerpt**

- fundamental flight mechanics
  - relationship between lift, thrust,
  - weight and drag
  - lift to drag ratio
  - effect of angle of attack
- Bernoulli's principle and its application to
  - venturi effect
  - lift
- bending stress
  - airframes
- propulsion systems including
  - internal combustion engines
  - jet including turbofan, ram and scram
  - turboprop
  - rockets
- fluid mechanics
  - Pascal's principle
  - hydrostatic and dynamic pressure
  - applications to aircraft components and instruments

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## 3.4 Engineering materials

**Syllabus Excerpt**

- specialised testing of aircraft materials
  - dye penetrant
  - X-ray, gamma ray
  - magnetic particle
  - ultrasonic

- aluminium and aluminium alloys used in aircraft including aluminium silicon, aluminium silicon magnesium, aluminium copper
- structure/property relationship and alloy applications
  - changes in macrostructure and microstructure
  - changes in properties
- heat treatment of applicable alloys
- thermosetting polymers
  - structure/property relationships and their application
  - manufacturing processes
  - compression moulding
  - hand lay-up
  - vacuum lay-up
  - modifying materials for aircraft applications
- composites
  - types including reinforced glass fibre, Kevlar, carbon fibre and Fibre Metal Laminate (FML) as used in aircraft construction
  - structure/property relationships and their application in aircraft
- corrosion
  - common corrosion mechanisms in aircraft structures
  - pit and crevice corrosion
  - stress corrosion/cracking
  - corrosion prevention in aircraft

–Engineering Studies Stage 6 Syllabus, NESA

## 3.5 Communication

**Syllabus Excerpt**

- freehand and technical drawing
  - pictorial and scaled orthogonal drawings
- Australian Standard (AS 1100)
- developments
  - transition pieces
- graphical mechanics
  - graphical solution to basic aerodynamic problems
- computer graphics, computer aided drawing (CAD)
  - 3D applications

- collaborative work practices
- Engineering Report writing

–Engineering Studies Stage 6 Syllabus, NESA

CHAPTER

FOUR

# TELECOMMUNICATIONS ENGINEERING

> One or more examples of telecommunications engineering must be used to develop an understanding of the scope and nature of this profession. Some examples include: telephone systems (fixed and mobile), radio systems, television systems and satellite communication systems.
>
> –Engineering Studies Stage 6 Syllabus, NESA

## 4.1 Scope of the profession

**Syllabus Excerpt**

- nature and scope of telecommunications engineering
- health and safety issues
- training for the profession
- career prospects
- relations with the community
- technologies unique to the profession
- legal and ethical implications
- engineers as managers
- current applications and innovations

–Engineering Studies Stage 6 Syllabus, NESA

### 4.1.1 Nature and Scope

Telecommunication Engineers are responsible for:

- Equipment: design, build, maintain, repair
- Transmission Media (copper, optic fibre, radio waves): design, build, maintain, repair, evaluate, control, write software to control and manage

Nature

- Training - university + postgraduate
- Systems Analyst - identifying faults & correcting them in systems

### 4.1.2 Health and Safety Issues

- In the past, chemical and waste from materials used, e.g. fumes from soldering
- Now, only (untrue) concerns about radiowaves

### 4.1.3 Training for the Profession

- Trade skills for installation and maintenance
- University Training in engineeering, mathematics, physics, IT software/hardware, design, manufacture, and materials
- Graduate + Postgraduate Training is often necessary for jobs
- On-job training
- As a growing field, so the training is often growing and rapidly developing alongside

### 4.1.4 Career Prospects

- 40% of ASX companies have engineer-trained managers
- Many jobs will exist that do not exist yet
- **Can be government or private companies**
  - Smaller companies are at the forefront of innovation as they are agile and can innovate rapidly

### 4.1.5 Relations with the Community

- Generally quite good as people like phones & the benefits it provides
- **BUT:**
  - visual pollution from wires + infra
  - Annoyance due to delays in installation & management
  - Quality & speed of the Transmission
  - Radiowave safety

### 4.1.6 Technologies Unique to the Profession

### 4.1.7 Legal and Ethical Implications

### 4.1.8 Engineers as Managers

### 4.1.9 Current Applications and Innovations

## 4.2 Historical and societal influences

**Syllabus Excerpt**

- historical development within the telecommunications industry
- the effect of telecommunications engineering innovation on people's lives
- materials and techniques used over time and development of cathode ray television including B/W and colour

  –Engineering Studies Stage 6 Syllabus, NESA

## 4.3 Engineering materials

**Syllabus Excerpt**

- specialised testing
  - voltage, current, insulation
  - signal strength and testing
- copper and its alloys used in telecommunications including copper beryllium, copper zinc, electrolytic tough pitched copper
  - structure/property relationships and their application
- semiconductors such as transistors, zener diodes, light emitting diodes and laser diodes
  - uses in telecommunications
- polymers
  - insulation materials
- fibre optics
  - types and applications
  - materials

  –Engineering Studies Stage 6 Syllabus, NESA

## 4.4 Engineering electricity/electronics

**Syllabus Excerpt**

- telecommunications including:
  - analogue and digital systems
  - modulation, demodulation
  - radio transmission (AM, FM, digital)
  - digital television transmission and display media such as plasma, LED, LCD, 3D
  - telephony: fixed and mobile
  - transmission media
    - cable

        * wireless
        * infrared
        * microwave
        * fibre-optic

- satellite communication systems, geostationary, low orbit satellite and GPS
- digital technology (AND, NAND, NOR, OR GATES)

  –Engineering Studies Stage 6 Syllabus, NESA

## 4.5 Communication

**Syllabus Excerpt**

- freehand and technical pictorial drawing, graphical design drawings
- computer graphics; computer aided drawing (CAD)
  - graphical design
  - in the solution of problems
- collaborative work practices
- Engineering Report writing

  –Engineering Studies Stage 6 Syllabus, NESA

# CHAPTER FIVE

# GLOSSARY

**toughness** Resistance to impact

**hardness** Resistance to permanent deformation

**anisotropic** Having a different value when measured in different directions

# INDEX

## A



## H



## T