1. Engineering Materials

1. *Properties of Materials*

TENSILE STRENGTH: withstand stretching loads.
COMPRESSIVE STRENGTH: withstand squeezing loads.
SHEAR STRENGTH: withstand offset loads (trying to pull two bars apart).
HARDNESS: withstand indentation or scratching.
TOUGHNESS: withstand impact loads.
BRITTLENESS: breaking under a sudden load.
ELASTICITY: stretch and return to same shape/size.
DUCTILITY: ability to be drawn into wires.
MALLEABILITY: deform via forging or rolling.
CORROSION RESISTANCE: resist corrosion through heat, moisture or pollution.
ELECTRICAL CONDUCTIVITY: measure of ability to allow current to pass through.
THERMAL CONDUCTIVITY: ability to transmit heat through conduction.
MACHINABILITY: ease/difficulty that a material can be machined or cut.

1.2 Characteristics and Forms of Supply

Things to consider when choosing a material: Relative Cost, Availability, Ease of Use, Safety in Use, Sustainability, and Forms of Supply:

- Sheet and Plate
- Forgings
- Tubes
- Castings
- Coil Strip
- Wire
- Bars and I sections
- Drums of plastic pellets/moulding powder

1.3 Ferrous Metals

Iron alloyed with carbon to improve properties.

- **Grey Cast Iron (3.5% Carbon)**

Low cost, easily cast, doesn't vibrate, is self- lubricating. Supplied as forgings, used for vices and gears.

- **Low Carbon Steel (1% Carbon)**

Used for pressings for car bodies, rods and tubes.

- **Medium Carbon Steel (1.2% Carbon)**

Used for crankshafts, axels and leaf springs.

- **High Carbon Steel (1.4% Carbon)**

Used for coil springs, chisels, knives, taps and dies.

More Carbon = Harder, but more Brittle, due to structural change.

- **Stainless Steel (0.04 - 0.3% Carbon)**

Chromium Oxide film surface protects from corrosion. Supplied as bar stock, used for food equipment.

- **High Speed Steel (0.5 - 1.5% Carbon)**

Alloyed with tungsten, chromium, vanadium and molybdenum for hardness and corrosion resistance. Supplied as bar stock for cutting tools and drill bits.

4. *Non-Ferrous Metals*

- **Copper (Melting Point = 1000°C)**

Is the basis of Brass and Bronze alloys. Soft, dense, ductile, resists corrosion but has low tensile strength. Supplied in all ways for pipes and cooking.

- **Aluminium (Melting Point = 660°C)**

Pure metal is weak, alloyed to improve. For aircraft parts (including Titanium alloys), engine parts and cans. Supplied all ways. Categories: Wrought Alloys (nht/ht) and Cast Alloys (nht/ht).

- **Lead**

Quickly tarnishes in air to a dull colour. Dense, ductile, soft, malleable and a poor conductor. Very corrosion resistant, so used for roofing/batteries. Supplied all w.

- **Zinc**

Hard and brittle up to 100°C, then malleable, at 210°C, becomes brittle again. Low m.p, fair conductor. In most alloys, used in galvanised steel barriers.

- **Tin**

Malleable and ductile, but brittle when cooled. Alloyed with lead for solder.

- **Titanium**

V. Good corrosion resistance & strength/density ratio. Alloyed with Fe, Al, vanadium and molybdenum for strong light alloys. Supplied: bar stocks, forgings.

Alloys: mixture of two or more metals, combined to produce better properties.

- **Brass**

Copper and Zinc alloy, in variable ratios. Supplied as tube, sheet bars and castings for cooking utensils and taps.

Standard Brass: 65/35.

Increasing Zinc makes alloy cheaper, but properties are worse – less ductile.

- **Bronze**

Copper and Tin alloy, softer and weaker than steel. Resists corrosion, fatigue, good conductor. Supplied as bar, sheet and castings for bells, propellers.

5. *Ceramics*

- **Glass**

Heated silica, brittle and hard. Cut with water jet.

- **Tungsten Carbide**

Hard and brittle, used for cutting tips. Formed by heating and compressing powders.

- **Silicon Nitride**

Used for bearings, is expensive and hard. Doesn't oxidise or expand.

1.6 Composites

A mixture of two or more different materials,

eg: reinforced concrete (steel rods and concrete).

- **Glass Reinforced Plastic**

Glass fibre strands bonded in epoxy or polyester resin can create large complex shapes. Thermosetting at rtp no press required.

- **Carbon Fibre**

Produced by heating fibres and bonding in epoxy, very strong, rigid and high tensile strength (2900N/mm^2).

- **Kevlar**

Like the above materials, used in bulletproof armour.

1.7 Thermoplastics

Plastics: vary in weight and strength, good insulators, extremely corrosion resistant.

Thermoplastics: can be re-melted, recycled, not as rigid as thermosetting, but tougher, easier to mould.

- **Polypropylene**

Vinyls group, moderate cost, good resistance, used for packaging and pipes.

- **PVC**

Good chemical resistance, moderate costs, used for packaging and upholstery.

- **Nylon**

High cost, member of polymides group, used to make yarn, rope, cable covers etc

- **ABS**

Low cost, good chemical resistance, makes pipes, tool handles and helmets.

- **Polyethylene**

Vinyls group, similar to ABS. Makes food containers, toys, toilet parts, can come in foam form.

1.8 Thermosetting Plastics

Thermosets: once set, cannot be re-melted and reused. Undergoes polymerisation. Can have pigment added for colour, or a filler such as wood flour or $CaCO_3$.

- **Polyester Resin**

Ease of handling, low cost, stability, good properties, is the resin for carbon fibre, and GRP.

- **Poly-urethanes**

Good hardness, tensile strength, impact and abrasion resistance.

- **Silicone**

Low conductivity, toxicity and reactivity. Used as rubber sealant, produced as a hardening liquid.

1.9 Smart Materials

Smart Materials: react to the environment (eg. heat/light), reversible and repeatable change.

- **Shape Memory Alloy**

Remembers its shape and will return upon the application of heat. Used in aerospace/medial.

- **Electrochromic Materials**

Reversible colour change when voltage applied.

- **Smart Glass**

Controls glass transparency used for mirrors and meeting rooms.

Photochromic: Chemical reaction to light.

Electrochromic: Reacts to changing voltage.

- **Quantum Tunnelling Composite**

In its normal state, is a perfect insulator, but when pressure is applied, it conducts. Made in sheets or small pills, for smartphones etc. Is a pressure sensitive variable resistor.

2. Testing

1. *Non-Destructive Testing*

Testing the component for the application it was designed for, without breaking it.

Dye Penetrant: coloured/fluorescent liquid applied to component surface. Is drawn into any surface imperfections, making them visible. A UV light may be used to improve visibility to the naked eye.

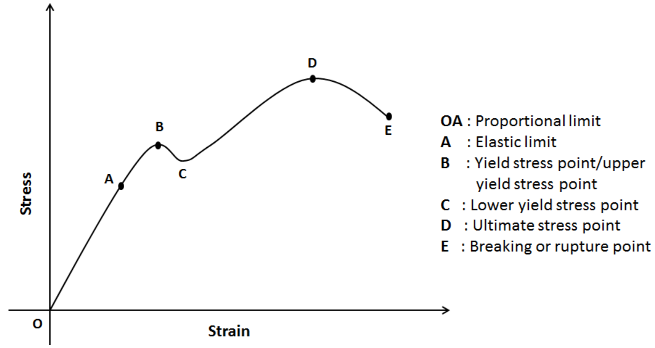
Conductivity Testing: by measuring the electrical conductivity, metal failures can be caught, as the electricity will not flow through the material, producing no reading.

2.2 Destructive Testing

Testing the component to its limits, so it cannot be used again. Destroys it.

Hardness: Rockwell and Vickers systems work by indenting the material to determine hardness.
WORKSHOP TEST: drop plumb bob from set height and compare indentations.

Tensile: grip a standard size sample into machine that stretches one end until material fails.



Impact: sample is clamped into machine and swinging weight produces a measurement upon collision.

3. Engineering Processes

1. *Material Removal*

Sawing: hacksaws used to cut metal into billets or to remove surplus.

SAFETY: blade shouldn't be twisted, broken or discoloured. Teeth must face cut direction.

Filing: used to remove sharp edges, where machining would be impractical. Files can be single cut or double cut.

SAFETY: always use a handle on the tang.

Threading: taps made from hardened high-speed steel. Dies are used to cut external threads. Tap wrench/die stock holder used to secure tool. Split on die is to change size.

SAFETY: do not over twist - snap.

3.2 Hand Forming

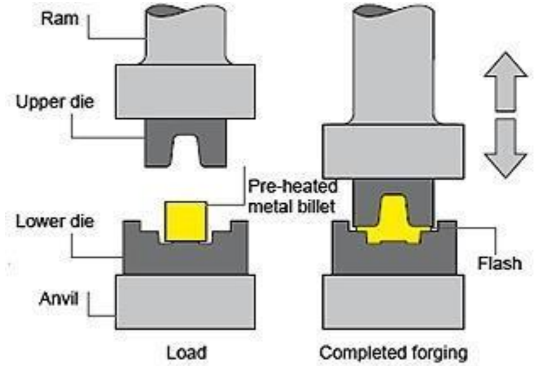
Strengthening/forming the part by hand. Copper, Steel, Aluminium and Titanium allows are forged. Where the component/force is too large to be done by hand, machine power is used.

ADVANTAGES: Aligns grain structure – very strong. Less wasted material, and less material to be cut/machined.

Forging: applying pressure to the metal when it is red hot, which aligns the grain structure to give maximum strength.

Hand Forging: accuracy depends on operator.

Drop Forging: heated metal placed on bottom plate, and top plate raised and then dropped from 3-6ft. The force squeezes metal into shape. Remove flash.



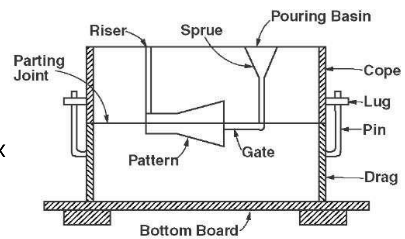
3.3 Casting

Where the metal is poured into a mould.

ADVANTAGES: intricate shapes easily produced, large hollow shapes can be produced, little to no waste with a good surface finish.

Sand Casting: pattern made from wood larger than final component to allow for shrinkage. Drag on top, sand on bottom, runners and risers to top section allow gases to escape, pattern is removed. Metal is poured in, then mould broken.

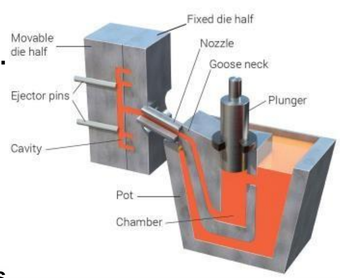
Cast Iron, Steels, Brass, Copper, Aluminium.



Investment Casting: higher degree of accuracy, but not renewable. Wax pattern produced and attached to sprue tree, coated in slurry. Wax melts out and molten metal poured in. Allowed to solidify.

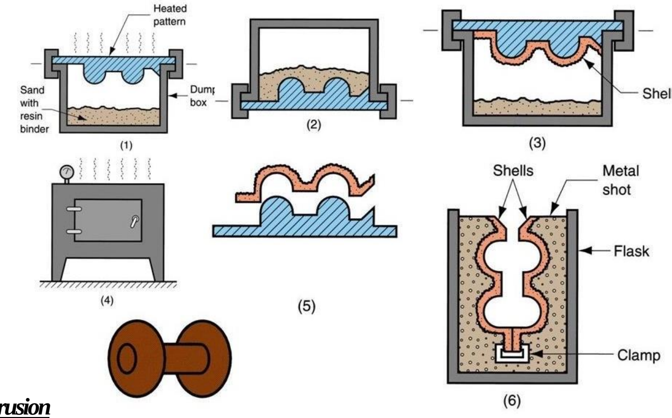
Stainless Steels, Alloy Steels, Titanium.

Die Casting: Uses a steel mould that can be reused, molten metal is forced into the cavity using pressure, ensuring good fill and quality – used for small/intricate parts.



Aluminium, Zinc and Magnesium Alloys.

Shell Moulding: pattern is heated, placed over sandbox with resin, and inverted to coat the pattern. Heated to cure the pattern, and then stripped. Mould assembled and filled.



3.4 Extrusion

Material is forced out through a die in a process similar to forcing toothpaste out of a tube. Forms long, uniform cross-sections.

3.5 Bending

Common operation on sheet metals, often completed on CNC machines – easier and more accurate. Involves forcing the sheet around a point.

3.6 Joining Methods

Affixing metals together.

Soldering: a low mp (300°C) alloy ran between parts. Creates a low strength, leak proof joint. Material must be dirt free.

Brazing: molten (450°C) filler drawn by capillary action between parts. Creates a high strength joint. Brazing Brass (60% Copper, 40% Zinc) or Silver Brazing (Silver, Copper, Zinc) used.

1. Clean both parts. Place parts in position.
2. Apply flux to each joint. Heat the start of the joint.
3. Draw the brazing rod along the joint.
4. Cool/Quench. Remove scale and excess.

Adhesives: non-metallic filler material used, but material must be perfectly clean.

Threaded Fasteners: cheap method but may suffer fatigue. eg. screws, nuts and bolts.

Self-Tapping Screws: screws that can cut or form threads into pre-existing cavities.

3.7 Welding

Oxyacetylene: oxygen and gasses produce a 3000°C flame. Filler material is drawn along the joint. No flux needed, combustion products protect the material.

Manual Arc: high intensity spark produced from an electrical circuit. Electrode is the filler and flux. Highly skilled.

Tungsten Inert Gas: used for thin metal sheets, non melting electrode used. Argon is shielding has, so no reaction with oxygen. Filler material fed by hand.

Metal Inert Gas: similar to TIG welding, but melting electrode fed in at a controlled rate. Different shielding gasses allow a range of metals to be joined.

Spot Welding: high current is passed through two electrodes with sheet metal between. High pressure contact. Little skill required, no filler, quick, automated, little distortion. Types are: seam, projection or butt. Used during car manufacture.

3.8 Riveting

Ideal due to speed, low-cost and dependability. Used on permanent joints and pivots. Male and female either side of join.

1. Drill rivet hole.
2. Place rivet in hole.
3. Secure by hammering into place to round top.

Blind Rivets: used when only one side is accessible. Used to join metal sheet – gripping jaws force rivet and pull sheets together.

4. Heat Treatment

Used to improve a materials performance. Carbon content is crucial, as low carbon content cannot be hardened by quenching. More carbon = harder, but more brittle.

In copper and brass, **QUENCHING = ANNEALING**. To achieve soft copper, must be quenched.

4.1 Hardening

Hardens the materials outer layer.

1. Plain carbon steels heated +50°C critical temp.
2. Quickly cooled in oil, brine or water.
3. Forms new outer structure.

- **BRINE:** rapid, hard and brittle, may crack.
- **WATER:** quick, needs agitating, quite hard.
- **OIL:** slower, won't crack, sufficiently hard.
- **AIR:** slow, won't crack.

Case Hardening: infusing the surface layer with carbon. Allows low carbon steels to be hardened. Higher temp = most carbon penetration.

- **SOLID:** packed in carbon and heated.
- **LIQUID:** placed in molten salt, small parts.
- **GAS:** precise control, diff temps, most penetration.

4.2 Normalising

Used to soften the material and relieve stresses from heavy machining.

1. Place in furnace, > critical temperature.
2. Allow to cool at rtp, grain is finer and spaced.

4.3 Annealing

Makes the material as soft as possible, increases ductility.

1. Place in furnace, > critical temperature.
2. Cool in a slow cooling furnace.

4.4 Tempering

Heat applied reduces hardness and brittleness. Used after hardening to soften the steel. Uses a temperature sensitive dye to indicate temp:

- 200°C straw colour (eg. gauges and scribes)
- 300°C blue colour (eg. springs)

5. Surface Finishing

To improve or reach a specified surface finish.

5.1 Linishing

Belt sanding technique. Use a finer grade for polishing.
SAFETY:firm grip, don't touch belt, parthot.

5.2 Polishing

Fine abrasive that removes scratches and leaves perfect surface finish. Applied to cloth/wheel and moved in a circular motion.

5.3 Powder/Plastic Coating

Powder is charged to 90kV within gun and sprayed. Cured at 300°C. Used thermoplastics such as nylon, or thermosets like polyesters. Needs electrostatic attraction, cannot be used where surface isn't visible.

5.4 Painting

Most common finish, cheap and has wide range of applications. Oil/Polymer based paints used, and enamels/lacquers when paint layers are finished. Commonly sprayed but can be brushed or dripped.

5.5 Electroplating

Second most common, very useful and effective. Component is cathode (-) in salt electrolyte and plating metal is anode (+) – uses electrolysis. Zinc, Gold and Tin.

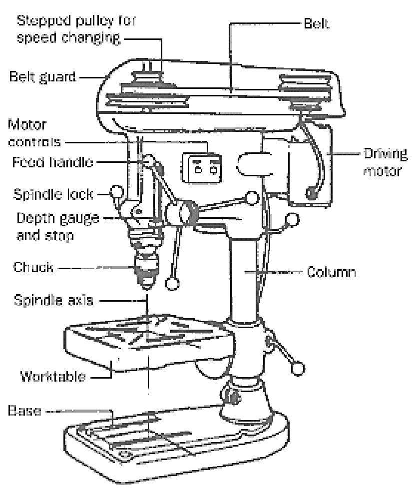
5.6 Galvanising

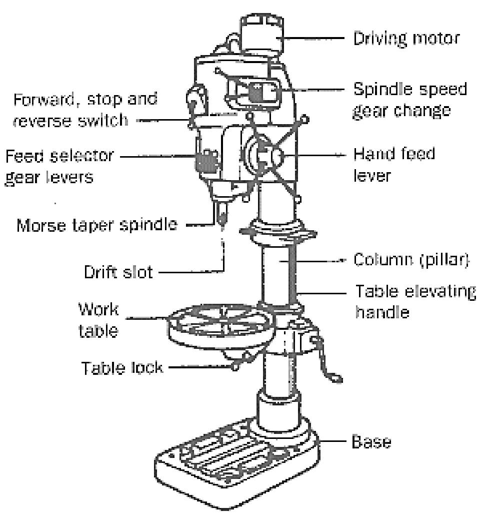
Zinc coating on metal. Applied by hot dipping or electroplating. Used on lamp posts, barriers etc…

6. Machine Processes

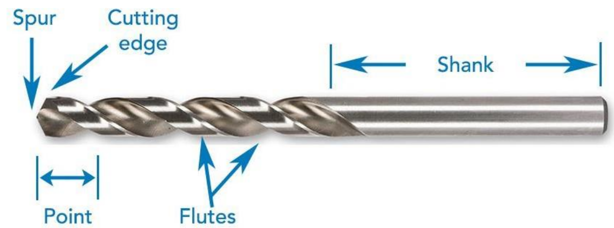
1. Drilling

- Portable power drill used for small holes in large structures. Air or electrically powered.
- Sensitive Bench Drill and Pillar Drill are similar in design. SBD is for light work, and PD for larger parts with a range of cutting speeds due to the gearbox.





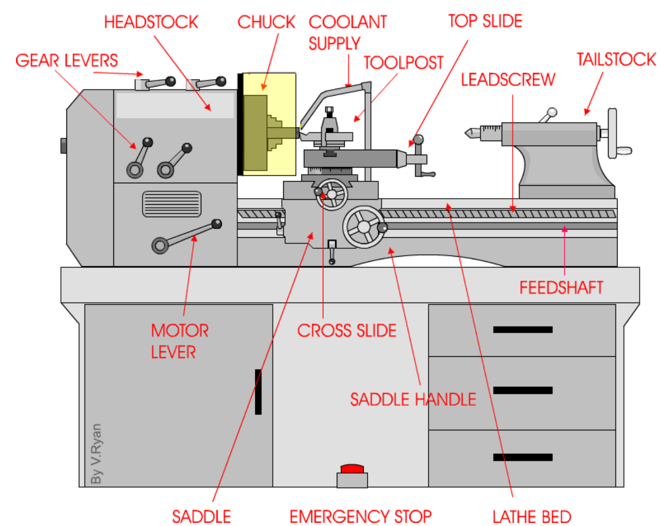
- Twist drill used for cutting metals, made from HSS. Has two cutting edges and two flutes. Each flute has a friction reducing raised section. Used for roughing out, produces a slightly larger hole than needed.



- Reamers are multi-fluted, used to finish off drilled holes with accuracy and a good surface finish.

6.2 Turning

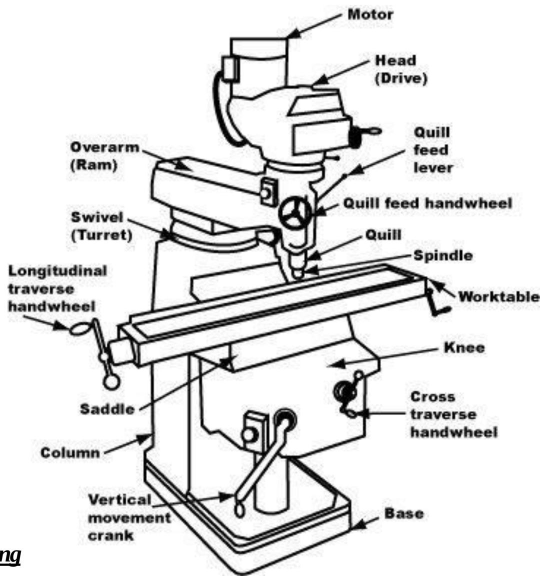
- Uses a centre lathe to produce turned, drilled, tapered or tapped parts.
- Spindle is driven through a gearbox and carries a 3/4jaw chuck and face/drive plates.
- Tailstock for drilling components.
- Bed made from cast iron carries the saddle – moves up/down the bed.
- Processes include: **Facing Off, Knurling, Turning Parallel Diameters/Tapers, Drilling, Parting Off, Chamfers etc...**



Milling

- Part is secured into worktable and fed under a rotating, multi-tooth tool.
- Vertical Mill = cutter in vertical axis, Horizontal Mill = cutter in horizontal axis.

- Used to machine flat surfaces and to cut steps/slots.
- Spindle is driven through gearbox to change speed. Knee moves up and down, carries saddle. Saddle carries worktable. Worktable can directly clamp part, or use a vice.
- END MILL = 3/4 flutes. SLOT DRILL = 2 flutes. TEE SLOT CUTTER, DOVE TAIL CUTTER, RADIUS CUTTER.



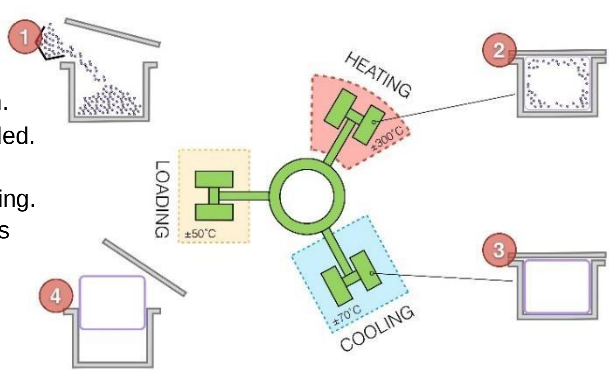
4. Grinding

- Produces accurate flat surfaces.
- Consists of grinding wheel, table and clamp.
- When using; material, surface finish, speeds and wheel contact must be considered.

5. Rotational Moulding

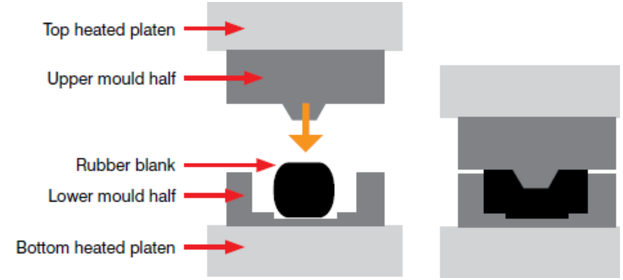
- Gravity inside a mould achieves a hollow form.

1. Set amount of polymer added.
2. Heated and rotated.
3. Mould is cooled while rotating.
4. Mould is opened and part is unloaded.



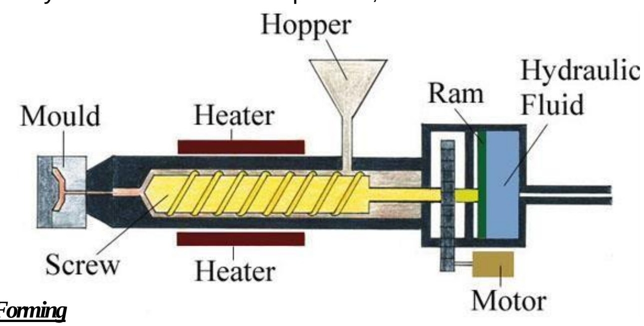
6.6 Compression Moulding

- Widely used process for thermosets.
- Used for rubber tyres.
- Moulding compound is pellets, liquid or preform.
- Amount of **charge** must be precisely controlled.



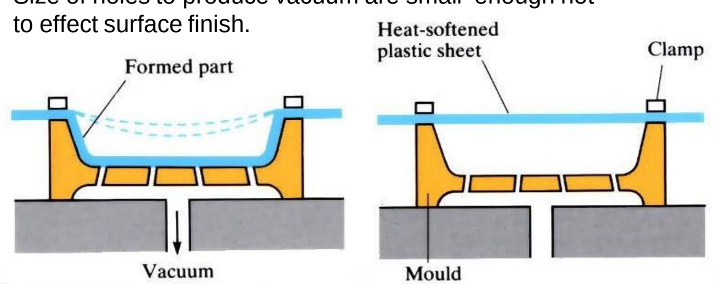
7. Injection Moulding

- Heated to a highly plastic state and forced into a cavity under high pressure where it solidifies.
- 10s to 1 minute cycle time.
- Normally used to mould thermoplastics, and some thermosets.



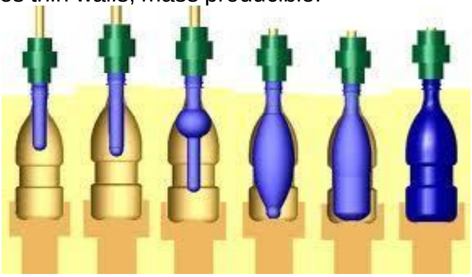
6.8 Vacuum Forming

- Preheated sheet is drawn into a mould by a vacuum.
- Size of holes to produce vacuum are small enough not to effect surface finish.



6.9 Blow Moulding

- Air pressure inflates soft plastic inside a mould cavity.
- Creates thin walls, mass producible.



7. Automation

Processes or procedures performed without human assistance.

Impacts:
- Increased output, faster to market.
- Zero defects, better quality.
- Smaller workforce, retraining, better conditions.
- Initial capital outlay, workforce savings, reduced production costs.

7.1 CNC

Traditional style machines adapted to have some/all axes computer controlled.

ADVANTAGES	DISADVANTAGES
• Precise • Accurate • Repeatable • High productivity • Optimum cutter use (tool racks) /environment	• Higher initial purchase cost • Jobs lost • Programmer needed

7.2 Robots

Handle materials and products, for loading and unloading, pick-and-place assembly. Typically, a programmed arm with an effector.

ADVANTAGES	DISADVANTAGES
• Use in hazardous environments • Highly repetitive tasks • Lower labour costs • Accurate	• Limited abilities • Cannot complete tasks needing sensory feedback or judgement

7.3 Automated Guided Vehicles

Small vehicles to move stock, or function as mobile workstations, along pre-set routes. Use cables in the floor to navigate by magnetic induction.

ADVANTAGES	DISADVANTAGES
• Independent movement • Flexibility	• More expensive than conveyor belts • Crash risk

7.4 Flexible Manufacturing System

Integration of technologies, incorporating computer managed systems. Extremely versatile.

ADVANTAGES	DISADVANTAGES
• Increased output • Reduced times • Consistency • Right-First-Time • Reduced cost • Improved working conditions • Smaller workforce	• High investment costs • Needs programming • Vulnerable if a cell fails • Job loss • Re-training costs

8. Digital Communications

Aid the manufacturing process.

8.1 Barcodes

Small blocks of alternating white and black lines scanned with a red laser. Used to track products and update stock databases. Can be linked to automatic ordering systems and stock control.

8.2 RFID Tags

Microchips with an induction coil to receive energy.

Microchip stores data, so acts like an 'Intelligent Barcode'. Used for the same things as barcodes, scanned with an RFID reader.

8.3 Stock Control Systems

Monitor stock levels using sensors and database information (which is updated using barcodes and computers). Can order items when stock is running low, to maintain supplies.

8.4 Computer Aided Design

Digital files and use of standards allow drawings to be distributed across the world. Makes design process easier, and less risk of error in Global Manufacturing operations.

5. ***Research***

Using the internet to develop ideas.

6. ***Video Conferencing***

Reduces travel costs, creating more productive time, and allowing problems to be solved more quickly.

9. Material Supply and Control

Automating the process increases control and reduces lead time.

9.1 Just-In-Time

Strategic supply of materials in an organised way, providing them just when needed.

ADVANTAGES	DISADVANTAGES
• No overproduction • No stock build up • Streamlines production • Reduces cost and production time • Limits TIMWOOD waste	• Stock may arrive late • Leaves production halted • No stock for emergencies • Delays/disasters mean lost money

9.2 Automatic Ordering

Captures customers requests, sends information to accounting/ shipping/manufacturing departments. Tracked stock arrives when needed.

ADVANTAGES	DISADVANTAGES
• Makes orders more reliable • Customer satisfaction increases • Reduces errors • Maximises profitability • Runs on-time	• Needs to be flexible • Expensive

10. Electronic Data Transfer

Using computer systems to send and receive files.

ADVANTAGES	DISADVANTAGES
• Cost effective (paper) • Efficient (limits error) • Fast, consistent • Accurate • Faster service = better customer service	• High investment cost • Cross compatibility issues • Technical errors occur

11. Global Manufacturing

The exporting of tasks to other countries, due to skill availability and proximity to materials. Standardised processes and procedures.

ADVANTAGES	DISADVANTAGES
• Financial incentives • Lower costs • Close to raw materials • Eased by digital comms • Exchange rate benefits • Close to developing markets • Made to international standards	• High investment cost • Requires high volume • Potential for disaster – economic, environmental, social.

12. Safety Precautions

1. ***Risk Assessment***

   1. Identify hazards – anything causing harm.
   2. Decide who might be harmed.
   3. Assess the risks and take appropriate action.
   4. Record findings.
   5. Review the risk assessment.

2. ***Precautions***

   - Ensure machine guards in place.
   - Check component is secure.
   - Keep area clear, ensure proper training.
   - Keep machine in good condition.
   - Ensure PPE worn (boots, goggles, overcoat).

13. Developments in Processes

1. CNC Machines

Covered in **7.1**, understand the adaptions made to each type of machine, and how it impacts production.

2. Laser Applications

Laser machines can be used to cut or engrave sheet metal/plastic. They work by firing a high-powered laser at the material's surface.

This is somewhat similar to water jet cutting, but water jet can only cut, not engrave.

ADVANTAGES: more precise, flexibility in surface finish, no rounded corners, unlike mill bits.

3. Rapid Prototyping and Additive Manufacture

Rapid Prototyping is used to quickly produce a physical model that can be felt and visualised, allowing the product to develop. Use of CAD software allows the design to be instantly changed and then the model reproduced. Products can get to market faster.

1. 3D model produced in CAD software based on primary designs.
2. This model is then sliced up by the 3D printing software.
3. Prototype on a range of machines:

3D printing (SLA): a laser solidifies layers of liquid polymer to produce a solid product.

3D printing (FDM): filament is heated above its melting point and layered, each layer cooling one by one, to produce a physical model.