Material Processing Technology

1 Introduction to material processing ....................................................................................................................3

2 Material forming ................................................................................................................................................3

   (a) Bending ..........................................................................................................................................................4
       (i) Metal .........................................................................................................................................................4
       (ii) Timber ..................................................................................................................................................5
       (iii) Plastics .................................................................................................................................................5
   (b) Pressing ..........................................................................................................................................................5
   (c) Rolling ............................................................................................................................................................6
   (d) Moulding .........................................................................................................................................................6
       (i) Mould forming .........................................................................................................................................6
       (ii) Blow moulding .....................................................................................................................................7
       (iii) Vacuum moulding ..............................................................................................................................7
       (iv) Compression moulding .......................................................................................................................7
       (v) Injection moulding ..............................................................................................................................8
   (e) Casting ..........................................................................................................................................................8
       (i) Sand casting ...........................................................................................................................................8
       (ii) Mould casting .....................................................................................................................................9
   (f) Lamination of materials ................................................................................................................................9

3 Material cutting ................................................................................................................................................9

   (a) Hand cutting ................................................................................................................................................10
   (b) Machine cutting .........................................................................................................................................10
       (i) Lathe .......................................................................................................................................................11
       (ii) Drilling machine ................................................................................................................................12
       (iii) Sawing machine ................................................................................................................................14
       (iv) Milling machine ................................................................................................................................15
       (v) Grinding machine ................................................................................................................................16

4 Material joining ..............................................................................................................................................17

   (a) Permanent joining .......................................................................................................................................17
       (i) Electric arc welding ...............................................................................................................................17
       (ii) Gas welding .........................................................................................................................................18
       (iii) Soft soldering ......................................................................................................................................19
       (iv) Hard soldering ....................................................................................................................................20
       (v) Riveting ...............................................................................................................................................20
       (vi) Pop riveting ........................................................................................................................................21
       (vii) Seaming .............................................................................................................................................21
       (viii) Gluing ...............................................................................................................................................23
   (b) Semi-permanent joining methods ................................................................................................................24
       (i) Screw thread joining ............................................................................................................................24
       (ii) Knock-down fitting ............................................................................................................................26
   (c) Joining of different materials .......................................................................................................................26
5 Material surface processing .............................................................. 27
   (a) Surface smoothing .......................................................................................... 27
      (i) Metal ........................................................................................................ 27
      (ii) Timber .................................................................................................... 27
      (iii) Plastics .................................................................................................... 27
   (b) Surface finishing .............................................................................................. 28
      (i) Electroplating ............................................................................................ 28
      (ii) Dip coating ............................................................................................... 29
      (iii) Painting .................................................................................................. 29
      (iv) Plastic coating .......................................................................................... 31
      (v) Wax and protective layers ........................................................................ 31
      (vi) Veneering ................................................................................................. 32
      (vii) Enamelling ............................................................................................... 32
   (c) Surface polishing and buffing ........................................................................ 33
      (i) Polishing ................................................................................................... 33
      (ii) Buffing ..................................................................................................... 33

6 Choosing method of material processing .................................................. 34
   (a) Choosing the cutting method ....................................................................... 35
      (i) Limitation of resources ............................................................................ 35
      (ii) Size and shape of workpiece .................................................................... 35
      (iii) Material of workpiece ............................................................................ 36
      (iv) Surface quality and preciseness ............................................................... 36
      (v) Quantity of production ............................................................................ 38
   (b) Choosing the method of joining .................................................................... 38
   (c) Choosing surface processing methods ....................................................... 39

7 Introduction to modern production technology ......................................... 39
   (a) Electrical discharge machining ................................................................. 39
   (b) Electric discharge wire cutting ................................................................. 40
   (c) Laser cutting .............................................................................................. 41
   (d) Dip etching .................................................................................................. 42
   (e) Automatic machining centre ....................................................................... 43
   (f) Chemical vapour deposition (CVD) ............................................................ 44

8 Introduction to methods of production ..................................................... 44
   (a) Mass production .......................................................................................... 45
      (i) Templates .................................................................................................. 45
      (ii) Fixtures and jigs ...................................................................................... 46
   (b) Assembly line ............................................................................................. 46
   (c) Production line ........................................................................................... 47

Exercise .............................................................................................................. 48
Material Processing Technology

1 Introduction to material processing

For easy storage and transport, materials are generally changed into simple shapes after collection and initial processing. For example, metals are changed into sheets, bars, boards or rods (Fig. 1a); timbers are cut into boards (Fig. 1b) and wooden sticks; and plastic materials are converted into plastic grains, plastic boards and plastic strips, etc.

Fig. 1 (a) Metallic sheet and bar   (b) Boards

The purpose of cutting, forming, joining and surface processing of materials is to make products suit our needs. These processes are called ‘Material Processing’. For example, metals are used to make tools (Fig. 2a), timbers are used to make chairs (Fig. 2b) and plastics are used to make stationery (Fig. 2c). To raise the quality of the artefacts, we should have a comprehensive understanding on various kinds of material processing technology.

Fig. 2 (a) Metallic tools   (b) Wooden chair   (c) Plastic stationery

2 Material forming

Material forming refers to the process of turning materials into appropriate shapes. There are many ways of material forming, e.g. Bending, Pressing, Rolling, Moulding, Casting and Lamination.
(a) Bending

(i) Metals

Metallic sheets can be beaten into different shapes by using hand tools, as well as by applying mechanical bending operations. There are various ways to bend metallic sheets mechanically. Fig. 3 shows some common bending methods and Table 1 introduces their processes and characteristics.

![V-Die bending](image1)

![Roll bending](image2)

![Folding](image3)

![Draw bending](image4)

Fig. 3 Some bending methods for metals

<table>
<thead>
<tr>
<th>Bending Methods</th>
<th>Process</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-Die Bending</td>
<td>Pressing the sheet into mould by using a hard V-Die</td>
<td>Metals can be bent into different curves and angles by using different moulds</td>
</tr>
<tr>
<td>Roll Bending</td>
<td>Bending metallic sheets by rolling a set of cylinders</td>
<td>Metals can be bent into smooth angles with greater radii</td>
</tr>
<tr>
<td>Folding</td>
<td>Clipping metallic sheets tightly with holders and then bend the sheets with hard moulds</td>
<td>Moulds are simple</td>
</tr>
<tr>
<td>Draw Bending</td>
<td>Drawing the soft heated metal sheet through the mould</td>
<td>Long metallic strips can be bent rapidly</td>
</tr>
</tbody>
</table>

Table 1 Processes and characteristics of bending methods
(ii) Timber

Timbers can be bent by steam bending or board clamping. Under steam bending, timbers are heated and softened by steam cases, and then immediately placed in a mould and clamped for a long time until dry to have their shapes fixed. Board clamping refers to the bending process of clamping glued laminated veneer with mortise-and-tenon moulds. The laminated veneer will form curved pieces after the glue dries.

(iii) Plastic

Thermoplastics can be bent by heating. For example, acrylic is a common thermoplastic. When heated to about 170°C in an oven or by using an electric rod heater, acrylic will soften and can be bent into desired shapes.

(b) Pressing

Pressing is to stamp metals into desired shapes. Firstly, heat and soften metallic materials. Then use a hydraulic press to drive the stamping tool so that metals can be pressed into artefacts with different shapes and thickness (Fig. 4a). Desired appearances can be cast on the material surface if such appearances are produced on the surface of the stamping mould. For example, coins are minted from metals (Fig. 4b).

![Fig. 4 (a) Principle of pressing](image1)
![Fig. 4 (b) Coins](image2)

The principle of pressing can also be applied to stamping large pieces of metal into sheets with different shapes or holes (Fig. 5a). Computer control pressing machines (Fig. 5b) can even change stamping moulds automatically according to the designs of the sheets, so that metallic sheets can have complicated and meticulous surfaces.
(c) Rolling

The theory of rolling is to reduce the thickness (Fig. 6a) or to change the cross-section (Fig. 6b) of a long workpiece by using a set of rollers. Rolling is usually classified as Cold Rolling and Hot rolling. Table 2 compares the two.

<table>
<thead>
<tr>
<th></th>
<th>Cold Rolling</th>
<th>Hot Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principles</td>
<td>Start rolling without undergoing heating process</td>
<td>Start rolling after heating the metal to working temperature</td>
</tr>
<tr>
<td>Materials</td>
<td>Soft metals with higher ductility, e.g. aluminium</td>
<td>Hard metals, e.g. steel</td>
</tr>
<tr>
<td>Merits</td>
<td>Improve physical properties, smooth surface, precise size</td>
<td>Can turn hard, thick metals into sheets or rods with smaller radii</td>
</tr>
<tr>
<td>Limitations</td>
<td>Not suitable for condition of great difference in thickness between raw materials and artefacts</td>
<td>- Rough surface of the product</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• higher cost because the tools have to withstand high temperature</td>
</tr>
</tbody>
</table>

Table 2 Comparison between cold rolling and hot rolling

(d) Moulding

Moulding refers to the process that changes the form of plastics into desired shapes by the use of moulds. Moulding methods include mould forming, blow moulding, vacuum moulding, compression moulding and injection moulding etc.

(i) Mould forming

Mould forming is to fill thermosetting plastics such as polyester resin into the moulds. When the resin hardens, shapes can be fixed and artefacts can be released from the moulds. Decorations can be sealed if they are added before the resin hardens.
(ii) Blow moulding

Blow moulding can blow thermoplastic strips (e.g. polyvinyl chloride) into desired shapes. Clamp the plastic strips tight, heat and soften them. Then blow in air using blowing machine and press the strips into the shape of the mould.

(iii) Vacuum moulding

Vacuum moulding turns thermosetting plastic strips into desired shapes using atmospheric pressure. Firstly, clamp tight, heat and soften the strips. Then raise the mould on top of the strips (Fig. 7a). Remove air using vacuum forming machine and the plastic strip will be pressed into desired shapes by atmospheric pressure (Fig. 7b).

(iv) Compression moulding

Compression moulding can produce plastic bottles rapidly and automatically. Heat and soften materials with compression moulding machine. Then fill the materials into the mould. Bind and hold tight the ends. Blow in air and press into the shape of the mould (Fig. 8a). Plastic bottles are then produced after the hardening of the materials and removal of excessive parts (Fig. 8b) by the machine.
(v) Injection moulding

Injection moulding is an automatic method for mass production of plastics. Plastic materials are first heated and softened in the machine and then injected into the moulds (Fig. 9). Artefacts can be produced when the materials are hardened. Merits of this moulding method are that costs can be lowered by means of mass production and the quality of products is higher. Moreover, products do not need further processing and they require less plastic consumption. This is why injection moulding is widely adopted in the industry.

![Injection Moulding](image)

(a) Plastics injected into the mould  
(b) Hardened Artefacts

Fig. 9 Injection moulding

(e) Casting

Casting is to fill melted metals into moulds and to get the artefacts after hardening. This method can produce metallic products with high complexity in shape such as blades of propellers, sculptures and water pumps.

(i) Sand casting

Sand casting is to produce sand mould by using sand. Firstly, put a wood mould into the lower case. Then cover the mould with sand and press until the surface is smooth (Fig. 10a). Put the lower case upside down and place the upper case on top of it. Place the pouring pipe. Fill the case with sand and press tight. Use a spoon to remove the sand and form a pouring basin after removing the pipe (Fig. 10b).

![Sand Casting](image)

(a) Cover the wooden mould with sand  
(b) Remove the sand and form a pouring basin

Fig. 10 Sand Casting
Then remove the upper case as well as the mould from the lower case. Use a spoon to open a pouring trench and place back the upper case (Fig. 11a). Finally, pour melted metal into the sand mould and get the artefacts from the lower case after cooling (Fig. 11b).

![Fig. 11 Sand casting](image)

(ii) Mould casting

Mould casting is a rapid way of casting. Melted metals (e.g. aluminium) are squeezed into steel mould in the mould-casting machine (Fig. 12a). When the metals turn into solid, the mould will be opened for workers to get the artefacts (e.g. Fig. 12b). Some moulds in mould casting machine are complimented by water for shorter cooling time.

![Fig. 12 (a) Mould Casting Machine and (b) Artefacts of mould casting](image)

(f) Lamination of materials

Lamination refers to the process of cohering multi-layered materials with thermosetting plastics, e.g. thin wood skins, paper, cloth, etc. Soak paper or cloth in thermosetting plastics (e.g. resin). By using a compressor to press and heat the materials, laminated plastic sheet (e.g. Formica) can be produced.

3 Material cutting

Material cutting refers to the cutting or removal of excessive parts of the materials. For example, to cut material into desired dimensions, to drill holes or to make a trench. Materials can be simply cut by hand tools. To enhance the effectiveness of cutting, machines can also be used.
(a) Hand cutting

Fig. 13 Some hand tools for cutting

There are various types of hand tools that can be used for cutting. They include hammer, handsaw, file, hand drill, plane etc. Fig. 13 shows some hand tools for cutting. Some portable small-scale machines (e.g. portable power hand drill) are also very common for speedy material cutting. Table 3 outlines the use and examples of applying hand tools for cutting.

<table>
<thead>
<tr>
<th>Hand tools for cutting</th>
<th>Usage</th>
<th>Examples of tools</th>
<th>Examples of materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer, chisel</td>
<td>Cut material with neat edges</td>
<td>Mallet, chisel</td>
<td>Timber</td>
</tr>
<tr>
<td>Saw</td>
<td>Separate materials into two parts</td>
<td>Wooden saw, steel saw, coping saw, portable jigsaw</td>
<td>Timber, metal, plastic</td>
</tr>
<tr>
<td>File</td>
<td>Have slight cut on material surface</td>
<td>Flat file, half-round file, square file, round file, triangular file</td>
<td>Timber, metal, plastic</td>
</tr>
<tr>
<td>Drill</td>
<td>Drill holes on material surface</td>
<td>Hand drill, portable power hand drill</td>
<td>Timber, metal, plastic</td>
</tr>
<tr>
<td>Plane</td>
<td>Have deeper cut on material surface</td>
<td>Jack plane</td>
<td>Timber</td>
</tr>
<tr>
<td>Tap</td>
<td>Produce internal thread in round holes of metal with the aid of tap wrench</td>
<td>Taper tap, second tap, plug tap</td>
<td>Metal</td>
</tr>
<tr>
<td>Die</td>
<td>To produce external thread on metallic cylinders with the aid of die holder</td>
<td>Circular split die, combination die</td>
<td>Metal</td>
</tr>
</tbody>
</table>

Table 3 Some common hand tools for cutting

(b) Machine cutting

Cutting machines can cut materials rapidly and efficiently. These machines include lathe, drilling machine, sawing machine, milling machine and grinding machine. All of them carry specific functions.
(i) Lathe

The major function of a lathe is to cut cylindrical workpieces made of materials such as timber and metal (Fig. 14). Fig. 15 shows different parts of a lathe. Cylindrical workpieces are clamped by the chuck and rotate at a high speed. Cutting can be done by moving the turning tools clamped in the stock according to the shape of the workpiece. Lathes are categorized as woodwork and metalwork lathes.

Turning tools of lathes are usually made of high-speed steel and they are abraded into different shapes and angles by abrasive wheels before use (Fig. 16) so that they can cut materials effectively. Turning tools are designed according to their purposes (Fig. 17) and lathes have different cutting functions. Fig. 18 shows some cutting methods of using lathe and Table 4 lists their uses.
(a) Face cutting
(b) Parallel turning
(c) Knurling
(d) Parting off
(e) Boring
(f) Cone turning

Fig. 18 Cutting methods of lathe

<table>
<thead>
<tr>
<th>Cutting Methods</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Face Cutting</td>
<td>Turning tool moves on the surface of the ends of the workpiece and cuts rough areas.</td>
</tr>
<tr>
<td>(b) Parallel Turning</td>
<td>Turning tool moves according to the shape of workpiece and does the cutting.</td>
</tr>
<tr>
<td>(c) Knurling</td>
<td>Knurling tool stamps knurls on the round surface of workpiece.</td>
</tr>
<tr>
<td>(d) Parting off</td>
<td>Move turning tools back and forth in parallel directions according to the shape of workpiece, and move into the center gradually.</td>
</tr>
<tr>
<td>(e) Boring</td>
<td>Move drilling tool in parallel directions inside holes of workpiece so as to enlarge the diameter of the holes.</td>
</tr>
<tr>
<td>(f) Cone Cutting</td>
<td>Make use of the angles of the turning tools to cut bevel parts with short distances on the top of the workpiece.</td>
</tr>
</tbody>
</table>

Table 4 Uses of lathe cutting methods

(ii) Drilling machine

The main function of a drilling machine is to drill holes with different diameters by using bits. Drilling machines are categorized into table and floor (Fig. 19). Fig. 19c shows different parts of a drilling machine.
The cutting tool of the drilling machine is called bit (Fig. 20) and it is divided into two parts called drill head and drill body (Fig. 21). The drill head is responsible for cutting and directing the bit into the workpiece and the edges are responsible for cutting. There are threads on the drill trough which help to direct drill chips out of drill holes and to let cooling agent flow into the hole. Drill stocks are clamped by chucks and are categorized as straight and taper stocks.

Bits are usually made of high speed steel to resist the high temperature generated during the process of drilling. Table 5 lists the uses of some common bits.

<table>
<thead>
<tr>
<th>Bits</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre Bit</td>
<td>To drill centre hole on workpieces in order to enable entrance of larger bits</td>
</tr>
<tr>
<td>Countersink Bit</td>
<td>To turn tops of round holes into conical shape</td>
</tr>
<tr>
<td>Twist Bit (straight stock)</td>
<td>To drill holes with diameters not larger than 13 mm</td>
</tr>
<tr>
<td>Twist Bit (taper stock)</td>
<td>To drill holes with diameters larger than 13 mm</td>
</tr>
</tbody>
</table>

Table 5 Uses of common bits
(iii) Sawing machine

Sawing machines are mainly used to cut workpiece into pieces by using saw blades. They are categorized as jigsaws, hand-sawing machines and hack-sawing machines (Fig. 22). Table 6 lists the properties of different sawing machines.

<table>
<thead>
<tr>
<th>Sawing Machines</th>
<th>Characteristics</th>
<th>Compatible Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jigsaw</td>
<td>Saw-teeth should face downwards. It is used to cut curves.</td>
<td>Cardboard, plastic sheets, etc.</td>
</tr>
<tr>
<td>Hand-sawing Machine</td>
<td>Used for cutting straight lines or curves, but not suitable for workpieces which are small in size or great in radius.</td>
<td>Timber, acrylics, etc.</td>
</tr>
<tr>
<td>Hack-sawing Machine</td>
<td>Blades are made of high speed steel, greater motor power. Used for cutting large-scale workpieces.</td>
<td>Metallic materials such as copper, aluminium and mild steel.</td>
</tr>
</tbody>
</table>

Table 6 Characteristics of different sawing machines

(a) Jigsaw

(b) Hack-sawing machine

Fig. 22 Different sawing machines

The following precautions should be strictly followed when using sawing machines:

1. Sawing machines can only be used under the teacher’s supervision.
2. Users should wear safety goggles and install safety shield before operating the sawing machines.
3. Start the machine only when there is sufficient light.
4. Keep fingers and body out of reach of the working blades during the process of sawing.
5. Never shift blades from the neutral line during sawing.
6. Do not propel, twist or change directions violently to avoid accidental damage of the blades.
7. Clear working table only when the power is switched off and operation is completely stopped.
(iv) Milling machine

Milling machine is mainly used for cutting various surfaces (e.g. planes, bevels, troughs and cams) of materials including timber and metals. Fig. 23 shows the different parts of an erect milling machine.

![Milling machine parts](image)

Fig. 23 An erect milling machine

Milling cutters are generally made of high-speed steel and the erect ones are cylindrical in shape with screw threads at the ends (Fig. 24a). Milling cutters are clamped by chucks and they rotate at high speed. Cutting can be done by moving the cutters according to the shape of the workpiece.

![Milling cutter and process](image)

Fig. 24 (a) Erect milling cutter (b) Milling process of an erect milling cutter

The following precautions should be strictly followed when using milling machines:

1. Wear protective uniforms and goggles.
2. Milling cutter, fixtures and workpiece should be firmly installed on the machine.
3. Use a cloth when taking and changing milling cutters.
4. Change and adjust cutters only when operation is finished.
5. Feeding depth and rotation speed should be carefully chosen according to the hardness of material.
6. Add appropriate amount of cutting fluid when it is necessary.
(v) Grinding machine

Grinding machines are used to abrade metallic workpiece by using abrasive wheels in order to raise the preciseness and smoothness of the surface. Grinding wheels cohere hard abrasive sands. When the wheel rotates at high speed, the sands remove tiny metallic chips like the action of small teeth. Abrasions can be categorized into non-precise ones and highly-precise ones. Non-precise abrasion is to abrade workpiece under great force of the abrasive wheel and it is mainly used to remove protruding objects on rough workpiece such as metallic cast products. There is no need to consider the preciseness of this kind of abrasion. However, highly-precise abrasion should have a good calculation on the abrasion size.

(a) External cylindrical grinding  (b) Internal cylindrical grinding  (c) Surface grinding

Fig. 25 Abrasion with high preciseness

Abrasion with high preciseness can be classified into three categories, namely, external cylindrical, internal grinding and surface (Fig. 25). The structure of cylindrical grinding machine is similar to that of a lathe. During the grinding procedure, workpiece will be clamped at the chuck and rotate at high-speed, while the wheels will rotate on the symmetric axis and abrade the workpiece precisely (Fig. 26a). Preciseness can generally be controlled within $5 \times 10^{-6}$ m. The structure of surface grinding machine is, on the other hand, similar to that of a milling machine, and it can grind the surface of metallic workpiece rapidly (Fig. 26b and c).

(a) Cylindrical grinding machine  (b) Surface grinding machine
4 Material joining

Most articles consist of various components and hence joining becomes necessary. Joining can be categorized as permanent and semi-permanent.

(a) Permanent joining

Permanent joining is to join components firmly with fixed and inflexible form that makes it difficult for parts to be separated afterwards. Permanent joining has various forms such as metallic welding which includes electric arc welding, gas welding, soft soldering, hard soldering, riveting, pop riveting, seaming and gluing.

(i) Electric arc welding

Electric arc welding is to melt weld stick and metallic materials using energy emitted by electric arc to reach a permanent joining between metals (Fig. 27). The phenomenon of strong and persistent electric emission between electrodes is called an electric arc. An electric arc can generate high power to the temperature of about 6000°C and generate strong UV light at the same time (Fig. 28a).
Fig. 28 (a) Process of electric arc welding (b) Welding joints

Joints formed by electric arc welding are very stiff since they are melted from metal (Fig. 28b). Other merits of welding joints include high resistance to heat, time-saving and material-saving. Hence, electric arc welding is widely used in joining parts for cars, aircrafts and construction projects. However, the quality of welding joints may still be affected by factors such as welding stick materials, welding skills and oxides.

The following precautions below should be strictly followed when conducting electric arc welding:

1. Wear light-filtering goggles to prevent hurting the eyes from the strong light and hot solder.
2. Keep the workpiece out of reach of inflammables to avoid catching fire as the surface may still be very hot after welding.
3. Keep a good ventilation of the workplace to avoid inhaling the gases generated by flux.
4. Wear appropriate gloves during welding to avoid contact with heat, UV light and corrosive fluxes.
5. Switch off all power after work.

(ii) Gas welding

Gas welding refers to the production of welding rod by melting welding stick and workpiece, using the flames produced by a mixture of oxygen and acetylene.
Properties of gas welding and electric welding are similar, but gas welding has lower operating temperature and hence is much easier to control. As a result, this joining method is more preferable on meticulous work such as the joining of metallic sheets and pipes. Due to its cheaper devices, easy operation and convenience in transportation, gas welding is widely used. Safety precautions of gas welding are similar to that of electric arc welding.

(iii) Soft soldering

Soft soldering is to produce welding joints by melting solder (e.g. aluminium) onto workpiece under high temperature (Fig. 30). This is a common method of permanent joining for electronic circuits (Fig. 31a) and putting high-temperature electric solder iron onto the junction point of wire with the melted solder (Fig. 31b). Since fluxes can melt oxides on metal surfaces, direct solder flow and clear workpiece surface, substances such as resin are usually added during soft soldering.

The following precautions should be strictly followed during the process of soft soldering:

1. Wear safety gloves.
2. Never touch the fluxes by hard as they are corrosive in nature.
3. Use welding bits carefully to avoid scald.
4. Keep a good ventilation of the workplace.
5. Never place inflammables in the workplace.
(iv) Hard soldering

Hard soldering is the method of joining metals by the use of alloy. Its joints are stiffer than soft soldering and it is generally applied to join steel workpieces. Fluxes are usually added in the process of soldering. Among various fluxes, borax is the most common one as it can smoothen soldering procedures by avoiding the formation and breakdown of oxides. Hard soldering is divided into two types, namely silver soldering and brazing. Table 7 lists their characteristics.

<table>
<thead>
<tr>
<th>Types of Soldering</th>
<th>Solders</th>
<th>Melting Points of Solders</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver-soldering</td>
<td>Silver Solder (Copper + Zinc + Silver)</td>
<td>Lower Melting Point (600°C~630°C)</td>
<td>Firmer soldering effect; temperature needed is lower due to application on meticulous structure of ornaments.</td>
</tr>
<tr>
<td>Brazing</td>
<td>Brass Solder (Copper + Zinc)</td>
<td>Higher Melting Point (850°C~950°C)</td>
<td>Commonly applied to steel-made workpiece in industry, e.g. carbonized tips connecting to the front of cutting tools.</td>
</tr>
</tbody>
</table>

Table 7 Silver soldering and Brazing

The high temperature required for the process of hard soldering is supplied by brazing torch in the brazing hearth. The brazing torch burns flammable gas mixture and compressed air to generate sufficient energy. Common brazing torches are classified into traditional ones and modern ones. Among the modern ones, some produce soft flames while others produce hard flames: combustion area of the soft flame is larger and the heat is even, while heating by hard fire is limited to a small area.

(v) Riveting

Riveting is the technique of joining two or more workpieces together by rivets. There are various types of riveting (Fig. 32a) for different uses. Metallic outer shells of cars, aircrafts and ships are all users of rivets (Fig. 32b).

Fig. 32 (a) Different types of rivet  
(b) Example: outer shell of aircraft
The procedures of riveting is simple. Take the mounting of a round head rivet as an example. Firstly, bind two workpieces together, drill a hole and smoothen chips surrounding the hole with the help of a file. Then, place an appropriate length of rivet into the hole (Fig. 33a). Press the workpieces using rivet set and beat the workpieces with a hammer (Fig. 33b). Finally, beat edges of the rivet until a small rounded top is formed (Fig. 33c).

![Fig. 33 Steps of riveting using a round head rivet](image)

**(vi) Pop riveting**

The principle of pop riveting is similar to that one of riveting. Pop riveting is much easier to operate as only rivet gun and pop rivets are needed (Fig. 34). Open the rivet gun, place an appropriate chuck inside and insert a pop rivet. Put another end of the pop rivet into the hole of the workpiece (Fig. 35a). Give handles of the torch a hard push until the steel pin between the pop rivet is broken (Fig. 35b). Release handles and take out the pin inside the chuck (Fig. 35c).

![Fig. 34 Rivet gun and pop rivet](image)

![Fig. 35 Steps of pop riveting](image)

**(vii) Seaming**
Seaming is to join material edges together, for example, by folding a metallic sheet and linking the edges by welding. Seaming can be used to join two pieces of metallic sheets, the bottom of a can, etc.

To join two pieces of metallic sheet, beat one edge of the workpiece into an angle of 90° (Fig. 36a) with a hammer, place a piece of steel sheet on the fold and smoothen the fold (Fig. 36b). Fasten the folds of the workpieces together and beat the fold with a hammer so as to make the joint stiff (Fig. 36c). Finally, use a trough mould and a hammer to produce a trough (Fig. 36d).

(a) Beat the edge to an angle of 90°  (b) Smoothen the fold with a hammer

(c) Fasten the folds  (d) Produce a trough with a hammer and a mould

Fig. 36 Seaming of two pieces of metallic sheet

To join bottom with the cylindrical part of a can. Beat and smoothen one edge of the workpiece into a fold with an angle of 90° (Fig. 37a). Beat another circular sheet into a 5 mm fold of 90° (Fig. 37b). Join the workpiece with the sheet and smoothen the 5 mm fold by beating with a hammer (Fig. 37c). Finally, smoothen the bottom (Fig. 37d).
(a) Beat into 90°

(b) Fold a circular sheet

(c) Join the workpiece and the sheet

(d) Beat and smoothen the bottom

Fig. 37 Folding a can bottom

(viii) Gluing

Gluing is the technique of using adhesives to stick materials together. Most of the solid materials such as timber, plastics and metal can be joined by gluing. There are various types of adhesives, such as contact glue, all-purpose adhesive and chloroform. Since adhesives usually carry great shearing force but poor tensile force, joining surface of materials should be enlarged as much as possible to avoid easy tearing. Fig. 38 shows different gluing methods and their effects.

(a) Weak gluing

(b) Weak gluing

(c) Strong gluing

(d) Strong gluing

(e) Strong gluing

(f) Strong gluing

Fig. 38 Gluing effects
(b) Semi-permanent joining methods

Semi-permanent joining refers to joining in fixed shapes but easy separation afterwards. Methods of semi-permanent joining include screw thread joining and knock-down fitting.

(i) Screw thread joining

Screw thread joining is to use screws to join materials. When thread on a screw twists, screw bevels will generate a huge force which can tightly fasten two or more workpieces. This joining method can be used to fasten most of the materials such as metal, timber and plastics, for example, to hang a plastic sheet onto wooden materials. There are many types of screw components (Fig. 39). Table 8 lists some of them.

Fig. 39 Examples of screw components
### Screw Components

<table>
<thead>
<tr>
<th>Screw Components</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Screw</td>
<td>To fasten two wooden objects</td>
</tr>
<tr>
<td>Mechanical Screw</td>
<td>A widely used screw which has threads all over its body.</td>
</tr>
<tr>
<td>Machinery Screw</td>
<td>Mainly for fastening thicker workpieces of larger scale. Put the bolt through holes of two or more workpieces and fasten with a nut.</td>
</tr>
<tr>
<td>Set Screw</td>
<td>To fix two pieces of workpieces, e.g. to fix components on rotation axis of gears and propellers.</td>
</tr>
<tr>
<td>Stud</td>
<td>A tiny cylindrical rod with threads on its ends or its whole body.</td>
</tr>
<tr>
<td>Steel Screw</td>
<td>To press and produce threads on workpieces by using the firm and sharp threads on the body. Suitable for joining thin metals.</td>
</tr>
<tr>
<td>Anchor Screw</td>
<td>A screw set for hanging heavy objects onto the ceiling.</td>
</tr>
</tbody>
</table>

Table 8 Some screw components

![Different washers](image1)

![A wing nut](image2)

![An acorn nut](image3)

![Machinery nuts](image4)

**Fig. 40** Some screw-supporting components

Some supporting components may be needed when using screws (Fig. 40). Table 9 lists their functions.

### Supportive Components

<table>
<thead>
<tr>
<th>Supportive Components</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washers</td>
<td>To avoid the formation of abrasive signs on workpiece surface when fastening the nuts.</td>
</tr>
<tr>
<td>Nuts</td>
<td>To facilitate fastening action during twisting of machinery screws.</td>
</tr>
<tr>
<td>Cap nuts</td>
<td>Mainly for aesthetic and safety purposes.</td>
</tr>
<tr>
<td>Wing nuts</td>
<td>To be applied on parts with needs frequent knock-down or adjustments.</td>
</tr>
</tbody>
</table>

Table 9 Some supporting components for screws
(ii) Knock-down fitting

Knock-down fitting is a joining method especially designed for joining surfaces of composite furniture such as tea table, cabinets, wardrobes, beds, chairs, dining-tables, etc. This method makes components easy to be assembled, knocked down, transported and stored. Moreover, damaged parts can be repaired and changed easily and hence it can lower the production cost. Fittings include cam-action, interlocking and screw-action (Fig. 41). Table 10 lists their characteristics.

(a) Knock-down screw fitting  
(b) Knock-down screw fitting

Fig. 41 Knock-down fitting

<table>
<thead>
<tr>
<th>Fittings</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cam-action Fitting</td>
<td>Just use a screw-driver to screw the eccentric outer shell, usually applied on high-class furniture.</td>
</tr>
<tr>
<td>Interlocking Fitting</td>
<td>Suitable for internal joining only.</td>
</tr>
<tr>
<td>Screw-action Fitting</td>
<td>Usually applied on cheap furniture made of chipboard.</td>
</tr>
</tbody>
</table>

Table 10 Characteristics of knock-down fitting methods

(c) Joining of different materials

Joining methods for different materials are similar to those of same materials. However, collocation is different. For example, we may use stapler chips to fix leather or fabric onto wooden shelves when assembling sofa, and we may use bolts to install plastic handles onto cooking pots for insulation. Table 11 concludes joining methods for various materials.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Metal</th>
<th>Timber</th>
<th>Plastics</th>
<th>Fabrics/Leather</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td></td>
<td>A,B,R</td>
<td>A,B,R</td>
<td>/</td>
<td>B</td>
</tr>
<tr>
<td>Timber</td>
<td>A,B,R</td>
<td></td>
<td>A,B</td>
<td>S</td>
<td>B</td>
</tr>
<tr>
<td>Plastics</td>
<td>A,B,R</td>
<td>A,B</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Fabrics/Leather</td>
<td>/</td>
<td>S</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Concrete</td>
<td>B</td>
<td>B</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

Keys:  
A represents Adhesive gluing  
B represents Bolting  
R represents Riveting and pop riveting  
S represents Stapler-gun chip joining

Table 11 Joining methods for different materials
5 Material surface processing

Material surface processing refers to the processing of materials for safety, aesthetic and durability purposes. For example, timber materials should undergo surface polishing in order to reduce thorns that hurt our hands. Generally, materials have to undergo surface smoothing and coating processes.

(a) Surface smoothing

The process of smoothing rough material surfaces is called surface smoothing. There are different surface smoothing methods for different materials.

(i) Metal

Burr formed during cutting processes (e.g. drilling) can be smoothened by using a file (Fig. 42). To rub off excessive materials surrounding the pouring mouth of metallic workpieces, sawing and hand filing can be applied. If there are tiny holes formed due to bubbles on metal surface, weld to inject metallic fillings. Then, use an abrasive wheel to abrade metal surface after filing so as to get smooth and artistic artifacts.

(ii) Timber

Solid timber surface is always rough and full of wood joints. Use smoothing planes and then a blade to smoothen the joints. Finally, use sand paper or sander to polish the surface. Since thin wooden sheets are usually added onto plywood, only sand paper is needed for smoothing. Timber after cutting (e.g. sawing) may easily develop burrs or rough surfaces, smoothing plane and hand file may be useful if this happens.

If there are gaps or small holes on the wood surface, fill them with fillings and then abrade. This operation is also applicable on gaps of cracks, screw joints and other joints.

(iii) Plastics

There are always excessive materials or rough edges on plastics after processes of moulding and cutting. Such undesirable parts can be removed by using blades and files. For signs of scraping that remain on plastics after processing, silicon carbide paper can be used for smoothing. Choose softer abrasive wheels if such wheels are needed for smoothing plastic surfaces.
(b) Surface finishing

Material surfaces after smoothing may still be damaged easily, for example, iron articles are easy to rust, and wood surface is easy to be scraped. In order to make surfaces more beautiful and durable, appropriate protective materials can be coated. There are various ways of coating surfaces. They include electroplating, dip coating, painting, plastic coating, wax and protective coating, veneering and enamelling, etc.

(i) Electroplating

Electroplating is a common method of metallic coating. Its principle is to coat a metal onto metallic surfaces by electrolysis. Hard and shiny metals which are resistant to abrasion and oxidation are suitable materials for this process. Such metallic materials include nickel, copper, chromium, silver and gold. Hence, metallic surfaces after electroplating are shiny and strong (Fig. 43a).

The process of electroplating can be briefly explained by using copper as an example. The metallic workpiece is placed into electrolyte and connected to the cathode, while a copper rod is connected to the anode. The electrolyte copper (II) sulphate, carries copper cations (Cu$^{2+}$) and anions (SO$_4^{2-}$). When the power is on, cations of copper (Cu$^{2+}$) will adhere onto the workpiece and form a thin copper membrane gradually. The copper rod connected to the anode will emit copper ions slowly and its volume will decrease.

![Fig. 43 (a) Artefacts of electroplating](image1)

![Fig. 43 (b) Mechanism of electroplating](image2)

**Fig. 43** (a) Artefacts of electroplating  (b) Mechanism of electroplating

In the industrial sector, mass electroplating is usually done by using an electroplating production line (Fig. 44). In order to guarantee that protective coatings can adhere onto the workpiece firmly, grease, dust and oxides on workpiece surfaces are first removed using water and chemicals before the process.

![Fig. 44 Production line of electroplating](image3)
(ii) Dip coating

Dip coating is another method to produce a coating on metal surfaces. However, electrolysis is not necessary, and hence it is different from electroplating. A zinc coating on steel plates can avoid oxidation and rusting. First, place a clean steel plate into melted zinc of 430℃~495℃. Solution of melted zinc will attach onto the plate after soaking for a period of time. Take out and cool the plate, and zinc solution adhered on the plate will turn into a protective layer.

Usually, metals with low melting points such as tin, zinc, lead, aluminium and some alloys are used for dip coating. Generally, metallic layers formed by dip coating are thicker, so they can be used for a prolonged period even under corrosive condition, e.g. galvanized sheet and water pipe.

(iii) Painting

Painting is a common method of surface coating to beautify and protect materials such as metals and timber. Paints can be formed into protective layers on material surfaces after drying. As they are effective in insulating air from material surface, rusting and rotting can be avoided. Paints are categorized into natural (e.g. raw lacquer), artificial (e.g. enamel paint, lacquer, spray) and special paints. Table 12 shows the main ingredients of paints.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>Materials which form protective layer, can adhere the layer firmly after drying.</td>
</tr>
<tr>
<td>Resin</td>
<td>Mainly used for dissolving ingredients of protective layer (oil and resin).</td>
</tr>
<tr>
<td>Solvent</td>
<td>Colouring material in paints are important ingredients for the formation of protective layer and can enhance the strength, water-resistibility and hardness of the layer.</td>
</tr>
<tr>
<td>Colour</td>
<td>Used for adjusting the paint into appropriate viscosity.</td>
</tr>
</tbody>
</table>

Table 12 Major ingredients of paint

Ways of painting include brushing, dip painting, spraying and steaming. Table 13 lists their characteristics respectively and Fig. 45 shows some common tools for painting.
<table>
<thead>
<tr>
<th>Methods</th>
<th>Operation</th>
<th>Characteristics</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brushing</td>
<td>Paint manually with paintbrushes</td>
<td>Simple tools, no limitations on environment, shape and size of work piece</td>
<td>High labour input, lower efficiency, tearing off of brush hair, unstable quality</td>
</tr>
<tr>
<td>Dip painting</td>
<td>Soak workpieces into containers and let excessive paint drop naturally, so as to leave a thin paint layer</td>
<td>Paint rapidly and evenly</td>
<td>Size of workpiece is restricted by that of the container, thicker paint layer</td>
</tr>
<tr>
<td>Spraying</td>
<td>Turn paints into spray and spray paints on workpieces evenly</td>
<td>Convenient, efficient, evenly sprayed layer, smooth surface</td>
<td>Requires expensive tools and protective devices to avoid inhaling of paints</td>
</tr>
<tr>
<td>Steaming</td>
<td>Spray paints onto surface then dry workpiece under infrared light</td>
<td>Even paint layer, smooth surface, high adhesiveness of paints</td>
<td>Requires expensive equipment and spacious workplace</td>
</tr>
</tbody>
</table>

Table 13 Different painting methods

Fig. 45 Painting tools

Paints are categorized into bottom paint and surface paint according to their purposes. In general, bottom paints are unpleasant in appearance but they are more protective and adhesive in nature, e.g. shellac. Surface paints are usually better in appearance but provide poor protection and adhesiveness, e.g. cobal varnish. Hence, to make artifacts pleasant in appearance and durable at the same time, we should use surface paints on top of the bottom paints.

As most of the thinners in paints are poisonous and in flammable, regulations below should be followed strictly for safety:

1. Keep good ventilation in workplace.
2. Never light fire or place inflammables in workplace.
3. Wear mask during painting.
4. Large-scale painting procedures should be done in workplace with air exhausting devices.
(iv) Plastic coating

Plastic coating is to adhere plastics onto metallic artifacts so that the products can be insulating, resistant to rusting and durable under abrasion. Moreover, using plastics of sharp colours can improve the appearance of metallic artifacts. This is a simple and cheap method and hence it is commonly applied on home utensils such as wire gauge inside refrigerators, coat hanger (Fig. 46a), handles of hand pliers (Fig. 46b), etc. Coating materials used are usually thermoplastics such as PVC, nylon and polyethylene.

![Coat hanger](image1)

![Hand pliers](image2)

Fig. 46 (a) Coat hanger (b) Hand pliers

(v) Wax and protective layers

Protective layers can be coated on material surfaces for aesthetic and caring purposes. For example, wax is a common protective layer. Waxing is a simple and effective surface processing method which can increase luster, while keeping the original colour and grain at the same time. Resistance to heat and water will also result if waxing is done on different paint surfaces. For example, surfaces of cars and wooden furniture painted with different paints can both be waxed.

The types of waxes include white wax, wood wax, beeswax, paraffin wax and furniture wax. White wax and wood wax are vegetable waxes, while beeswax is extracted from insects’ secretions. Paraffin wax is a composite mineral wax which is extracted from oil, while furniture wax is an artificial wax containing silicon.

Other common materials of protective layers include linseed oil, teak oil, vegetable oil and engine oil. Table 14 lists their characteristics.

<table>
<thead>
<tr>
<th>Protective Layers</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linseed Oil</td>
<td>Not easy to dry, hard, highly permeable, easy to melt under high temperature. Melted linseed oil is highly absorbable for paper and cloths. Hence, this is not suitable for bookshelves or wardrobes.</td>
</tr>
<tr>
<td>Leak oil</td>
<td>Protect and improve the appearance of wood effectively, simple processing steps, short drying time, heat-resistant</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td>Avoid chemical corrosion on woods, commonly applied to wooden utensils such as salad bowls</td>
</tr>
<tr>
<td>Engine oil</td>
<td>Common surface processing method for metals and tools, lubricating rust and water leakage resistant</td>
</tr>
</tbody>
</table>

Table 14 Characteristics of different protective layers
(vi) Veneering

Veneering is to protect and beautify wooden material surfaces by coating on a thin wooden layer. This is a method generally used for covering edges or small surface areas of wood. Timber with clear grains are major materials for the process. The grains, having a better outlook though, may easily lead to formation of cracks.

Clean wood surface beforehand and apply contact glue. When the glue is little dry, stick wooden sheets of larger size on and press with plywood. Smooth and artistic surface will result when wooden sheets are firmly adhered to the surface. Excessive sheets are smoothened by file and sand paper.

Fig. 47 There are many types of thin wooden layers available in the market

(vii) Enamelling

Enamelling enables surface coating on objects with ceramic effect. This gives the surfaces beautiful colours and patterns as well as a high resistance to corrosion and oxidation. For example, metallic basins after enamelling are not easy to rust.

To carry out enamelling, heat and cover enamel powder onto metallic surface. Then, place the workpiece into a kiln of high temperature (about 700°C-850°C). Artefacts can be produced after heating.

Fig. 48 Example of enamelling: a dish
(c) Surface polishing and buffing

(i) Polishing

Polishing refers to the process of turning rough surfaces into smooth ones and this enables beautifying and adjustment of object surfaces. For example, polishing can be applied to adjust uneven thickness of material and deep signs of scraping on material surface. Moreover, polishing is the prerequisite for even coating on the surface of a workpiece.

![Grinder](image_url)

Fig. 49 Grinder

Polishing can be done by either manual or mechanic means. Hand polishing is suitable for polishing small metallic or plastic workpieces. Firstly, use a rough file to smoothen workpiece surface. Then, choose a finer file to continue the filing procedure. File grains selected can be from ‘second cut’ ones to ‘draw-filing’ ones. Finally, use sandpaper with extra-fine grains for polishing until the surface is the smoothest. Mechanic polishing is, on the other hand, the means of rapid surface polishing using a grinder (Fig. 49).

(ii) Buffing

Although material surface is smoother after surface processing, dim colours may still be present as there are full of traces of abrasion. Buffing is to smoothen surfaces precisely so that surfaces can be glossy. This method is generally applied to materials such as plastics, copper and aluminium.

![Buffing Machine](image_url)

Fig. 50  (a) Buffing Machine

![Principle of buffing](image_url)

(b) Principle of buffing

Buffing can be done manually or mechanically. Hand buffing refers to the method of using fabric (cotton) and smooth metal polish to rub the surfaces repeatedly. Buffing can make surfaces shinny and smooth but this is not a process for smoothening a surface. Machinery buffing, on the other hand, makes use of buffing machine which can polish object surface rapidly (Fig. 50). Force applied should not be too great when using buffing machine as workpieces may be overheated under excessive pressure and the surface will be damaged.
For safety, regulations below should be strictly followed when using polishing or buffing machine:

1. Install safety shields on all rotating parts of the machine.
2. Wear goggles.
3. Never buff sharp edges or angles.
4. Allow only one user to use the machine.

6 Choosing method of material processing

There may be various ways to produce an object. For example, hand tools such as saws and files, and machines like sawing machine and milling machine are all suitable for making an L-shape metallic workpiece. So, which is the best material processing method?

Normally, the best method is the one which incurs the lowest production cost and fits all requirements of the artifacts. For example, appropriate size and preciseness, suitable surface-processing, time limit and quantity. Costs always include fixed cost and variable cost. Fig. 51 shows the typical relationships between cost and quantity of production.

![Fig. 51 (a) Fixed cost](image)

![Fig. 51 (b) Variable cost](image)

Fixed cost is the cost which is independent from changes in quantity of production, say cost of purchasing machines and rent for workplace, etc. However, if quantity of production is large enough to an extent that additional machines are needed, fixed cost will be triggered up (Fig. 51a).

Variable cost refers to the cost that increases with the quantity of production. For example, electricity expenses for operation of machines and expenses on the purchase of raw materials (Fig. 51b). The larger the quantity of production, the lower the fixed cost that each product shares, while there is no change in variable cost.

Processing methods such as cutting, joining and surface-processing which suit the requirements for products should be listed out before calculating and comparing production costs.
(a) Choosing the cutting method

The following factors should be considered when choosing the best cutting method:

1. Limitation of resources
2. Size and shape of workpiece
3. Material of workpiece
4. Surface quality and preciseness
5. Quantity of production

(i) Limitation of resources

Limitation of resources includes factors such as labour, technique, equipment, venue, power and time. For example, only hand tools or small-scale machines are available in watch factories. It is impossible for their equipment to cut large-scale workpieces such as steels for construction purposes. Hence, information on equipments available should be collected before choosing the cutting methods. If there are hand saw, electric saw and sawing machine in a workplace, the choice of using one of them to cut aluminium rods depends on the particular situation (Fig. 52a).

![Fig. 52 (a) Hand saw](image)

![Fig. 52 (b) Large-scale factory](image)

The more the resources required, the higher the fixed cost is. For example, there are large-scale machines as well as various types of resources in a large-scale factory to meet the needs of different products. Fixed cost of each piece of product will be very high if equipments are used to produce only a small amount of cheap decorations (Fig. 52b).

(ii) Size and shape of workpiece

 Usually, different cutting devices have their limitations. For example, chucks in lathe can clamp small or medium cylindrical workpieces only. There are, however, limitations to the length, width and height of workpiece in using a milling machine (Fig. 53a). However, cutting machines with greater power can cut and remove a greater amount of materials quickly. If computer formulae are applied to machinery control, cutting machine can cut workpieces with complicated shapes automatically and precisely.
On the other hand, cutting with hand tools and portable tools are not suitable for cutting hard materials, as strengths, speeds and efficiencies are lower. However, they can be used flexibly under manual control and are suitable for cutting small workpieces with irregular shapes, e.g. excessive parts of workpieces after casting (Fig. 53b).

(iii) Material of workpieces

Different cutting tools are necessary for different materials. For example, wood planes can be used to smoothen timber surface, while milling and grinding machines are needed for metallic workpieces. Mechanical and machining properties such as hardness, toughness and cutting properties should all be considered when choosing the best cutting method and tools. For example, to drill holes onto soft aluminium sheets, hand drills, electric hand drills and drilling machines are suitable tools. To drill holes on hard steel sheets, drilling machine or special cutting methods such as laser cutting should be considered.

(iv) Surface quality and precision

Different products have different requirements of surface quality and precision, for example, the surface of the electrical appliance is usually required to be smooth, while all the parts must be tightly joined. Therefore, surface quality and precision of the products must be taken into consideration when cutting processes are employed.
Different cutting tools produce different surface qualities on the cutting surfaces of the materials. For example, the results of the cutting surfaces of the metal cylinders are different when using the sawing machine and the lathe. The cutting surface of a metal is found rough by using sawing method, but the cutting surface is smooth when using the turning tools of lathe (Fig. 55).

Besides, there is always a discrepancy between the dimensions of the drawing of the design and the actual product, no matter how carefully we process. The smaller the average discrepancy, the higher the precision of the processing procedures that are involved. To ensure meeting the requirements of the design, the error value (±) is used in many design drawings to represent the maximum tolerant errors in dimensions. It is called the precision. For example, 25 ± 0.1 mm represents that the length of a product must be made between 25 - 0.1 mm and 25 + 0.1 mm, that is within 24.9 mm to 25.1 mm. Fig. 56a shows the dimensions with the error values marked on the design drawing.

When we choose the cutting tools, we must pay attention to the precision of the size of the product. If we have to cut a long metal rod into several pieces of rods, we can choose the methods of cutting, for examples, sawing and cutting by lathe. However, the precision of the length of the shorter rods cut by sawing will not be high. Therefore, we can use turning tools to cut the rods for higher precision.

With the advancement of technology, the precision of the cutting machines become higher and higher. On the contrary, the precision of the product is usually low when it is processed by the hand tools, and the quality of the product is also determined by the skills of manipulation of the hand tools. However, hand tools are easier to control and thus we can usually cut materials with high precision. For example, we can use coping saw to cut the tenon join of a piece of wood more precisely than using a sawing machine.
Some cutting methods can raise the degrees of smoothness and precision of a product, for example, polishing and buffing. Therefore, if we need to make parts with precise and tight fitting, we can first cut the parts slightly larger than the sizes assigned. Then we can use file or grinder to polish the rough cutting surfaces till they are ground to the desired lengths precisely. Lastly, the parts can be buffered to be smoother so that they can join rigidly and precisely.

(v) Quantity of production

Quantity of production and requirement for speed are important factors for choosing suitable tools and cutting methods. For example, CNC lathe and automatic machining center (Fig. 57b) may be considered for mass production of chessmen using metallic rods (Fig. 57a). On the contrary, hand tools, drilling machine, lathe and milling machine can be used if only one metallic object is produced.

(b) Choosing method of joining

Joining method should be considered when designing an object which has different components. Material, function, time of use and environment are all important factors that affect our choices. For example, semi-permanent joining methods such as bolting can be used for flyover construction (Fig. 58a), so that joining can easily be reassembled afterwards. On the contrary, permanent joining methods such as pop riveting and welding should be applied on building durable high voltage power towers so as to avoid accidental falls (Fig. 58b).
Different joining methods can be applied to different parts of an object. For example, metallic basketball stands are joined using permanent joining methods (e.g. welding) so as to keep structure under long term stability. Wooden backboards are, however, easily damaged after prolonged exposure to sunlight and rain. To facilitate easy repairs, they are usually joined by semi-permanent methods (e.g. bolting).

(c) Choosing surface processing methods

There are various surface processing methods including painting, steaming, electroplating, dip-coating, plastic coating, wax and protective layers. Factors such as size, shape, surface material, function, duration of use and environment should be considered before choosing the best method. For example, the size of metallic basketball stand is huge and hence the stand is difficult to be electroplated, dip-coated or plastically coated. Since there is not much aesthetic requirement for the stand, paint brushing is the most common method for surface processing to avoid oxidation and corrosion. Metallic watchbands require a good outlook to support elegant image. Therefore they are processed with electroplating for glossy, as well as oxidation and corrosion resisting purposes (Fig. 59).

Fig. 59 Watchbands

7 Introduction to modern production technology

With the advancement in life style, our demand for both quality and quantity of products becomes greater. Hence, production technology has to be improved to cope with the changes in the product markets. Methods different from those using traditional tools, such as electrical discharge machining, electrical discharge wire cutting, laser cutting and dip-etching, are introduced. They are called non-conventional processing methods. More and more machines will be controlled by computer for greater preciseness and production efficiency such as the automatic machining centre.

(a) Electrical discharge machining

Fig. 60 shows an electrical discharge machine. It is mainly used to process electric conductive (e.g. metallic) workpiece. A workpiece is placed into the processing case first, and the mould is clamped by a chuck. The workpiece and the mould are then connected to the anode and cathode respectively. Soak the workpiece thoroughly in conductive chemicals inside the case, lower the mould and connect with high voltage power. Electric current will pass through all gaps
between the workpieces and the protruding parts of the mould, and form a huge amount of high power electric sparks. These sparks will then corrode a small amount of metallic trenches (Fig. 61a). The eroded parts will be washed away by the liquids. Trenches of the same shapes as the protrusion on the mould will be formed on the workpiece surface after some time (Fig. 61b).

There are many merits of using electrical discharge machining. This is an effective method in cutting strong and hard metals. Moreover, workpieces will not be damaged or broken even if they are fragile. Another point is that it possesses high degree of preciseness and can produce accurate workpieces such as high quality plastic moulds.

(b) Electrical discharge wire cutting

Fig. 62 shows an electrical discharge wire cutting machine. It cuts metallic workpieces by using a thin metallic thread (with diameter of about 0.02–0.3 mm) connected to the power supply. The workpiece is placed in the processing case and the moving thread gets close or travels through the workpiece from the top to the bottom. The metallic thread and the workpiece are connected to different electrodes respectively. Soak the workpiece in the processing case with conductive
chemical. Pulsing current (the one which transfers electricity consecutively) passes through the metallic thread and the high power electrical sparks produced in the gaps between the metallic thread and the workpiece will corrode the metal and form a small trench (Fig. 63). The eroded metal will be washed away by the chemical.

![Fig. 62 Electrical discharge wire cutting machine](image)

![Fig. 63 Principle of cutting by electric sparks](image)

Electrical discharge wire cutting machine is usually controlled by computer programmes. It moves and cuts the workpieces into desired shapes by a metallic thread without producing electrodes. This cutting method has many merits. For example, it can precisely cut fine holes, troughs, narrow gaps and curved circles.

(c) Laser cutting

Laser is a high-energy ray. If laser is focused on a very tiny dot, this area of the materials such as metal will be subject to high temperature. Metal will melt and evaporate rapidly (Fig. 64). Thus this method can be applied to break, cut and weld metals.

![Fig. 64 Principle of laser processing](image)

Fig. 65a shows a laser-cutting machine controlled by computer programmes. There are many merits of using laser cutting, including stable surface temperature due to focusing of energy on a point or a very small area. Laser can be applied when cutting narrow gaps or fine holes. Moreover, since laser does not hit the workpieces like what other tools do, cutting can be done rapidly (Fig. 65b).
(d) Dip etching

Dip etching is also known as photo chemical machining, it processes metallic sheets with the techniques of developing films. For example, to produce hundreds of tiny electronic circuits within 1 sq cm. This kind of circuit can greatly reduce the volume of electronic products (Fig. 66). The principle of dip etching is to adhere a piece of plastic layer which is UV sensitive onto the metallic surface (Fig. 67a). Then, place films with printed patterns onto the layer and expose the parts which need etching to UV light (Fig. 67b).

Print films with plastic layers and remove exposed part (Fig. 68a). Then, put the metallic sheet into the dip-etching machine. The metal not covered by plastic will be corroded by iron chloride in the machine and troughs or holes will form (Fig. 68b). Artefacts can be collected after the etching and mould-removing processes.
Fig. 68 (a) Machines for film development and printing  (b) Dip-etching machine

There are two ways to produce the etched films. The first one is to take pictures using a large-scale camera and to reduce the pattern size by 5-10 times in order to raise the accuracy. Finally, print all films with fine patterns (Fig. 69a). The second method is to design patterns using computer software and to print films with printers of high preciseness. For example, the printer in Fig. 69b is able to print 8,000 dots in one inch.

(e) Automatic machining centre

A digital system is a system which gives commands through numbers and can operate automatically and accurately. Numerical control machines (NC machines) were still categorized into lathe, drilling machine and milling machine when the principles of digital control were newly introduced to traditional machines. They were known as automatic machining centre (Fig. 70a) later when such systems were developed into multi-purposes NC ones. A typical automatic machining centre has three rotational axes, each with a turntable which can rotate at 360° and can operate different processes such as milling and drilling. Different tools are stored at the warehouse and are installed onto the chuck according to the instruction of the operating programmes (Fig. 70b). Many NC machines are now controlled by computer and hence they are called Computer Numerical Control (CNC) Machines.

Fig. 70 (a) Automatic machining centre  (b) Warehouse for tools
(f) Chemical vapour deposition (CVD)

Chemical vapour deposition can add a thin metallic or composite layer onto metallic and non-metallic surfaces. There are various ways of operation e.g. vacuum ion plating. When using this operation, just put the workpiece into a container and extract air to make a vacuum (Fig. 71). Then, heat metals (e.g. aluminium) or composites into steams rapidly with an electric arc. Steam will be laminated on all surfaces of the workpiece and condense into thin aluminium layer (Fig. 72a).

Fig. 71 (a) Vapour deposition controller   (b) Vapour deposition container (outlook)

Fig. 72 (a) Vapour deposition container    (b) Artefacts of vapour deposition process

Metallic layers produced by chemical vapour deposition are very thin, and their typical thickness is about $25 \times 10^{-9}$ m to $125 \times 10^{-9}$ m. Hence, they will not alter the shape and smoothness of the workpiece. If expensive hard metals (e.g. chromium) are laminated onto common steel drill bits, sharpness of the bits will retain while the hardness is strengthened (Fig. 72b). This makes it easier and cheaper than producing the whole bits with hard metals.

There are many merits of using chemical vapour deposition processing. Layers produced are even thinner than that of electroplating. It needs less materials and energy, and it is environmental friendly. Although equipment for this method is more expensive, it can process a large amount of workpieces rapidly at one time and it does not induce pollution.

8 Introduction to methods of production

With the advancement in technology, production methods are developed from traditional manual ones to speedy and mass production in large-scale factories using huge amount of labour and machinery.
(a) Mass production

Total production cost includes fixed cost and variable cost. Relationships between total cost and quantity of products is shown as Fig. 73a. Average cost of producing each product can be calculated by dividing total cost with the quantity of products produced. Fig. 73b indicates that there is a negative relationship between total cost and quantity of products. The more the products produced, the lower the average cost.

Fig. 73 (a) Change in total cost     (b) Change in average cost

Producers may lower production cost by means of mass production. At the same time, they can lower the selling price of their goods in order to raise sales and competitiveness of the product. Total profit will also be increased if products can be sold at a large scale. At the same time, consumers will also benefit. For example, production of a car by one technician needs lots of time and extremely high cost compared with mass production in cars factories. However, not every product can be produced by mass production. For example, civil aircrafts may not be mass produced as operation cost for them is very high and lower manufacturing cost is not efficient to stimulate demand.

Special technology and methods are needed to speed up the process of mass production. First of all, a product is broken down into different components, and each component is to be processed by different workers. Processed parts are then assembled into the final product. Since every worker is responsible for one production procedure only, workers can concentrate on their own procedures and have their skills practised, thus raising the efficiency of production at the end. Moreover, templates, jigs, fixtures and simplified procedures are designed by technical engineers to save production time.

(i) Templates

In order to have mass production of products with similar qualities, product size and shapes should be standardized. However, lots of working time will be spent if workers have to do the measurement on every product they process. Templates are aids designed by engineers according to the size and processing procedures of the workpieces. Workers can do the processing work efficiently by placing the workpiece onto the template and follow the dimensions. This not only increases production efficiency, but also lowers opportunities for workers to make mistakes.
(ii) Fixtures and jigs

Fixtures are devices used to fix and hold the workpieces and their functions are similar to that of templates. Strictly speaking, traditional holding tools (e.g. vice) also fall in this category. However, fixtures usually have specific functions and are used with lathe, milling machine and grinding machine. Specified processing procedures can proceed once the workpiece is clamped by fixtures. Since there is no need to carry out measurement, the chance for workers to make mistakes is small.

Jigs are also devices for holding and fixing position of workpieces. Jigs, especially bits of drills, can direct the cutting at the same time. They make bits fixed to a point when drilling begins. Drilling procedure can be started once the workpiece is clamped by the fixture. This not only saves time from adjusting position for drilling, but also lowers the possibility of making mistakes.

![Fig. 74 Jigs](image)

(b) Assembly line

Parts should be assembled to form final products after individual processing. Usually, engineers would design an assembly line to raise the speed and efficiency of product assembling. Fig. 75 shows a typical assembly line, in which four workers cooperate to assemble clocks. Firstly, worker A adds the minute-hand on the clock. Then the clock will reach worker B by the transport belt moving forward so that worker B can add the hour hand. Similarly, worker C and D add the round top and glass surface respectively to produce the clock.

![Fig. 75 Assembly Line](image)
Since every worker is responsible for a simple processing procedure in an assembly line, workers can perform their work skillfully and rapidly, and hence raise the production efficiency. Some factories even make use of various technologies to improve their production, for example, finding the most simple and direct procedure by analyzing workers’ motions; applying ergonomics on reducing the distance and time spent on hand moving. However, workers should be allowed to have rests frequently in order to avoid over-exhaustion.

(c) Production line

Production line results from replacing workers in assembly line with different processing procedures. Many procedures that are operated by man in the past are now by automatic machinery. For example, clocks can be assembled automatically by machines (Fig. 77). This method is efficient in saving labour cost as well as in raising production speed and quality. Hence, more and more factories use automatic production line to have 24-hour production to raise production to a greater extent. Production line is also useful for large-scale car producers but investment is great as it is expensive to purchase, install and maintain automatic production devices. Therefore, labour-intensive production may still be more economical for areas with cheap labour.
Exercise

1. Give one practical use of each of the following material forming methods for metals and explain briefly why the method is best suitable for the use.
   (a) V-die bending
   (b) Cold rolling
   (c) Pressing

2. A piece of bent wood is necessary for making the rocking stick in the wooden horse shown above.
   (a) Suggest and briefly describe two methods of bending for wood.
   (b) Compare the suggested two bending methods. Which one would you use most likely?

3. Give one practical use of each of the following metal casting methods and briefly explain why the method is best suitable for the use.
   (a) Mould casting
   (b) Sand casting

4. The following cutting methods are usually used for metal cutting:
   (i) Sawing
   (ii) Milling
   (iii) Turning
   (iv) Drilling

   Give one practical use of each of the above cutting methods. Explain briefly why the method is best suitable for the use.

5. A copper electric wire is usually wrapped with a plastic coating. Briefly describe the method, with illustration, of making the plastic coating.
6. Briefly describe each of the following manufacturing methods:
   (a) a metal beam with a cross-section of ‘I’
   (b) Plastic bottles made from plastic grains
   (c) Copper threads made from a copper rod
   (d) Washers made from a metal sheet
   (e) Propellers made from metal plates

7. (a) Give three machining methods for turning materials into a product with circular cross section.
(b) Give one practical use of each of the above machining methods. Explain briefly why the method is best suitable for the use.

8. (a) Give three methods to make a plane surface of a material.
(b) Give one practical use of each of the above surface processing method of material. Explain briefly why the method is best suitable for the use.

9. (a) Briefly explain a method for joining metallic sheets semi-permanently.
(b) Give one practical use of the above joining method. Explain briefly why the method is best suitable for the use.
(c) If the joined metal sheets in (a) above are subject to vibration that may loosen the joint, suggest a firmer joining method.

10. Give one practical use of each of the following plastic moulding methods and explain briefly why the method is best suitable for the use.
    (a) Injection moulding
    (b) Vacuum moulding

11. Describe and explain briefly, with illustration, a joining method for each of the following situations:
    (a) Make a permanent framework from square metal tubes.
    (b) Join a horizontal stepping rod onto the wooden ladder.
    (c) Join a stainless steel ring of anchor onto a wooden boat.

12. Give an example, with illustration, of metal product made mainly by:
    (a) welding
    (b) bolt and nut joining

13. Give one practical use of each of the following surface finishing methods and explain briefly
why the method is best suitable for the use.
(a) Electroplating
(b) Painting
(c) Plastic coating

14.
(a) Describe briefly a case of problem solving by applying adhesives.
(b) Suggest the steps taken to join materials firmly in the above case.

15. Rust prevention is an important work in designing and manufacturing cars. Rusting often occurs on the edges, doorsill and the bottom parts of the door.
(a) Briefly explain why rusting often occurs in the mentioned areas?
(b) Suggest one method of preventing rust in each of the following situations:
   (i) during the design process
   (ii) daily use of car

16.
(a) Briefly explain the basic principles of electric discharge machining.
(b) Give one practical use of electric discharge machining. Explain briefly why this method is best suitable for that practical use.
(c) Collect the information of an electric discharge machine with its model number and relevant information in the internet.

17.
(a) Briefly explain the basic principles of laser cutting for metals.
(b) Give one practical use of laser cutting for metals. Explain briefly why this method is best suitable for that practical use.
(c) Collect the information of a laser cutting machine with its model number and relevant information in the internet.

18.
(a) Briefly explain the basic principles of chemical vapour deposition.
(b) Give one practical use of chemical vapour deposition. Explain briefly why this method is best suitable for that practical use.

19. A hanging board for posting students projects is to be placed at the front door of the school.
The dimensions of the board are 2000 mm × 1400 mm with 30 mm thickness. There are two areas on the board for pins and staples to be punched. These areas can be used repeatedly. The edges of the boards should be fixed with a smooth frame.

(a) Write down the conditions for choosing the materials for making the board, including the display area, coating materials and the frame.

(b) Choose the appropriate materials in making each part of the board.

(c) If the board is to be made in the workshop of the school, briefly describe the material processing methods involved. Estimate how much time would be spent on the making.

(d) If the board is to be produced by mass production, briefly state the differences in the choice of materials and the corresponding material processing methods.

20.

The figure above shows a part made of low carbon steel.

(a) Suggest suitable manufacturing method(s) to produce:
   
   (i) one piece;
   
   (ii) a lot of 500 pieces;
   
   (iii) 100,000 pieces per annum

(b) State the manufacturing methods involved in each of the cases in (a) above.