Design and Applied Technology
(Secondary 4 - 6)

Learning Resource Materials

Elective Module 3

Design Implementation and Material Processing

Materials, Components and Systems

Computer-aided Manufacturing (CAM)

Processing and Manufacturing

Design and Applied Technology

(Secondary 4 – 6)

Elective Module 3
Design Implementation and Material Processing

[Learning Resource Materials]

Resource Materials Series
In Support of the Design and Applied Technology Curriculum
(S4 – 6)

Technology Education Section
Curriculum Development Institute
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PREFACE

A set of curriculum resource materials is developed by the Technology Education Section of Curriculum Development Institute, Education Bureau for the implementation of the Design and Applied Technology (Secondary 4-6) curriculum in schools.

The aim of the resource materials is to provide information on the Compulsory and Elective Part of the DAT (Secondary 4-6) to support the implementation of the curriculum. The resource materials consist of teacher's guides and student's learning resource materials of each Strand and Module of the DAT (Secondary 4-6) arranged in eight folders.

All comments and suggestions related to the resource materials may be sent to:

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CONTENTS

INTRODUCTION

This module focuses on the implementation of design and material processing, and on how computer-aided manufacturing (CAM) is used in production. The module embodies the knowledge, skills, values and attitudes; and provides opportunities for students to solve practical and technical problems in realization of design ideas.

After the completion of this module, students should be able to understand the properties and working characteristics of different materials available in the market. Students will also be able to design appropriate structures in a system and apply mechanisms for control systems. The module will look at a range of manufacturing processes used in industry, and introduces different scales of production to students so that students can select, explain and execute appropriate manufacturing processes and techniques. The use of Computer Numerical Control (CNC) machines, CAM systems, Computer-integrated Manufacturing, and Flexible Manufacturing System that are employed in industry will be presented to students.

CHAPTER 1 – MATERIALS, COMPONENTS AND SYSTEMS

This chapter covers topics on:

1.1 Properties and Choice of Materials
1.2 Materials and Structures
1.3 Mechanisms
1.4 New Materials

These topics include learning materials and activities that facilitate you to:

(a) understand that properties and working characteristics influence the choice of materials and components;
(b) understand the strength of material and design appropriate structures in a system;
(c) apply mechanisms for control systems; and
(d) understand the use of new materials

1.1 PROPERTIES AND CHOICE OF MATERIALS

In order to select appropriate material for a product, designers and engineers should have a thorough knowledge about the properties of materials, such as:

- electrical conductivity
- magnetic properties
- mechanical properties
- optical properties
- thermal conductivity
- thermal expansion

1.1.1 Materials Properties

In order to help us to compare different properties and working characteristics of materials, Scientists and engineers tabulated results obtained through experiments and observation for easy reference. These tables list out the important properties which you may need to know when drafting design specifications. Let us examine the following products and explore how we can choose suitable materials to produce the desired products with the help of the Table of Material Properties:

- Glass scraper
- Padding container
- Swing
- Winch

H I G H L I G H T

TABLES OF MATERIAL PROPERTIES

These tables enable us to compare the properties of different materials. In compiling such tables, scientists and engineers have to ensure that the laboratories, as well as the equipment used are kept at a standard temperature and pressure, as properties may vary with temperature and/or pressure. The tables that are included in the Appendices are:

(a) Physical Properties of Metallic Elements
(b) Physical Properties of Alloys
(c) Physical Properties of Non-Metals
(d) Mechanical Properties of Metals
(e) Mechanical Properties of Alloys
(f) Mechanical Properties of Non-Metals
(g) Safe Stresses in Structural Timbers
(h) Mechanical Properties of Timbers
(i) Stiffness of Sections
(j) Special Properties
(k) Physical Properties of Plastics
(l) Density of Metals
(m) Comparative Tensile Strengths of Materials
(n) Typical Brinell Hardness Numbers
(o) Density of Woods

First of all, let us refer to the tables in the Appendices to study the following examples.

(I) Glass Cleaning Tool

You are required to make a small cleaning tool to remove dust from glass surface. This tool should be made from one kind of material. Consider which material will be strong enough to meet the requirement and at same time will not scratch the glass surface?

Figure 1.1 Glass Cleaning Tool

Let us refer to the table of Typical Brinell Hardness Numbers (BHN) (Appendix N) which compares the properties of metals and plastics, and find out the most suitable materials step by step:

- The edge of the cleaning tool should not be worn out easily. Therefore, we need a hard material. Mild steel is hard enough but certainly it will scratch the glass surface.

- According to the list, plastic materials appear to be suitable, but polythene may be too soft that will be worn out easily. As both acrylic or polystyrene are suitable in this case, we then need to check their tensile strength from the table of Physical Properties of Plastics (**Appendix K**).

- In terms of tensile strength, acrylic is the strongest material. However it is weak for impact resistance, which means it will crack easily when compress against hard surface.

- After examining all the relevant factors, polystyrene is the best choice of material in this case.

(II) Padding Container

When we go to a picnic, sometimes we need a container to store foods and drinks which are kept at a certain temperature. Please suggest any padding materials that are suitable for insulation purpose in the container.

Figure 1.2 Padding Container

- Let us look at the table of Special Properties (**Appendix J**) which lists a number of materials that are especially good for insulation. However these materials are found not suitable for this project.

- The table of Physical Properties of Non-metals (Appendix C) provides figures of *thermal conductivity* of different materials. A small number in this table means that the material is a poor conductor of heat.

- In this table, paper is a very poor conductor of heat but it is also suitable to be used as a cheap insulator! It performs well when formed in layers because it traps pockets of air which make it becomes the best choice in this situation.

(III) Swing

You are designing and making a child's swing with a tubular metal frame, in which their ends are to be joined together. Can you suggest any form of tubes for the frame?

Figure 1.3 Swing

Referring to the table of the Stiffness of Sections (**Appendix I**):

- a tube of large diameter of a given cross-sectional area of material is stiffer than the one with smaller diameter.

- tubes with larger cross-sectional diameter have good torsional resistance.

- therefore round or square section tube are the most suitable materials in considering its stiffness and torsional resistance.

(IV) Winch

You are looking for a suitable timber to construct a winch. What is the best available material to meet this requirement? You have to consider its strength and weight.

Figure 1.4 Winch

If we compare *density* against *compressive strength* in the table of Mechanical Properties of Timbers (**Appendix H**), we know that Spruce is the most suitable material.

1.1.2 <u>Selection of Appropriate Materials</u>

The properties and the uses of materials should be considered in the selection of suitable materials for a product, such as:

- the required usage of the properties
- costs of the material
- the manufacturing processes engaged

Sometimes, the final decision may be a compromise among these three factors.

Let us examine the following examples.

S T O P A N D T H I N K

Public Seating

The following examples illustrate different materials are employed in public seating design. Please state the types of materials and explore why they are being used in terms of the three basic considerations.

MTR Station

Recreational Area

Podium

1.1.3 Cost-Effectiveness

In order to make a product that could be sold in the market at a competitive price, cost-effectiveness is one of the essential factors. The price engaged could be minimized in two ways:

- use the lower-quality material to produce product; and/or
- employ less expensive manufacturing method

Ideal materials are often expensive. Therefore using readily available and low-cost standard components would be desirable. Details about standard components will be discussed in topic 1.1.4.

H I G H L I G H T

Car Panel

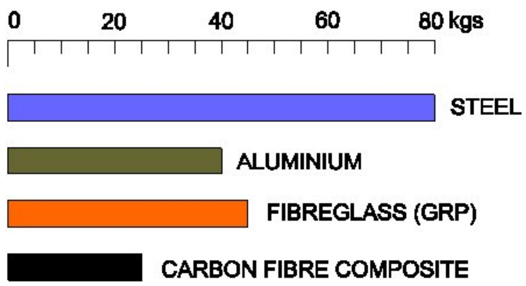
Let us explore what is the most appropriate material for a sports car panel (Figure 1.5). If cost is the primary concern, then material with highest stiffness-to-cost ratio will be a suitable choice. However, if the weight is the major concern, then the material with the highest stiffness-to-density ratio would be selected.

Figure 1.5 Sports Car

The above considerations concern about the mechanical properties of materials. However, crash resistance, corrosion and large quantity manufacturing are important issues too. Fibreglass (GRP) and wood are good in strength but weak in toughness. Moreover these two materials do not provide adequate protection when crashes. Although aluminum is good at both toughness and corrosion resistance, it requires special joining techniques that are not suitable for mass production. Therefore most vehicle bodyworks are made from steel and materials with similar toughness.

The following chart shows the comparison of weight of four materials that are currently used in manufacturing car panels. The information is based on the material with an area of 10 m^2 and thickness of 1mm.

H I G H L I G H T



Weight is an important factor because the lighter the car, the faster it accelerates. In terms of cost, the lighter the car, the lower the fuel it consumes.

The following chart shows the comparison of relative labour cost required to produce a car panel with four different materials.

GRP and carbon fibre composite are expensive because they are labour-intensive. The materials are laid in the moulds and worked by hand manually, whereas steel and aluminium are shaped by presswork. Carbon fibre composites are lighter but cost more. As a result, there is no *right* material for vehicle bodywork, for it all depends on the particular design specifications and requirements.

This example indicates that it is not really possible to separate the issues of selecting the material and the manufacturing method, but how to process the material is best discussed in Chapter 2. Besides, materials producers are continuously striving to improve their products and thus designers and engineers may find that their designs can be improved to take account of new materials (see Topic 1.4).

1.1.4 Selecting Standard Components

Manufacturers often employ standard components or product subsystems that are produced by other companies in order to minimize the cost. These companies design and produce these standardized components or subsystems as required by the end-product manufacturers and these components can be assemble into their products immediately. The costs for purchasing standard components refer to the *component costs*.

There are different kinds of standard components being used in the fabrication of a product, such as mechanical, electrical or electronic components, as well as fittings and fixtures to join different parts together. Some standard components will be discussed below.

(I) Nuts, Bolts, Rivets and Fittings

Many products nowadays use fasteners such as pins, clips, circlips, pop rivets, dowelling joints, rivets (thermal or mechanical), spring clips, bolts, nuts, machine screws, self-tapping screws.

Figure 1.6 Fasteners

The advantage of such fittings is that they are independent of the materials that are being joined, and therefore

- the materials to be joined can be wood, metal, polymer or ceramic
- adhesives or mixing of substances are not required.
- the method of joining does not affect the mechanical or other properties of the materials that are being joined.

(Useful website: http://www.boltscience.com/pages/glossary.htm)

(II) Gears, Bushes and Bearings

Gears are used to transmit power between shafts. This topic will be further discussed in Topic 1.3.

Figure 1.7 Ball Bearing

Bearings and lubrication are important parts in moving machinery and equipment. The successful operation of a machine depends on the performance of the bearing. A plain bearing in which the lining is closely fitted into the housing is called a bush; it is usually surfaced with a bearing alloy. Ball and roller bearings are usually used to prevent or minimise rubbing (Figure 1.7). They are able to support heavier loads with lower friction than plain bearing.

(Useful website: http://www.efunda.com/DesignStandards/bearings/bearings_introduction.cfm)

(III) Electrical/ Electronic Components

The following electrical/ electronic components are commonly found in the school:

- Battery
- Battery Snap
- Battery Box
- Bulb
- Buzzer
- Cable/ Wire
- LED
- Motor
- Switch

Figure 1.8 Cables and Wires

1.1.5 Availability and Types of Resistant Materials

The following are commonly used materials:

- Metals
- Plastics
- Timbers

(I) Market Forms of Materials

The market forms of materials are the shapes, sizes and sections that commonly available in commercial market. Most types of material such as wire, sheet, plate, flat strip, round and square bar are available from suppliers in standard shapes, forms and sizes. Common practice and demand have established a set of standard preferred sizes. However using non-standard materials in manufacturing will increase the costs considerably.

Commonly used materials

(II) Industrial Standards

Standard components are produced according to National Standard of the People's Republic of China [Guóbiāo], British Standards [British Standards Institution (BSI)] or International Standards [International Standards Organisation (ISO)]. These institutions and organisations set standards, sometimes called conventions, to ensure that engineers and designers around the world have a common understanding to these items.

1.2 MATERIALS AND STRUCTURES

Introduction

If a structure is in *equilibrium,* it should be stated at rest. That means all the forces acting on it are balanced and have no *resultant*. In the following figure (Figure 1.9a), a person sits on the chair that the downward force exerted by his/her own weight will be balanced by the upward forces exerted by the floor (the *reactions*).

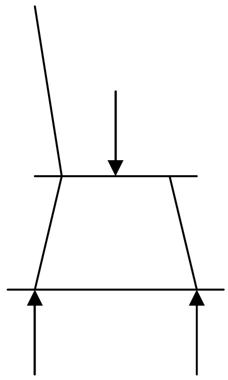


Figure 1.9 (a) Chair at rest

The equilibrium state of a structure is *stable* if it returns to its original position after being disturbed. In Figure 1.9(b), if the weight acts within the two reaction points (two legs of the chair), the chair can still manage to return to its original state.

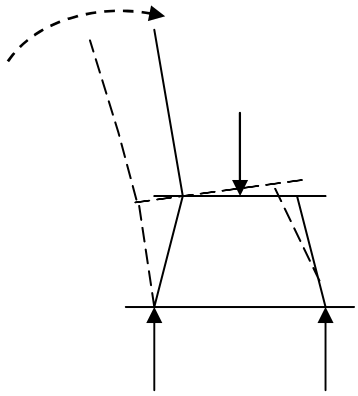


Figure 1.9 (b) Chair at stable equilibrium

However, when the person sits on the chair and leans backward until his/her weight is acting in the same line with the back legs of the chair (Figure 1.9(c)). The reactions at this point can still balance the weight, but a slight disturbance can cause the chair to topple. In this case, the equilibrium state is *unstable*.

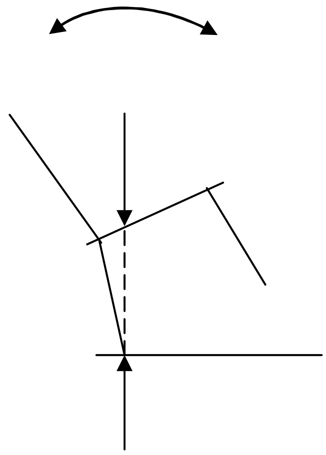


Figure 1.9 (c) Unstable equilibrium

In order to ensure a structure in stable equilibrium, every member of the structure should be strong enough to withstand the forces exerted on them.

1.2.1 Types of Man-made Structures

There are two main types of structure – *natural structures* and *man-made structures*. Natural structures exist everywhere, for example, caves that are formed naturally. However man-made structures are things being constructed such as bridges, buildings, furniture, ships, or towers. There are three categories of man-made structures:

(I) Mass Structures

These are solid structures such as dams that are designed to resist the loads by means of their own weight (Figure 1.10).

Figure 1.10 Dam

(II) Shell Structures

A shell resists loads through its ‘skin-like’ structure. Balloons and the domes of buildings are examples of shell structures (Figure 1.11).

Figure 1.11 Brick Kiln

(III) Framed Structures

Framed structures are structured by joining the bars together at their ends to form a framework. These structures are sometimes called skeletal structures. If the bars all lie in the same plane, they are called *plane frames* (Figure 1.12). However, if they are constructed in three dimensional formats, they are called *space frames* (Figure 1.13).

Figure 1.12 Plane Frame – Roof Truss

Figure 1.13 Space Frame – Pier, Central

Space frames are usually covered with sheet materials. For example, a green house is consisted of metal frames and a shield of glass (Figure 1.14).

Figure 1.14 Green House

(Useful website: http://www.greatbuildings.com/gbc.html)

H I G H L I G H T

Types of Load

Loads are the forces applied to structures and this term also refers to forces being transmitted by individual members within structures. Loads are measured in Newton (N) and practical values are often given in kilonewton (kN). Sometimes only the mass of an object being supported by a structure is given, and it is necessary to calculate the corresponding load. Suppose a 50 kg person stands on a bench. What is the load that the bench will carry? On earth, a mass of 1 kg equal to 9.81 N (i.e. 1 kg x 9.81m/s^2). Hence:

$$\text{Load} = 50 \times 9.81 \text{ N} = 490.5 \text{ N}$$

Sometimes, the weight of an object carried by a structure can be considered as a force acting at a single point (at its centre of gravity) (Figure 1.15). Such loads are called *point* or *concentrated loads*. Other loads such as the aerodynamic lift on an aircraft wing may be spread over a large area (Figure 1.16). We call these *distributed loads*. The term uniformly distributed load (UDL) is used when the load is spread evenly over the surface.

Figure 1.15 Weight of vehicle taken to be a point load on a bridge

H I G H L I G H T

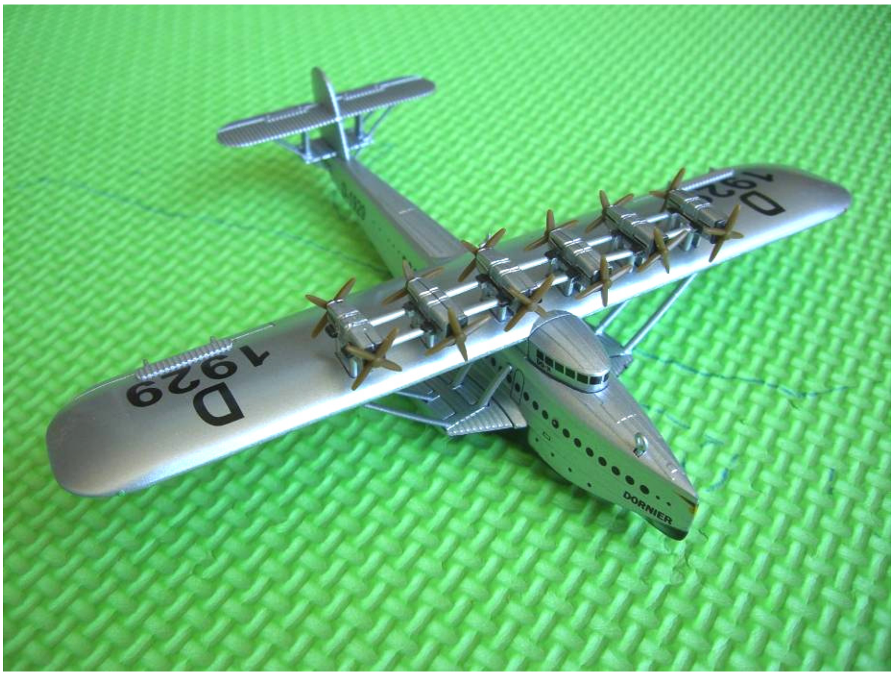


Figure 1.16 Aerodynamic lift distributed over wing

The effect of a load on a structure depends on three things:
- its magnitude (measured in N);
- its direction (measured anticlockwise from a horizontal datum); and
- the point at which it is applied.

The last two defined a line along which the load acts. This is called its *line of action*.

S T O P   A N D   T H I N K

There are many situations that the loads act on a structure are the weights of objects it is supporting, including itself. For a bridge, its own weight is greater than any of other loadings acting on it, for example, the vehicles (Figure 1.17). On the other hand, there are some structures capable of carrying large loadings greater than their own weights. Can you find out some examples about these structures?

Figure 1.17 Tsing Ma Bridge

1.2.2 Plane Frames

The basis of many structures is in a form of triangular shape, and it can be extended to a number of joints (Figure 1.18). Structures built up from triangles are *triangulated frames* and are said to be *just stiff* or *perfect*.

Figure 1.18 Triangulated Frame

Starting with a triangle, it is clear that each extra joint requires 2 additional bars if it is to be just stiff. For 3, 4, 5, … joints, the required numbers of bars are 3, 5, 7, … respectively. If j is the number of joints, the required number of bars b is given by:

$$b = 2j - 3$$

In practice, many framed structures consist of more bars than they are actually needed for to be just stiff. For example, an additional diagonal member could be added to a frame with four joints, as shown by the broken lines in Figure 1.19. This frame is regarded as *overstiff* or *redundant*. This does not mean that extra bars are unnecessary because sometimes the engineer intend to increase the strength of the structure.

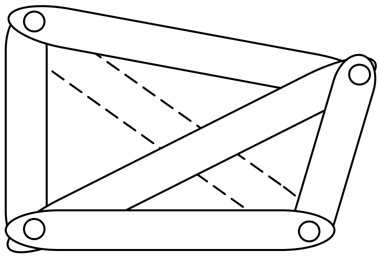


Figure 1.19 Overstiff Triangulated Frame

1.2.3 Equilibrium of Concurrent Forces

A set of *coplanar* forces consists of several lines of action lying in the same plane. If all the forces pass through the same point, they are called *concurrent*. In order to achieve equilibrium with only two forces, they must act along the same line, to be equal in magnitude and opposite in direction. They act towards each other such as the forces exerted by the jaws of a vice, or away from each other such as the pulls on the rope in a tug of war game. These are examples of *compression* and *tension*.

Figure 1.20(a) illustrates another case. Suppose the body shown in the figure is in equilibrium under the action of three forces X, Y and Z. The lines of action of any two of them, for example X and Y, will intersect at some point P (unless they are parallel). By using the parallelogram of forces, they can be replaced by their resultant which will also pass through P. The force system is then reduced to two forces and these must be equal and opposite, and act along the same line. For equilibrium, therefore, the third force Z must act through P and be equal and opposite to the resultant of X and Y.

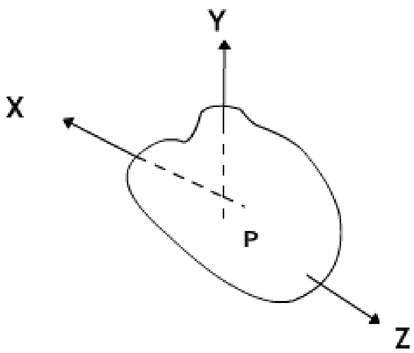


Figure 1.20 (a)

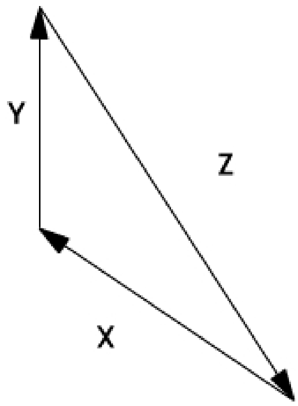


Figure 1.20 (b)

Lines are drawn to represent X and Y taken in order. For an equilibrium state, the line representing Z must complete a triangle (Figure 1.20(b)). In brief, if three non-parallel forces are in equilibrium, they must be concurrent and they can be represented in magnitude and direction by the sides of a triangle taken in order.

1.2.4 <u>Resultant of Concurrent Forces by Calculation</u>

The component of a resultant in a given direction is equal to the sum of the components of all the separate forces in the same direction. As shown in Figure 1.21, the horizontal and vertical components (or resolved parts) of a force F which makes an angle θ with the horizontal are F cos θ and F sin θ. For a set of forces, the horizontal and vertical components of the resultant (H and V) can be written:

$$H = \Sigma F \cos\theta \quad \text{and} \quad V = \Sigma F \sin\theta$$

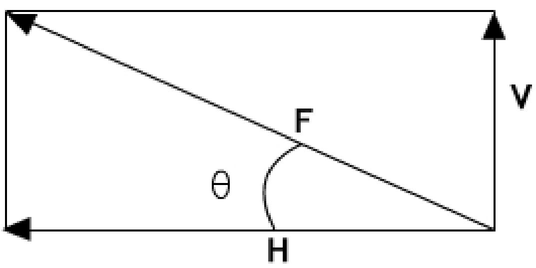


Figure 1.21

The resultant itself corresponds to the diagonal of a rectangle whose sides are H and V as in Figure 1.21. Its magnitude, by Pythagoras, is $\sqrt{(H^2 + V^2)}$ and it makes an angle $\tan^{-1}(V / H)$ with the horizontal datum. Note that the second result gives two possible angles between 0^o and 360^o and the correct one is chosen by examining the signs of H and V.

E X A M P L E

Problem

Find the resultant of the four concurrent forces shown in Figure 1.22. What additional force is needed to produce equilibrium?

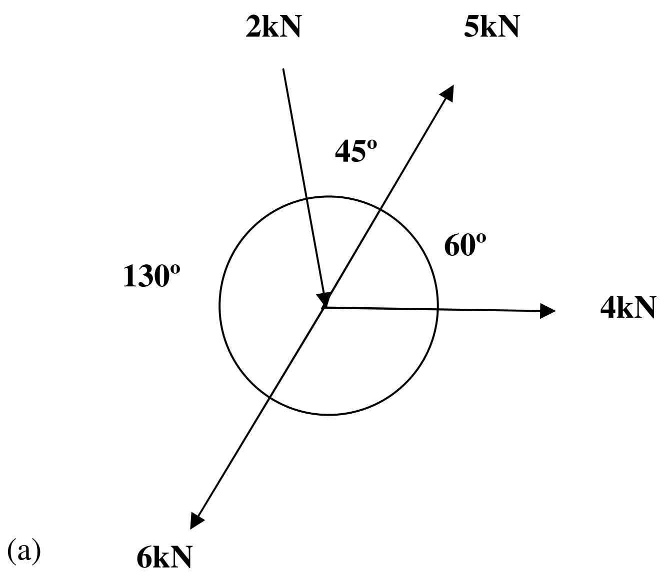


Figure 1.22 (a)

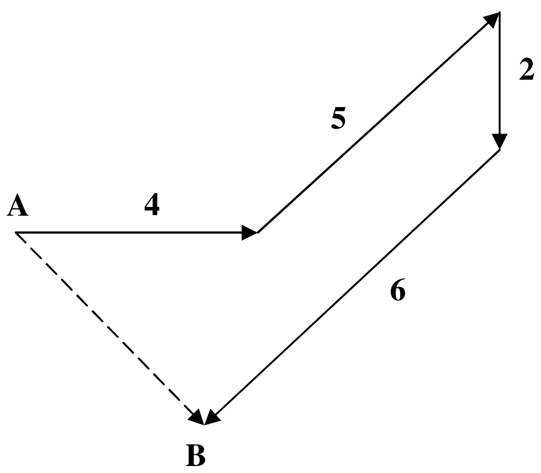


Figure 1.22 (b)

Solution

Let the direction of the 4 kN force be the horizontal datum. Then the forces of 4, 5, – 2 and 6 kN are drawn at the angles (anticlockwise) of 0^{o}, 60^{o}, 105^{o} and 235^{o} respectively with the datum. The force of 2 kN is regarded as negative because it is pushing inwards to the point of intersection. Using the results above for H and V, the horizontal and vertical components of the resultant are:

$$H = 4\cos 0^{o} + 5\cos 60^{o} - 2\cos 105^{o} + 6\cos 235^{o} = 3.576 \text{ kN}$$

$$V = 4\sin 0^{o} + 5\sin 60^{o} - 2\sin 105^{o} + 6\sin 235^{o} = -2.517 \text{ kN}$$

The magnitude of the resultant is therefore:

$$\sqrt{(H^2 + V^2)} = \sqrt{\{3.576^2 + (-2.517)^2\}} = 4.373 \text{ kN}$$

and its line of action makes an angle with the horizontal of:

$$\tan^{-1}(V / H) = \tan^{-1}\{(-2.517) / 3.576\} = -35.1^{o} \text{ or } 144.9^{o}$$

Since H is positive and V is negative, the correct answer is -35.1^{o} and the resultant act downwards to the right.

1.2.5 Types of Support

Figure 1.23(a) shows a pin-jointed *cantilevered* frame with 4 members attached to a vertical wall. If the supports A and B are also pinned (or hinged), they provide a reaction in any direction perpendicular to the axis of the pin. The number of joints including these supports is 4 and, using the formula obtained above, the number of bars needed to make the frame just stiff is:

$$b = 2j - 3 = 2 \times 4 - 3 = 5$$

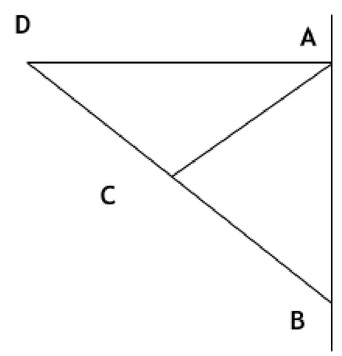


Figure 1.23 (a) Cantilevered pin-jointed frame

This is achieved in this example because the wall acts as a bar in addition to the members AD, AC, BC and CD. A simpler way is to distinguish between the pinned supports A and B and the free joints C and D. The required number of bars is then twice the number of free joints. This means that with 2 free joints 4 bars are required and, since 4 bars are already presented, the frame is just stiff or perfect.

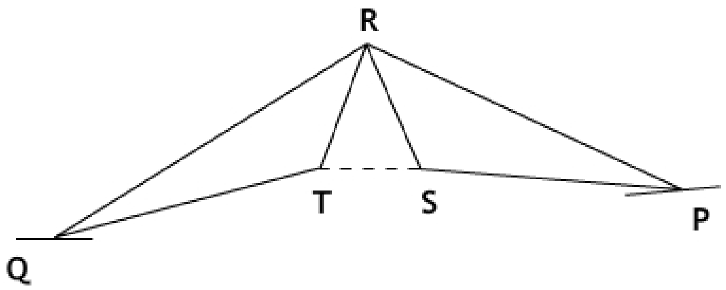


Figure 1.23 (b) Frame pinned at both ends

Figure 1.23(b) shows a frame pinned at its ends (P and Q). It is a roof truss used for supporting the roof of a building. This frame consists of 3 free joints (R, S and T) and therefore needs 6 members to be just stiff. The inclusion of a bar between S and T (shown by the broken line) would make a total of 7 and this bar would be redundant.

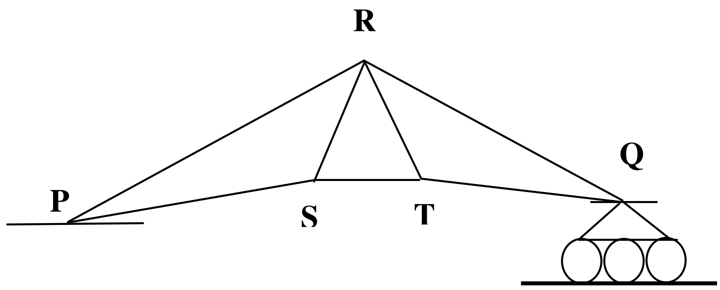


Figure 1.23 (c) Roller support at one end

Figure 1.23(c) shows another example, suppose one of the supports Q is not pinned but consists of a frictionless roller on which the frame rests. In this case, the reaction at this support must then be normal to the surface on which the frame rests. In many large bridge structures, roller supports of this kind are commonly used.

1.2.6 <u>Internal Forces in Plane Frames</u>

Pin-jointed frames are usually designed so that the external loads are carried at the joints. As a result, there are two forces acting on each bar, one at each end. For the equilibrium of the bar, these forces must act along the axis of the bar, be equal and opposite. There are two possibilities shown in Figure 1.24(a). The first one is that the forces are acting outwards tending to stretch the bar. This is called *tension* and the bar is termed *tie* or *tie-bar*. The other possibility is that the forces are acting inwards from the ends of the bar tending to shorten it. This is called *compression* and the bar is then termed *strut*.

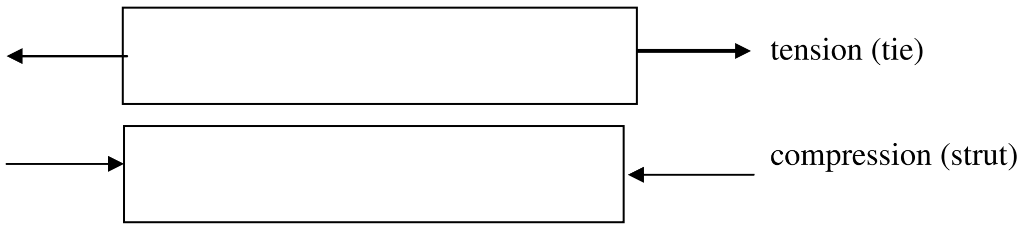


Figure 1.24 (a) External forces acted on the bar

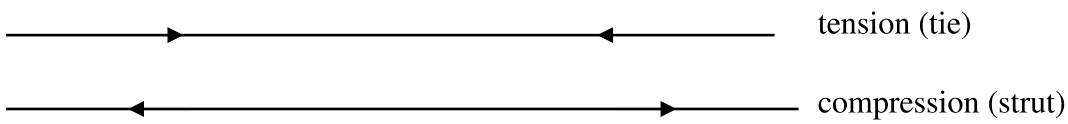


Figure 1.24(b) Internal forces exerted by the bar

The forces exerted by the bar on the joints are in the opposite directions in each case (Figure 1.24(b)). A tie pulls inwards on the joints and a strut pushes outwards on them. This is the way the forces will be shown on diagrams for the rest of this chapter.

1.2.7 Moment of a Force

We know from everyday experience that the turning effect of a force on a body depends on the point at which it is applied (Figure 1.25). We define the moment of a force about a point (***P***) as its magnitude (***F***) multiplied by the perpendicular distance (***d***) of the point from its line of action. The distance is called the *moment arm*. The moment of a force about a point on its own line of action is zero because the moment arm is zero. The unit of moment is the Newton metre (Nm).

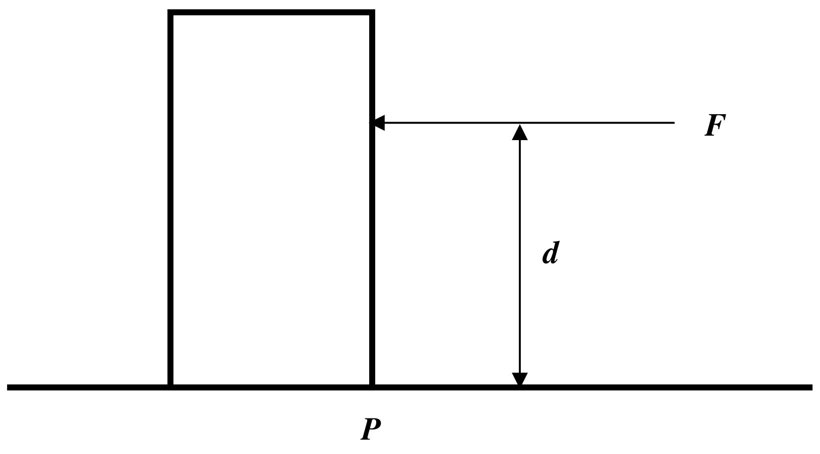


Figure 1.25 Moment of a force

The sum of the moments of a set of forces about a given point equals to the moment of their resultant about the same point. This result is useful in finding the line of action of the resultant of non-concurrent forces. Furthermore, it is important to distinguish between clockwise and anti-clockwise moments when making calculation; one is chosen to be positive and the other as negative.

1.2.8 Strength of Materials

Designers and engineers have to make sure that each member of a structure is strong enough to carry the loads acting on it. The strength of a member depends on the material of which it is made and also its shape and size. The following sections will discuss the stresses within a member and the relationship between its shape and the loads acting on it.

1.2.9 Beams and Cantilevers

A beam is a bar that carries external forces inclined to its axis. Many beams are horizontal and the loads they carry are weights acting vertically downwards. Figure 1.28 shows a beam carrying *point* (or concentrated) *loads* and a *uniformly distributed load* (UDL). Point loads are denoted by arrows and a UDL is shown by a shaded block here. A common example of a UDL is the weight of the beam itself.

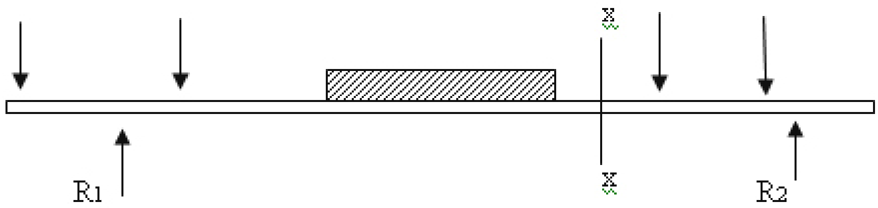


Figure 1.28 Beam carrying point and uniformly distributed loads

A *simple* (or *freely*) supported beam is one that rests on knife-edges. These are supports that provide upward forces of the point but do not prevent the beam from rotating at the supports. The beam in Figure 1.28 is resting on two such supports (R1 and R2). The set of forces acting on a beam at rest must satisfy the laws of equilibrium. In particular, by taking moments about one point of support, the reaction at the other can be calculated.

Figure 1.29 shows a *cantilever*, it is a beam that is supported at one end only. The support cannot be in the form of a knife-edge otherwise the whole cantilever would rotate about it. In addition to a vertical upward force, the support must provide a moment equal and opposite to the sum of the moments of all the loads acting on the supported end. This is called the *fixing moment*.

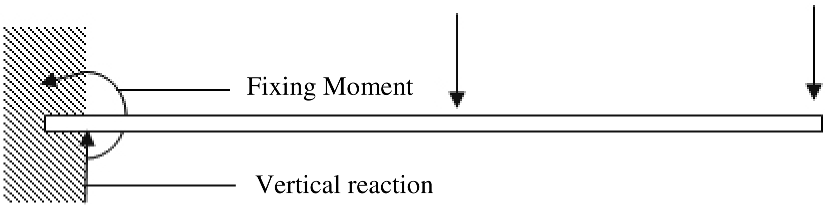


Figure 1.29 Cantilever

1.2.10 <u>Shearing Force and Bending Moment</u>

All the forces (including reactions) should be considered in order to examine the equilibrium of a beam. If we consider the forces on one side of a section only, such as X-X in Figure 1.28, they are not a equilibrium, because those forces acting to the left have a resultant equal and opposite forces to the resultant of those to the right.
The *shearing force* at a section of a beam is the sum of the forces on one side or the other, including reactions. If the resultant force to the left of the section is upward, then the forces to the right will be equal but downward. Shearing force is abbreviated as SF. It is the lateral force that the beam has to resist at the section.

The *bending moment* at X-X is defined as the sum of the moments of all the forces acting on one side of the section about a point. The total amount for all the forces on the left will be equal and opposite to all the forces to the right. Bending moment is abbreviated to BM. It is the moment that the beam has to resist in bending at the section.

In Figure 1.30, shearing in which upward resultant force to the left of the section and downwards to the right will be considered positive. Bending moments will be taken as positive if the resultant moment of the forces on the left is clockwise, and the resultant moment of those on the right is anti-clockwise. These moments that make the beam concave downwards are called *sagging* bending moments. If the moment is anti-clockwise on the left and clockwise on the right, the beam will become convex upwards and the bending moment is called *hogging*.

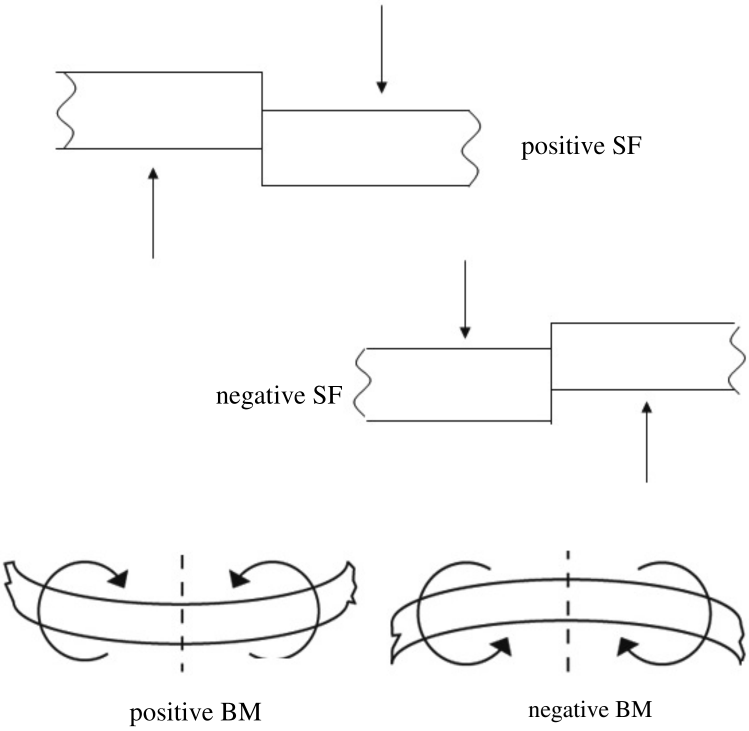


Figure 1.30 Sign convention for shearing forces and bending moments

1.2.11 SF and BM Diagrams for Uniformly Distributed Loads

If a beam carries a uniformly distributed load over the whole or part of its length, then the total amount can be regarded as acting at its centre of gravity when taking moments to find the reactions. Since the distribution of load is uniform, the load will be regarded in the midpoint of the load. For the portion of the beam that is carrying the UDL, the SF diagram is a sloping straight line and the BM diagram is a curve. Therefore, it is necessary to calculate the value of the BM at several points and plot a smoother graph.

1.2.12 Standard Cases of SF and BM

Table 1.1 shows four cases that occur frequently in your design work. In each one, L is the length and W the total downward load. For the two UDL cases, $W = wL$ where w is the load per unit length.

It is unnecessary to find the vertical reaction and fixing moment before calculating the SF and BM for a section of a cantilever. It is because if the forces on the free end side of the section are considered, the reaction and fixing moment at the support will not appear in the calculations. Moreover, if the cantilever carries downward forces only, the BM will be hogging (negative) all the way through.

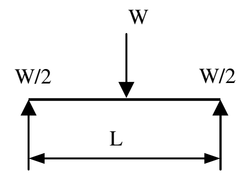
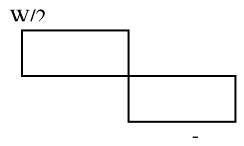
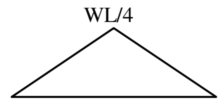
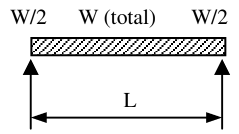
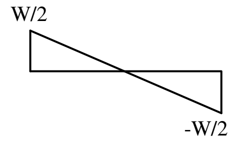
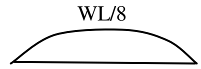
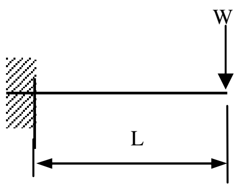
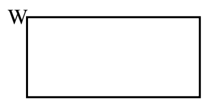
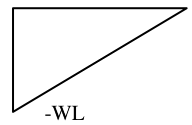
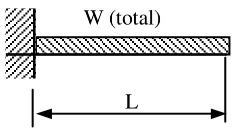
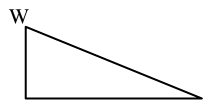
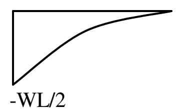
<table>
<tr><th></th><th></th><th>loading diagrams</th><th>SF diagrams</th><th>BM diagrams</th></tr>
<tr><td rowspan="2">Simply supported beams</td><td>central point load</td><td></td><td></td><td></td></tr>
<tr><td>UDL</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">cantilevers</td><td>end point load</td><td></td><td></td><td></td></tr>
<tr><td>UDL</td><td></td><td></td><td></td></tr>
</table>

Table 1.1 Standard cases of SF and BM

The results for point loads apply to a central load on a beam and an end load on a cantilever, and the greatest bending moments will be smaller for loads applied at other points. Hence, the formulae given in the table represent the *worst* cases, and designs based on them will be on the *safe* side if the loads move to other points.

Besides, note that a beam supported at its ends is stronger than a cantilever, and that the UDL causes a smaller BM than if the same load were concentrated at the midpoint of the beam.

1.2.13 Structures Design

The structures we mentioned before are constructed through calculation, such as a pin-jointed frame, the external loads are specified and the problem is to find out the forces exerted on some or all the members. However, to design a structure is a different story. Designers and engineers have to estimate the loads it will carry, choose the materials from which it will be made and decide the shape and form of construction.

(I) Load Factor

If we are designing a storage unit, we have to work out the weights of all the items, such as books, toys, compact discs, and any other items that will be included inside. Secondly, for safety purpose, we have to design the structures that are able to carry a greater load than that of a normal condition. The ratio of the *design load* to *expected load* is called the Load Factor. In many cases, it relates to the *factor of safety* but there are instances where these two are different.

(II) Factor of Safety

Designers and engineers are responsible for ensuring every member of a structure can withstand the forces acting on it. The first step is to decide a safe stress for the material of the member. This is usually called the *working stress* and it is obtained by dividing the failure stress by a factor called the *factor of safety*. The failure stress is obtained by experiment (see Strand 2). If this failure is happened because of the start of permanent strain, this is called the yield point. In some situations, if the failure is considered to have fracture, then this ultimate strength is regarded as failure stress.

The value of the factor of safety will depend upon the type of loading to be expected. If the structure carries only static loads, the value as low as two may be used. However, if there are unexpectedly applied or impacted loads, a higher value will be used.

The factor of safety can be obtained by increasing the load acting on a member by a *load factor*. It will not matter whether the factor is used to reduce the stress or increase the load in simple tension or compression case. However the use of load factor and factor of safety lead to different results in complex loading cases.

1.3 MECHANISMS

Mechanisms are designed to transmit a force to the applied load in order to generate a required outcome, such as basic motions or movements. The method required to apply such a force will depend upon the design of the mechanism.

Mechanisms use levers, gears, linkages, toggles, cams and followers in combination with structures to change the mechanical advantage and minimise the effort required, though the velocity ratio will change. Most mechanisms are designed to generate very little friction and therefore the mechanical efficiency will be high.

1.3.1 Mechanical Advantage and Velocity Ratio

The *mechanical advantage* (MA) is an expression of the amplification of the effort and is defined as:

$$\text{mechanical advantage} = \frac{\text{load}}{\text{effort}} \quad \text{or, in symbols, MA} = \frac{L}{E}$$

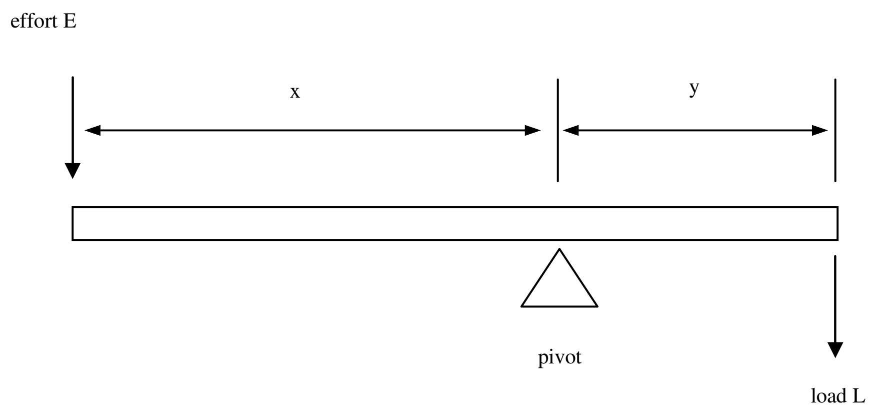


Figure 1.34

We can express the MA in terms of the distances x and y by taking moments about the fulcrum of the lever in Figure 1.34. For equilibrium, the anticlockwise moment due to E is equal to the clockwise moment of L. Hence,

$$Ex = Ly \quad \text{and} \quad \text{MA} = \frac{L}{E} = \frac{x}{y}$$

The greater the ratio of x to y, the greater the MA. Note that MA may be greater or less than 1 depends on the values of x and y.

However this analysis ignores the frictional forces. The value of MA is reduced if taking into account of frictional forces. In practice, the MA of a machine should be obtained experimentally by measuring test values of effort and load. Instead, the MA can be determined if the efficiency of the machine is known or can be estimated.

The lever magnifies the force if MA is greater than one. Then again, the work input must be equivalent to the work output and therefore the effort must move a greater distance than the load (as work = force x distance). The *velocity ratio* (VR) of a machine is the ratio of distance moved by the effort (d_E) to the distance moved by the load (d_L), and can be obtained either by calculation or graphical means. Consequently,

$$\text{velocity ratio} = \frac{\text{distance moved by effort}}{\text{distance moved by load}} \quad \text{or} \quad VR = \frac{d_E}{d_L}$$

The *mechanical efficiency* η is the ratio of the work output to the work input. Therefore,

$$\text{mechanical efficiency } \eta = \frac{\text{work output}}{\text{work input}} = \frac{Ld_L}{Ed_E}$$

Substituting from equations of MA and VR, this equation denotes the efficiency in terms of the MA and VR. In symbols,

$$\eta = \frac{MA}{VR} \quad \text{or, as a percentage, } \eta = \frac{MA}{VR} \times 100\%$$

When a load is raised by a lifting machine, it will remain securely in its new position if the efficiency of the machine is less than 50%. However, if the efficiency is greater than 50%, the potential energy gained by the load is greater than the work needed to overcome the frictional forces when it is being raised. The machine will then turn back to its starting position. This is called *overhauling* and should be prevented for the safe operation of the machine. A ratchet mechanism or brake is usually used for this purpose.

S T O P   A N D   T H I N K

Study a crane (Figure 1.35), and try to find out which class of lever is being used to lift a load. What are the MA and VR of such a machine?

Figure 1.35 Crane

1.3.2 Gear Ratio

The *gear ratio* is the relationship between the number of teeth on two gears that are meshed. The following picture shows gears on a piece of farm equipment:

Figure 1.36 Gears

(I) Simple Gear Train

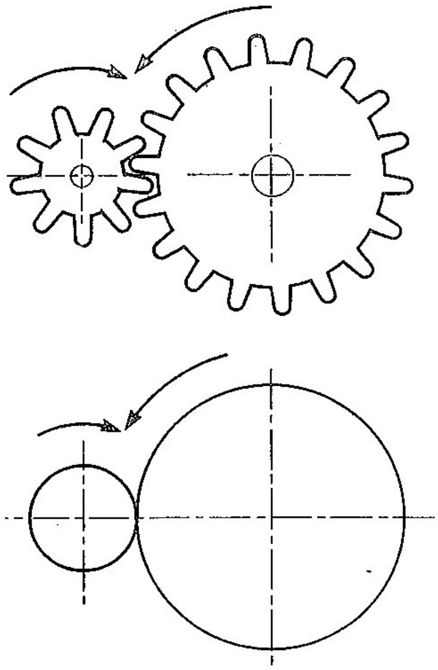


Figure 1.37 A simple gear train

Figure 1.37 shows two spur gears of different sizes meshed together. This is an example of a simple gear train. The smaller, 9-toothed pinion will have to perform two revolutions for each revolution of the larger, 18-toothed wheel. Therefore, when the wheel is used as the *driver* (input) gear, the output motion will be faster than the input. In this case,

$$\text{VR} = \frac{\text{angular movement of wheel (effort)}}{\text{angular movement of pinion (load)}} = \frac{1}{2}$$

Or

$$\text{VR} = \frac{9}{18} = \frac{\text{number of driven teeth}}{\text{number of driver teeth}}$$

The VR for a gear system is usually referred to the gear ratio, and the above value would be quoted as a gear ratio of 1:2. It is also equals to the ratio between the speeds of the driver and the driven gears.

E X A M P L E
Find the gear ratio of a simple gear train where the driver gear has 15 teeth and the driven gear has 60 teeth. $\text{The gear ratio} = \frac{\text{number of driven teeth}}{\text{number of driver teeth}} = \frac{60}{15} = \frac{4}{1}$ or 4:1

(II) Compound Gear Train

In a compound gear train, at least one shaft would carry a compound gear where two wheels are being rotated at the same speed (Figure 1.38). The advantage of a compound gear train is that it can produce a high gear ratio without the disproportionate gear sizes that are being used in a simple gear train.

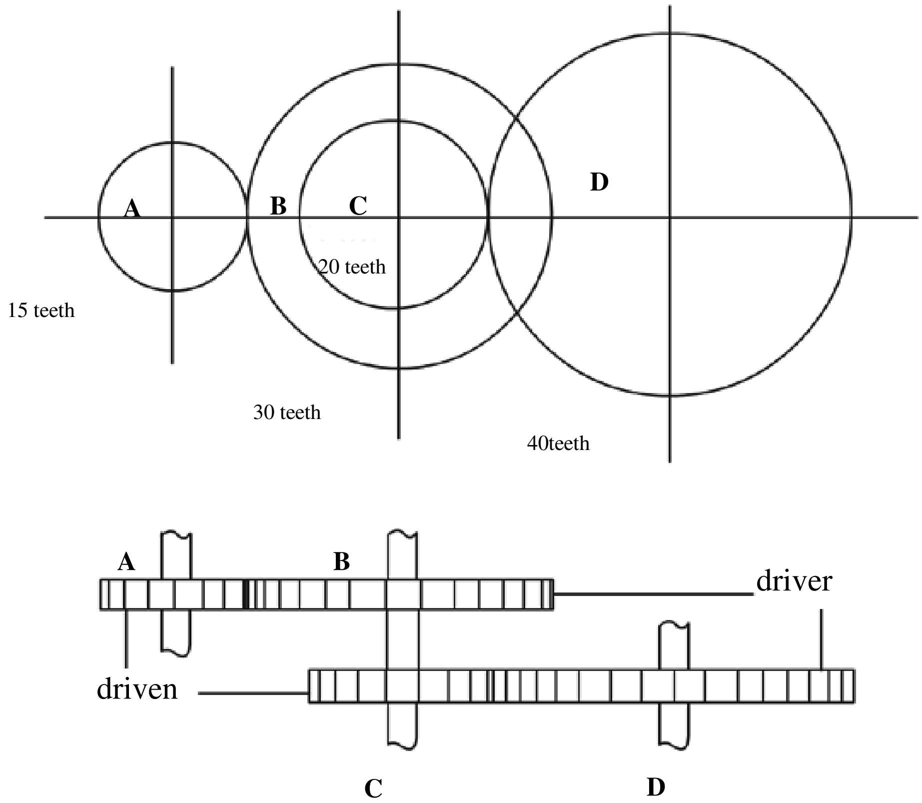


Figure 1.38 A compound gear train

In Figure 1.38, the driver gear A has 15 teeth and an angular speed of 120 rev/min (r.p.m.). For one revolution of gear A, the meshing gear B (30 teeth) will rotate half a revolution. Gear C is mounted on the same shaft as gear B, and will also rotate half a turn. For half a turn of gear C (20 x 1/2 = 10 teeth), gear D (40 teeth) will rotate for one quarter of a revolution. Therefore, we have the following equation:

$$\text{gear ratio} = \frac{\text{distance moved by input}}{\text{distance moved by output}} = \frac{1}{1/4} = \frac{4}{1} \quad \text{or } 4{:}1$$

Generally, for a compound gear train, A and C are the driver gears while B and D are the driven gears,

$$\text{gear ratio} = \frac{\text{product of numbers of teeth in driven gears}}{\text{product of numbers of teeth in driver gears}}$$

Hence, in the figures for the gear train of Figure 1.38,

$$\text{gear ratio} = \frac{30 \text{ x } 40}{15 \text{ x } 20} = \frac{4}{1} \quad \text{or } 4{:}1$$

1.3.3 Gear Wheel Speed

Referring to Figure 1.38 again, wheel B takes twice as long as A to turn through a full revolution. Therefore, the speed of B will be half the speed of A, that is, 60 rev/min. In order to find the relationship between the angular speed of a gear and its number of teeth, we assume that the rate at which the teeth pass the point of contact will be the same for each gear. The number of teeth per minute passing any point is given by the product of its rotational speed, N in rev/min, and the number of teeth, t. Hence, for a simple gear train consisting of two gear wheels A and C,

$$N_B \times t_B = N_A \times t_A \quad \text{or} \quad N_B = N_A \times \frac{t_A}{t_B}$$

Thus,

$$\text{speed of driven gear} = \text{speed of driver gear} \times \frac{\text{number of driver teeth}}{\text{number of driven teeth}}$$

Apply this result to gears C and D,

$$N_D = N_C \times \frac{t_C}{t_D}$$

We also know that gears B and C rotate at the same speed as they are mounted on the same shaft. Hence $N_B = N_C$ and the last result becomes:

$$N_D = N_B \times \frac{t_C}{t_D}$$

Substituting for N_B the relationship derived above for gears A and B, we get:

$$N_D = N_A \times \frac{t_A}{t_B} \times \frac{t_C}{t_D}$$

This result can be extended for any number of compound gears and the general result for any compound train gear is:

$$\text{output speed} = \text{input speed} \times \frac{\text{product of numbers of driver teeth}}{\text{product of numbers of driven teeth}}$$

E X A M P L E

Find the angular speed of gear D of the compound gear train in Figure 1.38

$$\text{output speed} = \text{input speed} \times \frac{\text{product of numbers of driver teeth}}{\text{product of numbers of driven teeth}}$$

Thus,

$$N_D = 120 \times \frac{15}{30} \times \frac{20}{40} = 30 \text{ rev/min}$$

The speed of gear D is 30 rev/min.

1.3.4 Power and Torque

For a gear train, the power input is equal to the product of the driving torque and the angular speed of the drive shaft ($P=Fv$). If there is no power loss, this power will be the same for each gear in the train. Therefore, torque and angular speed are inversely related. If the speed is increased, the torque will decrease. Therefore when we climb up the hill by a bicycle or by a car, we need to use the start-up gears, despite that it is slow, in order to achieve a higher torque.

There is a simple gear train with driver gear A and driven gear B, T_A and T_B are the torques, and ω_A and ω_B are the angular speeds in radian per second. Since the power is the same for gear A and gear B, therefore

$$\text{output torque} = \text{input torque} \times \frac{\text{angular speed of driver gear}}{\text{angular speed of driven gear}}$$

and it can be represented as:

$$T_B \times \omega_B = T_A \times \omega_A \quad \text{or} \quad T_B = T_A \times \frac{\omega_A}{\omega_B}$$

As the number of teeth of a gear is inversely related to its angular speed, therefore the more the number of teeth in the driven gear will result the larger output torque for a constant input. Since $\omega_B \times t_B = \omega_A \times t_A$ the ratio of the speeds ω_A/ω_B equals t_B / t_A and the torque on gear B becomes:

$$T_B = T_A \times \frac{t_B}{t_A}$$

Therefore,

$$\text{output torque} = \text{input torque} \times \frac{\text{number of driven teeth}}{\text{number of driver teeth}}$$

and for a compound gear train,

$$\text{output torque} = \text{input torque} \times \frac{\text{product of numbers of driven teeth}}{\text{product of numbers of driver teeth}}$$

E X A M P L E

Find the power supplied by the motor to the 20-teeth driver gear A to rotate it at an angular speed of 120 rev/min with a torque of 200 Nm. Furthermore, if gear A is simply meshed with a 40-teeth driven gear B, find the torque on gear B.

T_A = 200 Nm; input speed = 120 x 2π / 60 rad/s; and power = $T \times \omega$

Hence,

input power = $T_A \times \omega_A$ = 200 x 120 x 2π / 60 = 2.513 kW

and torque on gear B,

$$T_B = T_A \times \frac{t_B}{t_A} = 200 \times \frac{40}{20} = 400 \text{ Nm}$$

E X A M P L E

Find the output torque on gear D of the compound gear train in Figure 1.38 if there is an input torque of 500 Nm on gear A.

$$T_B = T_A \times \frac{t_B}{t_A} = 200 \times \frac{40}{20} = 400 \text{ Nm}$$

1.3.5 Worm and Wheel, Chain Drive

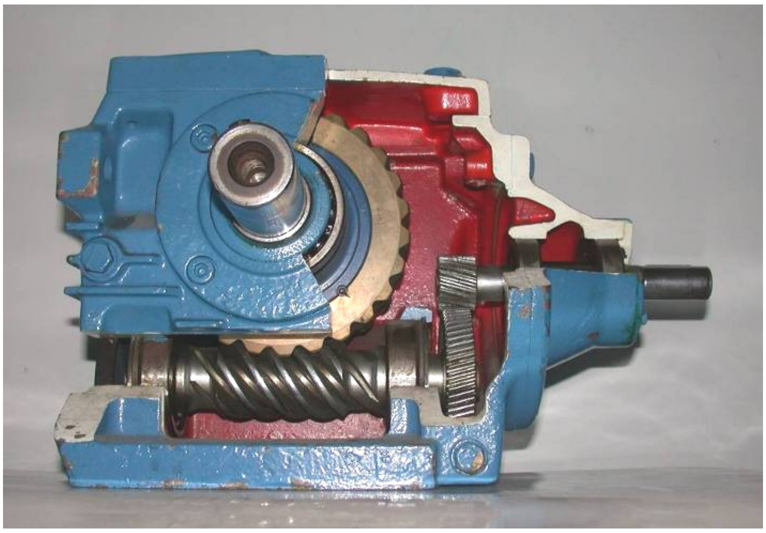


Figure 1.39 Worm and wheel in a gear box

(I) Worm and Wheel

We have considered the gear trains with parallel input and output shafts. However in many cases, the output shaft will be perpendicular to the input shaft. In strand 2, you have already learned how bevel gears turn the motion through a right angle in the operation of a hand drill. Besides, the worm and wheel can be used to turn the drive through 90 degrees and obtain a very high gear ratio (Figure 1.39). One revolution of the worm moves one tooth of the wheel. Hence the ratio of the angular speed is given by the number of teeth on the wheel. Therefore,

$$\text{the number of teeth in wheel} = \frac{\text{angular speed of worm}}{\text{angular speed of wheel}}$$

and so,

$$\text{gear ratio} = \text{the number of teeth in wheel}$$

A high output torque is created because of the large reduction in the speed of drive that is obtained when using a worm and wheel. Figure 1.40 illustrates how this is used to tighten the strings of a musical instrument in tuning. It is necessary for the tuning mechanism remains less than 50% efficient in order to prevent overhauling, i.e. prevent the strings to slack when the tuning peg is released.

Figure 1.40 Tuning mechanism of a musical instrument

(II) Chain Drive

A chain drive consists of toothed wheels where its gear ratio and the output speed are similar to a simple gear train (Figure 1.41). Therefore,

$$\text{gear ratio} = \frac{\text{number of teeth in the driven sprocket}}{\text{number of teeth in the driver sprocket}}$$

and the angular speeds are calculated by:

$$\text{output speed} = \text{input speed} \quad \text{x} \quad \frac{\text{number of teeth in the driver sprocket}}{\text{number of teeth in the driven sprocket}}$$

Figure 1.41 Chain drive of a bicycle

S T O P A N D T H I N K

Figure 1.42 and 1.43 show a motorised toy car and a motorised toy train respectively. In each case, a unique type of gear is used to transmit forces. Describe these two different types of gears and analyse their advantages and disadvantages.

Figure 1.42 (a)

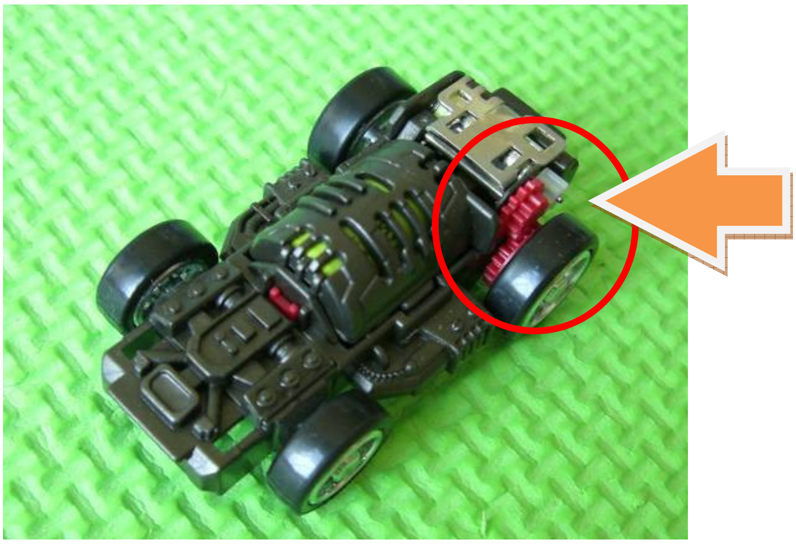


Figure 1.42 (b)

Figure 1.43(a)

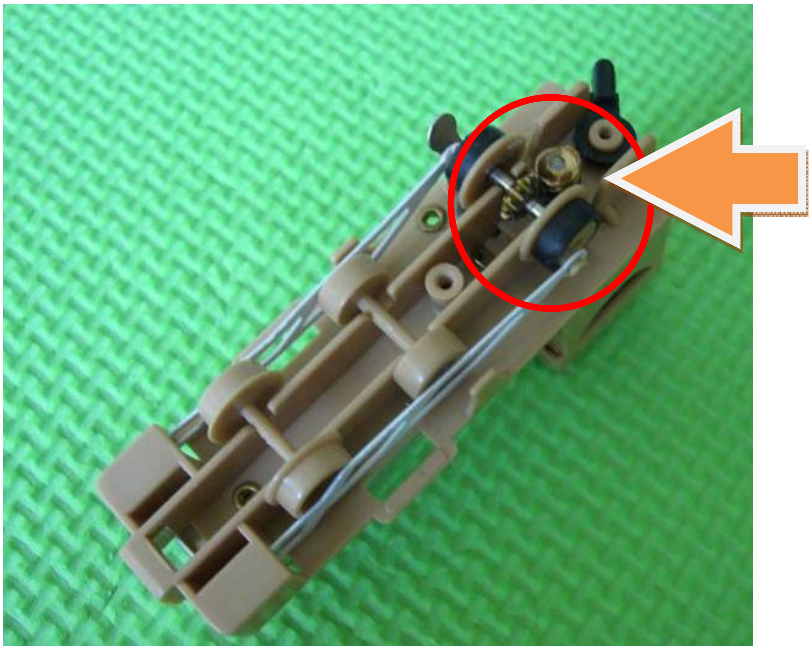


Figure 1.43(b)

1.4 NEW MATERIALS

We are going to explore the evolution of materials. Most new materials are developed through the invention of improved processes and are designed to perform a particular function.

Over the past two decades, a range of "smart and modern materials" have been developed.. However, they are not really intelligent , some of them do respond to external input or stimulus such as heat or light. Many smart and modern materials are developed for specialised applications, and eventually available for general uses. Examples of these materials include:

- Shape memory alloys
- Carbon fibres
- Photovoltaic cells
- Liquid crystal display
- Advanced ceramics
- Nano-materials
- Superconducting materials
- Fibre-optics

1.4.1 Modification of Material Properties

Many materials are mixed or combined to provide different, often improved properties. Let us review several predecessors of modern and smart materials in order to realise the basic principles of modifying material properties through mixing or combining different materials. In many cases, the reason for blending materials is to give added strength, therefore reinforcing materials are used. For example, alloys are metallic materials formed by mixing two or more elements. In addition, materials which have been bonded together are called composites; they are classified into two distinct categories:

- Particle Composites
- Layered Composites, or Laminates

H I G H L I G H T

Alloys

A combination of two elements is a binary alloy and a combination of 3 elements is a ternary alloy.

Figure 1.44 Window frame made of aluminum alloy

Metals are alloyed together for many reasons, and usually aim to make use the added advantages from different materials. Alloying can:

(a) change the properties of electrical conduction and thermal conductivity by adding copper
(b) change the colour, such as brass are produced by alloying copper and zinc
(c) improve resistance to corrosion by adding chromium to steel to produce stainless steel
(d) increase hardness or ductility
(e) increase strength by adding molybdenum to steel
(f) lower the melting point by adding carbon to iron

Figure 1.45 Hand rail made of stainless steel

H I G H L I G H T

Particle Composites

Concrete is a good example of a particle composite. It is made up of particles of stone and sand, with cement to bond the particles together. The bonding takes place when water is added to the mixture, as this reacts with the cement, causing it to set.

Concrete Block

The amount of certain particles in a material can also change its properties. For example, carbon particles are added to strengthen the rubber which is used for manufacturing car tires. (More details will be discussed in Topic 1.2)

Layered Composites

Layered composites, or laminates, are used to strengthen materials. Lamination involves a combination of several *layers* of material to make the original material stronger. Three common examples are Formica, melamine and plywood:

- *Formica* is a decorative material, used as a hard-wearing surface. It is made up of laminates or layers of brittle resin and paper. It is tough because it contains cellulose fibres.
- *Melamine* is a layered plastic and is commonly used for kitchen work surfaces.
- *Plywood* consists of several thin layers of wood (veneers) which are glued together.

Composite materials can also gain their strength from reinforcing *fibres*. Fibres that are short in length will be added into the materials in random patterns, while long and continuous fibres will be woven, spun or twisted depends on the application. A good example of a fibre reinforced composite material is *Glass Reinforced Plastic*, or GRP (Figure 1.46). A number of working processes are engaged in the moulding of GRP parts. Please refer to a brief description on these procedures can be found in:

http://www.bpf.co.uk/bpfindustry/process_plastics_GRP_Moulding.cfm

Figure 1.46 Canoe made of GRP

S T O P A N D T H I N K

Find out the reasons of using alloys/composite instead of conventional material in making the following two products:

(1) Car wheel made of alloys

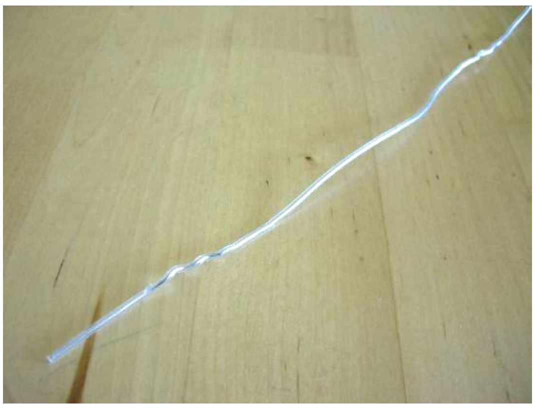
(2) Boat hull made of GRP

1.4.2 <u>Shape Memory Alloys</u>

Shape Memory Alloys (SMA) is one of the smart materials invented recently; it exhibits special behaviour and provide quick responses to a specific context. For example, SMA can be conditioned to change its shape at specific temperatures.

SMA was discovered and has been developed since the 1970s. SMA deform plastically below a given critical temperature. These temperatures tend to be very low when compared to the melting temperature of the component metals. The material will revert to its original shape when the temperature is above its critical temperature. The following pictures show the changing cycle:

(1) Original form



(2) Deformed

(3) Reheated in hot water

(4) Revert to original form

Great forces will be produced when the material returns to its original length or shape. Nitinol (an alloy of Nickel and Titanium) exhibits this phenomenon. A sample of cross-section 10mm x 10mm will generate a force of 20kN (around 2 tonnes) on returning to its original length from only 5% elongation.

One of the application of SMA was in the window-opening mechanisms of green houses. We do not need to hire someone to go around and open the cooling vents when the temperature rises above a specific level. It is because the vents will open automatically when the activation mechanism responds to the temperature changes in the morning.

Please refer to the Case Study of Shape Memory Alloys for more details.

1.4.3 Carbon Fibre

GRP is a strong fibre reinforced composite often used for boat hulls and car bodies. It comprises layers of glass fibre and resin, usually polyester. The strongest laminate is produced from a large amount of glass fibre with minimal use of resin.

Carbon Fibres are increasingly being used in place of GRP to strengthen materials as composite material technology advances. Carbon fibres and a wide range of plastics are bonded together by heat and pressure, producing a very strong but light materials which can be used in similar applications of GRP (Figure 1.47). A lot of racing cars are now constructed from one piece of carbon fibre reinforced shell which is very light and robust.

Figure 1.47 Pen barrel made of carbon fibre reinforced plastic

Please refer to the Product Analysis of Racket and the following website for more details.
(Useful website: http://www.fibreforce.co.uk/)

1.4.4 <u>Photovoltaic Cells</u>

A Photovoltaic Cell is an array of photodiodes connected together that produces electric current when light strikes on it (Figure 1.48). It has a large surface area to catch as much light energy as possible. They are commonly used in solar panels installed in calculators or wrist watches.

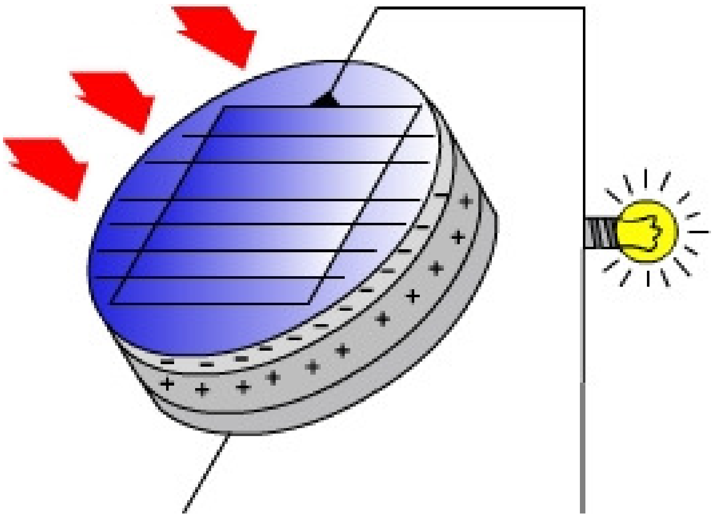


Figure 1.48 Photovoltaic Cell

Basically, a photodiode is a semiconductor diode with a p-n junction near the surface of a clear package, so that light can get through it (Figure 1.49). When photons, packets of light energy, reach the p-n junction, they release their energy as electrons going through the p-n junction and conduct electricity. The current producing through a photodiode is proportional to the amount of light striking it when it is connected to a circuit.

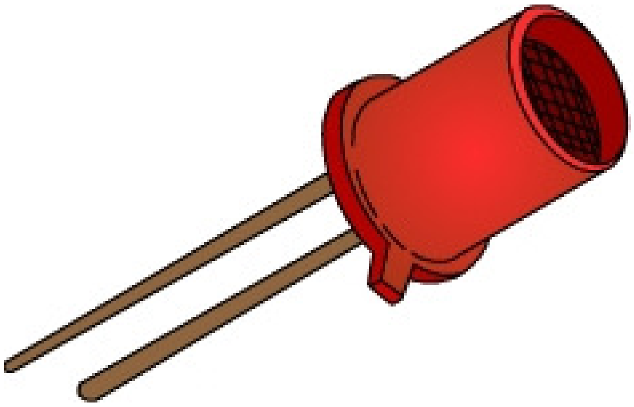


Figure 1.49 Photodiode

It is important to select appropriate photovoltaic cell because these cells can be manufactured to respond to different wavelengths of light such as infra-red (heat) or visible light.

Please refer to the Case Study of Photovoltaic Systems for more details.

1.4.5 <u>Liquid Crystal Display (LCD)</u>

Liquid Crystal Display (LCD) are commonly found on laptop computers and video camera (Figure 1.50). They differ from LEDs as they produce no light on their own.

Figure 1.50 LCD panel

LCD are made from a thin layer of light polarising liquid crystal packed in between two layers of thin glasses (Figure 1.51). Certain areas of the crystal are attached to electrical contacts which allow electric current to pass through the crystal. As the current flows, the crystals will line up in the direction at right angles to those crystals without the current.

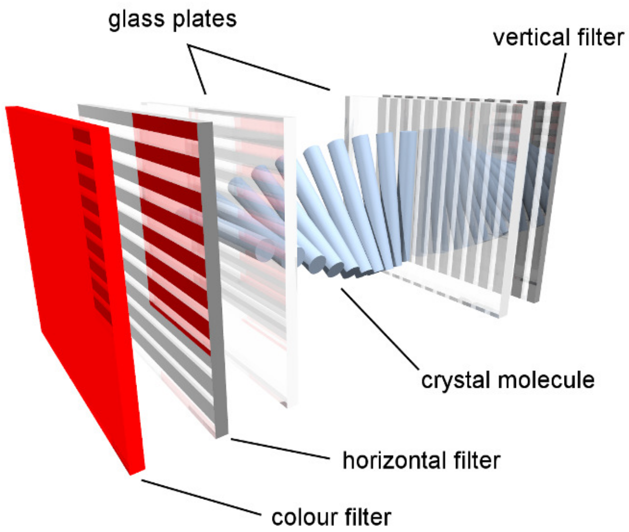


Figure 1.51 LCD Pixel

The front sheet of glass is light polarising and is aligned to allow light passing through in the same direction as the crystals are at rest. When the crystals are not activated by current, the display looks bright because light can pass through it. When activated, the crystals rotate the light so that it can not pass through the front glass, then part of the display will turn dark. As a result, the display can be changed and show characters by activating different parts of the crystal (Figure 1.52). Since the display does not produce any light of its own, it must be illuminated from its side or behind.

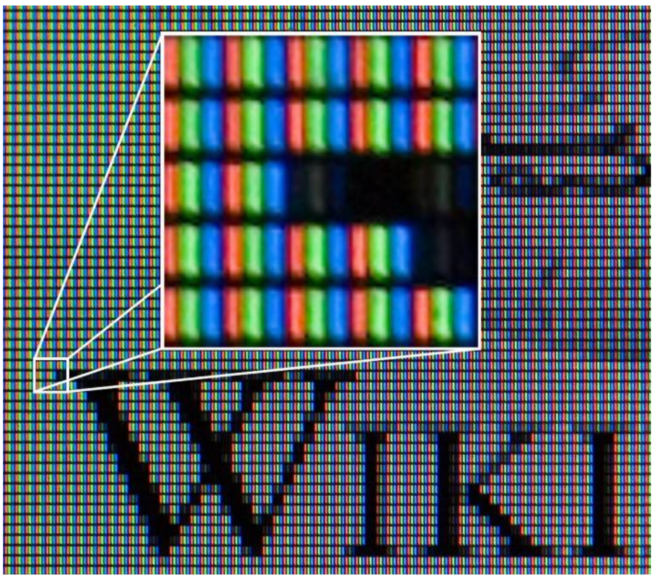


Figure 1.52 Characters shown on LCD

1.4.6 Advanced Ceramics

Advanced ceramics, also known as special ceramics, fine ceramics, technical ceramics or engineering ceramics, are a group of industrial ceramic materials which have been carefully prepared in order to improve mechanical properties. Their toughness and strength are comparable to those of metals. Basically, ceramics can be crystalline or amorphous (glassy). They are complex combinations of metallic and non-metallic elements. With such properties, these ceramics are able to resist high temperatures and corrosive fluids. In the industry, they are used to build furnaces in manufacturing iron or glass. In domestic area, they are used to form a coating on the surface of cooking equipment (Figure 1.53).

Figure 1.53 Pan coated with thermo-/ thermal ceramic material

(Useful website: http://www.dsf.co.uk/)

1.4.7 Nano-materials

One of the greatest developments recently in the field of material science is Nanotechnology. Nanotechnology is a technology on the atomic scale which combines chemistry and engineering.

New electron microscopes use a beam of electrons rather than a beam of light to magnify the atoms within a molecule, 10 million times. To give you an idea of scale: if you magnified a coin 10 million times, it would be 200km across – that would stretch from Hong Kong to Guangzhou. This level of magnification allows us not only to see atoms but manipulate them as well. The technique is to manipulate atoms individually and place them exactly where they are needed to produce the desired structure. Following is an illustration of the nanoscopic gears that could be constructed one atom at a time to form nanoscopic machines:

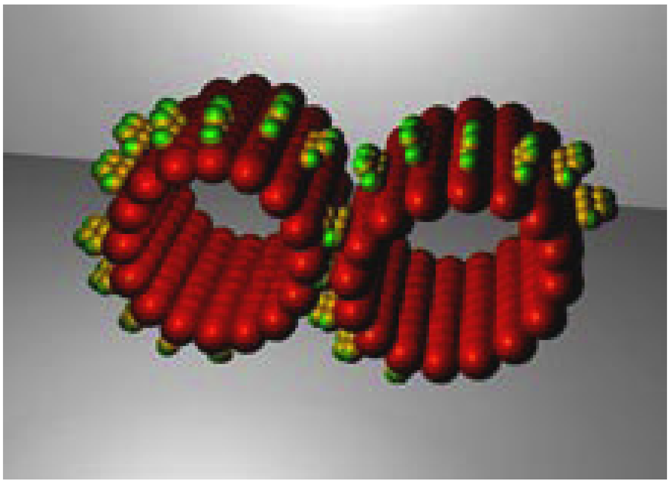


Figure 1.54 Nanoscopic Gears

Nowadays, by using the innovative production system, manufacturers are able to use nano-materials to create outstanding products. Bicycle frame made of carbon nanotubes is a good example. Carbon nanotube is the strongest fibre that will ever be made - it has a strength-to-weight ratio which is 100 times better than aluminum or 10 times better than normal carbon fibre. Therefore, the bicycle manufacturer are able to build a bicycle frame with minimal weight and maximal strength.

Furthermore, nanotechnology is changing the world. Computers could become so small that they will be no larger than a human cell. They could be billions of times faster than the computers used today; they can control nanoscopic robots that patrol inside our bodies and act as an artificial immune system.

1.4.8 <u>Superconducting Materials</u>

Superconducting materials have no electrical resistance and therefore generate no ohmic heating. Theoretically it means that electricity can be generated and transmitted without creating heat energy. However, superconducting materials only exhibit such property at very low temperatures.

Superconducting materials can be alloys or ceramics. One test for them is the Meisner or *magnetic mirror* effect. If a superconductor is placed over a magnet, it will levitate above it, this is because the superconductor produces a magnetic field exactly equal to the one produced by the magnet; these fields exactly cancel each other out. This effect has been utilised in MagLev (magnetic levitation) trains, where a train will hover over a magnetic track and can be propelled at high speed with little friction (Figure 1.55). Another main application for superconducting materials is the production and manufacture of small, powerful and efficient motors.

Figure 1.55 MagLev in Shanghai

1.4.9 Fibre-optics

Fibre-optics is a bundle of glass fibres (Figure 1.56). Very small diameters of glass fibres (down to 0.001mm diameter) are used to allow optical signals of light to pass through them. Since the material used is very efficient to do this, they replace the traditional copper wire and carry far more information in a much smaller component.

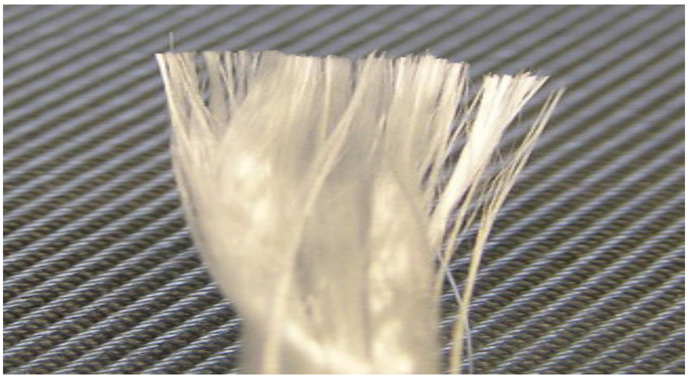


Figure 1.56 Bundle of glass fibres

There is a much smaller reduction in signal with distance than for copper and so they are particularly useful for cables crossing oceans. Most telephone trunk lines (lines between exchanges) are fibre optic cables nowadays. The light signal is transformed into an electric signal using a photovoltaic cell we mentioned above.

Because fibre optics' operation based on the principle of total internal reflection, some of the light may *leaks out* when the filament is bent. Engineers are now taking advantage of this phenomenon and using fibre optics to develop systems that can test components such as rail track to see if they are worn out.

CHAPTER 2 – PROCESSING AND MANUFACTURING

This chapter covers topics on:

2.1 Manufacturing Processes and Techniques
2.2 Scale of Production
2.3 Quality Assurance and Quality Control

These topics include learning materials and activities that facilitate you to:

(a) select, explain and execute appropriate manufacturing processes and techniques;
(b) explain when is most appropriate to use different scales of production; and
(c) consider the application of quality control in production.

2.1 MANUFACTURING PROCESSES & TECHNIQUES

2.1.1 Casting Techniques

Figure 2.1 Examples of iron castings

A lot of materials can be casted – pour the material when it is in molten state into a mould of specific shape and wait until it become solid (Figure 2.1).

(I) Sand-casting

Damp sand will retain its shape when squeezed together, and this is the basis of the sand-casting technique which can be used for any metal castings. A special pattern is usually used to create the cavity, or we can make impressions in the sand on the foundry floor using tools, templates or existing products to create the shape of the pattern. In its usual form, the pattern is taken out by dividing it into two pieces with a split box. When the sand is formed round the pattern, the box is opened and the two halves of the pattern are removed from their respective sides of the box. The typical sand-casting process is shown below:

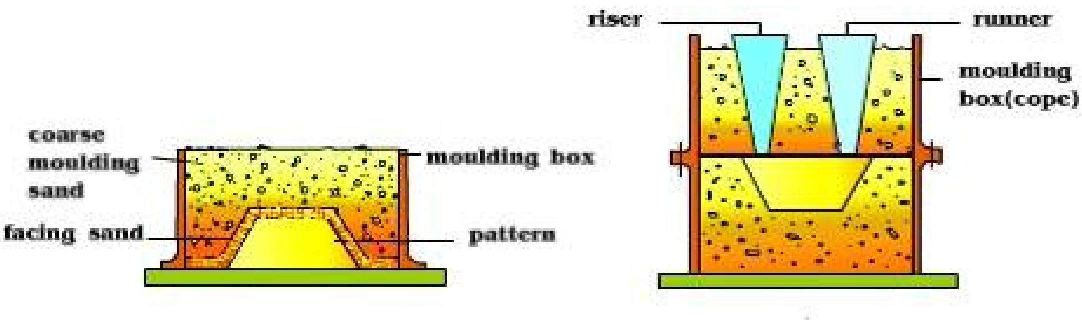


Figure 2.2 The Sand-casting Process

In the first stage of the process, high quality (very fine) facing sand is put over the pattern and the remainder of the moulding box (the drag) is filled with coarse moulding sand. They are then compressed with a ram and the excess sand are removed from the top to leave it level. The drag is then inverted, and the other half of the moulding box (the cope) is located on the top. A runner is added to create the tapered hole through which metal will be poured, and a riser to allow the metal to flow through the mould cavity. The moulding box is then split open to take out the pattern. Casting is then poured in when the box has been reassembled. A hollow cavity can be formed inside a sand-casting by placing a sand core in the required position.

The advantages of sand-casting are listed below:

- economical for any production quantity because of the low tooling cost,
- can be used to produce castings of any size.

The disadvantages are:

- comparatively slow production time, caused by the slow cooling rate,
- poor accuracy
- poor finish.

The traditional sand-casting process has been developed for quantity manufacturing. Production rate for sand-casting can be increased by mechanising all the operations using metal patterns and pneumatic ramming equipment. Nowadays, automatic sand-casting facilities produce various products such as the bodies of bench vices (Figure 2.3).

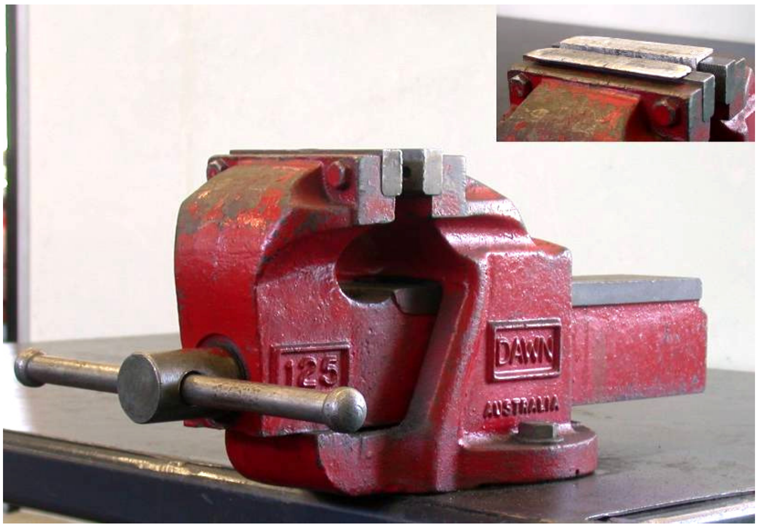


Figure 2.3 Bench Vice

(II) Die-casting Methods

Instead of using a sand mould, a metal mould is used in die-casting. This process exists in four primary forms – high pressure die-casting with hot and cold chambers, low pressure die-casting and gravity die-casting. The choice between the hot and cold chamber methods depends very largely on the material being used. Hot chamber method can be used with zinc and low melting point alloys which are kept molten and injected by a plunger when required. However, molten aluminum tends to react with steel and cannot be casted using this method. In the cold chamber method, molten metal is transferred to the machine between castings. That means the production time is slowed down. In spite of this, it is necessary when using metals with higher melting points, such as brass and magnesium alloys. Sometimes, centrifugal action is used to help the molten metal to flow into the mould. The shape of the cavity and the general design considerations are similar in all these process alternatives. The differences are tool size and material used must be able to withstand the temperatures and pressures involved.

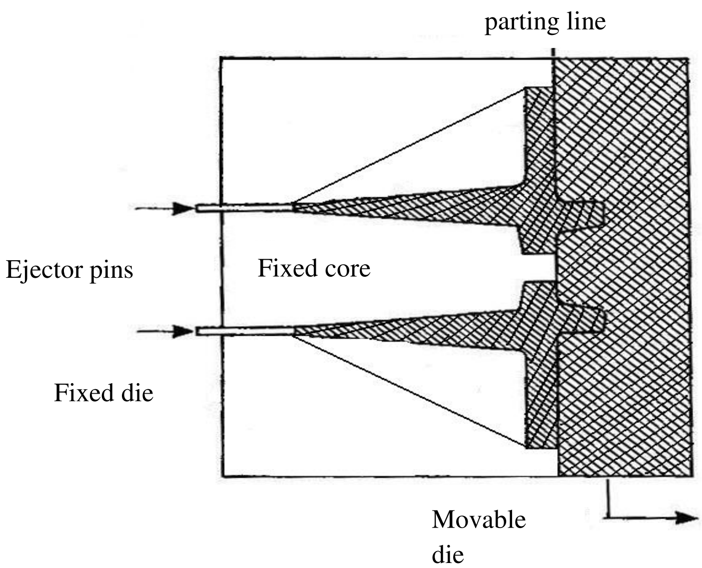
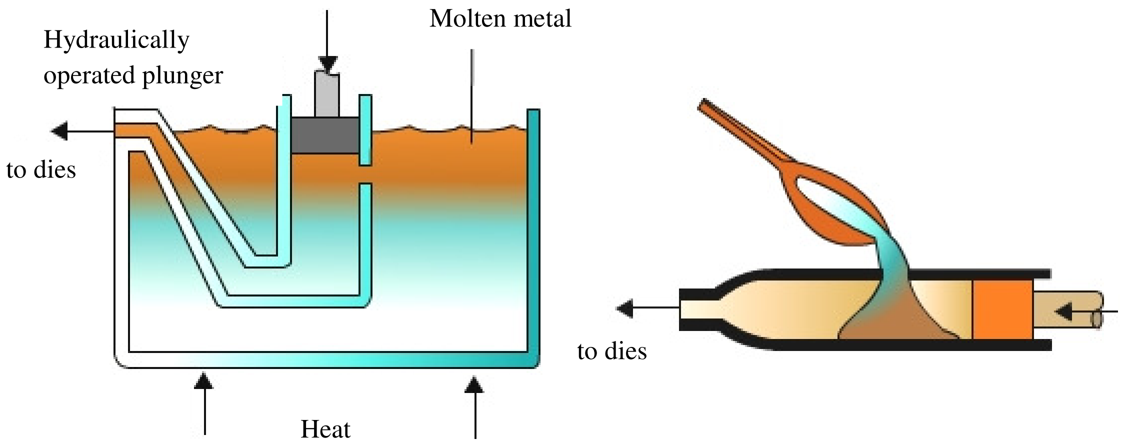


Figure 2.4 Simplified layout of a die-casting tool

Figure 2.4 shows the simplified layout of a die-casting tool. There is a draft angle (or taper) on the cores so that they can be removed easily. Small radii in the mould help to ease the removal of the casting, but it is still necessary to make provision for ejector pins. Since there is no flash, runners or risers, the surface finish of die-cast product is always excellent. In order to avoid unnecessary machine operation, the ejector pins must act on a sufficiently large and preferably an unimportant area.

High-pressure Die-casting

Zinc, aluminum and magnesium alloys are usually used for high-pressure die-casting. Ferrous alloys can be die-casted but this is less commonly done. Cycle time need typically about one minute, although this can be longer for very large machines. Generally, the dies are made from special alloy steels and weigh several tones. Figure 2.5 shows schematically the differences between the hot and cold chamber methods:



(a) (b)

Figure 2.5 Schematic layout of the high-pressure die-casting process (a) hot chamber and (b) cold chamber

Comparing with the hot chamber process, the cold chamber process operates at a higher pressure of between 14 MPa and 70 MPa and is only cost-effective for production quantities more than 20000. On the other hand, because of the lower pressures – typically 2.5 to 3.5 MPa – and smaller tooling associated with the hot chamber process, this can be cheaper for quantities as low as 10000. Since the finish obtained with high pressure die-casting process is excellent and only requires polishing before painting or plating. Therefore, this process is the most accurate among all casting processes giving a tolerance of approximately ±0.05 mm on a 25 mm dimension.

Low-pressure Die-casting

Low-pressure die-casting process is illustrated schematically in Figure 2.6. Molten metal is forced up into the die by air at a pressure of approximately 2.8 to 5.6 kPa. As with high-pressure die-casting, complex components can be produced to close tolerance and with a good surface finish. Though the cycle time is longer, tooling is much cheaper to produce.

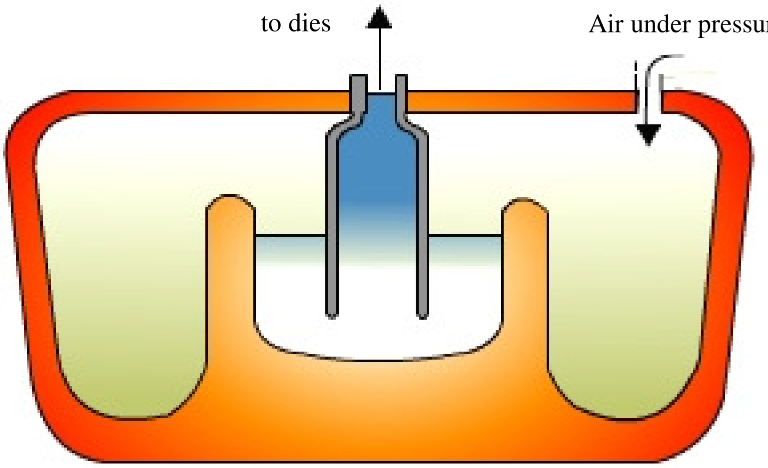


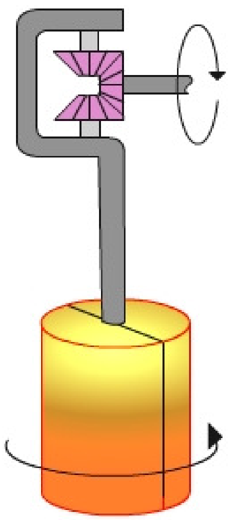
Figure 2.6 Schematic layout of the low-pressure die-casting process

Gravity Die-casting

Different ways of gravity die-casting have been known for thousands of years. The metal flows into the mould under the influence of gravity. It solidifies and the mould is then opened to take out the cast. As a result of much lower pressures involved, the required clamping force and tool dimensions are decreased. Therefore, cost-effective production quantities can be as low as 500 to 1000. However, it is not possible to produce sections much thinner than about 4 mm thick due to the lower operating pressure. In addition, the surface finish is not as good as pressure die-castings for the same reason. Such process can be used with a range of aluminum, copper and magnesium alloys, but it is not suitable for zinc. The moulds are usually made from machined casted iron.

Centrifugal Methods

In general, we can use centrifugal action to cast products in two ways. It can either be used to force the metal into the die by simply rotating the whole assembly, or it can be used to produce hollow products in metals and plastics. Metal pipes are produced by pouring the metal onto a rotating mould. The centrifugal effect causes the metal to flow outward resulting in the formation of a hollow cylinder. Hollow plastic products can be formed from PVC paste in a similar way. A measured quantity is placed in the die cavity and the assembly is then spun horizontally and vertically (Figure 2.7). The mould is heated which causes the plastic to fuse. Once cooled, the die is split open to withdraw the completed casting. Typical examples of products formed this way are footballs and moulded furniture.



Split mould
Figure 2.7

Rotational Casting

(III) Injection Moulding of Plastics

In general, the most common process employed by manufacturers for plastic product is injection moulding (Figure 2.8). The main reason for this is that the dimensions and shapes can be accurately controlled and the process is very reliable in production. A schematic illustration of this process is shown in Figure 2.9.

Figure 2.8 Injection Moulding Machine

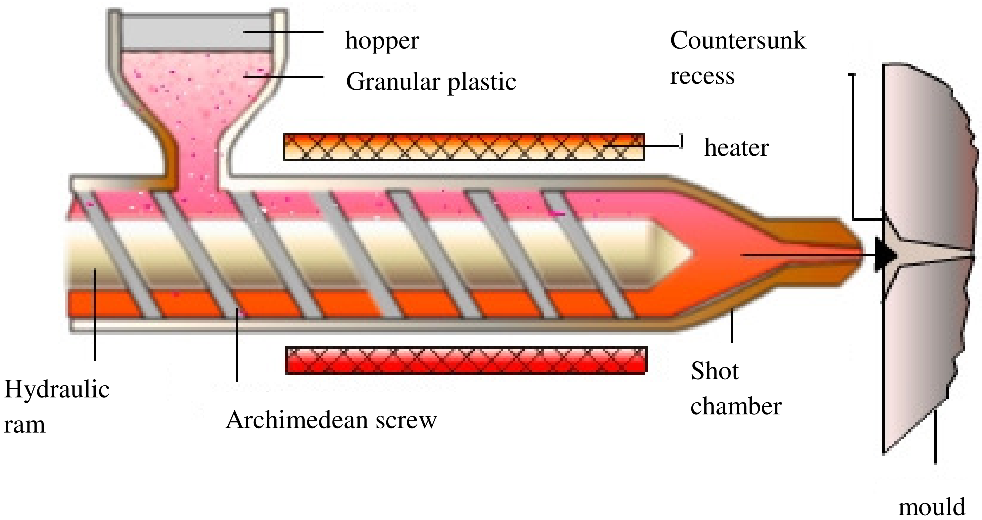


Figure 2.9 Schematic illustration of the injection moulding process

In the beginning, thermoplastic beans are fed from the hopper and forced through the heating units by an Archimedean screw (Figure 2.10). The screw stops rotating and a plunger forces the plastic paste into the mould when sufficient amount has collected in the shot chamber. The mould can be opened and the product removed when they cooled down (Figure 2.11).

Figure 2.10a Different plastic beans used for injection moulding

Figure 2.10b Hopper of an injection moulding machine

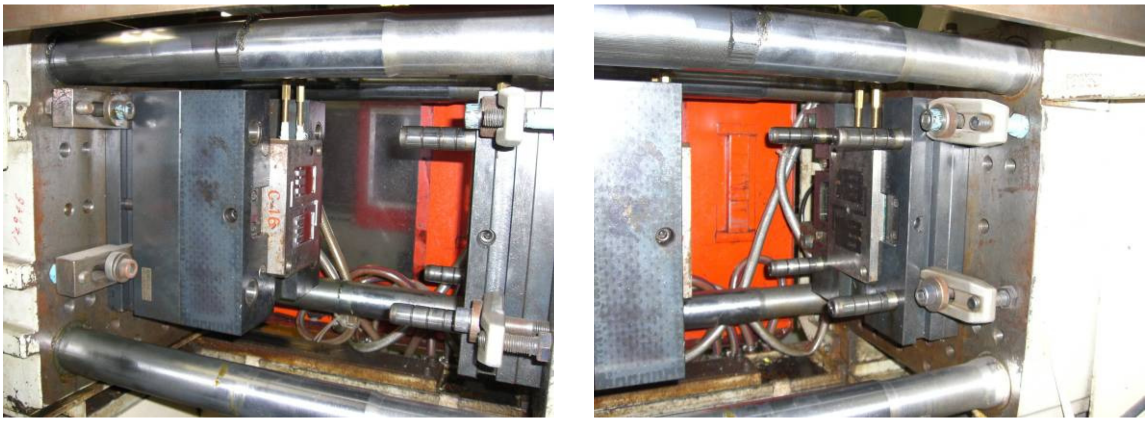


Figure 2.11a Opened mould

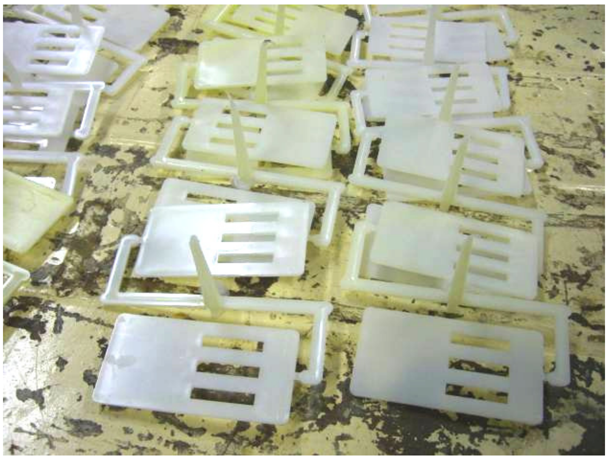


Figure 2.11b Removed products

Injection moulding can be used to produce both extremely small and large products. One of the smallest example may be a gearwheel used to drive the seconds hand of a wrist watch which has a diameter less than 2 mm. Among the largest, the garbage container and the hull of a training canoe that are all made using injection moulding (Figure 2.12).

Figure 2.12 Canoe made by injection moulding

Furthermore, multi-component injection mouldings are commonly found in our daily life. For examples, the ball joints and the push-button pads that used in telephones set. The push-button pads are made with a twin mould. The numbers or letterings are injected in a bold coloured plastic in the first mould. The buttons and the remainder of the pad are then injected round them in the second mould. Similarly, ball joints can be produced by injecting plastic round a steel or plastic ball.

2.1.2 Forming Techniques

Forming techniques change the shape of materials in a controlled manner. It is achieved by which the material is forced into the required position.

Putting the material to a correct shape is often the initial stage of the forming process. Some materials will not stay in position unless they are being held for a period of time. Thermoplastics will need to be held until they are cooled sufficiently. Forming of laminated wood depends on the time which the glue dries, and moulding of GRP depends on chemical reaction which the resin sets.

(I) Bending Operations and Using Presses

Bending Sheet and Tubing

Figure 2.13 shows a pair of bookends made by bending. This technique can be applied to thermoplastics where the bending area (along the line to be bended) is required to be heated by a strip heater (Figure 2.14).

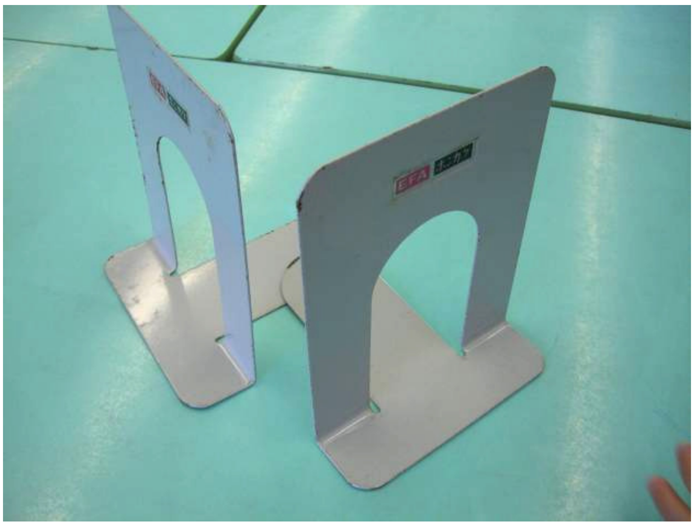


Figure 2.13 Pressed Bookends

Figure 2.14 Strip Heater

A straight edge can be bended without deformation, however outer side of the edge will stretch and the inner side of the edge will buckle (Figure 2.15).

Figure 2.15 Material being stretch and compressed during bended

Figure 2.16 Hand-operated bending tool with circular face and roller control

Similar problems occurred when a bend is required in tubing. Some bends are made by flattening the tube before bended in order to avoid the uneven thickness of the tube after bended. However this is not always aesthetically acceptable, and therefore sometimes the tube will be filled with sand to avoid this happened.

Presses

Presswork is generally referred to the process of pressing metals. However plastics and wood can also be formed by using presses. Metals are pressed at room temperature, and the metal sheet should be annealed in order to ensure ductility. Similarly, glass must be heated before it can be pressed. Both thermoplastic and thermosetting plastics are supplied in sheet form. Thermoplastics such as polythene, polypropylene, nylon reinforced with glass or carbon fibre mat must be soften by heated prior to the press process begins. The press should remain in the closed position until the material has cooled down. Thermosetting plastics are being pressed with heated tools.

Figure 2.17 shows the tooling required for making a V-bend using a press. There are two key components, the punch and the die. For economic reason, both tools should be manufactured from a very hard material, which are resistant to wear and impact loads. The punch is normally placed in a standard punch holder, and the die is placed in a standard bolster. Apart from securing the tools, the punch holder and the bolster also support the punch and die to withstand the impact forces.

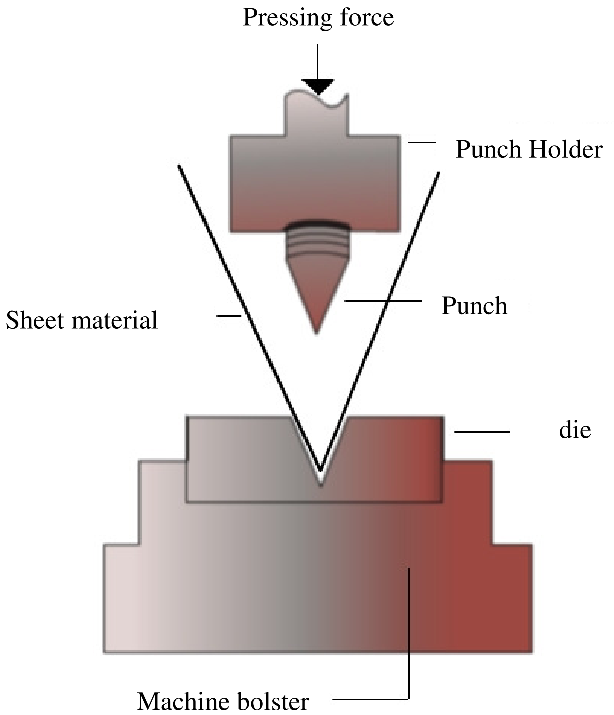


Figure 2.17 Tooling for forming V-bends

In schools, we usually bend the material by using a toggle mechanism or hand-operated presses. However industrial presses are often power-operated. Figure 2.18 shows typical power presses as used in industry.

Figure 2.18 Industrial Power Press

During the growth of mass production, the advantages of using pressed metal components have been exploited in various industries. Many consumer products are made by pressed components. The following factors should be considered when handling sheet metals in press operation:

- Blanking - cutting the original shape
- Piercing - the punching of small holes

- Trimming - the removal of surplus material after pressing

The tooling required for blanking or piercing is indicated in Figure 2.19. In the blanking process, the shape and size of the punch is equal the component to be produced, and the die has a corresponding aperture to the punch. There are two important additions when comparing with bending process: a stripper plate and the guide bars are being used. The stripper plate is used to allow the remaining sheet after blanking to leave the place when the punch is withdrawn,. The guide bars control the feeding of the sheet in order to ensure sufficient space between blanks. Otherwise the tools will become blurred and the process will cause more wastage of materials.

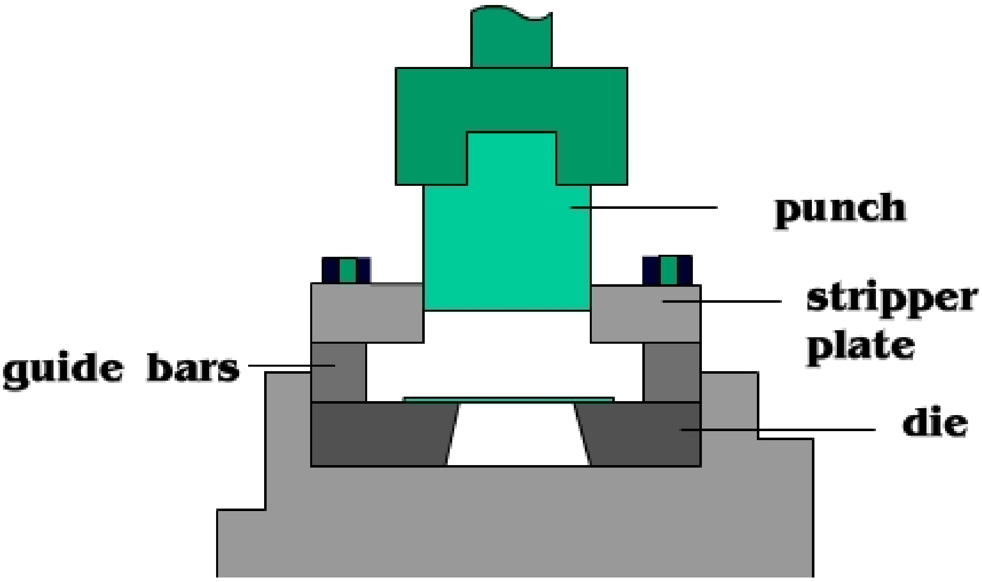


Figure 2.19 Tooling requirements for blanking or piercing

Figure 2.20a

Figure 2.20b

Figure 2.20a is an industrial blanking and piercing machine and Figure 2.20b shows its product.

Producing a washer requires blanking and piercing operations, and these processes are normally combined in a progression tool as shown in Figure 2.21. A hole is initially pierced in the first place, and then followed by the circular shape produced by the blanking punch.

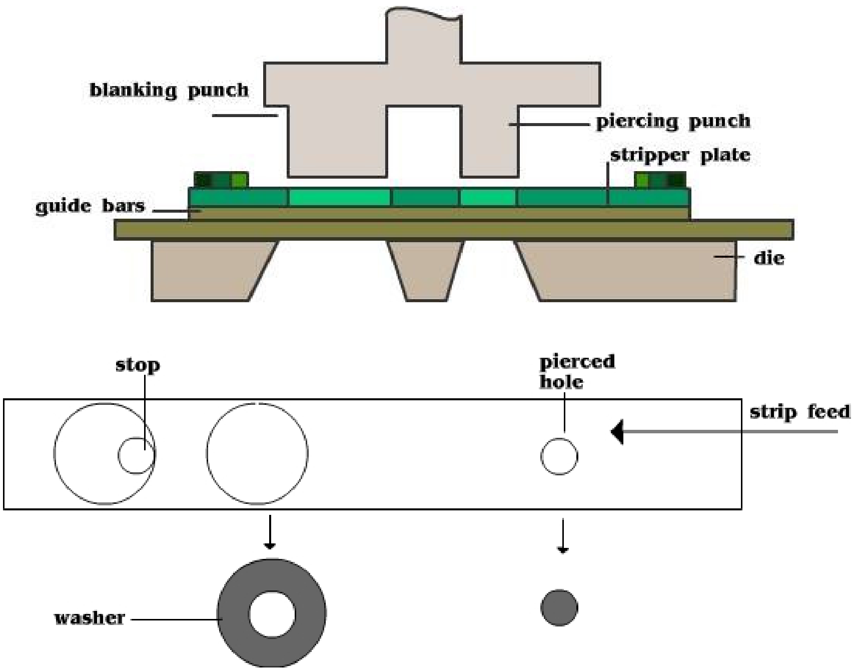


Figure 2.21 Progression tool for manufacturing

The cost for each component is associated with the total amount of sheet metal consumed, which includes the scrap remained after blanking. Figure 2.22 shows an example that designers and engineers aim to fit components within a standard sheet in order to minimize wastage.

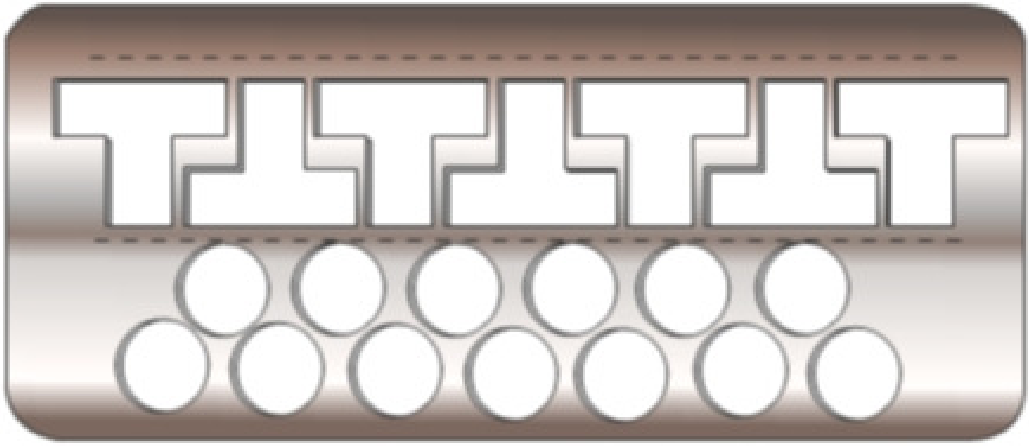


Figure 2.22 Economy in blanking operations

Deep Drawing

This process is applied in the production of 3-D curved pressings, such as the cover of an electrical motor. Figure 2.23 shows the tooling requirements for deep drawing. The depth which can be drawn in a single stroke depends on many factors, including the kind of sheet material used, its tensile strength and the tool design. Greater depths can be obtained by *redrawing operations*, but it may be necessary to anneal the material first.

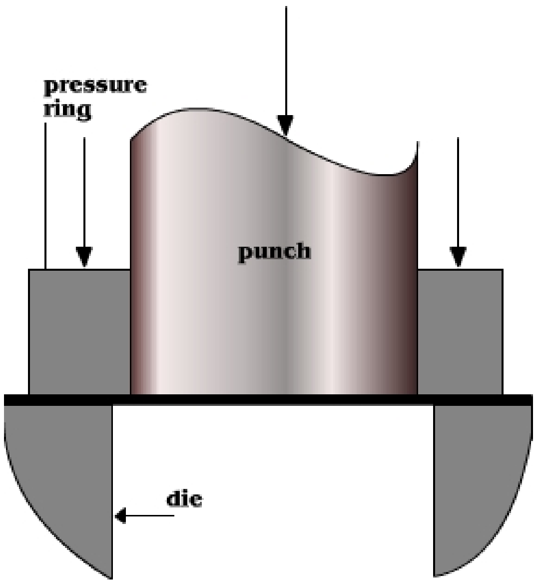


Figure 2.23 Deep Drawing

The following pictures present various steel components made by blanking, piercing and/or deep drawing:

Figure 2.24 Pressed steel components

(II) Vacuum Forming and Blow-moulding

Vacuum forming and blow-moulding are manufacturing processes that are closely related to sheet forming techniques as described in the previous sections. These two processes rely on the use of heat and pressure to form the sheet material into shape. In vacuum forming, this is done by sucking the sheet material onto a former (Figure 2.25).

Figure 2.25a Vacuum former used at school

Figure 2.25b Vacuum-formed product

In blow-moulding, material is forced against the mould by increasing the pressure in the blow-moulding machine. When making bottles, a liquid glass gob is dropped into a preliminary (or parison) mould. The neck is formed with a per-formed thick-walled body. The parison is then transferred to a finishing mould where the final shape is blown. This process was adapted to form thermoplastic bottles from a cylindrical-extruded mould. This technique is illustrated in Figure 2.26.

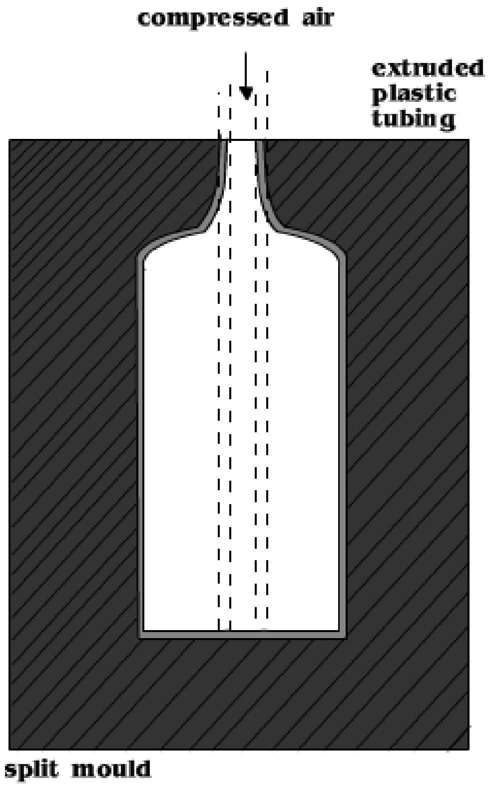


Figure 2.26 Blow-moulding

The blow-moulding process is widely used in manufacturing of a wide range of plastic bottles and containers (Please refer to the Case Study of PET Bottle). One of the advantages of this process is that the limitations to making different shapes are minimal when compared with metal pressings.

The cost for tooling of these two processes is much lower than that of presswork, and it is possible to achieve a higher quality finishing. However, one disadvantage is that the pressure required to deform the material cannot be too high. Thus the materials which can be used and the shapes that can be formed are limited.

(III) Laminating and Steam-bending Timber

Timber can only be bent in one direction because of its grain structure, and can only be bent at right angles to the grain flow. Bending along the grain will cause the timber to split even at a low angle of curvature. Consequently, laminated timber is best bent across the grain, as shown in Figure 2.27.

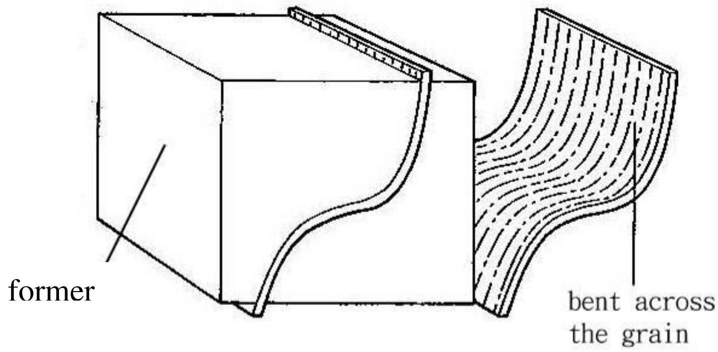


Figure 2.27 Laminating Timber

Strength properties have to be considered in lamination. For example, the back of a chair is laminated as shown in Figure 2.28, so that stresses generated along the grain can support the loading when a user sits down and leans back on it.

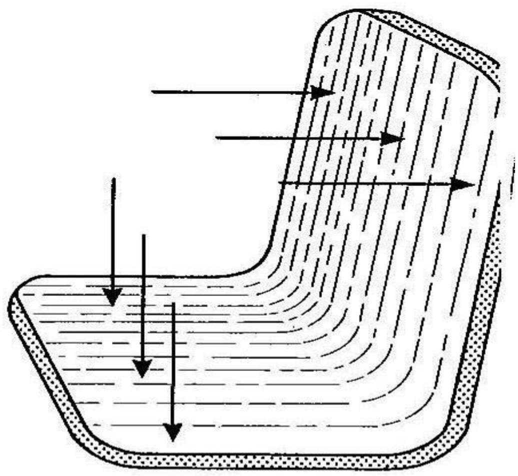


Figure 2.28 Laminated Chair Back

The preparation for bending a large number of timber strips, and the manufacture of the former will take a long time. It would be more efficient if timber of the required size could be bent together. This is done by steam-bending - firstly the wood is being softened by steam before bending. The bending strength of wood is dependent on its moisture content. If the timber is held in the bent position, it will tend to settle to this shape as it dries. However, the timber is likely to twist when drying and may result to an inaccurate position.

(IV) Forging

Strong metal components and decorative metal work are usually made by forging. Hot forging of copper alloys and cold forging of steels are major applications.

Hot Forging

Forming steel by hammering it against an anvil is known as open-die forging. To achieve a quality desired shape required skillful workers. Therefore shaped dies are being used in the industry to replace skilled craftsmen for economical purposes. Hot metal is placed in the die and then being forged by a power driven hammer. This process is known as closed die or drop forging. Crankshafts and spanners which require great strength are made by this process.

For some components, it is necessary to use a series of dies in order to achieve the required form – each stage forged the work closer to its final dimensions. Figure 2.29 shows the typically tooling required for a close-die forging operation.

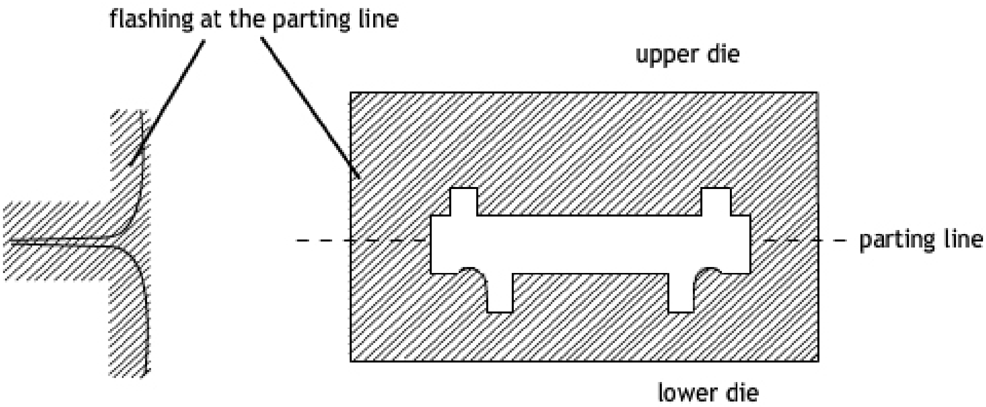


Figure 2.29 Closed-die Forging

The significant advantage of forged components is the improvement in their grain structure which result from hot working.

Cold Working

Figure 2.30 Cold-worked Bolts and Screws

Many commonly used components are assembly products made by the cold working of steel. For examples, rivets, bolts and screws are made at low cost and with good working properties

(Figure 2.30). There are two important processes:

Cold-roll Forming

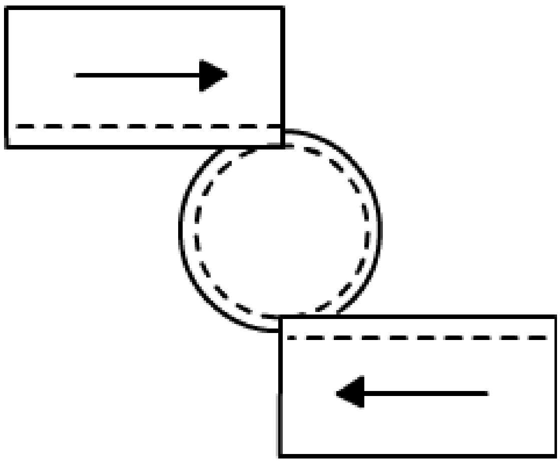


Figure 2.31 Cold-roll Forming

Figure 2.31 shows the basic cold rolling technique. This is used to put threads, splines, serrations, knurling and other grooves and indentations onto steel or other metals. The component to be formed is mounted between two centres and the tools are then moved towards each other. Cold-roll forming produce much stronger teeth than machining because the grain fibres followed the thread profile rather than being cut (Figure 2.32). The surface is also work-hardened in a rolled thread to improve wear resistance.

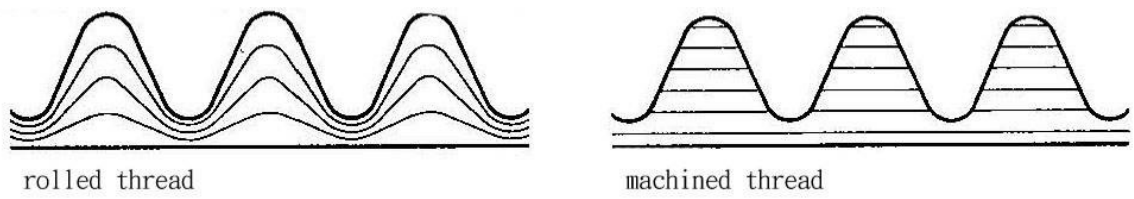


Figure 2.32 Grain flow in rolled and machined threads

Cold Heading

Cold heading machines are used to produce the heads of rivet, screws, bolts and similar components. Material is fed to the machine from a coil, sheared to length and then transferred to the die, followed by a punch to produce the required head form. A series of punches are employed for complicated head forms, and more than one blow is needed for hard alloy steels. Figure 2.33 indicates the tooling requirements for the cold heading process.

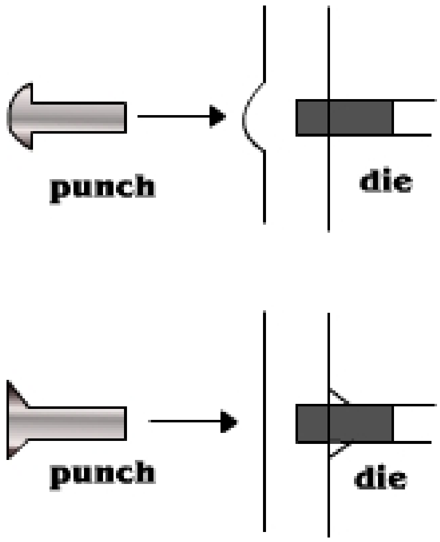


Figure 2.33 Cold Heading

(V) Compression Moulding of Plastics

Compression moulding is used to form thermosetting plastics such as phenol-formaldehyde and urea-formaldehyde. Usually, a measured amount of plastic powder is placed into the mould cavity where it is heated and plasticised (Figure 2.34). It is then compressed into the required form by a punch which is also pre-heated. Power sockets, knobs and dishes which resist high temperature changes are made by this process (Figure 2.35). Generally, the properties and finish are good by using this method of production.

Figure 2.34 Thermosetting plastic powder

Figure 2.35 Compression moulded dishes

H I G H L I G H T

Tool Design

The basic layout of the tools for pressing ceramic powders, powder metallurgy and the compression moulding of plastics are similar (Figure 2.36). They have the following aspects in common:

- a female mould or die which contains the measured amount of plastic powder (Figure 2.37a)
- a punch compresses the powder and produces the required form (Figure 2.37b)
- an ejector (sometimes it may not be necessary for thermosetting plastics if contraction happened after cooling)

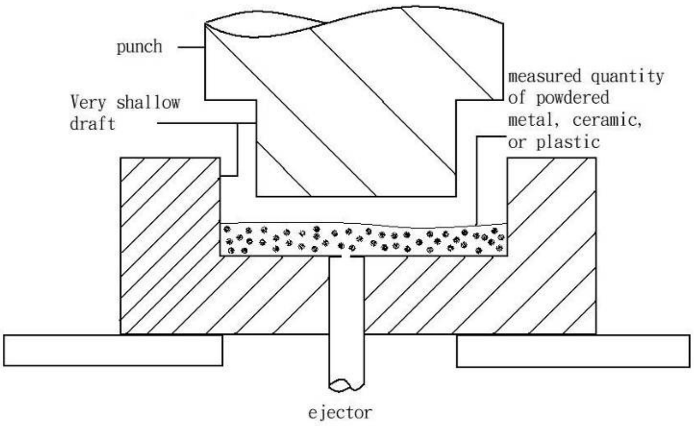


Figure 2.36 Tools requirements for compression moulding

Figure 2.37 a mould

Figure 2.37b Punch

(VI) Extruded, Drawn and Rolled Sections

Extrusion

Figure 2.38 shows the basic extrusion process. One of the common extruded products is tubing, for example, PVC tube.

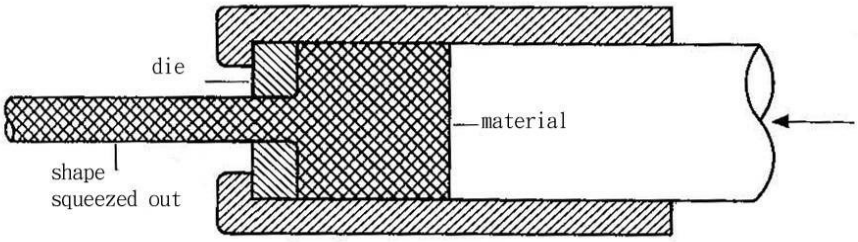


Figure 2.38 Basic Extrusion Process

Material, either plastic or metal, is forced through a die with the same required cross-sectional area. It is similar to a toothpaste when being squeezed from a toothpaste tube (Figure 2.40). Metal extrusions can be produced by either hot or cold working. Aluminum and copper alloys are most commonly used metals. The extrusion of thermoplastics basically follows the same process except that temperature control is essential. The newly formed plastic extrusion is usually cooled by water (Figure 2.41).

Figure 2.39 Extrusion Machine

Figure 2.40 Die

Figure 2.41 Water bath for cooling

Blended powders, whether they are purely ceramics, metals or mixtures, can be easily be extruded as well. Composites materials can also be extruded. Plastic coated wire is produced by feeding a cold drawn copper wire through the centre of the die while thin-walled plastic tubing is being extruded.

Extrusion of metal will result in an even grain structure if it passes through the die at an uneven speed. However, the metal will tend to flow faster in the middle because of friction. Plastics extrusions need to be uniformly produced. Differences in the flow of polymers can lead to differential cooling and warping of the product. Figure 2.42 shows the shapes (parts of an aluminum ladder) that could easily be produced by extrusion. In designing these shapes, designers and engineers have tried to keep the sections as uniform as possible. Symmetrical sections are generally easier to produce (Figure 2.43).

Figure 2.42 Cross-sections of shapes that are easily being extruded.

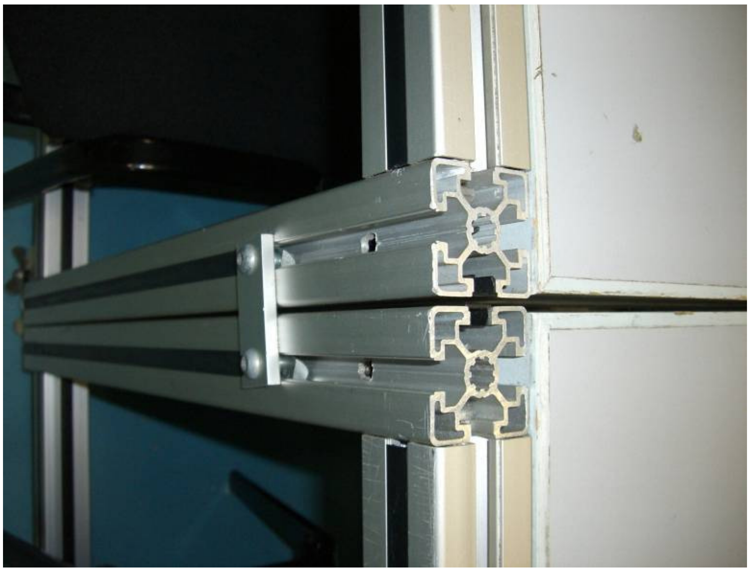


Figure 2.43 Symmetrical section

Drawing

Rods, wires and metal tubing are generally produced by drawing the material through a series of dies of gradually reducing diameter. This is shown schematically in the following figure:

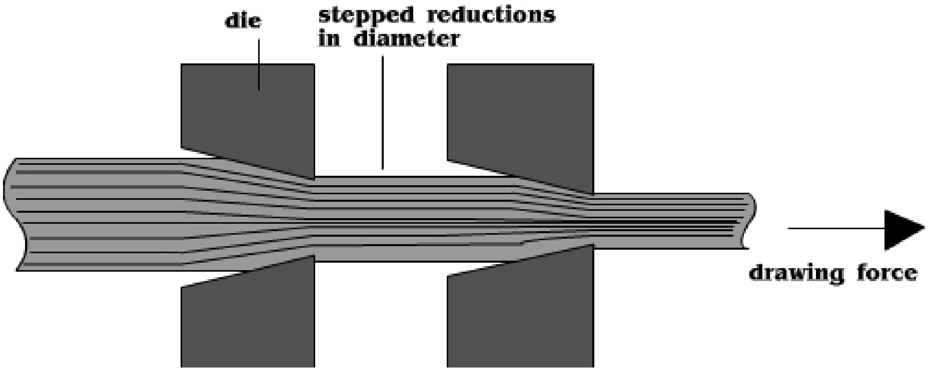


Figure 2.44 Basic principle of drawing

The amount by which the diameter can be reduced at each stage is limited by the force which is exerted in pulling the material and its ductility. Material will tend to work-harden as it is cold worked. If tubing is being produced then the initial section from which the tubing is drawn would be formed by the extrusion process. For example, copper tubing is produced by extruding a thick heated copper piece and cold drawing to reach the necessary size. It is then annealed before the final drawing operation is carried out.

Rolled Sections

Some of the extruded shapes can be formed progressively from sheet materials using a series of rollers. Metals such as steels, aluminum and copper alloys can all be formed by this technique, and it is also possible to use the metals which have been pre-coated with zinc or plastic. Figure 2.45 shows an example of rolled sheet metal.

Figure 2.45 Rolled Sheet Metal

Roll-formed sections are generally thinner than extrusions and usually much cheaper. Rolled sections are also available in sheet steel. As steel is cheaper than aluminium or copper alloys, rolled steel sections should always be considered.

2.1.3 Machining (Material Removal) Techniques

When shapes are produced by removing material from a solid mass, this is usually refers as machining technique. In many cases, it may be possible to use or recycle the removed material. Problems associated with designing for a machining technique are considered in several areas:

- How to remove the material?
- How to hold the workpiece?
- How to manipulate the (cutting) tool?
- How to provide the required power?

These problems are related to the design of jigs, fixtures and machines. It is essential for designers and engineers to develop an awareness of the capabilities of existing components, tools and machines. The methods available for removing materials can be categorised into four groups: mechanical, electrical, chemical and thermal methods. Mechanical methods are the most commonly used approach. Electrical methods are applied in working with hard materials and chemical methods are employed to deal with large components. Thermal methods are used to cut shapes from metals and plastics, and all of them are important production processes.

(I) Mechanical Methods

Wedge-shaped Cutting Tools

The wedge-shaped cutting tool is the basic design for most hand tools; for example, chisels, or planes (Figure 2.46).

Figure 2.46 Plane Blade

Form Tools

Under some circumstances, it is possible to use a form tool to cut the required shape, but this operation requires large cutting force. It is only possible to cut soft materials or use very fine feeds with a long cut profile. Figure 2.47 shows a variety of situation where form tools can be employed:

(a)

(b)

(c)

(d)

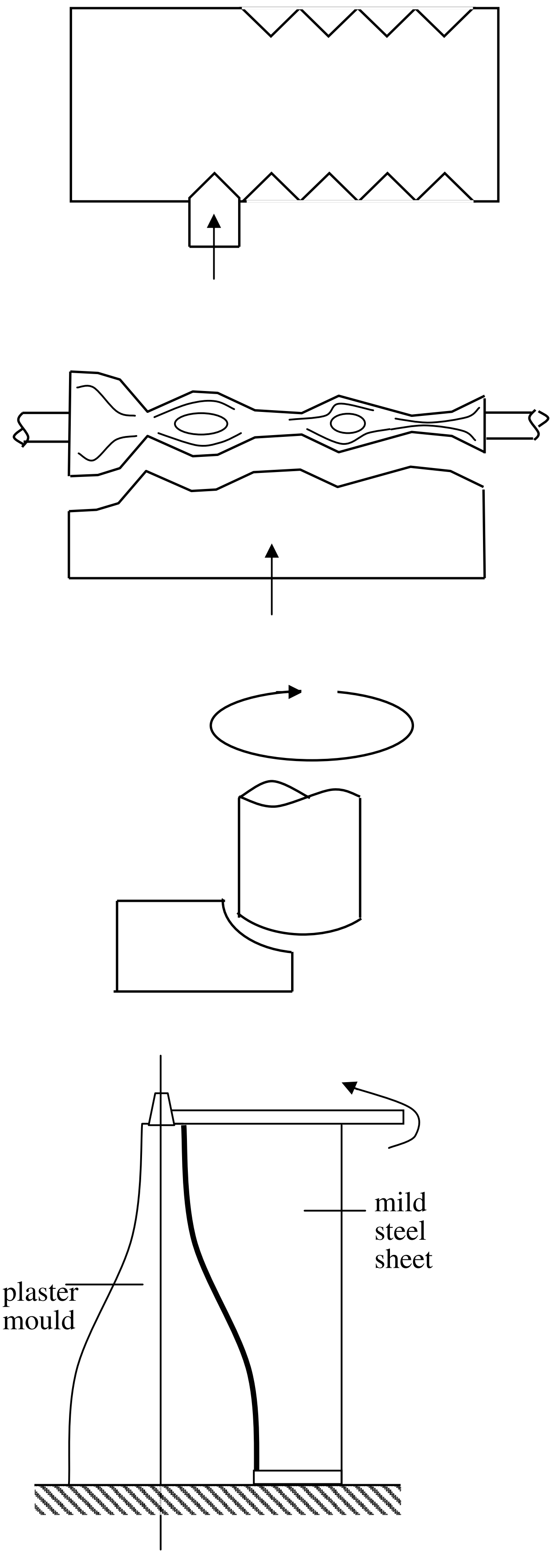


Figure 2.47 Using form tools to cut different materials

Figure .2.47:

(a) screw-threading tool
(b) industrial wood turning tool
(c) form tool for cutting hemispherical end
(d) plaster strickling

Ultrasonic Machining

In addition to grinding, another way of cutting materials using abrasive particles is ultrasonic machining (Figure 2.48). A high frequency mechanical oscillation is produced using an electromechanical transducer. A tool of the required shape is fixed to the mechanical amplifier so that it vibrates in a direction perpendicular to the workpiece surface. Abrasive particles in slurry are pumped under the tool and impacted into the surface which is being gradually removed.

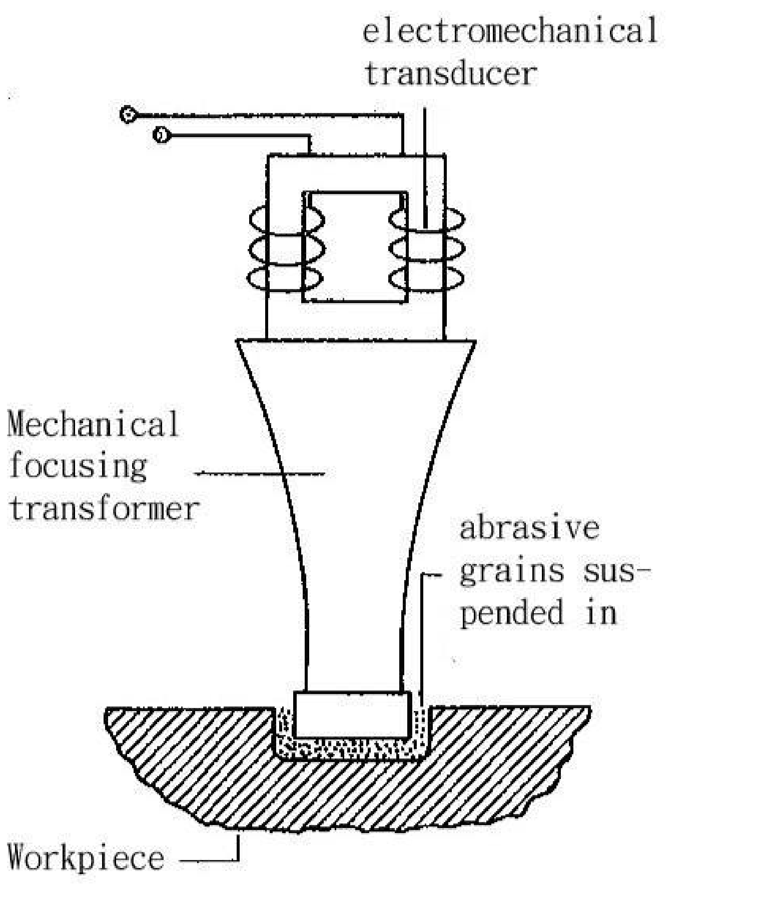


Figure 2.48 Ultrasonic Machining

Ultrasonic machining can be used on most material, and is particularly useful for working on hard tool steels that are used for extrusion, press and forge tools. It can also be used to cut brittle materials such as glass, ceramics and precious stones. Ultrasonic machining can give an excellent surface finish and dimensional accuracy of ±0.005 mm, and the maximum penetration speed is around 20 mm per minute.

(II) Electrical Methods

There are two primary electrical machining methods:
- Electrical discharge machining (or spark erosion)
- Electrochemical machining

Electrical Discharge Machining (EDM)

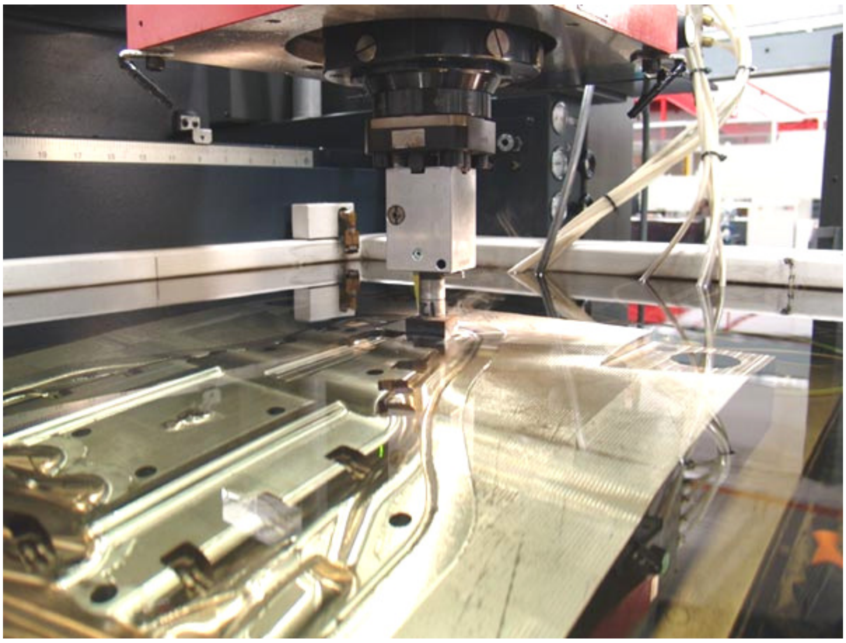


Figure 2.49 Electrical Discharge Machining

Electrical discharge machining works as a result of eroding effect of arcs, i.e. sparks, formed between the electrode and the workpiece (Figure 2.50). The arcs are generated at voltages from 20 to 500 V and frequencies from 1000 to 2000 Hz. The whole workpiece is immersed in a dielectric liquid such as paraffin, so that the arc discharges are quenched rapidly. Electrodes are usually made with the required shape – usually from brass. The following figure shows a typical arrangement:

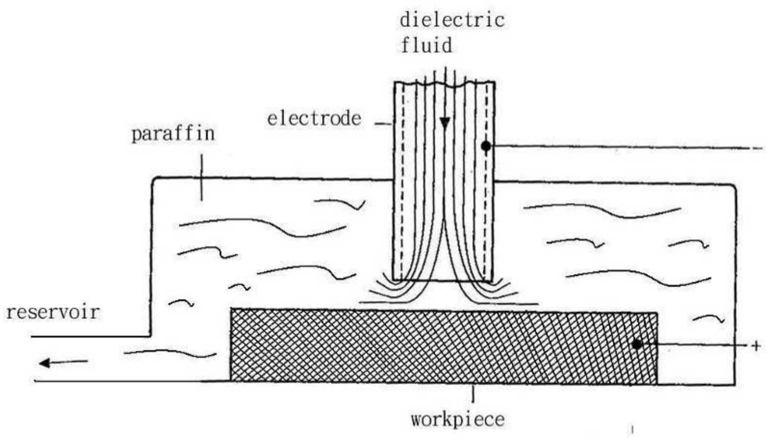


Figure 2.50

The advantage of electrical discharge method is its ability to machine very hard materials such as sintered carbides and hardened tool steels. It is an ideal way to produce holes in drawing and extruding dies, nozzles and similar components made from very hard and wear resisting materials. However, it can only be applied to conductor of electricity.

Electrochemical Machining

Electrochemical machining is based on electrolytic action. A current is passed from a copper cathode to the workpiece through an electrolyte – normally salt water. The voltage is kept low enough to prevent arcs from occurring, and consequently the machining action depends on the metal dissolving at the anode. The arrangement of an electrochemical machining tool is similar to that of an electrical discharge machine. The electrode is made of copper and moulded into shape required. The process has the same advantages as electrical discharge machining, but can give a finer surface finish. Moreover, the electrode will not be worn away by the electrolytic action. However, very high power levels have to be employed to achieve acceptable rates of metal removal.

(III) Chemical Methods

In the compulsory part, you may already be familiar with etching processes in one form or another, such as production of prints or circuit boards. This technique depends on masking those areas which are needed and exposing the remaining surface to chemical reaction. This approach can be particularly useful in manufacturing because of its ability to deal with large areas and with both sides of a component simultaneously. Besides, there is no tooling cost. It was originally developed in aircraft industry using aluminum alloys. Different etchant and working temperature are required for each material, but a removal rate of about 1 mm depth per hour is generally achievable.

(IV) Thermal Methods

Thermal methods of removing material depend on melting or vaporising material. There are two common types of process:

- Cutting with high energy heat sources
- Cutting with hot wires

High Energy Heat Sources

There are two primary heat sources which are used for cutting materials: a mixture of oxygen and acetylene gases and lasers. Both of them are used to cut shapes from flat sheet or plate.

Oxy-acetylene cutting is used on steels based on exothermic reaction that occurs between steel and pure oxygen at above 875°C (which is the ignition temperature of iron) (Figure 2.51). This process can be used on steel plate from 6 mm to 150 mm thick.

Figure 2.51 Oxy-acetylene Cutting

When laser is employed to cut steels, a jet of pure oxygen is used to blow away the molten material. The heat generated by the exothermic reaction will help the laser to heat the material and the jet action helps to blow the oxide from the cut. Moreover, lasers are also used to cut other materials such as nonferrous metals, plastics, gasket materials and wood. The following figure shows a laser engraver / cutter used in school:

Figure 2.52 Laser Engraver

Hot-wire Cutting

Plastic materials such as polystyrene can be cut effectively by using a hot wire. It is heated by a low voltage supply and the current is limited to prevent the temperature of the wire from rising towards its melting point. If operates correctly, the hot wire will leave a very smooth cut surface. Once again, this process is primarily used to cut shapes from flat sheets.

2.1.4 Fabrication (Joining) Techniques

Previous sections of this chapter concerned about the manufacture of a single piece of component. For some reasons, it would be better to produce a number of parts and then assemble together. This is known as fabrication or joining. The reasons why fabrication is effective are listed as below:

- a combination of materials with different properties are required;
- the mould tools for injection moulding or casting can be significantly simplified;
- substantial weight savings are possible in large castings because there is a limit on the minimum section size which will allow the molten metal to flow;
- thickness, widths or lengths can be built up if the required size of material is not available
- much of the material removal associated with a machining technique can be avoided; and
- standard components can be incorporated into the design.

Whatever the reasons for employing a fabrication technique, the particular difficulties lie in the joining of parts. Basically, there are three approaches to join these components:

- Mechanical joints
- Thermal methods
- Chemical methods (or adhesives)

(I) Mechanical Joints

The classical methods of joining materials mechanically were developed by craftsmen many centuries ago. Woodworkers developed a large variety of joint configurations for use in different situations – some would allow movement as wood expands and contracts when humidity changes, some of them are being combined with adhesives, and others incorporate with mechanical wedge.

From a manufacturer's point of view, the key requirements are to ensure that the joints should have appropriate mechanical properties such as strength and stiffness, and can be produced using available tools.

Early metalworkers developed riveting methods and forge welding techniques, which also adopted some of the joint configurations from woodworkers' practice. Most of the modern mechanical fasteners, as you have learned in Topic 1.1, require only the production of holes or grooves in metal, but it is sometimes necessary to machine flats for bolts or rivet heads. Mechanical fasteners are under continuous development and improved designs are constantly coming onto the market, particularly those designed for knock-down furniture and self-assembly products. The major advantage of mechanical fasteners is their independence of materials being joined. Parts can be produced from metal, plastic, wood or ceramic and the joining process does not require any mixing of materials or adhesion between surfaces.

(II) Thermal Methods

Soldering, brazing and welding are thermal joining methods which can produce joints directly between components without any fasteners such as springs, screws or clips.

Soldering

The term soldering should only be used when the filler material melts below 450 °C. The molten filler metal is drawn into the gaps between materials by capillary action. The heat for soldering can be made from gas flame or soldering iron, as the temperatures needed are quite low.

Brazing

Brazing is similar in operation to soldering and, with appropriate filler materials, it can be used on nearly all metals and many ceramics. It can also be used on complex composite materials produced by sintering powders. The melting temperature (usually above 450 °C) of filler materials is much higher than those used in soldering. It has the advantage that the filler alloys are of much higher strength.

Welding

Oxyacetylene Welding
This is one of the commonly used techniques in schools and is typically be used to produce single pass welds in steel sheet of 0.5 to 4 mm thickness. The following figure shows the equipment needed:

Figure 2.53a Welding Torch

Figure 2.53b Compressed Gas Cylinders

Electric Arc Welding

This technique uses a metal electrode with a flux covering. The arc is struck between the electrode and the workpiece, and it generates a very intense heat source as shown in Figure 2.54.

Figure 2.54 Electric Arc Welding

The metal electrode melts and droplets are transferred across the welding arc to help forming the weld bead (Figure 2.55). The flux is specially formulated to generate a gas shield to protect the molten weld pool and a glassy slag which solidifies over the weld bead, protecting it whilst cooling. The slag can be chipped away when it is cold.

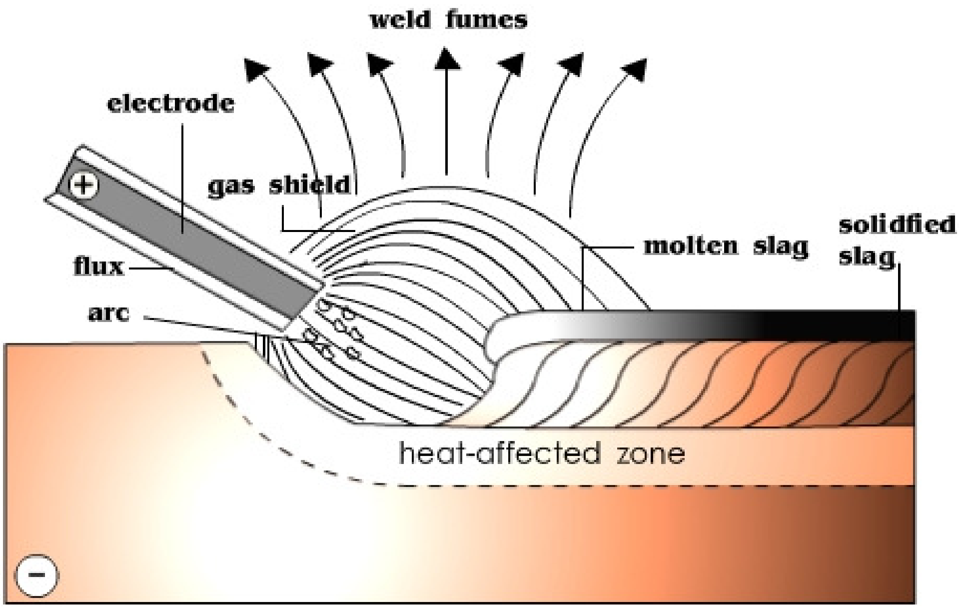


Figure 2.55 Schematic Illustration of Electric Arc Welding

Resistance Welding

Although less commonly available in schools, resistance welding processes are vital in industry. The commonest form is resistance spot welding as shown in the following figure:

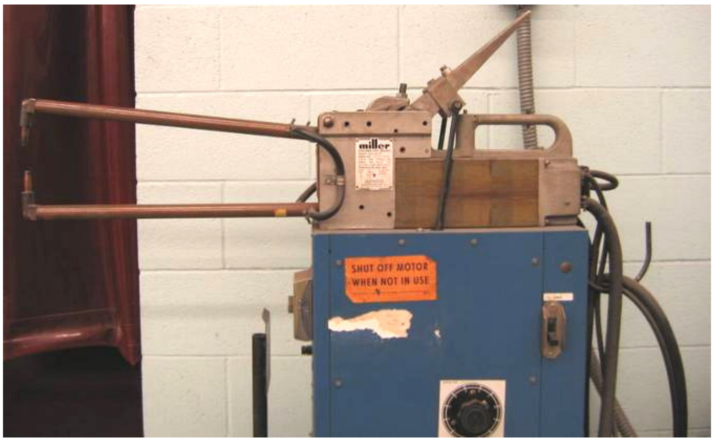


Figure 2.56 Resistance Spot Welder

The sheet materials are clamped between copper electrodes and, when a current is passed, heat is generated at the interface (Figure 2.57). The electricity takes the form of low voltage, high current pulse of short duration. The pressure is held on after the current pulse in order to forge the sheets together as the weld solidifies. The outcome is a weld nugget, which is slightly wider than the electrode tip diameter and surface indentation where the electrode pressure was applied. The process is most commonly used for welding sheet steel, particularly for the production of vehicles and washing machines. The difficulty in getting resistance spot welding to work effectively on aluminium sheet is one of the primary reasons why aluminium vehicles are not mass produced. In order to function well, however, very high currents are required, however the electrodes will wear rapidly too.

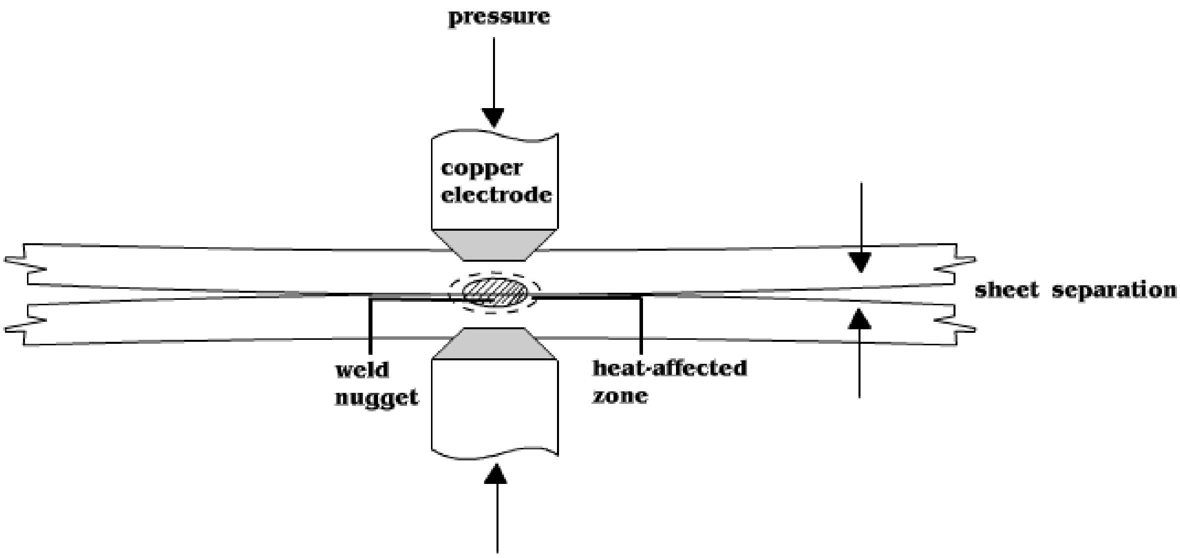


Figure 2.57 Resistance spot welding

Forge Welding

This is the oldest welding process and for several thousand years it was the only process. It was used by metalworkers for joining iron parts. The parts are heated to over 1000 °C, and at this temperature the metal is in a softened state and the surface oxides are in liquid form. The parts are then hammered together forcing out the molten oxides and bringing them into suitably close contact to form bonding. The parts can, of course, be rolled, squeezed or otherwise brought together and using hammer blows is not essential.

Friction Welding

This is a modern development of forge welding. One of the components to be joined is held stationary and the other is rotated in contact with it. The heat generated raises the temperature in the section to be joined, and when the temperature is high enough, the components are forced together. The rotary action is a very efficient way of removing the oxides from the surfaces and also flattening out any irregularities. The result is that the surfaces are brought closely together everywhere and a reliable joint is formed. As it is a solid phase process, welds can be produced between both similar and non-similar metals, for example, copper to aluminum. Friction welding has become a vital joining process in industry, and is used in manufacturing twist drills to join the high-speed steel ends to the softer carbon steel shanks.

(III) Chemical Methods

In ancient times, various adhesives were used widely to join things. Natural adhesives are typified by glues, waxes, casein gums, carbohydrates such as starch, rubber and its derivatives. Generally, these adhesives are nontoxic substances and hence release few hazards in manufacturing the joints or from the final product. In contrast, their modern synthetic counterparts tend to have toxic substances and require care when using, although they are usually safe when cured. Most thermoplastic materials can be welded, but the only method available for thermosetting is adhesive bonding.

Modern adhesives are characterised in a number of ways: as structural or nonstructural, for interior or exterior use and as thermoplastic or thermosetting. The eight groups shown in Table 2.1 cover those in general use.

Type	Curing Method	Notes
1. anaerobic acrylic resins	action of a catalyst out of contact with the air	One type, cyanoacrylates cure by reacting with moisture on the surfaces.
2. modified phenolic resins	application of heat and pressure	These resins provided the first successful adhesives for metal-metal, metal-wood and metal-plastic joints. The basic phenol formaldehyde resin is typically mixed with nylon, neoprene or polyvinyl butyrate. These are thermosetting
3. epoxy based adhesives	action of a hardening compound on the epoxy resin, although some one-part epoxy resins are cured by heat	Generally
4. PVA adhesives	removal of water from the emulsion	Used to bond porous materials such as wood or concrete. PVA is a thermoplastic material.
5. hot melt glue	action of heat	Special polymers used to produce quick joints for lightly loaded structures
6. polyurethane adhesives	reaction between two compounds	Fast acting.
7. modified PVC dispersions	action of heat	
8. rubber based adhesives	evaporation of a solvent	

Table 2.1 Common Adhesive Groups

The adhesive is applied to cleaned and prepared surfaces and the adhesive must then be cured. The components must be held in place until the adhesive has gained sufficient strength. The process may take a few minutes or up to a day if at room temperature. Increasing the temperature through infrared panels, ovens or heating pads will reduce the curing time significantly. Accelerators can also be used to reduce curing times, but there will be some loss of strength.

Adhesives have some specific advantages and disadvantages when comparing with other joining methods. The advantages are:

- the ability to bond non-similar materials and composites;
- a separate sealing operation can sometimes be avoided; and
- there is reduced risk of galvanic corrosion between dissimilar metals because the adhesive joint will act as insulator.

Amongst the disadvantages are:

- joints must be held firmly during curing;

- strength tends to fall off sharply between 80 to 100 °C; and
- adhesives are often expensive and limited shelf life.

H I G H L I G H T

Selection of a Joining Methods

There are a number of factors which may influence the selection of the best joining method, but the following are the most significant:
(a) the degree of permanency required;
(b) the necessary strength of the joint;
(c) the type of (static or dynamic) loading;
(d) the effect of heat on the materials involved,
(e) the appearance of the product round the joint; and
(f) the environment, particularly potential corrosion sites.

S T O P A N D T H I N K

(a) The following pictures show some commonly found facilities in a playground. In each case, please describe the manufacturing process and technique which are best fit to the application and illustrate your ideas with sketches and notes.

(b) Please find four more facilities commonly found in your neighborhood and illustrate the manufacturing processes and techniques used.


Swing


See-saw

Gazebos

Slide

Details of the panel of a gazebo

Climbing-frame

Details of the climbing-frame

Protective Mat

2.2 SCALE OF PRODUCTION

Introduction

Various manufacturing systems have been developed to produce a wide range of products. Each system meets the distinctive characteristics of the product and the demand of the market.

There are a number of ways in which manufacturing systems can be classified:

- continuous production
- mass production
- batch production
- jobbing production

Selecting an appropriate system is essential for the development of a company.

2.2.1 <u>Continuous Production</u>

Continuous production, or process production, is where the plant or factory may run twenty-four hours a day for weeks or months. It is usually employed in industries such as chemical processing, electricity, food production and steel making (Figure 2.58). Products which have a short life span or which are in high demand, are often continuously produced.

Figure 2.58 Beer factory is one kind of continuous production

The production line is controlled by computers to avoid unnecessary stoppages or failures. Therefore, only a few workers are needed to monitor the production line.

The amount of products produced by continuous production systems are normally very large. At the last stage of the production line, the products are often stored in large silos and tanks (Figure 2.59).

Figure 2.59 Tanks for storing beer

2.2.2 Mass Production

Large quantities are involved in mass production. Similar to continuous production, specialised and expensive machines are used in this type of production. Robots are used increasingly for machining and assembly jobs – they fabricate products faster and with consistent quality, and do not become tired. In mass production systems, equipment, labour and supply of materials and components are highly organised (increasingly through the use of computers to monitor and control processes) to ensure a smooth flow of work through the factory and thereby minimise the cost.

Take the manufacturing of cars as an example (Figure 2.60). Once a car is designed, the automobile manufacturer has to build and test prototypes to ensure that the car meets the specifications. A lot of money has to be spent ensuring that the car meets safety standards.

Figure 2.60 Car production line

The bodies are constructed by welding together parts produced using sheet metal forming. These processes require huge investments in jigs and fixtures on production lines to assure high quality. The only way to sell cars at an affordable cost to the users is to spread the vast cost of design and development over a large volume. Car manufacturers have therefore had to sell their models across the world and use mass production methods to produce them.

2.2.3 <u>Batch Production</u>

Products that are batch produced are made in specific quantities, e.g. a batch of bread produced in one go,' or a batch of 1000 bricks. Products are sometimes made in one production run or batches may be repeated at particular times,

A batch can be a very small number of products – only 2 or 3 – or a very large number – for example 100,000 cans of baked beans. Large products like aeroplanes are produced in small batches (Figure 2.61). On the other hand, cars, garments and furniture items are often made in large batches of thousands.

Figure 2.61 Aeroplanes are produced in batches

Machinery and labour needed to make batch products must be adaptable. Machines may be used to make different products according to the batch in production, e.g. the same sewing machines are used to make trousers, skirts or blouses.

Large factories, such as textile garment factories, food and printing industries, have many batches of diverse products being produced at the same time, all with their own schedules and delivery dates for the various customers. The use of computer controlled production systems provides machine control (CNC machines), production control and management control. These systems help to provide order and diminish costs through a reduction in labour and management costs. You will learn more about this issue in Chapter 3.

As global market changes rapidly, modern batch production needs to respond quickly to demand for products. Manufacturing cells provide flexibility and versatility, and are an essential part of Flexible Manufacturing Systems. These are systems that can respond quickly to changes in product manufacture. A good example of a sudden change that can affect production is an early, unexpected spell of very warm weather in April / May. This can lead to a rush for shorts and T-shirts, etc. Production has to be quickly changed to meet demand.

Carbonated drinks plants operate with large batch production. Bottlers in Hong Kong may be owned by the drinks company or simply bottling under license to mix syrup, water and gas in only. Most flavours of drinks can be handled by individual production line. Cans and bottles are of standard designs so as to be interchangeable (Figure 2.62). It is only with very large plants located close to major markets that there are lines dedicated to one product.

Figure 2.62 Canned drinks

2.2.4 Jobbing / One-off Production

Jobbing / one-off production is also known as custom manufacturing. This system of manufacturing normally produces one product at a time, to a single customer's particular specifications. Skillful workers and equipment for general purposes are used.

In this type of production, problem-solving and trouble-shooting skills are necessary because each product represents new challenges. Products which are custom-manufactured are usually expensive, and might include large yachts, space satellites, oil rigs and other special machines. Traditional craft artifacts such as jewellery, statue and pottery are usually made with jobbing production techniques (Figure 2.63).

Figure 2.63 Bronze Statue

2.2.5 Choosing an Appropriate System

Choosing the most appropriate type of manufacturing system for a particular product depends on the following factors:

- the type of product to be made
- the life cycle or durability of a product
- the volume (quantity) to be produced
- the availability of necessary equipment, machinery and skilled workers

A production line is a widely used in quantity production, as it is relatively quick and efficient. The process usually involves the product moving slowly down a line of specialist workers - they carries out their particular task in turn.

Basically, the workers are likely to do the same thing every day; however, they may need training for the task in the first place. At the end of the line, the output will be the finished product.

2.2.6 Improving Manufacturing Processes

Manufacturers are constantly looking at updating and enhancing their manufacturing processes because:

- reduced costs – less material wastage and workers
- increased output – more products made per hour/day
- better profits

However, new process has a price to pay, such as the cost of new machines, installation and staff training. Therefore, manufacturers must find out the cost benefit ratio of their business before making the expenditure. Installing computerised systems such as CAD/CAM, has been one of the major areas of investment by all manufacturers since the 1970's/1980's. In addition, Value Engineering is another technique used to cut cost and improve a process.

2.2.7 Value Engineering

Value engineering uses a unique, systematic methodology to analyse the functions of items and systems to ensure they are achieved at the lowest possible life-cycle cost. It differs from other cost-saving techniques because it seeks to optimise function rather than merely reduce cost. In addition, value engineering can improve reliability, conserve resources, eliminate non-essential functions and simplify operation and maintenance.

Generally, a value study brings together a multi-disciplinary team of people who own the problem and have the expertise to identify and solve it. The study team follows an established set of procedures to review the production process, making sure themselves understand customer's requirements and develop a cost-effective solution. Mainly, the job plan is composed of six phases:

- Information gathering

- Function analysis
- Creation of alternatives
- Evaluation of all alternatives
- Proposal
- Implementation

(Useful website: www.value-engineering.com/vmtell.htm)

2.3 QUALITY ASSURANCE & QUALITY CONTROL

Whatever the product, there is a guaranteed quality which customers or users find acceptable. Hence, manufacturers must make sure that all products are of an acceptable quality. Assorted techniques have been developed to help check and maintain quality over a long production run.

2.3.1 <u>Tolerance Level</u>

You probably discover that it is difficult to make things accurately. In complicated products, a high accuracy is indispensable to guarantee that all components fit together precisely. However, the question is how accurate does it needed to be? It depends on the specifications of the product. The answer to this question is recognised as the Tolerance Level – the extent to which the size of a component must be accurate. This is usually expressed by two numbers: the upper and lower limits.

For example, a component designed to be 100 mm in length could vary between 99.1 mm and 100.9 mm. Then the tolerance is the difference between the upper and lower limits, i.e. 1.8 mm or +/- 9 mm. New automated equipment tends to be quicker and more efficient at producing and testing components which are finely toleranced. You should notice that in the case of two components that must fit together, the cumulative effects of the tolerances must be taken into account.

In general, the higher the accuracy is, the better the quality of the product is. Achieving this greater accuracy requires careful measurement and skill in controlling tools (Figure 2.64). Nevertheless, these prerequisites usually increase the cost. Testing procedures are needed to ensure components are within the tolerance levels. These are usually set by the manufacturer, but in some cases they will be set by the client.

Figure 2.64 Using caliper makes a precise measurement

A C T I V I T Y
Try to cut five pieces of material to exactly the same length. Check to see if they are the same. Set your own tolerance level. Can you suggest an aid which will improve the accuracy of cutting?

2.3.2 Quality Assurance (QA)

Quality assurance is the inclusive approach that ensures high standards of product quality throughout the production process. QA comprises the development and monitoring of standards, procedures, communications and documentation across the manufacturer all together. Usually a quality manual is produced which contains all the relevant information to guide staff. In other words, QA is the overall endeavour made by a manufacturer to guarantee her products conform to a set of specifications and standards. These standards cover considerations such as:

- Dimensions (length, width, height, diameter, angle, etc.)
- Mechanical, physical and chemical properties
- Surface finish

In addition, standards are usually written to make sure proper assembly using compatible and defect-free components. All these standards are stated in the manufacturer's design manual.

2.3.3 Design Manual

Manufacturers usually produce their own design manuals which embrace all the necessary information needed for their design team. This information gives detailed engineering knowledge – everything that is related to the type of products being produced by that industrial sector. Design teams can use such information to make sure that everybody is working to the same standards and to prevent previous design mistakes being repeated.

The design manual will also specify the standard components to be used, such as an engine part or a fastener. This guarantees that the manufacturer can get the cost advantage of purchasing large quantities from their suppliers. Catalogues of components from these suppliers may be included in the manual giving technical specifications and price information.

2.3.4 Quality Control (QC)

As QA is the responsibility of every staff involved in a product's designing and making, then quality checks must be carried out at various stages. Certainly, you can check each final product to ensure its quality is satisfactory. However, this approach is very time-consuming and costly. A more sophisticated and quicker approach is to set up a Quality Control system. This involves inspecting a sample of components as they are made, and the gathering and analyzing of records of the samples.

Basically, a sample of components (say 1 in every 100) is subjected to rigorous tests which identify and record how close the sample is to its standard. The production will continue if it is checked to be within acceptable limits. It is possible to find out a particular machine is increasingly producing components which are getting close to unacceptable tolerance limits by looking at the data of a series of tests. In this case, the machine must be adjusted or repaired before it produces defective components. Therefore, the aim of QC is to achieve zero defects by foreseeing the failure of a machine before it occurs. Nowadays, computerised testing machines offer us higher standards of QC and therefore less malfunctioning products are made (Figure 2.65).

Figure 2.65 Computerised Testing Machine

In order to provide better QC, you must be able to:

- measure the level of quality quantitatively, i.e. measure things through having number, size, weight, etc.; and
- pinpoint all the materials and processes that can be controlled.

2.3.5 <u>Testing Product Samples</u>

Testing product samples for defects includes a series of steps:

1. Inspecting incoming materials to ensure that they have the appropriate properties, dimensions and surface finish.
2. Inspecting individual components to make sure they meet specifications.
3. Inspecting the product to ensure that parts have been assembled properly.
4. Testing the product to make sure it functions as designed and intended.

The best possible location for product inspections would be after each operation. However, this is impractical and costly because of the number of measurements and human resources involved. In practice:

- Precise tooling will reduce unnecessary inspections. Today, CAM technology with automated and integrated inspection contributes extensively to this.
- Where high volumes of the same part or component are to be checked, *samples* of the item are taken as representative of the whole batch.

2.3.6 Statistical Process Control (SPC)

There are several ways of testing samples for defects as they are manufactured, using a variety of Statistical Process Control (SPC) techniques. For example, by inspecting a selection of parts or components, it is possible to assess accurately the likelihood of any defects developing at a later stage.

SPC techniques use *statistically-based* tools to evaluate manufacturing processes. Such procedures are monitored by gathering and using data which relates to their performance, and by gathering the feedback required for corrective action where necessary. Consequently, the tools are used to fully interpret the information contained within the collected data.

2.3.7 Quality Inspection

The quality of a product must be built in during its manufacture; in other words, it cannot be added during its inspection. You should keep in mind that inspection is not a substitute for accuracy. Inspection is used more exactly to mark problems in order that they can be fixed. It involves measuring components or parts, comparing the measurement to specifications, and making a decision about the condition of the match. Generally, there are three possible decisions afterwards:

- Acceptable quality - this means the inspected component or part matches the tolerances specified.
- Rework - this means that the component or part does not meet specifications but it can be fixed.
- Reject - this means that the component or part cannot be modified to meet specifications, and thus must be scrapped, Figure 2.66.

Figure 2.66 Scrapped bottles

Basically, there are four areas where inspection occurs during manufacturing, Figure 2.67:

1. Incoming raw materials
2. Purchased components or parts – if defects are found in incoming materials or purchased

components / parts, the supplier is responsible for their replacement.

3. Work in progress – if a defect is found immediately after processing, that item will be reworked or rejected. This prevents a substandard item from appearing in the final product.
4. Finished products – if defects are not found until a product is finished, the entire product may have to be scrapped. It is because that disassembling or reworking the malfunctioning product is usually very troublesome and costly.

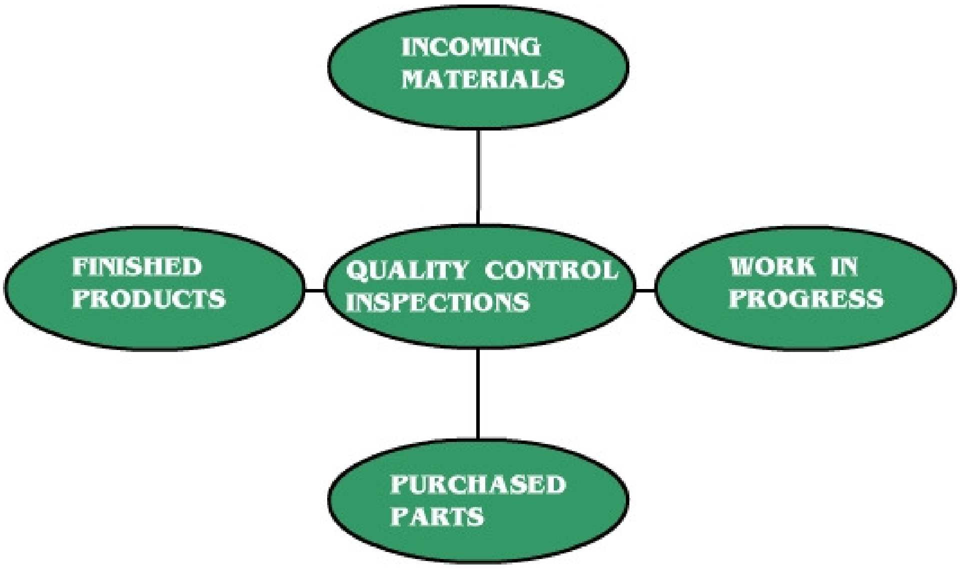


Figure 2.67 QC Inspection Areas

2.3.8 Quality Circles

Quality Circles are groups of workers who meet regularly to discuss and solve quality problems. They:

- investigate causes of faults;
- recommend changes; and
- take corrective action.

This results in workers being motivated to take pride in their work and become involved in maintaining and improving quality standards. Waste from defective products is reduced, at the same time as productivity and quality are increased.

Electronics companies have targets of *zero defects*, but in practice can achieve levels of one defect in 0.01% of products. In order to achieve such levels, the whole organisation must eager to achieve the targets; and the quality circles always play an important role in it. This means communications have to be right and staffs have to be trained to do the job properly.

IN YOUR PROJECT

If a company produces products of a quality that is unacceptable to the customer / user, the company will get a bad reputation and will be in trouble in doing business in the future. Hence, you have to consider the following points while carrying out your design project:

- How accurately do different parts of your design need to be made?
- When is the best time for checking accuracy?
- What kind of testing is to be carried out?
- What is the frequency of such checks?

CHAPTER 3 – COMPUTER-AIDED MANUFACTURING

This chapter contains topics on:

3.1 Computer Numerical Control (CNC) & Computer-aided Manufacturing (CAM)
3.2 Basic Concepts of Computer Integrated Manufacturing (CIM) and Flexible Manufacturing Systems (FMS)
3.3 The Impact of CAM on Manufacturing

The topics include learning materials and activities that facilitate you to:

(a) understand the use of CNC machines and CAM systems in industry; and
(b) understand CIM and FMS, and their wider application in industry.

There are some manufacturing activities that we neither enjoy nor repetitively inefficient on a continual basis. This has resulted in the development of mechanisation either to eliminate some labour on production work or to improve its efficiency. The computer revolution in the last two decades has fundamentally changed this situation, because it is now possible for machine to be provided with necessary computing power economically. Moreover, changes associate with the development of microprocessor goes much further than simply the control of individual machines.

Currently, the emphasis is on the development of *Computer Integrated Manufacturing* (CIM) and on *Flexible Manufacturing System* (FMS) which link *Computer-aided Design* (CAD) and *Computer-aided Manufacturing* (CAM) effectively. They allow faster development of new and improved products with better quality, shorter development and production cycles, faster delivery times, reduce production costs, and the ability to compete with the ever-changing demands of the international markets. In the following sections, two areas – the control of individual machines and recent developments in CIM and FMS – will be discussed.

3.1 COMPUTER NUMERICAL CONTROL (CNC) & COMPUTER-AIDED MANUFACTURING (CAM)

Introduction

Due to the ability of computers to store large amounts of data and commands, they are being used extensively in designing and manufacturing products. Computers now assist engineers and designers in:

- programming machine tools
- programming robots
- designing tools
- quality control

3.1.1 CNC Machines

Early machines use punched tapes to store machines' instructions in what is still known as a *part program*. They are said to be *numerically controlled* (NC) and hence these machines are known as NC machine tools (Figure 3.1). These machine tools use to produce numerous components or parts are said to be *computer numerically controlled* (CNC). That means they contain computer controllers directing the machine's operations. The controller reads a part program - a coded list of the steps necessary to perform specific machine job - and runs the machine by following the steps.

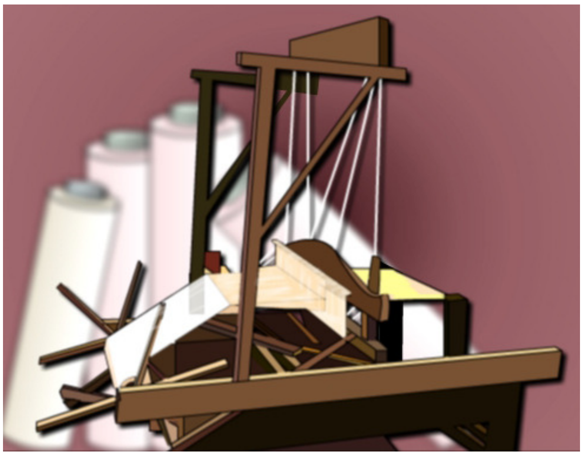


Figure 3.1 Early NC machine, Jacquard Loom in 1801

As precise movements are recorded in a part program that can be saved and retrieved again in the future, CNC machines tools allow high level of precision to be repeated consistently. They also allow different functions to be carried out with one setup, thus reducing the need for multiple and labour-intensive setups. The quality of products these machines produce depends largely on the part programs compiled by CNC programmers.

CNC Programmer

CNC programmers begin as machinists do - by analysing drawings, figuring the size and position of the cuts, determining the sequence of machine operations, selecting tools and calculating the machine speed and feed rates. After that, they compile the part program using the language of the machine's controller and store it, after verifying the program and the tool path.

Skilled machinists may also do CNC programming. As CAM software becomes more user-friendly and CNC machines being used broadly, machinists are increasingly expected to perform this task.

Programming CNC Machines

In order to help both users and suppliers of machine tools, an international system of standard codes has been developed to describe CNC machining operations. Table 3.1 shows the codes used on a CNC lathe. The full lists are very extensive and cover every conceivable machining operation. The codes most generally used are G-codes and entering these codes is commonly referred to as G-code programming. The user interface on most CNC machines is often designed to help in entering these codes without reference to a manual.

G00	rapid movement, point-to-point
G01	linear movement
G02	circular interpolation, clockwise
G03	circular interpolation, counterclockwise
G70	imperial units selected
G71	metric units selected
G81	outside diameter (parallel) turning cycle
G82	facing/grooving cycle
G83	peck drill cycle
G84	thread cycle
G90	absolute programming selected
G91	incremental programming selected
M02	end of program
M03	start spindle forwards
M04	start spindle reverse
M05	spindle stop
M06	tool change
M08	coolant on
M09	coolant off
M39	close air chuck
M40	open air chuck

Table 3.1 Selected codes used to describe turning operations

These G-codes represents instructions for tool movements, and are combined with other codes like M03 (to start the spindle forwards) and M06 (to change tools) to make up a block. A set of these blocks then forms a part program, Figure 3.2. Once the blocks are entered, there is normally a facility incorporated in the software to show the part program in a graphical representation on the computer screen. This screen simulation allows us to see exactly what has been entered before material is actually cut, Figure 3.3.

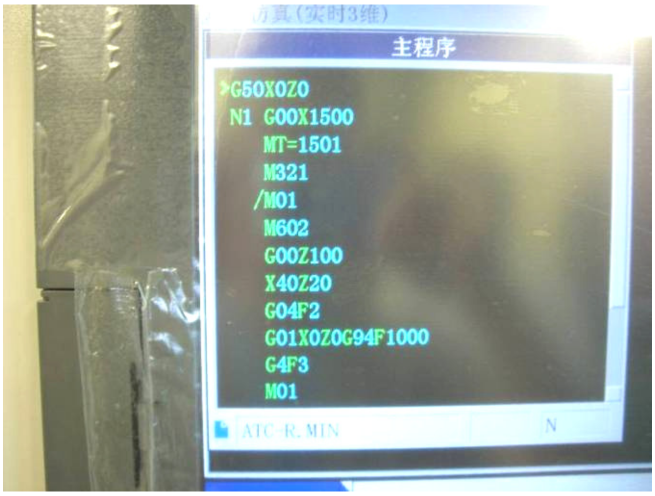


Figure 3.2 Part Program

Figure 3.3 Computer screen simulation of the cutting process

CNC Machining

As mentioned before, CNC machine incorporates a computer to make calculations and decisions based upon data received. It could be a lathe, milling machine, drilling machine or punch press which has its movements and other functions controlled by instructions or data received as a series of numbers. The numbers are interpreted electronically by the machine and are then acted upon. Information flows from the computer and the CNC machine sends feedback to the computer.

The moving parts of a CNC machine are usually driven by special electric motors called *stepper motors*. The computer switches these moving parts on and off, and hence controls their direction and speed. (You will learn more about this in Module 1 and 3.) After the computer has been programmed to make the machine tool to perform a sequence of operations, the program can run over and over again to produce many identical components or parts.

'Motor Cross' is a technologically advanced sport using specialized equipment. We can find some typical CNC products in this field. Components or parts of a motor cycle manufactured by CNC machining include, Figure 3.4:

- hubs
- brake discs
- chain rings
- sprockets

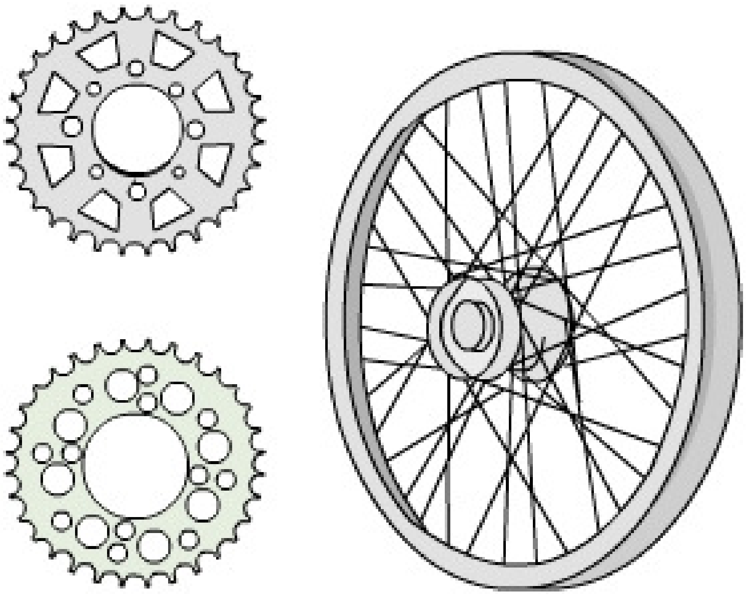


Figure 3.4 CNC machined components of a motor cycle

Figure 3.5 shows component production for a motor cycle brake disc. You will note that even though the amount of material removed is very significant as a result of CNC machining from solid blocks, it is still cheaper and have a better quality finished product.

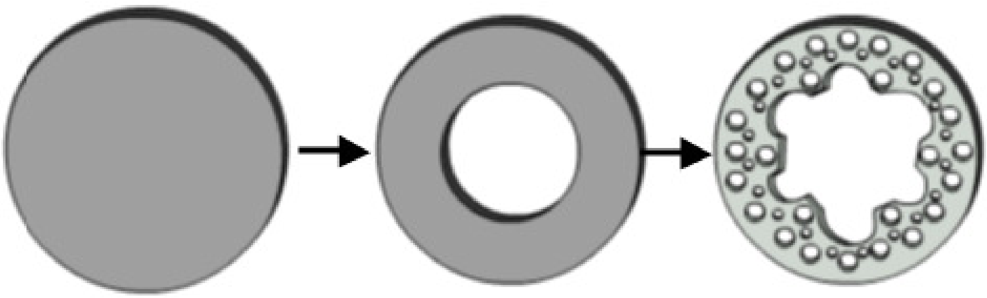


Figure 3.5 Making a brake disc

Comparison of CNC with Conventional Machining

Formerly, production techniques required skilled people to operate the machines. It took several years of apprenticeship to acquire the necessary skills. Today, the processes are automated using CNC machining. This has become possible because the technologies of the machines have been developed to an accuracy and reliability which far exceeds the most skilled people. Figure 3.6 shows the comparison of CNC and conventional machining:

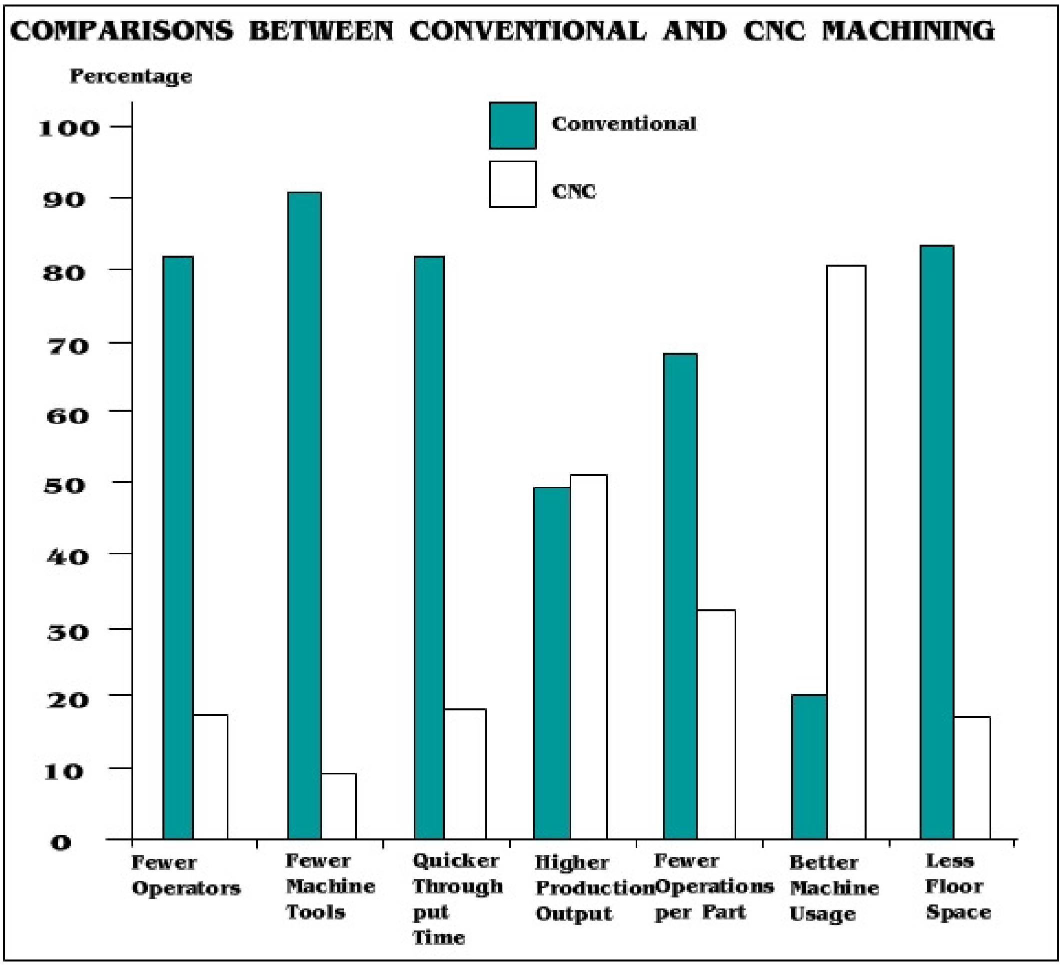


Figure 3.6

To put it in a nutshell, the advantages of CNC machining include:

- Consistent accuracy
- Increased productivity
- Less operator involvement
- Complex shapes can be easily machined
- Reduced tooling costs
- Uniformity of product
- Improved waste management

However, alongside these advantages, a manufacturer has to consider the following in advance:

- Initial cost of machines

- Installation costs
- Training of operators
- Cost of maintenance and servicing

CNC Equipment and Activities for Schools

In the market, there are CAD/CAM software packages that enable us simply to draw an outline of the required component or part on the screen, and then the software performs the program writing automatically by converting this image into a set of codes mentioned before. (The details of CAD/CAM will be discussed in next section.) Some packages have the ability to run a variety of CNC activities for schools (Figure 3.7). These include driving purpose-built milling machine and plotter device where a pen can be replaced by a cutter, allowing the production of card models, stencils and vinyl signs.

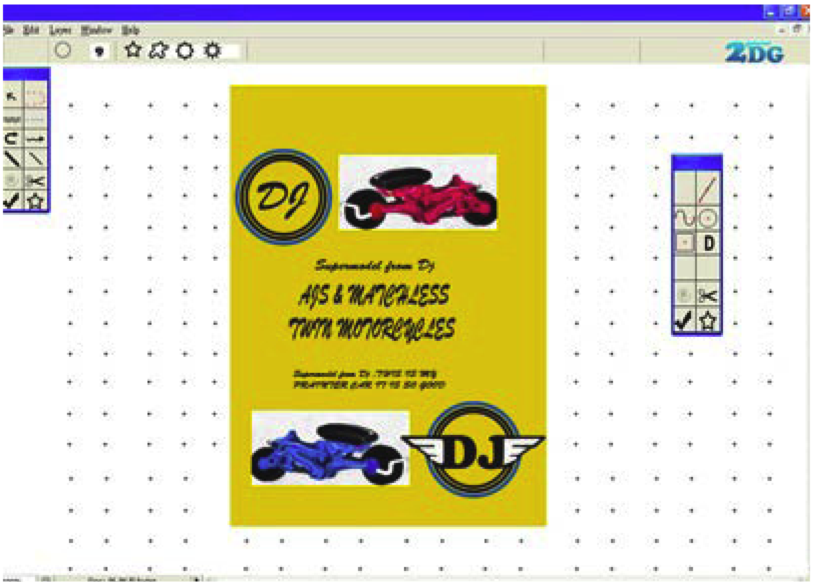


Figure 3.7 Example of CAD/CAM software package

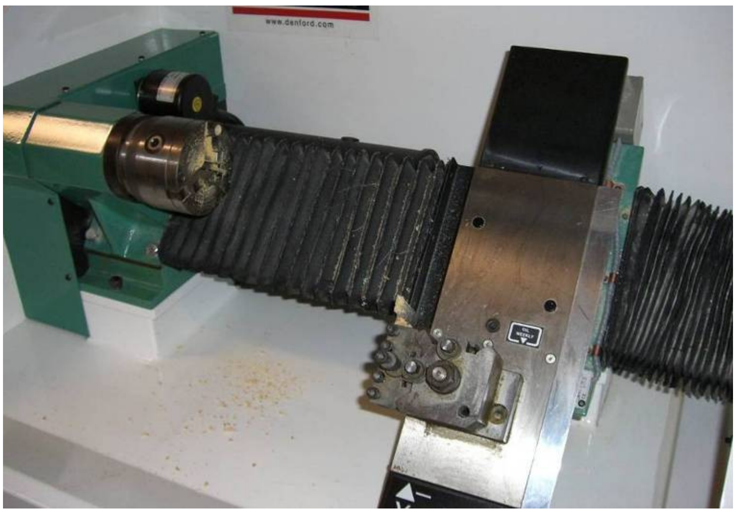


Figure 3.8 CNC Lathe used in schools

A series of CNC activities, based upon CAD/CAM software package integrated into cutting and drawing machines, are possible in schools. These include:

- milling and turning
- paper/vinyl printing and cutting
- laser engraving and cutting
- object coping

S T O P A N D T H I N K

1. Draw a small CNC machine and label the most important parts.
2. List the safety measures that people must be aware of before they operate a CNC machine.
3. List and explain some of the difficulties you had when manufacturing a product using a CNC machine.

3.1.2 CAM

Computer-aided Manufacture, or CAM, is the name given to the method of controlling the operation of manufacturing machines using a computer. CAM is very often used with Computer-aided Design (CAD) to develop products. For example, a designer can generate a design using a CAD package, and this design can be programmed into a manufacturing machine using CAM software. (You will learn more about CAD in Module 5.)

CAD is now used in many industries, ranging from mechanical engineering and car design, to the furniture industry and fashion design. It works by allowing the designer to input all of the required information into the computer, including drawings of the product or component itself, size information and the desired cutting and shaping techniques. The information is then programmed directly into the (CNC) manufacturing machine as numerical data. The machine is then able to cut, shape and make the component, being controlled by the computer. On the whole, CAM involves monitoring and controlling manufacturing operations. The entire process, from the beginning of the design stage to the actual manufacture is known as the CAD/CAM Process.

CAM technologies enable programs to be easily modified for use on other jobs with similar specifications, thereby reducing time and effort. They create the possibility for machines to replace workers, resulting in benefits as follows:

- machines can work 24 hours a day
- the quality produced by machines is more reliable
- machines can work in more hazardous locations

The Use of CAM

Figure 3.9 shows a multi-axis CNC machine used in a factory. This forms part of the CAM system and automatically operates the moulds used in injection moulding process. Such moulds have holes and grooves on different sides. Figure 3.10 shows a similar but smaller CNC milling machine used in a school, which is able to make relief-like models only. Undoubtedly, with more axes of movement, there are increased mechanical complexities, and more major problems are associated with programming the CNC machines.

Figure 3.9 Multi-axis CNC machine used in a factory

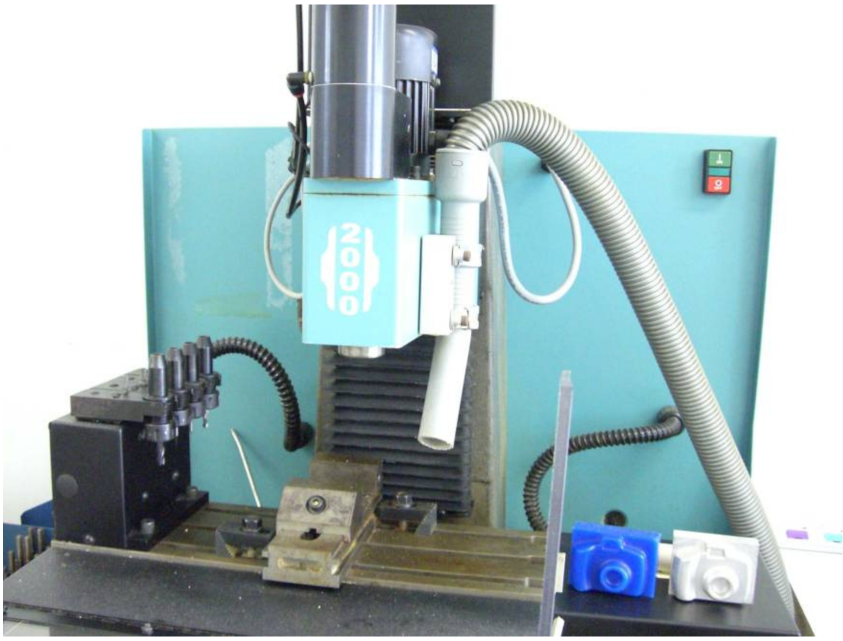


Figure 3.10 CNC vertical milling machine used in a school

However, it is not only CNC machines which are used in factories. Figure 3.11 shows the model of programmable robot arm used to transfer workpieces between different CNC machines. The first robots used were generally employed in pick-and-place operation – one of the earliest being used by General Motors for unloading a die-casting machine. Nowadays, robots are also commonly used for operations like welding and paint spraying.

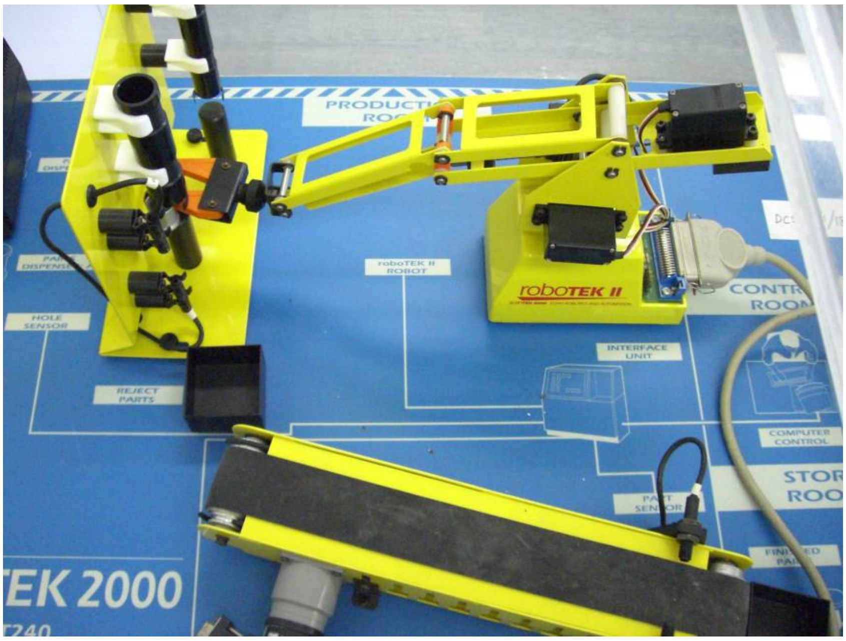


Figure 3.11 Model of pick-and-place operation with the use of robot arm

Choosing to use CAM

Deciding to use CAM imparts exactly the same kind of struggles as the selection of any other manufacturing process. It is a question of looking at the set-up (or fixed) costs and deciding whether there are consequential savings in the cost of each component or part produced (the variable costs) to justify the investment (refer to the compulsory part for detail). Generally, CAM is thought to compete effectively with production quantities from about 10 to 1000. However, there are situations where it is cost-effective to produce only a few components by CAM.

As we discussed before, CAM systems use detailed computer data produced by CAD systems to control CNC machining. Most engineered products require many machining operations to be carried out sequentially; CAD data must therefore be adapted to control each machine tool. CAM is advantageous remarkably where a range of slightly different products is required, since changes can be implemented simply by modifying the computer data.

The integration of designing (CAD) and production (CAM) with other disciplines such as planning, purchasing and financial control will give us a more versatile manufacturing structure. Moreover, groups of CNC machines and handling equipment such as transfer machines or robots, can be arranged in work cells to form more adaptable manufacturing systems. We will discuss this later in Topic 3.2.

3.2 IC CONCEPTS OF Computer Integrated Manufacturing (CIM) and FMS

3.2.1 Computer Integrated Manufacturing (CIM)

The use of computers has become increasingly important to the business of running an industry at any size. They are now an integrated part of designing, organising and monitoring materials, production, and, through bar-code systems for stock control and storage.

With sophisticated hardware and software, manufacturers are now able to:

- improve product quality;
- minimise manufacturing costs;
- reduce product development time;
- make better use of materials, people and machinery; and
- maintain a competitive edge in the domestic and international market-place.

As a result, the workplace of a designer or engineer working in a factory might look something like the one shown in Figure 3.12. Data input can be used directly in the manufacturing operations via computer links. Eventually, all of the movements and processing of raw materials, semi-finished and finished workpieces can be planned, executed, inspected and monitored using computer systems.

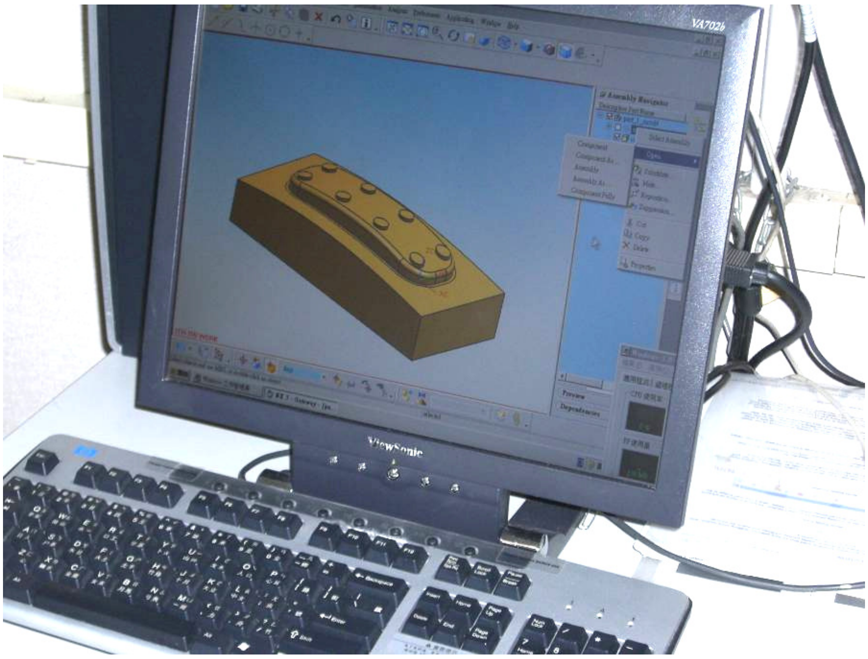


Figure 3.12 A CAD workstation

Work Cell

The achievement of such a goal – the integration, would require the expenditure of huge amount of money. Different manufacturers may progress towards it in ways which best suit their state of development and their products. It is unnecessary to do everything at one time, elements like flexible work cells and automated materials handling equipment can be introduced separately. Figure 3.13 shows a flexible work cell that is able to produce a variety of components which consequently form parts of a product.

Figure 3.13 A flexible work cell

Figure 3.14 Control panel of the work cell

In order to develop such work cells into a CIM system, other elements are still needed to be included – most notably automated inspection and materials handling equipment. Figure 3.15 shows a modular system developed by a company to train students in the principles of CIM.

Figure 3.15 Training CIM Module

During the development of a CIM system, we can use computer simulation of the complete production line to find out probable flaws, Figure 3.16. A computer controlling the overall cell operation will implement the programs on the machine tools when time is available.

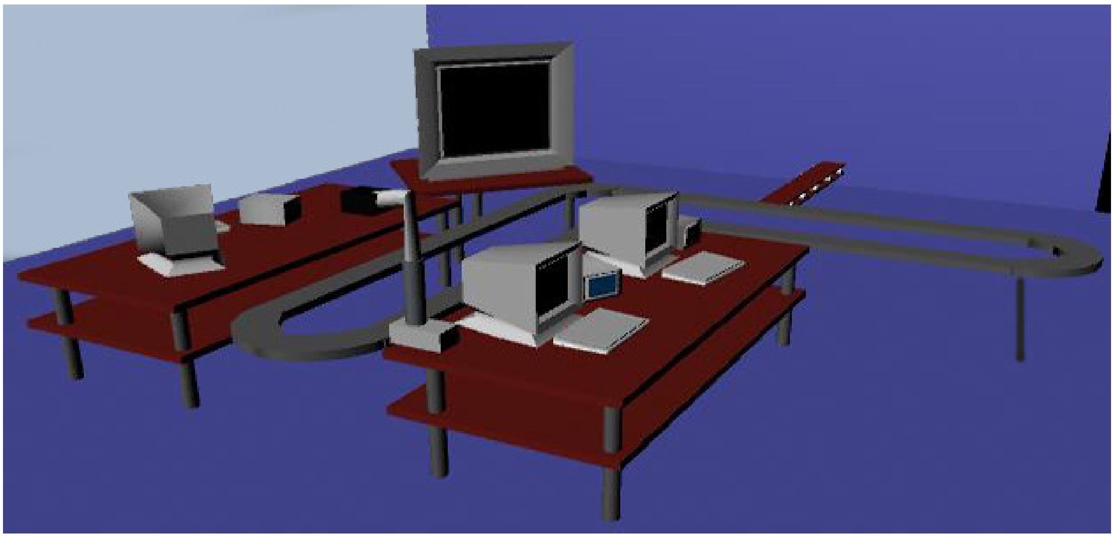


Figure 3.16 Computer screen simulation of a CIM system

CIM Elements

It is not just the use of computers that is important - it is the way how a manufacturer's operations are planned and integrated that brings success. Elements of a CIM include the following (Figure 3.17):

- CAD which allows new products to be developed and visualised more easily.
- Computer-aided Design and Drafting (CADD) which puts early designs into 3D form

that can be rotated and scaled. It can also simulate the product in use, helping to identify potential problems.

- CAM which involves controlling and monitoring manufacturing operations.
- Computer-aided Process Planning (CAPP) which estimates costs or the time taken to perform a certain manufacturing operation.
- Management information systems for marketing, finance, payroll etc.

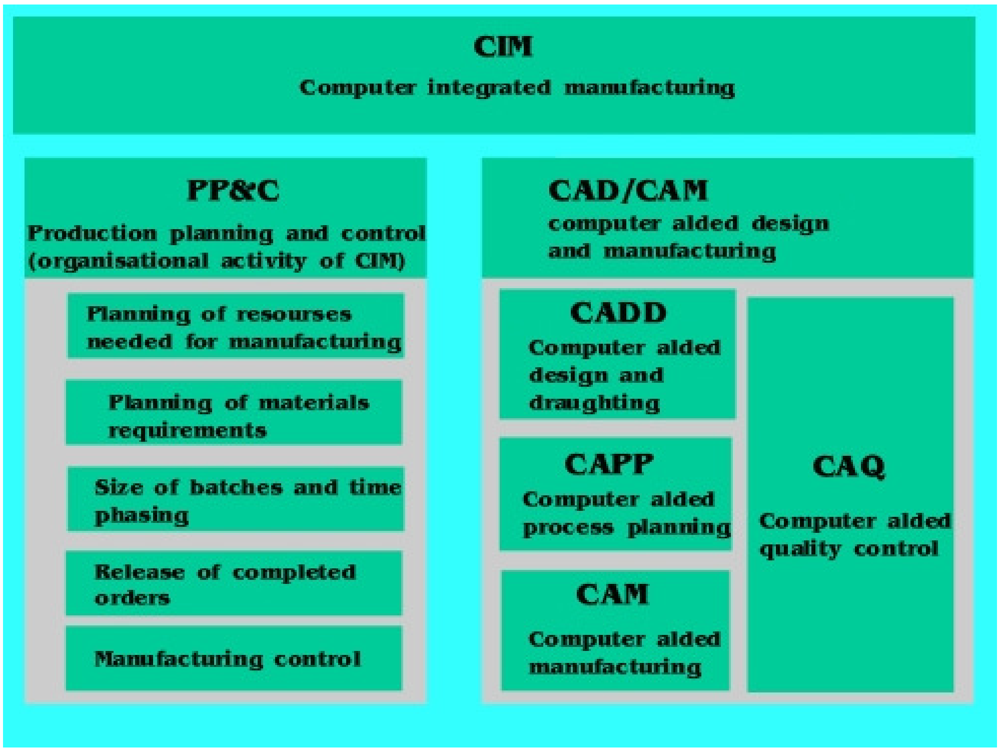


Figure 3.17 CIM elements

Nowadays, a manufacturer may use computers in operations. It is important that all these computer systems are well planned and integrated to work together if they are to work efficiently.

3.2.2 Flexible Manufacturing Systems (FMS)

FMS integrates all the major elements of manufacturing into a highly automated system. It normally consists of a number of work cells, each containing an industrial robot serving several CNC machines, and an automated materials handling system, all linked to a central computer (Figure 3.18).

Figure 3.18 Work cells in FMS / car production

FMS are highly automated and are capable of optimising each step of the total manufacturing operation. These steps may include one or more processes, such as machining, grinding, cutting, forming, heat treatment and finishing, as well as handling raw materials, inspection and assembly (Figure 3.19). Generally, such automated systems of batch production are able to operate on a continuous basis.

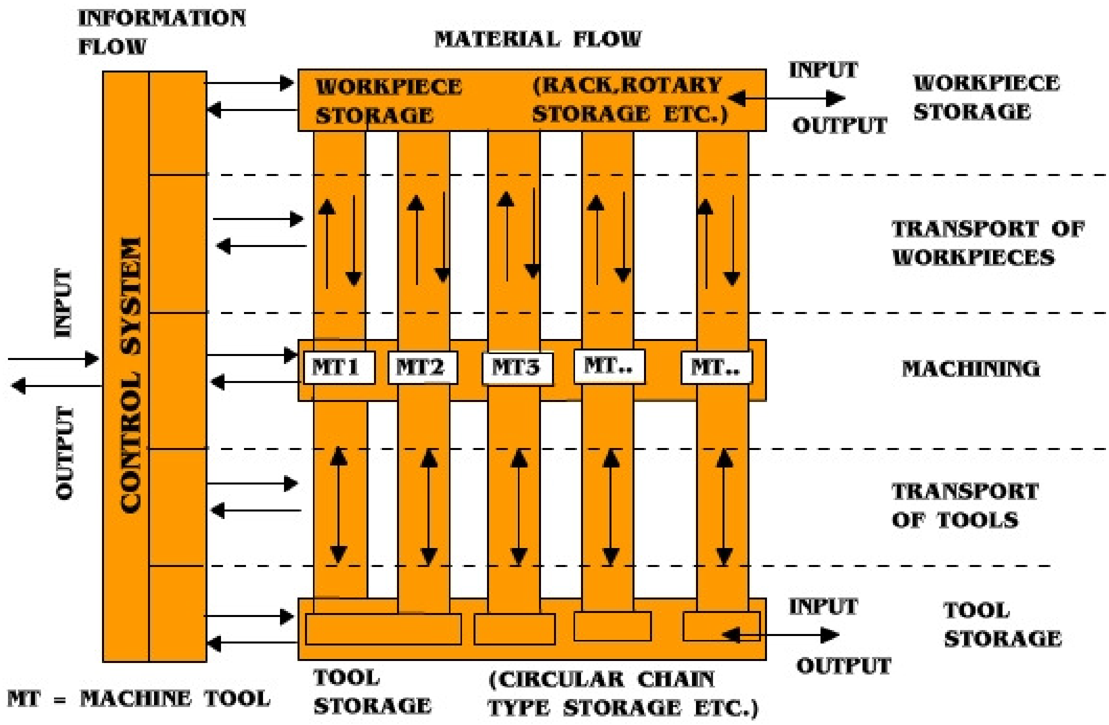


Figure 3.19 Conceptual map of a FMS

Work cells are normally groups of machines, usually involving sheet-metal forming or machining operations, with each piece of equipment performing a different operation on a component or part. The machines can be re-tooled and re-grouped for different product lines within the same family of parts. The cells are usually attended by one operator overseeing the group of machines, although increasingly they are becoming computer-controlled, employing robots for materials handling.

S T O P A N D T H I N K

Visit the following websites to see the work cells applied in real industrial situations:

- http://www.bbmfg.com/ (B&B Manufacturing Co.)
- http://www.columbiagear.com/ (Columbia Gear Co.)

3.3 IMPACT OF CAM ON MANUFACTURING

3.3.1 Changing Industrial Environment

As advances are made in technology, it is inevitable that the way in which we live have to change. This means that technological change will result in changes to our lifestyles and to society in general. The two main areas of industry which will change as technology advances are:

- in the workforce, including labour and skills; and
- in the actual location of industries.

Workforce

The CAM technology used in industries is being relentlessly developed and improved, resulting in the need to make changes to the workforce. These changes will usually be in the areas of:

- the labour to be carried out; and
- the skills of individual workers.

Labour concerns that computers and robots are being used increasingly in manufacturing. This means that people are losing their jobs in favour of machines which may be able to carry out the tasks more effectively. Although humans may be capable of carrying out these tasks, there are some practical advantages of CAD/CAM (referring to section 3.1.2).

The increasing use of CAD/CAM in industry means that people's skills have to change. For example, as certain jobs are taken over by machines, people will be required to work in other industries such as the servicing, or perhaps will be needed as care assistants to the growing number of elderly people in society. Such changes mean that some traditional occupations will die out as new ones develop.

Advantages of Robots

The following are some advantages of using robots:

- They can be stronger than people, being able to lift heavier weights or apply greater forces.
- They are able to work for very long periods and they do not request holidays.
- They are reliable. Once they are programmed on how to perform certain task, they are able to repeat it with great precision. Human workers will become tired over a period of time, with a loss of productivity and the possibility of making mistakes.
- They can work in environments which humans will find either unpleasant or dangerous. For example, they are able to handle very hot or cold objects, as well as radioactive components. They can also work in the dark.

Employment

In Hong Kong, the profile of the working population in manufacturing industry has changed enormously since the 1980s. Some of the main causes are due to automation and using of microprocessors and control systems. The first change was the replacement of manual labour by machines through CAD/CAM. Simple clerical tasks are computerised. The current focus is on reducing the need for repetitive middle management tasks. Developments aimed at helping strategic management are now being undertaken.

Manufacturing industry now needs far less labour to manufacture larger quantities of goods, and people have to find new forms of employment. The types of job that used to exist in the past are no longer there. The emphasis on jobs for the future is likely to focus on those that are highly qualified and those that provide a service to others.

3.3.2 Advantages of CAM

The benefits of CAM to industry are:

- Quality products for the customer
- Manufacturing costs kept to a minimum
- Product development time reduced
- More efficient use of materials, machinery and workers
- Competitive price for home and international markets

The greatest advantage of CAM is the ability to do or make something exactly the same over and over again. It is often now much quicker than traditional manual methods of manufacturing and is almost always of superior quality. Moreover, machines and computers do not have rights equivalent to us and can be run constantly without the need for breaks such as food, rest and toilet trips. Expenses such as heating and lighting, may be reduced with the environmental needs of machines are less than humans. However, additional electricity requirements may even these out.

Machines can also perform many dangerous tasks that we either cannot do or have to perform extremely carefully under strict safety conditions in terms of clothing and environment, the nuclear industry is a good example, as well as the welding process in car production. Some elements of CAM also have built-in quality control with sensors or cameras that can spot faults when products are being made. In long term views, CAM may be economical; the initial equipment and set up costs are high, but with advantages of increased productivity and no need to pay wages, it will soon equal the initial expenditure.

3.3.3 Disadvantages of CAM

The greatest disadvantage of CAM relates to its running on electricity. Power cuts and blown fuses often haul a factory operation until the electricity is reconnected. The time to reboot the computer system and remove half-made products can often be long. The cost both in initial set up and in cases of faults can be argued for and against the increased productivity and no need for wages to compensate the initial and service costs. In general, a normal machine may be really cost-effective in the long run.

Another problem area is on sick-leave or resignation of a specialist worker. It may take time to train up a new employee or hard to get a qualified person. Besides, if a machine breaks down, it often gives little warning and is often recurring. Even though most machines have built-in safety features, up to now, they cannot repair themselves. Some machines are being developed with built-in diagnostics to report faults, though when the fault has occurred, an expensive engineer is still needed to fix the fault.

3.3.4 Controlling Industrial Processes

Manufacturing industry is in the business of making money. Making money happens when the income from sales is greater than the costs of making products. In brief, there are two key requirements:

- Making sales means making the customer satisfied
- Reducing costs will increase the profit made from each sale

The following control systems embedded in CAM are designed and implemented with the idea of meeting these often conflicting requirements.

Production Control Systems

Even the simplest product that you buy in a shop has many components built into it. The production of each component probably requires many operations on various machines. All the components or parts for each product must be available at the same time to be assembled, packed and delivered to the market. The problems get even more complicated because most manufacturers produce several products where demand for each product changes separately over time.

Hence, most manufacturers use computerised production control systems to help them with the planning of their production. However, the basis of these systems is similar to the sort of plan that you need to produce to make sure that your design project is submitted to your DAT teacher on time. If a manufacturer cannot manage this process, it will not be able to deliver products to the market and will not get any money.

Component Production

The production system chosen depends upon numerous factors. However, in the modern industrial environment, many manufacturers choose to buy components they need from other manufacturers. To make (by herself) or to buy (from others) decision is one of the key issues that a management team must make.

One of the major difficulties in the production of components is that they have to be made in advance. If the number of product sells is greater than what is planned, then the volume of components being produced has to be changed with short time notice and within lead time. If this happens, it is indispensable to have a good production information system which gives management an exact understanding of where everything is in the factory and what machining operations have been done.

Usually, it will be better to design components with a very short lead time and in small numbers, even if it costs more. This is because the flexibility that it offers reduces the commercial risk. For attaining this goal, manufacturers are likely to invest in FMS.

(Lead time is the time takes to make a component or product. A product that has a short manufacturing lead time offers greater flexibility of production because decisions do not have to be made a long time in advance.)

Production Information Systems

One of the difficulties in managing production in a factory is recognizing what is happening. The difficulty is getting information of each component and input to the computer in a reliable, timely and cost-effective way.

Many modern production systems have adopted bar coding as an effective way to do this. It is possible to ensure that as a component moves around a factory, it will pass under a bar code reader (similar to those used at supermarket). The bar code reader can automatically identify each component, and then demand the worker who has just carried out a production operation on the component record what he or she has done.

In automated systems, bar coding is still used, but the information is automatically recorded. Automated systems can provide much more information than workers do, and this can improve quality control and assurance.

Assembly

Current marketing ideas require that a customer should be able to choose the details of a product that is to be bought. If a manufacturer is to provide such a choice and still get the product to the customer in a reasonable time, either:

- there is a huge stock of all alternatives (it costs a lot of space and money); or
- the manufacturer is able to take an order and assemble a product for the customer quickly.

The products must therefore be designed in such a way that they can be assembled quickly. However, a manufacturer must invent an assembly control system to ensure that, for each product, the correct components are available.

Assembly Control System

The key to ensure an assembly control system work properly is to have reliable and updated information fed into it, and to be able to process that information quickly enough. Modern systems tend to be fully automated, often using bar code readers to input information. As just-in-time systems have been introduced, it has been necessary to make sure that the information of (material/component) supplier is integrated into the system and this leads to very close working relationships between companies.

Just-In-Time (JIT) System

Manufacturing industries have in the past been wasteful with materials, energy and labour by over-production to ensure that they can meet demand. Stocks of products were held in storage, which were again an expensive cost in space and locked-up money for the manufacturer.

However, the Japanese developed the JIT system to eliminate all these unnecessary costs. It is a system that relies heavily on electronic data handling using bar-coding systems. The JIT system is suitable for continuous production, mass production, batch production and jobbing production. The JIT idea has the following objectives:

- to purchase supplies of materials and components from outside suppliers just in time to be used;
- to produce parts just in time to be made into sub-assemblies;
- to produce sub-assemblies just in time to be assembled into finished products; and
- to produce and deliver finished products just in time to be sold.

The JIT system relies on outside suppliers meeting exact specifications for materials and components. Contracts will specify exact dates and times for deliveries. All materials and components will have a quality check on delivery. This principle has been developed to such an extent that, although absolute perfection is not attainable, the number of defects supplied should be measured in parts per million rather than parts per thousand.

The JIT system means that smaller quantities of materials and components are ordered but usually more frequently than before. The delivery of smaller quantities allows better quality control. Other advantages include:

- smaller stocks held in storage means lower storage costs
- quality checks on delivery means that better quality of raw materials and components, lower wastage rates in production
- final products are higher in quality and lower in costs

International competition and lessons from Japanese practice have encouraged the adoption of JIT methods and quality management methods. Technological advances, as well, have had an impact on stock control management:

- new mechanical and automated equipment has made stock movement more efficient with better use of warehousing
- IT-based stock control systems with bar codes are integrated with other systems to give better control over order assembly, stock availability and monitoring

Production Logistics

If a product is being assembled, it is essential that all of the components to be used are available in the right sequence and at the right time. If only one component is not available, assembly will stop before the product is completed and cannot start again until the component arrives.

The job of the assembly control system we discussed before is to make sure that all components arrive at the right place at the right time. Not having parts can involve a major cost, but any stock of components held in the factory has to be paid for, and stock can take up a lot of space which is also costly. Stock control is therefore becomes a very important issue.

Stock Control

Many factories allocate more space to storing components than assembling products. The production control system we mentioned before must decide how much stock to keep. Some of the major factors to be considered are:

- The larger the stock, the greater the amount of money must be spent in paying for the components held in stock.
- The more components held in stock, the more factory space is needed.
- The greater the factory size, the longer time it takes to get the components to the assembly site.
- The smaller the stock, the more likely a component will not be available at the assembly site at the right time.

As components are used, they must be replaced and this means that the stock control system must tell the suppliers when to deliver more stock.

Factory Size

Once a factory has been built, it generates business in the local community. Very often, other businesses will also set up besides the original factory, and soon all the land in that area will be occupied. Even if the owner of the original factory wants to expand the factory because business is good, it may not be possible to do so. Hence, when a manufacturer builds a factory, he will be wise to ensure that there is room for future expansion.

If there is no room for future expansion and yet output must be increased, company managers will be forced to reconsider how they use the space available. One option is to reduce the stock levels. In Hong Kong, there is a large population living on a small piece of land. To make things even worse, most of the land is very mountainous and not usable for industry. Therefore, it is not surprising that lack of space forces the local companies to develop the JIT system.

Packaging and Distribution

The whole effort in making a product is a complete wastage unless a customer receives it, pays for it and starts using it. Packaging can perform a variety of functions including making the product attractive to customers and protecting it from damage during transportation.

The product itself is assembled in one place, but it might be used by someone anywhere in the world. Getting the product to the customer is to ensure that it arrives at the right place and at the right time and the time spent is a major control problem. Some advanced mathematical techniques have been developed to make sure that distribution can be achieved at the lowest cost. Despite that, you may well recognize the cost of distribution is often significantly greater than the costs of production.

3.3.5 The Future of Manufacturing

Modern developments in CIM have changed the relationship between marketing and manufacturing. In the past, it was impossible for manufacturers to deliver customised products on a large scale. In car industry, however, the aim is now to build a car that a customer orders, and deliver it to the customer in such a short period of time that the customer does not have to compromise on choice. These developments create opportunities for remarkable careers in manufacturing.

Mass Customisation

Giving a customer choice can improve sales as it is more likely that manufacturers can deliver exactly what a customer wants. The problem is that the number of alternatives available increases rapidly and it becomes very difficult to manage. The decision in batch production as to the size of batch depends on financial criteria. There are two major criteria involved:

- the costs of setting up machinery for each batch; and
- the costs of stock in the factory.

If a small batch size is chosen, the cost of setting up the machines per unit produced is high (fixed cost divided by a small number). On the other hand, if a large batch size is chosen, the time spend on producing a batch will increase, and the amount of material being stocked will be large. Therefore, the optimum batch size is when the combined costs are minimised.

Modern CIM systems can computerize the set up process. In many cases, the only setup will be the loading of different computer/part programme. This reduces the cost of setup to a minimum and reduces the optimum batch size to a very small number.

STOP AND THINK

Examine a brochure of a new car. Look at the number of different options available. The list might include:

- Colour
- Trim type
- Engine size
- In-car entertainment
- Power steering
- Air conditioning

Work out the number of alternatives that are offering. You will be surprised at the size of the number.

THEME-BASED LEARNING TASKS

Manufacturing For Living ─ Case Study Of PET Bottle

Background

PET is used as raw material for making packaging products such as bottles and containers for packaging a wide range of food products and other consumer goods. Examples include soft drinks, alcoholic beverages, detergents, cosmetics, pharmaceutical products and edible oils. PET is one of the most common consumer plastics to be used, and is closely related to our daily living.

Some PET bottle facts are as follows:

- A typical 330ml PET fizzy carbonated drinks bottle weighs only 10 grams.
- A typical PET bottle has a wall thickness of 0.2mm which is made up by three separate layers or laminates.
- When a fizzy drinks bottle is shaken, it has to stand up safely to a pressure of approximately 4 bar – twice the pressure of a typical car tyre.
- If you work out the number of square inches on a 330ml bottle's surface, the total pressure load on the bottle is approximately 1.5 tons when the internal pressure is 4 bars.
- According to tests on pressure, a typical PET bottle can withstand up to 10 bars.
- PET bottles have reduced accident rate due to the fact that they are virtually impossible to break.
- It is estimated that more than 1 billion PET bottles are sold and thrown away in the HK each year.

Material Properties of PET

Density	1370 kg/m^3
Young's modulus (E)	2800–3100 MPa
Tensile strength (σ_t)	55–75 MPa
Elongation @ break	50–150%
Melting point	260 °C
Thermal conductivity	0.24 W/mK
Linear expansion coefficient (α)	7×10^{-5}/K

PET And Bottle Design

Almost all plastic bottles of fizzy drinks are made from a relatively new plastic material called PET. PET stands for polyethylene teraphthalate which is a mixture (co-polymer) of plastics which gives very special properties. These properties include:

- very high tensile strength - resistance to stretching;
- high impact resistance - the ability to withstand sudden knocks; and
- non-permeability - resistance to gas under pressure leaking through the material.

Most people take PET bottles for granted and throw them away without much thought. However, an enormous amount of effort has gone into their design to make them both cheap and safe.

To withstand high pressure, the shape of a fizzy drink bottle is very important. A good shape is a sphere which is sometimes used for natural/ town gas containers. It is not a very practical shape for bottles because spheres take up a lot of space in boxes or on shelves. The second best shape is cylindrical, but this presents a problem because of the base. A thin flat base would balloon outwards under pressure and cause the bottle to fall over. Some PET bottles do have a balloon base but these bottles also have a plastic ring at the bottom to stand on.

Design of Bottle Base

A majority of PET bottles now have either a champagne base or a petaloid base to overcome the problem of containing pressure and at the same time enabling them to stand upright. The champagne base gets its name from glass champagne bottles that have an inverted dome at the bottom.

Champagne Base

The petaloid base shown below is named because it resembles *petals* on a plant. It is really a number of balloon bases clustered together to make the bottle stands up. You may think this is an obvious solution to the problem, but it took several years of development work to arrive at this design.

Petaloid Base

Design of Bottle Cap

The screw cap and bottle top are also special designs. The cap has a built-in seal which gets tighter as it is twisted onto the bottle. Inside the cap is star shaped ribbing which helps to keep its top flat even under pressure. Without this, the cap will balloon out under pressure and cause the seal to break.

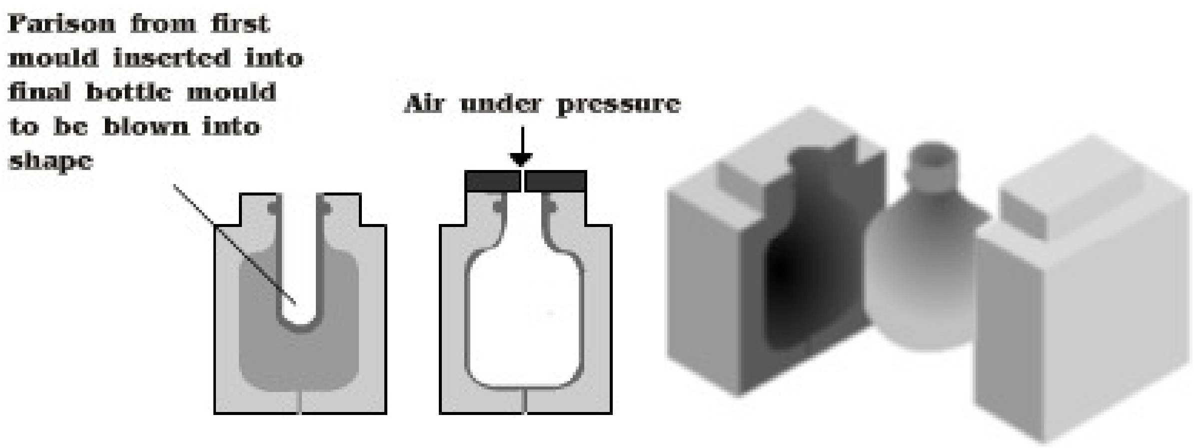
The Cap

The screw threads on both the bottle top and the screw cap are slotted. This is very important because when you unscrew a bottle top, it is important that pressure inside the bottle is released before the top has been fully unscrewed. Without these slots, the top can blow off and may cause injury.

How They Are Made?

PET bottles are made by a process called Injection Blow Moulding, see the figure below. In the first stage of this process, hot fused PET material is injected into a small mould and blown into a shape called parison by injection of air. It is then transferred to a larger mould and blown into the final shape of the bottle. You will learn more about this manufacturing process in the following website:

http://www.kenplas.com/



Recycling Of PET Bottles

Approximately 1.5 million tons of PET are collected each year worldwide. In many countries, including Hong Kong, PET plastics are coded with the number 1 which is a universal recycling symbol, usually located on the bottom of the container as shown below:

Post-consumer PET is often sorted into different colour fractions: transparent or uncoloured PET, blue and green coloured PET, and the remainder into a mixed colours fraction. This sorted post-consumer PET waste is crushed and pressed into bales, which are offered sold to recycling companies. Transparent post-consumer PET attracts higher selling prices comparing to the blue and green fractions. The mixed colour fraction is the least valuable.

Recycling companies will further process the post-consumer PET by shredding the material into small fragments. These fragments still contain residues of the original content, shredded paper labels and plastic caps, which are later removed by other processes, resulting in pure PET fragments, or "PET flakes". PET flakes are used as raw material for a range of products that will otherwise be made of polyester. Examples include polyester fibers, a base material for the production of clothing, pillows, carpets, etc., polyester sheet, strapping, or back into PET bottles.

In order to ensure a successful recycling process, it is a good practice to always remove the lids of the bottles and rinse them out thoroughly, as extraneous material inhibits the re-use ability of these goods. Therefore before putting out your PET bottles and Plastic Bottles to the recycle bin:

1. Remove the label
2. Remove the cap
3. Rinse the bottle
4. Empty the bottle of water

Follow-Up Activity

Look for symbols for recycling in other plastic containers/ packages at home.

Your group of 3-4 classmates can reuse PET bottles to make several water rockets and compare which one gets highest and farthest. In this activity, you will recognize how robust PET bottles are. The following website can help you learn more about designing and making water rockets: http://ourworld.compuserve.com/homepages/pagrosse/h2oRocketIndex.htm

Water Rockets

Spectacular Structure — Case Study of Skywalk at Grand Canyon

Background

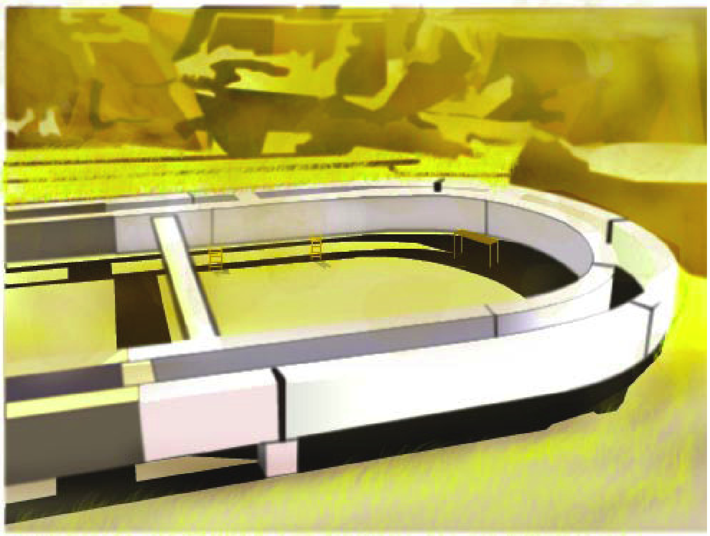
There are many spectacular structures in the world; our Tsing Ma Bridge is one of them. In 2007, a new amazing structure emerges in the United States. Located at Grand Canyon West's Eagle Point, the Skywalk is a cantilever-liked glass walkway to suspend more than 4,000 feet above the canyon's floor and extend 70 feet from the canyon's western rim. It is the highest man-made structure in the world, an attraction for sight seeing and a busy landmark.

Grand Canyon, United States

Identifying The Problems & Finding The Solutions

Skywalk was the idea of a businessman, Mr. David Jin. He wanted to provide a unique way for visitors to enjoy the Grand Canyon. Bridging dream and reality, he incorporated an architect and a construction company to assemble over a million pounds of steel. They had to design a structure to stand against gravity load, earthquake and strong winds. In the process, they needed to test the horizontal and the vertical wind speed that could be up to 80-90 miles per hour.

Once the environmental considerations were studied, the next step was to figure out how to suspend a walkway of 4,000 feet above the ground. The ideas started with like a diving board and then an angle structure. Finally, it turned out to be a U-turn in the end.



The U-shaped walkway

How It was Made?

To compliment the arts of this spiritual landscape, there should be no support from above or from below the walkway. Hence, it was a cantilever stretching out from the visitor's centre. That was achieved by mounting bolt spins. Each was 32-inch wide by 72-inch deep bolt spin mounting on the outside and inside of the walkway. Those bolt spins were mounted back to the visitor's centre. There were four holes on the canyon to support the walkway by holding the bolt spins.

Grand Canyon, United States

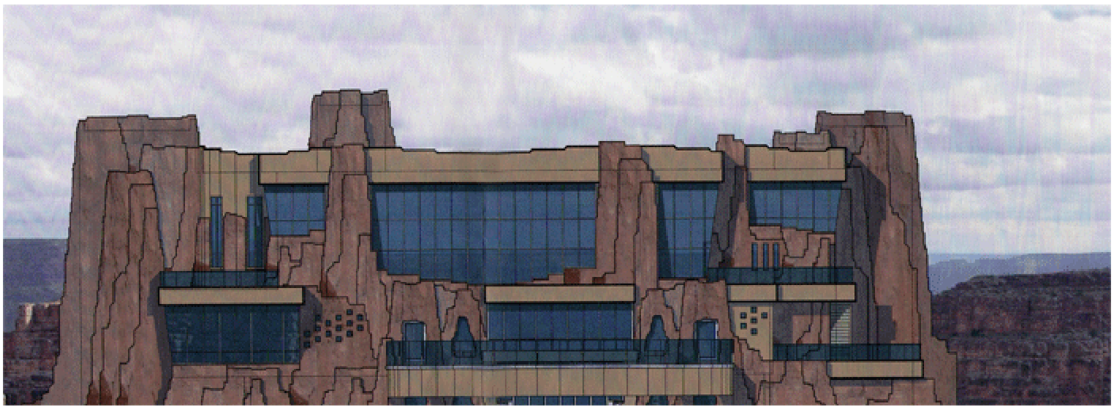
With the glass floor on the walkway, it could offer 720-degree view of the canyon. The glass for the walkway consists of five layers – three layers of 90mm thick, one layer of 6mm thick and one layer of 8mm thick. The glass is designed to hold 70 fully loaded 747 aeroplanes that are 70 million pounds! The walkway also has two mass dampers to prevent quick traffic vibration.

Grand Canyon, United States

Future Developments

The Skywalk facility will also include a 6,000 square-foot visitors' centre on three levels – underground, first story and second story – which will contain a museum, movie theatre, VIP lounge, gift shop, and several restaurants and bars, including a restaurant that will offer outdoor patio and rooftop seating on the edge of the canyon. The second story will be where visitors can access the Skywalk glass walkway. The visitors' centre will also offer private indoor and outdoor facilities for meetings, special events and weddings. You will find more about this spectacular structure in the following website:

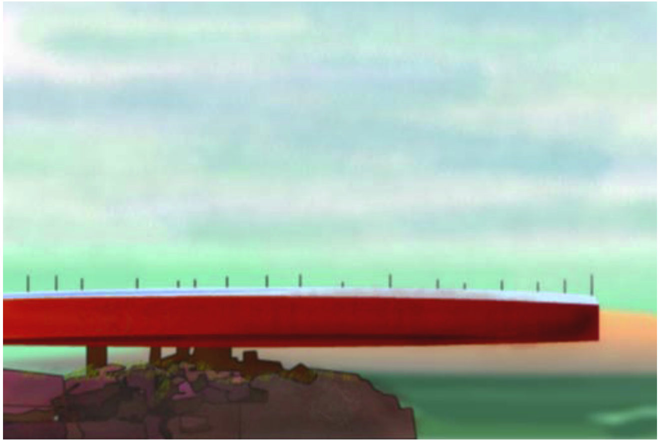
http://www.grandcanyonskywalk.com/



The Visitors' Centre in future

Pros and Cons

Building a tourist attraction has been an *ethical struggle*. Although some people criticise that human-made structures would destroy the natural environment and disturb the life of the local people – the Hualapai tribe. The Skywalk, however, gives a unique opportunity for visitors to experience the nature of Grand Canyon and is an economic development and benefit to the Hualapai. Hope that the development could preserve the view of the Grand Canyon and the legacy of people.



The completed Skywalk

Follow-up Activities

Work cooperatively in groups to carry out the following activities:

1. **Research**

- Find out other details and people's concern of the Skywalk at Grand Canyon.
- Look for other websites to find out about glass walkways designed elsewhere.
- Make a simple sketch of a glass walkway, and name the most important parts. Use notes to explain how each part helps to support the walkway.
- Find out about the properties of toughened/ tempered safety glass and how it is different from common glass. Use the findings to explain why the engineers chose this material for the walkway.

2. **Discussion**

Each member of the group has to be assigned different tasks for which they are responsible. You are required to present your findings and analysis in the group through presentations, debates or other forms of dialogue.

Hollywood Movie Star ─ Product Analysis of Transformer Toy

Introduction

Product analysis is important in assessing whether a product is fulfilling its intended purposes. In carrying out a product analysis, you should consider:

- the function of the product;
- how it works;
- whether it can work properly and is safe;
- whether it can meet its intended needs;
- how it is made, in terms of materials and manufacturing processes; and
- how much will it cost

The following example of product analysis is about transformer toy. Read the information and then carry out your own product analysis.

Background

There are many categories of toys in the market. Amongst which has become very popular is the transformer toy – so called because the basic parts can be re-formed to represent different things. Recently, movie producer in Hollywood presents a wonderful computer-generated animation that is based on a series of transformer toys. (The official website of this movie is http://www.transformersmovie.com/)

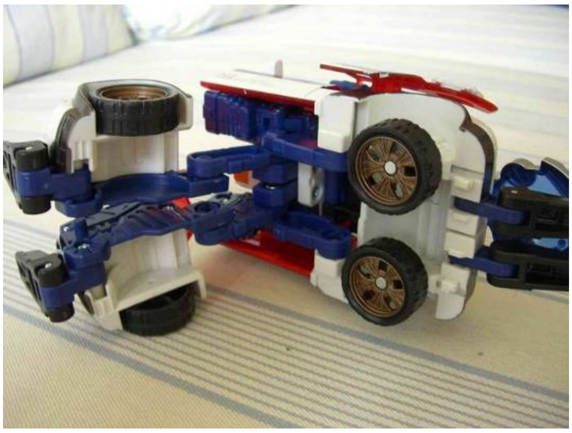
A typical transformer toy, for example, can be changed from a car to a robot by turning parts around and locking them into new positions.

Before transformation, it is a car

After transformation, it is a robot

The Secret

These toys are extremely clever in the way they convert in appearance from one thing to another. It is not widely appreciated, however, that they often involve highly advanced mechanical principles to enable the *transforming* movements to take place.



Linkages and Joints of the Toy

If you examine the joints of transformer toys, it is not always obvious how they work. At first glance, they are as mysterious as the mechanism of a Rubik's Cube. Have you ever wondered how all the parts can be turned around but still remain together as a cube? Sometimes transformer toys can be taken apart for closer examination because the joints are *popped* together. Achieving such close fits between two parts is only possible through moulding to tolerances of less than 0.01mm!

Rubik's Cube

How They Are Made?

Most transformer toys are injection moulded and are examples of high precision injection moulding – an advanced manufacturing method. This is where very high tolerances are achieved so that the parts which come out of different moulds can fit together accurately. In addition, precision injection moulding of components such as gears and other mechanical parts has eliminated the need for more expensively machined metal parts in products such as cameras, and has made these goods much more affordable

Some transformer toys are motorised so that they can move along as cars or perform mechanical movements as robots. This requires even greater design skill, and can compare with the ingenuity that goes into designing other more *serious* consumer products such as cassette recorder, food mixer etc.

Follow-up Activity

Search for and analyse other examples of transformer toys in the market. You can use the following points to help you:

- Identify features of the product that could result in product success.
- Identify materials used and explain why they have been used.
- What manufacturing processes were used? Explain why they were used.
- What are the link between the materials selected and the manufacturing processes used?
- Suggest some quality control checks that could be used to make sure that the product meets its specification.
- Where does your money go?

(Useful website: http://www.anex.com.hk/~hktf)

New Material for Product Design ─ Case Study of Shape Memory Alloys

Background

Shape Memory Alloys (SMAs) are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature. For example, a length of wire can be made to remember that it should be straight at temperatures above 70°C. If you bend this wire at normal room temperature into the shape of a paper clip, it stays bent and will continue acting as a paper clip. However, if you place it in a glass of water whose temperature is above 70°C, it will immediately straightens out! When cool, it remains straight until it is bent again.

This cycle of bending and then straightening when heated can be continued millions of times. The temperature at which SMA *remembers* its original form is called the *transition* temperature and when this point is reached, it changes shape. SMA has a relatively high electrical resistance and can be heated to its transition temperature by passing an electrical current through it.

The Secret

The SMAs have two stable phases – the high-temperature phase, called *austenite* and the low-temperature phase, called *martensite*. In addition, the martensite can be in one of two forms: *twinned* and *detwinned*, as shown in Figure 1. A phase transformation which occurs between these two phases upon heating/cooling is the basis for the unique properties of the SMAs. The key effect of SMAs associated with the phase transformation is *shape memory effect.*

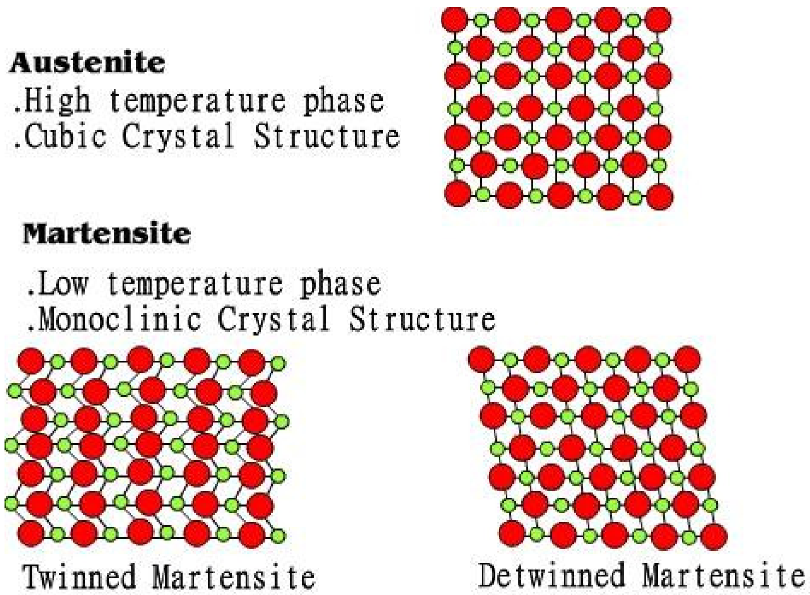


Figure 1 Different phases of an SMA

Upon cooling in the absence of applied load, the material transforms from austenite into twinned (self-accommodated) martensite. As a result of this phase transformation, no observable macroscopic shape change occurs. Upon heating the material in the martensitic phase, a reverse phase transformation takes place and as a result the material transforms to austenite. The above process is shown in Figure 2. Four characteristic temperatures are defined in Figure 2: martensitic start temperature (M^{0s}) which is the temperature at which the material starts transforming from austenite to martensite; martensitic finish temperature (M^{0f}), at which the transformation is completed and the material is fully in the martensitic phase; austenite start temperature (A^{0s}) at which the reverse transformation (austenite to martensite) initiates; and austenite finish temperature (A^{0f}) at which the reverse phase transformation is completed and the material is the austenitic phase.

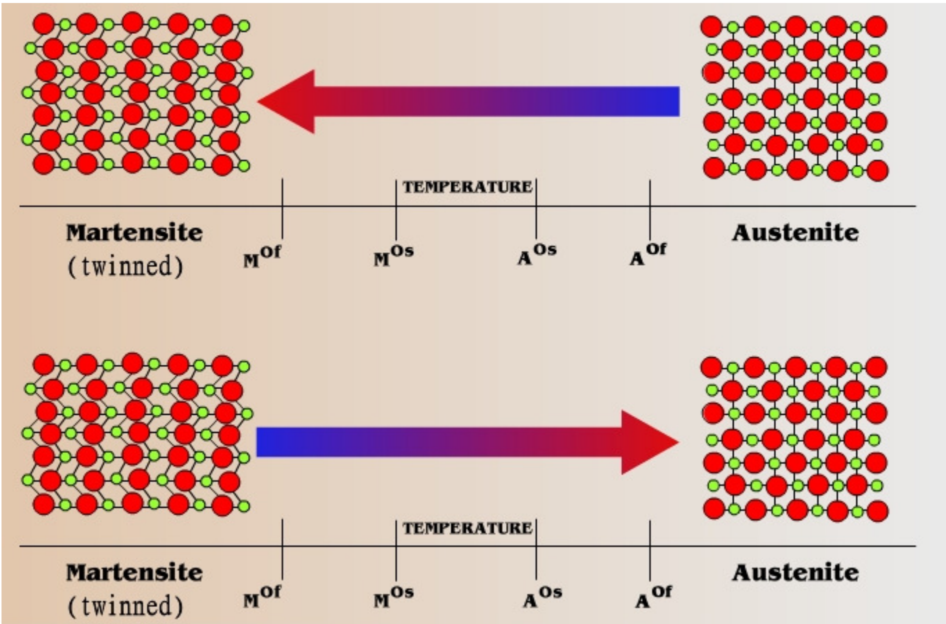


Figure 2 Temperature-induced phase transformation of an SMA without mechanical loading

Shape Memory Effect

If mechanical load is applied to the material in the state of twinned martensite (at low temperature), it is possible to *detwin* the martensite. Upon releasing of the load, the material remains deformed. A subsequent heating of the material to a temperature above A^{0f} will result in reverse phase transformation (martensite to austenite) and will lead to complete shape recovery, as shown in Figure 3. The above described process results in manifestation of the *Shape Memory Effect* (SME).

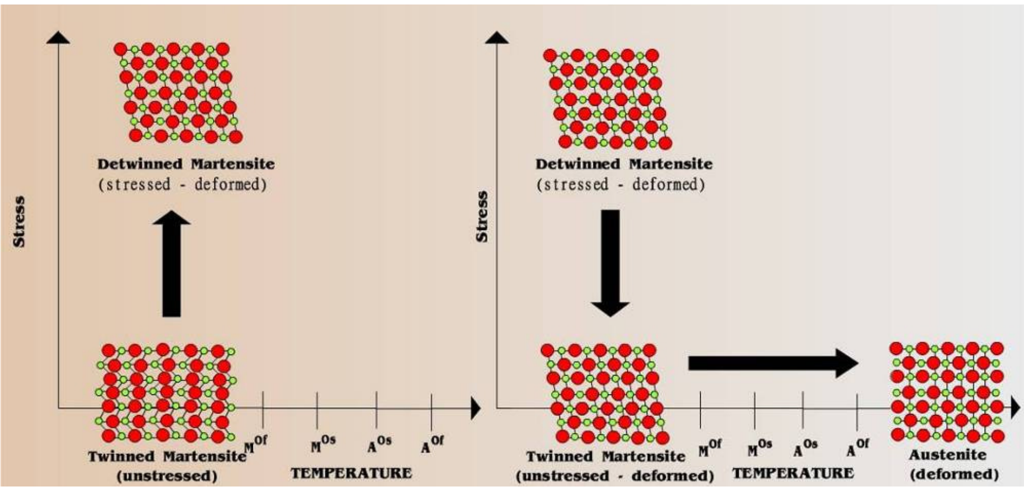


Figure 3 Shape Memory Effect of an SMA

How They are Made?

The three main types of SMA are the copper-zinc-aluminium, copper-aluminium-nickel, and nickel-titanium (NiTi) alloys. NiTi alloys (also known as Nitinol) are generally more expensive and possess superior mechanical properties when compared to copper-based SMAs. A thermoelastic martensitic phase transformation in the material is responsible for its extraordinary properties. These properties include the shape memory effect, superelasticity and high damping capability. The properties of SMAs can be modified to a great extent by changes in alloy composition, mechanical working, and heat treatment. In most cases, a trial and error process is required to optimise these factors for a particular application.

The nickel-titanium alloys were first developed in 1962–1963 by the Naval Ordnance Laboratory. Their remarkable properties were discovered by accident. A sample that was bent out of shape many times was presented at a laboratory management meeting. One of the associate technical directors, Dr. David S. Muzzey, decided to see what would happen if the sample was subjected to heat and held his pipe lighter underneath it. To everyone's amazement the sample stretched back to its original shape.

Applications of SMA

SMA can be used to give a mechanical movement when a set temperature is reached. For example, current applications include:

- seals for hydraulic tubing (which shrink into position)
- electrical connectors
- fire alarm systems – to trigger a sprinkler
- waste bins – to trigger a falling lid if fire occurs
- coffee machines – to open a valve so that hot water falls onto the coffee
- air conditioning units – to move flaps to direct air movement
- shower units – to control hot water control valves

The advantage of SMA in these and many other applications is the fact that it provides large forces and movement at a precise temperature. It is also possible to pre-shape the SMA in different ways – for example as a spring or a flat plate.

Rolls Royce (www.rolls-royce.com) has discovered another use for SMA in their aircraft jet engines. As a way of reducing noise levels of their jet engines, Rolls Royce has designed serrated nozzles for their engines, using SMA. When the aircraft is on the ground or flying at low altitude, the temperature is warmer and the SMA curves inwards. This creates turbulence and reduces the noise of the engines because the sound waves are dispersed. When the aircraft achieves a high altitude, the temperature drops considerably and the SMA is bent out of shape by another layer of metal which has been trained to lie flat. When the aircraft comes into land, the SMA warms up again and returns to its original shape, once more reducing the noise of the jet engines.

What is more, an Italian company, Corpo Nove (www.corponove.it), designs clothes incorporating SMA. They have woven SMA fibres into their shirts. The creases of a shirt can be smoothed out, just by applying hot air with a hairdryer. Even the sleeves roll up when it gets hot!

Follow-up Activity

SMA can be used in many different ways, from clothing to aircraft and even heat-activated switches, so what applications can you think of? Discuss with your classmates and look for other websites to find out more about this smart material for your suggestions.

New Material for Product Design ─ Case Study of Photovoltaic Systems

The focus of this case is about new materials that you are studying in Topic 1.4.

Background

Today, solar-generated electricity serves people living in the most isolated spots on earth as well as in the centre of our biggest cities. First used in the space program, photovoltaic (PV) systems are now both generating electricity to pump water, light up the night, activate switches, charge batteries, supply the electric utility grid and more. Whether you are a student, homeowner, businessman, architect or just someone who pays electric utility bills, PV may already touch your life in some way.

The following points are some interesting facts about PV:

- The most frequently seen application of PV is in consumer products which use tiny amounts of direct current (dc) power, less than 1 watt (W).
- More than 1 billion hand-held calculators, several million watches, and a couple of million portable lights and battery chargers are all powered by PV cells.
- PV is rapidly becoming the power supply of choice for remote and small-power, dc applications of 100 W or less.
- More than 200,000 homes worldwide depend on PV to supply all of their electricity. Most of these systems are rated at about 1 kW and often supply alternating current (ac) power.
- Worldwide production of PV modules includes 50% single-crystal silicon, 30% polycrystalline silicon and 20% amorphous silicon, mostly used in consumer products.

A Brief History

French physicist Edmond Becquerel first described the *PV effect* in 1839, but it remained a curiosity of science for the next three quarters of a century. At only 19, Becquerel found that certain materials would produce small amounts of electric current when exposed to light. The effect was first studied in solids, such as selenium, by Heinrich Hertz in the 1870s. Soon afterward, selenium PV cells were converting light to electricity at 1% to 2% efficiency. As a result, selenium was quickly adopted in the emerging field of photography for use in light-measuring devices.

Major steps toward commercialising PV were taken in the 1940s and early 1950s, when the Czochralski process was developed for producing highly pure crystalline silicon. In 1954, scientists at Bell Laboratories depended on the Czochralski process to develop the first crystalline silicon PV cell which had an efficiency of 4%.

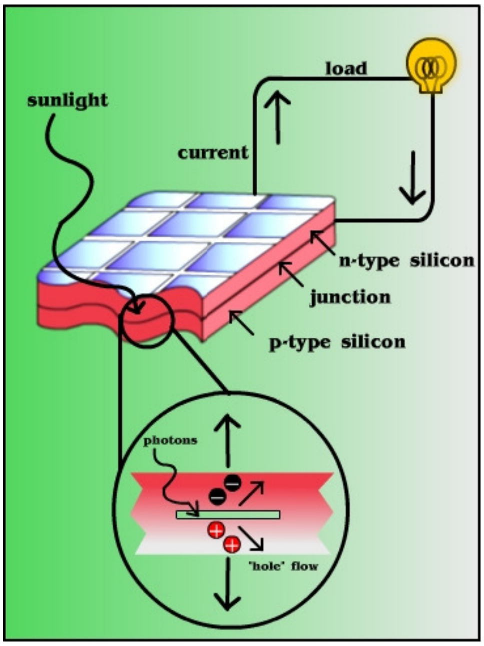
Although a few attempts were made in the 1950s to use silicon PV cells in commercial products, it was the new space program that gave the technology its first major application. In 1958, the U.S. Vanguard space satellite carried a small array of PV cells to power its radio. The cells worked so well that PV technology has been part of the space program ever since. Today, solar cells power virtually all satellites including those used for communications, defence and scientific research.

PV supplies nearly all power for a satellite

Despite these advances, PV devices in 1970 were still too expensive for most everyday uses. But, in the mid-1970s, rising energy costs, sparked by a world oil crisis, renewed interest in making PV technology more affordable. Since then, countries, industries and research organisations have invested billions of dollars in research, development and production. Today's commercial PV systems can convert from 7% to 17% of sunlight into electricity. They are highly reliable and last 20 years or longer. The cost of PV-generated electricity has dropped 15- to 20-fold.

Photovoltaic Effect / Material Properties / How It Works?

PV cells work because of PV effect – certain materials are able to convert light energy into electrical energy. They absorb some of the energy of light and cause current to flow between two oppositely charged layers. Fundamentally, PV cells need to fulfill only two functions: photogeneration of charge carriers, i.e. electrons and holes, in a light-absorbing material, and separation of the charge carriers to a conductive contact that will transmit the electricity to a load. The following diagram shows such process:



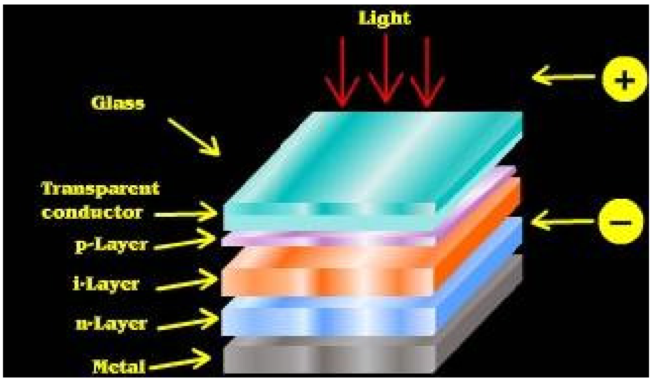
PV Effect

Sometimes, the term *solar cell* is reserved for devices intended specifically to capture energy from sunlight, while the term *PV cell* is used when the light source is unspecified. Individual PV cells provide a relatively small amount of power, but electrical output can be significant when they are connected together in a PV *module* and then a PV *array*. The PV cells, modules and arrays can be connected in series or parallel, or typically a combination, to create a desired peak voltage output.

PV Cell Design

The PV cell is the basic building block of a PV system. Individual cells can vary in size from about 1 cm to about 10 cm across. In general, the PV cells are designed to have an ultra thin (0.008 micron) p-type top layer; a thicker (0.5 to 1 micron) intrinsic (middle) layer; and a very thin (0.02 micron) n-type bottom layer. The top layer is made so thin and relatively transparent that most incident light passes right through it, to generate free electrons in the intrinsic layer. The p and n layers (produced by doping silicon) create an electric field across the entire intrinsic region to induce electron movement in that layer. The following figure illustrates the simplified configuration of a p-i-n PV cell, in which an intrinsic layer is sandwiched between a p-layer and an n-layer:

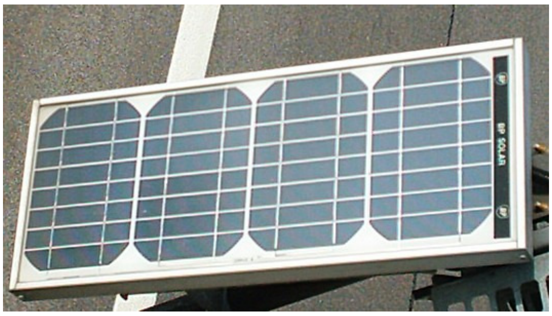
PV Cell



Configuration of a p-i-n PV cell

Design of a PV System

An individual PV cell typically produces between 1 and 2 W, hardly enough power for the great majority of applications. But we can increase the power by connecting cells together to form larger units called modules. Modules, in turn, can be connected to form even larger units known as arrays, which can be interconnected for more power and so on (see the pictures shown below). In this way, we can build a PV system to meet almost any power need, no matter how small or great. Modules or arrays, by themselves, do not constitute a PV system completely. We must also have structures on which to put them and point them toward the sun, and components that take the dc electricity produced by the modules or arrays and condition the electricity so it can be used in the specific application.



PV Module

PV Array

PV Applications

Generally, PV applications are grouped into the following categories:

(I) Simple PV Systems

The same sunny days that dry out plants, make animals thirsty, and heat up buildings and cars are also good days for generating electricity with photovoltaics. This electricity can be used to power water pumps for irrigation and drinking wells, and ventilation fans for air cooling. For this reason, the simplest PV systems use the dc electricity as soon as it is generated to run water pumps or fans. These basic PV systems have several advantages for the special jobs they do. The energy is produced where and when it is needed, so complex wiring, storage, and control systems are unnecessary. Small systems, under 500 W, weigh less than 68 kg, making them easy to transport and install. Most installations take only a few hours. And, although pumps and fans require regular maintenance, the PV modules require only an occasional inspection and cleaning.

(II) PV with Battery Storage

Storing electrical energy makes PV systems a reliable source of electric power day and night, rain or shine. PV systems with battery storage are being used all over the world to power lights, sensors, recording equipment, switches, appliances, telephones, televisions and even power tools. PV systems with batteries can be designed to power dc or ac equipment. People who want to run conventional ac equipment add a power conditioning device called an *inverter* between the batteries and the load. The following picture shows a garden lamp powered by a PV system with battery storage:

PV powered garden lamp

PV systems with batteries operate by connecting the PV modules to a battery, and the battery, in turn, to the load (e.g. LED). During daylight hours, the PV modules charge the battery. The battery supplies power to the load whenever needed, e.g. during the night. How much electricity can be used after sunset or on cloudy days is determined by the output of the PV modules and the nature of the battery bank. Including more modules and batteries increases system cost, so energy usage is carefully studied to determine optimum system size.

(III) PV with Generators

When power must always be available or when larger amounts of electricity than a PV system alone can supply are occasionally needed, an electric generator can work effectively with a PV system to supply the load. During the daytime, the PV modules quietly supply daytime energy needs and charge batteries. If the batteries run low, the engine generator runs at full power – its most cost- and fuel-efficient mode of operation – until they are charged. And, in some systems, the generator makes up the difference when electrical demand exceeds the combined output of the PV modules and the batteries.

Systems using several types of electrical generation combine the advantages of each. Engine generators can produce electricity anytime. Thus, they provide an excellent backup for the PV modules, which produce power only during daylight hours, when power is needed at night or on cloudy days. On the other hand, PV operates quietly and inexpensively, and it does not pollute. Using PV and generators together can also reduce the initial cost of the system. If no other form of generation is available, the PV array and the battery storage must be large enough to supply night time electrical needs. However, having an engine generator as backup means fewer PV modules and batteries are necessary to supply power whenever it is needed.

(IV) PV Connected to Utilities

Where utility power is available, a grid-connected PV system can supply some of the energy needed and use the utility in place of batteries. Some homeowners, considered pioneers in the energy field, are using PV systems connected to the utility grid. They are doing so because they like that the system reduces the amount of electricity they purchase from the utility each month. They also like the fact that PV consumes no fuel and generates no pollution.

The owner of a grid-connected PV system cannot only buy, but can also sell, electricity each month. This is because electricity generated by the PV system can be used on site or fed through a meter into the utility grid. When a home or business requires more electricity than the PV array is generating (for example, in the evening), the need is automatically met by power from the utility grid. When the home or business requires less electricity than the PV array is generating, the excess is fed (or sold) back to the utility. Used this way, the utility backs up the PV like batteries do in stand-alone systems. At the end of the month, a credit for electricity sold gets deducted from charges for electricity purchased.

(V) Utility Scale Power

Large-scale photovoltaic power plants, consisting of many PV arrays installed together, can prove useful to utilities. Utilities can build PV plants much more quickly than they can build conventional power plants because the arrays themselves are easy to install and connect together electrically. Utilities can locate PV plants where they are most needed in the grid because situating PV arrays is much easier than situating a conventional power plant. And, unlike conventional power plants, PV plants can be expanded incrementally as demand increases. Finally, PV power plants consume no fuel and produce no air or water pollution while they silently generate electricity.

(VI) Hybrid Power Systems

Hybrid systems combine a number of electricity production and storage pieces to meet the energy demand of a given facility or community. In addition to PV, engine generators, wind generators, small hydro plants, and any other source of electrical energy can be added as needed to meet energy demands and fit the local geographical and temporal characteristics. These systems are ideal for remote applications such as communications stations and rural villages.

Essential to developing a hybrid electric system is knowing the energy demand to be met and the resources available. Therefore, energy planners must study the solar energy, wind and other potential resources at a certain location, in addition to the planned energy use. This will allow them to design a hybrid system that best meets the demands of the facility or community. Following pictures show a hybrid electric system, including PV array and wind generator, which provides power for a street light in Ma Wan Park:

Hybrid powered street light in Ma Wan Park

Follow-up Activity

Now you know that PV cells have many applications. They have long been used in situations where electrical power from the grid is unavailable, such as in remote area power systems, Earth-orbiting satellites and space probes, consumer systems, e.g. handheld calculators or wrist watches, remote radiotelephones and water pumping applications. More recently, they are starting to be used in assemblies of PV modules and arrays connected to the electricity grid through an inverter. Furthermore, PV cells are regarded as one of the key technologies towards a sustainable energy supply.

Discuss with your classmates and look for different sources to find out more about photovoltaics, and then perform the following tasks:

1. Sketch and explain any other devices that are powered by PV cells you have seen or used.
2. With the aid of diagrams and notes, design a new or existing device that can be powered by PV cells/modules/arrays (fully powered or as a backup to the electricity power grid).

New Material for Product Design ─ Product Analysis of Racket

Introduction

Product analysis is one of the early sections in the design process. It involves listing as many questions as you can think of regarding your design project. The questions will vary from project to project but usually the majority of these questions are the same, whatever the project you are attempting. The following example of product analysis is about a common sporting equipment – Racket. Read the information and then carry out your own product analysis. The other focus of this task is about new materials that you are studying in Topic 1.4.

Background

Materials technology has played a vital, lately controversial role in the history of the game, especially during the modern era with the advent of powerful composite rackets. However, while the likes of Andre Agassi could beat most of us using a tea tray, for the average player modern rackets offer a range of benefits, such as oversized sweet spots and efficient vibration damping, that make the game hugely more attractive. In fact, new technology could lead to the effective elimination of vibration.

Andre Agassi at the US Men's Clay Court Championship

The area where new materials have made rapid inroads is sports equipment. Led by the competitive world of professional sport there is a high premium on performance, and the manufacturers, eager to have their equipment used by top professionals, constantly experiment with new materials.

Selecting the Right Racket / Material

The original rackets were made of laminated wood and strung with natural gut. The wooden frames were limited in stiffness and strength although they had good dampening properties. It was not until the late seventies that materials technology has developed sufficiently to offer viable alternatives. The key requirements of a good racket are strength and lightness. Other factors such as stiffness and shock absorption also need to be considered.

(I) Wooden Racket

The very first rackets were made from solid sections of woods such as ash, maple, etc. However, the anisotropic nature of these materials necessitated a change in racket construction to a laminated structure, which allowed the stiffness and strength of the racket to be increased in directions both parallel and perpendicular to its main axis. Although adopting laminates significantly increased racket performance, the problem of water absorption, resulting in pronounced warping in the structure and therefore variable performance, persisted.

(II) Aluminium Racket

In the 1970s, metal frames became feasible with the development of improved light alloys. Aluminium alloys are most common but alloys of magnesium have also been used. Aluminium frames offering increased stiffness and reduced mass enjoyed a brief period of success. They are competitively priced but the relatively poor vibration damping properties mean they are not liked by top players. The rackets are made from extruded or drawn tubing appropriately shaped (refer to Topic 2.1), with a separate *throatpiece* fitted. In the market, they usually cost less than $ 500.

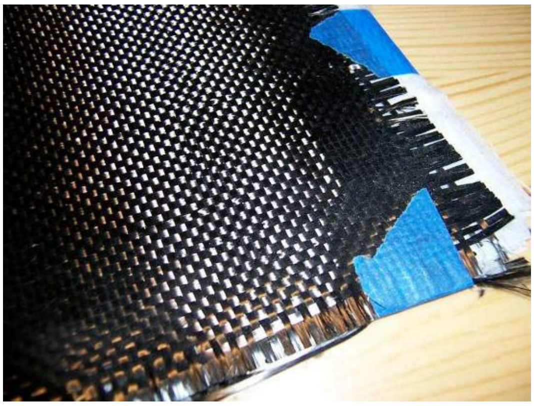
Racket made of aluminium alloy

(III) Fibre Reinforced Composite Racket

Towards the end of the decade, new continuous fibre composites were introduced that rapidly superseded aluminium as a frame material. The first of these composite materials consisted of glass fibres held within a polyester resin matrix, and later rackets went on to encompass various grades of carbon fibres within epoxy resin matrices. Most professional players now use rackets with composite materials of which there are many different types. Currently, the best performance rackets are the ‘graphite’ which use carbon fibres and always cost more than $700.

Racket made of carbon fibre composite

The short-lived success of aluminium has been attributed to a number of factors. Both glass and carbon fibre composites have a higher specific stiffness than aluminium, so rackets made from composites can be much lighter, particularly in the case of carbon fibre. Continuous fibres can be woven into a variety of weave styles, giving increased control of the racket's characteristics. For example, unidirectional fibres are incorporated along the main racket axis for high bending stiffness, and 0/90° weaves are stacked at ±45° for high shear strength and stiffness, (see the picture shown below). A variety of fibre grades are used, each with different levels of strength and stiffness. These fibres are coupled with epoxy resin matrices that often contain one or more property modifiers, such as rubber particles and thermoplastics that increase the toughness of the resin.



A cloth of woven carbon fibres

On top of these advantages, the fatigue performance of the composite rackets was superior to aluminium constructions. Tests on aluminium rackets have shown that a marked decrease in stiffness occurs at around 6000 impacts, compared with a change in stiffness for carbon fibre rackets of around 4% after 50,000 impacts. Another important factor in decline of aluminium rackets was the comparative damping properties of the frame materials, aluminium has a lower damping capacity than composite materials, and this has implications for the health of players. It will be discussed in next section.

Design Considerations

(I) Damping Properties

The damping properties of a racket's frame are extremely important. When a ball hits a racket, resonant modes are excited within the frame and strings, and these modes are felt by the player as vibration through the handle. The level of vibration perceived by the player depends on several factors. For instance, the modal response of a racket depends on whereabouts on the racket face the impact occurs. There is an area on the strings known as the ‘sweet spot’ in which the modal density is low. A ball striking this area excites few modes and the player perceives little vibration. However, if a ball hits outside this region, the resulting frame vibration is significantly increased, and the degree to which these vibrations are transmitted to the handle of the racket is then determined by the damping capacity of the frame materials.

(II) Tennis Elbow

If too much vibration is transmitted from the handle to the hand and arm of the player, the painful condition known as lateral epicondylitis or ‘tennis elbow’ often results. Tennis elbow affects around 45% of people who play regularly and is a particular problem for beginners who often find striking the ball with the sweet spot more difficult. Hitting with areas other than the sweet spot, where the modal density is higher, has the effect of increasing the amount of vibration transmitted to the hand which tightens its grip on the racket's handle to compensate and worsen the problem.

Due to the low damping capacity of aluminium, players using aluminium rackets in the 1970s experienced a high transmission of vibration to their hands and arms, and the number of reported cases of tennis elbow increased. Both glass and carbon fibre composites exhibit higher damping capacities than aluminium and in the case of epoxy resin matrices, the rubber toughness modifiers further increase the damping.

How They are Made?

There are two manufacturing methods used in making fibre reinforced composite rackets: Injection Moulding and Compression Moulding (refer to Topic 2.1). These use different types of materials and produce rackets with different properties. The injection moulding method uses chopped fibres in a matrix of nylon. This produces a racket with better vibration damping properties than the compression moulded ones which formed by long fibres in an epoxy resin matrix.

Carbon fibre composites came of age in the aerospace industry. Their true worth was recognised many years ago when aerospace engineers saw the weight savings that could be made compared with traditional materials like metals. Following table illustrates this quite clearly by showing the structural efficiency of a variety of materials that might be used in bending and compression (as in a strut).

Material	Young’s Mod E (GNm^{-2})	Density ρ (gcm^{-3})	Spec. Stiffness E/ρ	√E/ρ
Steel	210	7.8	26.9	5.2
Titanium	120	4.5	26.7	5.2
Aluminium	73	2.8	26.0	5.1
Carbon Fibre Composite	138	1.6	86	9.3

The efficiency of various materials in different roles

Why use Carbon Fibre Composites?

Referring to the table shown above, it will be noted that for the majority of traditional structural materials – steel, titanium, aluminium the specific stiffness (E/ρ) is constant, whereas carbon fibre composites offer far higher efficiencies for stiffness or deflection critical structures. When carrying a compression load, as in a column, the efficiency of the structure is governed by $\sqrt{E}/\rho$ and here again the benefit of using carbon fibre composite materials is demonstrated.

While the basic stiffness of steel is far greater than carbon fibre composites, the massive weight saving that can be made by using the material provides a tremendous driving force to choose carbon fibre composites. No matter which metal is chosen for use, the specific stiffness (Young's modulus divided by specific gravity) of all metals remains stubbornly fixed at 25-26 GNm^{-2}. It is not until we look at ceramics and high performance fibres that this barrier can be broken. And with a specific stiffness of at least 86 GNm^{-2}, it is easy to see why aerospace engineers wanted to take full advantage of this so-called *wonder* material. Fortunately, with the increasing demand for carbon fibre composites, the price has steadily declined over the years with increasing applications in the sporting goods area and more general engineering industries.

The combination of harsh performance demands, materials with high specific properties and competitive manufacturing techniques suited to both low and high volumes will ensure the growth of advanced carbon fibre composites.

Follow-up Activities

(I) Carbon fiber is most notably used to reinforce composite materials, particularly the class of materials known as Carbon Fiber Reinforced Plastics (CFRP). This class of materials is used in sporting equipment such as the subject of this analysis – racket or racing bikes, aircraft parts, wind generator blades and gears, and other demanding mechanical applications. Moreover, carbon fiber composite is one of the leading materials used in Formula One car production since the introduction of the fiber into common commercial use in the early 1980's. Research one of the following products:

- New Boeing 787 plane with wings made of carbon fibre composite
- Yacht with carbon fibre reinforced steering wheel and wind transducer
- Racing car with carbon fibre composite car body

(II) The analysis questions below may be useful especially if you adapt them to suit your current design project:

1. What are the functions of the product?
2. Will the design be safe?
3. What special features need to be built into the designs?
4. What 'ergonomic' factors need to be taken into account?
5. What materials are available?
6. What materials will be the most suitable?

7. How will the product be mass produced?
8. What equipment and machinery are need for manufacture?
9. What designs already exist? Could they be improved?
10. Who is going to buy the product?

Do any of the analysis questions listed above *not* apply to your project? If so, why? Can you think of any more relevant questions that apply to your product analysis?

ASSESSMENT TASKS

Design and Make Activity

Open-Day Gift — Project Guidelines

Design Brief

Your school principal / DAT teacher has asked you to design and make a number of "magnetic" memo holders (for the door of a refrigerator) that can be given away as gifts to the visitors in the coming school Open Day. These are to be identical products made from injection moulding with a moulded-in magnet like the items shown below.

Such open-day gifts will be dispensed from a capsule toy vending machine installed in the DAT Studio. You can learn more about "Capsule Toy" from the Information Sheet 1.

Design Considerations

The size of your product should not exceed 30 mm x 50 mm and not be thicker than 5 mm. You may design the form of the product, but it must be kept simple and should suggest an activity related to school or DAT.

First, you need to draw up a list of design specifications for your moulded product. Such list should fully describe what your product will be like, what it will do, and who will use it. Here are some questions to help you produce your specifications:

- Who are the gifts for?
- What theme will you use for the design?
- What will be the overall size of the gift?
- What colour should the gift be?

Before you can start your design work, you need to know what materials and equipment are available. To manufacture the product, you need to fabricate either a *wire outline* or a *laminated* mould. Information Sheet 2 will guide you through each of these two options. You will work with hot-melt glue as the moulding material and a glue gun as the injection moulding machine/ equipment.

Design Proposals

Having considered what is available to make it, you need to think about ideas for the gift and the mould. Suggested steps are as follows:

- set your ideas down on the worksheet;
- decide which is the best design with your classmates and/ or DAT teacher;
- prepare a detailed full-size working drawing of your design on drawing/ graph paper; and
- This final drawing is a working drawing, i.e. a drawing that you work from to make the mould.

While generating design proposals, you should also consider the feasibility of mass production of your design in an industrial environment. Please see Topic 2.2 for references.

Manufacturing in Quantity

If you wish to make more than one moulding – e.g. as part of a mini-enterprise activity (an extended activity) – you need to think about the manufacturing process. If it takes you 4 hours to make a moulding, it should be possible to make 10 identical moulding in far less than 40 hours. This is because once the injection mould has been made; it is a relatively fast to repeat the actual injection process.

Injection moulding is capital intensive. It is relatively costly and time consuming to make moulds. However, once the mould has been produced, it can soon pay for itself by producing thousands of mouldings! Think about setting up a production line for your design with the help of your classmates. You can use *block diagram* or *flow chart* to illustrate your production line on the worksheet. For details, read the Information Sheet 3.

Quality Checking

Checking for quality is very important when products are manufactured in quantity because a manufacturing fault could be repeated many times. You need to check your first moulding very carefully for any defects. If you are producing a batch of identical mouldings, check one or two at random to ensure they remain consistent. Repair the mould and/or modify the working procedure if the quality is poor. Write the defects found and the suggestions for improvement on the worksheet. Please refer to Topic 2.3 for details.

Evaluating Your Work (Mould and Moulding)

There are a number of things to consider when evaluating the success of your work. Here are some questions to help you evaluate your work:

- Was the mould successful and did it enable you to make what you intended to?
- Does the moulding meet the requirements of the brief and your specification?
- What do you estimate the moulding cost to make? How much would it cost to make ten as opposed to just one?
- Check your product against the competition by comparing quality, unique features, possible selling price, etc.

Open-Day Gift — Information Sheet 1 – Capsule Toys

Introduction

Capsule toys, also referred to as "Gashapon" in Japanese, are very popular in Hong Kong nowadays. Each capsule toy can cost from $5 – 10, and you can find capsule toy vending machines at the entrances of toy stores, supermarkets, 7-Eleven shops as shown in the figure below. It is an economical alternative to capitalize the consistently growing children's market. Kids cannot resist such machines that delight them with attractive outlook and a fun toy surprise.

Capsule Vending Machines

The Toys

Capsule toys are usually produced from high-grade plastics, and contain lots of moulding parts and carefully painted features like the figure shows below. However, these are not ordinary toys: they are rare collector's items which can fetch to extremely high prices.

Capsule Toys

The designs of such toys are often based on popular characters from video games, animations or comic books. These highly detailed toys are based on popular culture icons which have a large population of children and adults in Japan, and this trend is radiating to Hong Kong together with other popular culture influences.

Collections and Sets

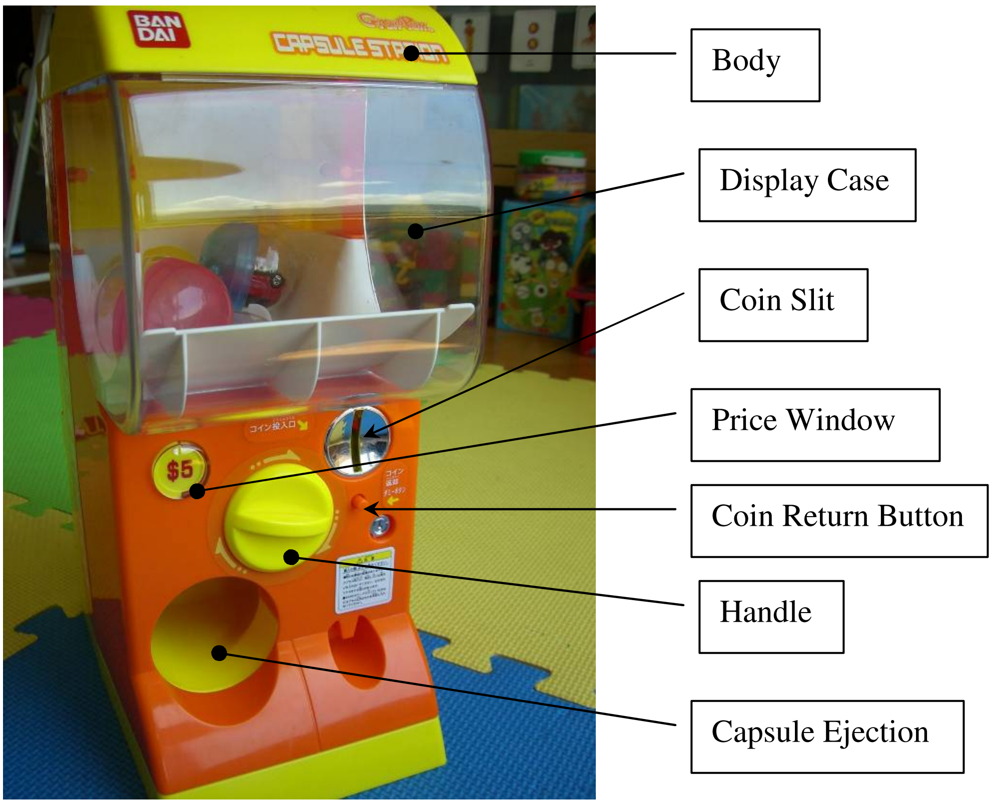
Virtually, all capsule toys are released in sets – each series will have a number of toys/ figures to collect. They are, by nature, a “blind purchase”; people insert coins and hope to get the toy or figure they desire. It may become frustrating, as one keeps getting the same toy or figure repeatedly. Most collectors will buy whole sets from toy stores in places such as Mongkok or Shamshuipo. These sets are usually cheaper to buy from stores than trying one’s luck from vending machines.

The Vending Machine

A typical capsule toy vending machine usually has the following specifications:

- Multi-coin operating mechanism
- Attractive display unit showing capsules inside
- ABS body in eye-catching colour(s)
- Stackable with other vending machines
- Holding approximately 60 capsules
- Coin return button

The following figure shows the main parts of a capsule toy vending machine:



Open-Day Gift — Information Sheet 2 – Injection Moulding (in School)

Introduction

Large industrial injection moulding machines (see Topic 2.1 for references) are expensive and not common in schools. Glue guns are sometimes used as injection moulding "machines" in a school environment. Heat in the glue gun melts the glue stick through its barrel and squeeze out a sticky fused adhesive at the front nozzle.

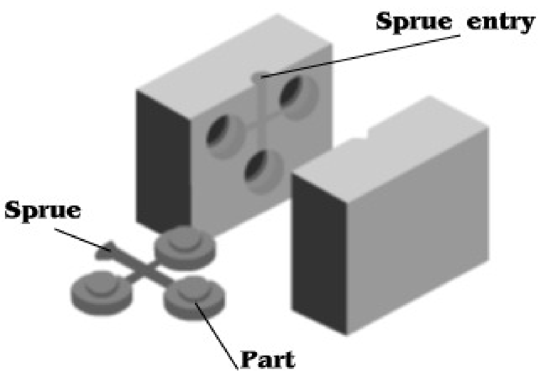
Glue Gun

Glue guns are not designed for injection moulding, but they can be used as a substitute to make precise identical mouldings if the hot-melt glue material is suitable for the product you want to make (i.e. the gift). Hot-melt glue stick is now available in a range of bright colours and although it is a flexible material, its properties are suitable for some moulded products.

Injection Mould for Industrial Use

An injection mould has to be made of steel precisely so that its parts fit exactly, and be well finished because the surface of the moulding is a "mirror image" of the mould surface. Any imperfection or tool mark at the surface will show on the product. Large moulds for products such as dustbins or television cases cost a lot of money to make. Much of the cost results from getting a good finish from the mould, see figures below.

Steel mould with good surface finish



A mould for making toy car wheels

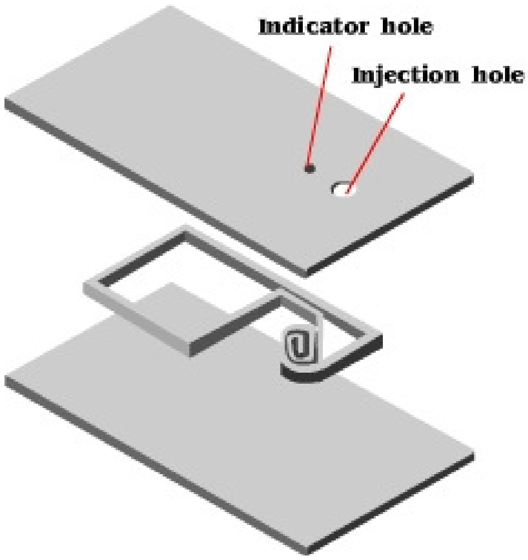
Moulds that you can make in school

There are two types of moulds that can be made quite easily in DAT room:

- wire outline mould (for simple 2-D shape); and
- laminated mould (for 3-D form).

(I) Wire Outline Mould

A wire outline mould uses a metal wire (for example, 3 mm wide by 1 mm thick) which is trapped between two metal plates to form a *cavity*. The molten plastic (i.e. the fused glue) is injected through a (injection) hole on one side of the plates. A smaller (indicator) hole near the injection hole is used to indicate when the mould is full, Figure below.

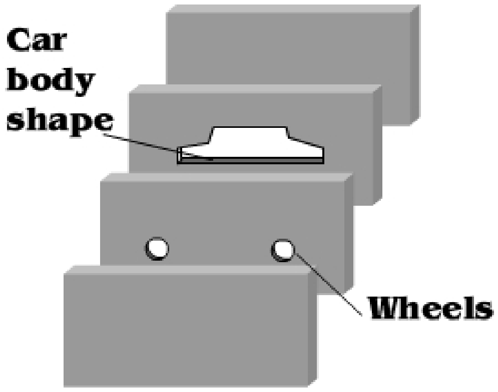


Explored view of a wire outline mould

Wire outline moulds can be made in a matter of minutes but their use is limited to moulding flat shapes. Also, since plastic shrinks on cooling, a *sunken place* appears where the molten plastic has been injected. Either this is accepted, or the wire shape has to be formed to allow for a *sprue* that can be cut off the final product.

(II) Laminated Mould

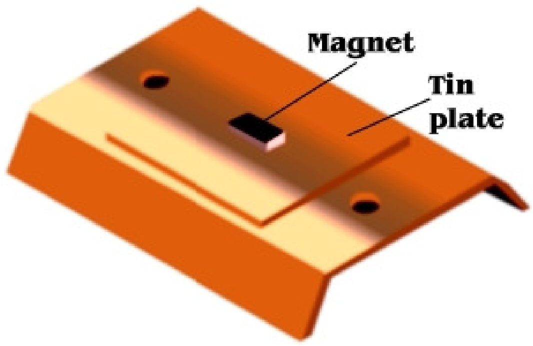
A laminated mould consists of three or more plates clamped together. In a three-plate mould, the centre plate is cut out so that when it is sandwiched between the other two plates, a cavity is formed. In laminated moulds, more than one cut-out plate can be used so that a complex form can be built up. The following figure shows the laminated mould for making a car-like *key fob*. One of the middle plates has two holes drilled in it to form wheels of the car.



Explored view of a laminated mould

Simplified Insert Moulding

One way of attaching your product to a refrigerator door is to incorporate a small magnet within it. When something like this is moulded in and trapped, the process is known as "Insert Moulding", Figure below.



Insert Moulding

You can buy ready-made magnetic plastic sheet as your raw material/ component. However, the plastic-covered strip used for magnetic wall planners can also be used for insert moulding. The strip can be cut into lengths of about 15 mm; and one of the pieces is put into the mould, as shown in the figure below, before the plastic is injected. The molten plastic will flow around the magnet and will be stuck securely on it after hardening.

Working Procedure

When the mould is ready, follow the procedure listed below to mould your product:

1. Both inner sides of the mould should be sprayed lightly with silicon release agent which will prevent the molten plastic sticking to surfaces.
2. The mould is put into position and tightened with the use of jig and fixture.
3. Place the nozzle of the glue gun into the injection hole and extrude fused glue by repeatedly pressing the trigger.
4. When the cavity is full, a small spot of glue appears in the indicator hole, you should stop injecting glue at this point.
5. The mould conducts heat away from the plastic inside very quickly, so it can be opened a few seconds later. However, if a large quantity of plastic is injected, the mould will get very hot and may need to be cooled in water before opening.

Open-Day Gift — Information Sheet 3 – Production Line Simulation (A Mini-enterprise Activity)

Introduction

In this hands-on activity, you will work together in groups of 8 to 10 on a simulated production line if you are working in the manufacturing industry. Besides applying the knowledge of several topics in this module, you need to utilize the knowledge and skills gained in the compulsory part. This activity is part of the design project "Open-day Gift". You may refer to the project guidelines for details.

You are going to simulate the manufacturing of capsule toys that will be sold in the coming school open-day. You will work for the DAT department which produces the toys. Your team will have a budget for the raw materials, equipment and other expenditures for manufacturing and assembling the parts to produce the products. You may also include the expenditure for the manpower used in the budget.

You will need to carry out market research about your product, such as personal interviews, focus group discussion or a number of surveys. The target audience includes the potential customers and "experts" in the industry. Plan a strategy to get all of the information you need.

Capsule Making

Capsule is an optional product in this design project "Open-day Gift". The main product is the toy inside the capsule. You can find the production method of making the toy on Information Sheet 2. There are two types of capsules that can be made in DAT room settings:

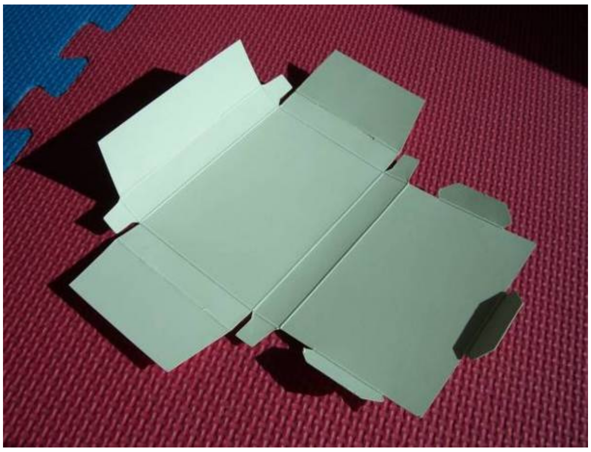
(I) Vacuum formed capsule

You can use a vacuum former to produce the two halves (semi-spheres) of a capsule with transparent or colour sheet plastic. After finishing the edges of the mouldings, you can make a complete the capsule by joining the two halves together with cellulose tape. Remember that the mould required for forming could comprise more than two halves of a capsule!

Capsules

(II) Folded-up capsule

A folded-up capsule is in the form of a card/ plastic box. First, you could draw the surface development of your capsule manually or using CAD software. After that, you could cut out the shape manually or using CAM equipment, e.g. colour plotter/cutter; laser cutter, from a piece of card or sheet plastic. Finally, fold up the cut-out to form your capsule.



An example of folded-up paper box

Depending on your school resources and facilities, you can design and make your own capsules in other ways. Generate ideas of your capsule on the worksheet.

Scaling Up Production

More than 500 visitors will come to your school on Open Day. The DAT department asks you to set up a production line to manufacture numerous capsule toys in for the Open-day gifts. When you need to make more than one product, say 100 capsules, you need to consider:

- How many capsules could you sell?
- What is the price?
- What is the cost?
- Will you make it the same way as you did for the *one-off* product (i.e. the prototype)?
- Will you use the same material?
- Will you use the same equipment?
- Do you need a jig or a special tool?
- Will you work to the same tolerances?

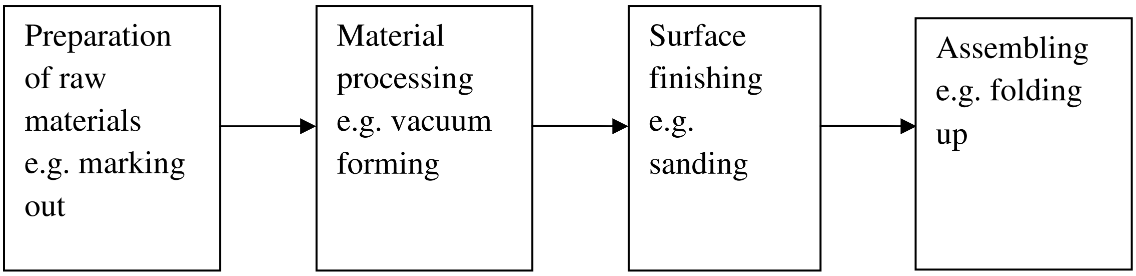
Answer the above questions and then write down your design specifications on the worksheet prepared by teachers.

Production Planning

Before setting up your production line, you have to list out the tasks for manufacturing the product and put them in the correct order. Afterwards, you need to identify the tasks that could be done at the same time. Use this information to work out a production plan for your product on the worksheet prepared by teachers. Remember to include the ordering and delivery times for raw materials and components which are bought in. The following tools are useful for formulating your production plan:

- Flow chart
- Block diagram
- Critical path network

For your reference, a simplified block diagram showing the work flow of making a capsule is shown below:



For each stage of production, you need to consider:

- the best approach to accomplish the task;
- the equipment and materials required;
- the time taken for the task; and
- the quality check point and the feedback to be collected.

Team Assignments

Having made a capsule toy by the workers, it will have to be checked by the inspector. If accepted, it is passed on to the sales person. The sales person then sells it to the customer for an amount not more than $10. At the end, the accountant will add everything up and see if you have made a profit. To start with, we suggest that your team has the following types of employee:

TYPE OF EMPLOYEE	DUTY	NO. OF EMPLOYEES
Supervisor	You are in charge of the team, and you may assign the jobs of your employees. However, you cannot hire or fire anyone. You have to complete the **Materials Checklist** (see sample) daily during the production period. You can seek the advice of your teacher who is leading this simulation if you wish.	1
Accountant	You must keep a record of all *money* received and paid by your team, on the **Accounting Sheet** (see sample). Your team will receive income on the sale of completed toys, up to $10 for each.	1
Former/ Folder	*For vacuum formed capsule:* You operate vacuum former to produce formed halves of a capsule. *For folded-up capsule:* You make neat and straight folds down all the dotted lines of a card/ plastic cut-out.	1-2
Cutter	*For vacuum formed capsule:* You cut out the formed halves of a capsule from the sheet plastic. *For folded-up capsule:* You cut out the shape of a capsule manually or using a CNC machine, e.g. a laser cutter or a colour plotter/cutter.	1-2
Assembler	*For vacuum formed capsule:* You put the toy into one of the two halves of a capsule and then seal them to form a capsule with cellulose tape. *For folded-up capsule:* You fold the cut-out round the toy to form a capsule and seal it with cellulose tape if necessary.	1-2
Inspector	You examine the finished capsule toys as they are produced. If you think they are satisfactory, pass them to your salesperson, making a note on your **Inspection Record** (see sample). If you think they are not satisfactory, pass them back to your supervisor so that the faults you have spotted can be noted. Note any faults on your Inspection Record.	1
Salesperson	You take the capsule toys to the customers, i.e. the visitors to your school, as they are produced and get the best possible price for them. A perfect one is worth $10. Fill in the **Sales Record** (see sample) and submit it to your accountant at the end of the day.	1

Materials Checklist (Sample)

Group No.__________________		**Date ____________________**	
ITEM	IN STOCK	QUANTITY USED	BALANCE
1. Sheet Plastic			
2. Cardboard			
3. Cutter			
4. Cellulose Tape			

Accounting Sheet (Sample)

Group No.____________		**Day 1 / 2**	
	n = no. of items	*t = time spent*	
(i)	INCOME: Total value of toys sold		$__________
(ii)	COSTS/ PAYMENTS: - sheet plastic - card - tools and equipment - power supply - packaging materials - others		$__________
(iii)	WAGES: Time-based or item-based calculation		$__________
(iv)	TOTAL COST: Costs plus wages	(ii) + (iii)	$__________
	PROFIT: Income minus total cost	(i) - (iv)	$__________

Inspection Record (Sample)

Group No.____________________		Date ______________________	
BATCH	PASS	FAIL	FAULT FOUNDED
1st. (Item 001 - 010)			
2nd. (Item 011 - 020)			
3rd. (Item 021 - 030)			
4th. (Item 031 - 040)			

Sales Record (Sample)

Group No.______________		Day 1 / 2	
TIME	NO. OF ITEMS SOLD	INCOME	REMARK
9:00 – 10:00			
10:00 – 11:00			
11:00 – 12:00			
12:00 – 13:00			

Design Projects

Project 1: Attachment for a ladder to support maintenance tools, equipment and materials

When working from a ladder carrying out maintenance of a house, there can be problems in handling of tools, equipment and materials while retaining balance and safety.

Investigate a range of tools, equipment and materials that are used when repairing a house. Design and make a device which can be attached securely to a ladder to store/support a variety of items to be used. You must ensure that the device can be fitted to ladders of various sizes.

Project 2: Display system

Displaying examples of students' work enhances the school environment and provides an area of interest for parents, teachers and students.

Investigate the knock-down fittings found in the market. With use of knock-down fittings, design and make a system for displaying students' work in the school entrance. Your product should be easily moved or adapted to cater for different demands.

Project 3: Monitor Stand

You are a designer and have been commissioned to produce a set of display stands for a company. Each stand should be able to support a display monitor at a height of 2m, so that the promotional video can be seen easily.

The main constraints are:

- Advertising area is very expensive.
- The structure must be absolutely safe (a falling monitor is very dangerous).
- The stand should project the image of the company and be smart and stylish.
- The product needs to be portable; the company would like to pack up and move it from one exhibition to another by a car.

Important research and development investigations include:

- Studies in stability of a tower-type structure which supports the monitor. How much weight will you need to put into the base of the structure to make it stable against typical sideways blows or tilting?
- Studies in bending of parts of the structure, e.g. the shelves or ledges which project from the boards. Will they bend too much under a large weight? Can they be supported by a strut or cable?

Design and make Activities:

- Think about the research and development which your design might need.
- Is stability and rigidity likely to be a problem? Why?
- What can you do about it? Can you experiment with a model to develop your design?
- Consider the possibility of mass production of your design using appropriate manufacturing process.
- Evaluate your design and compare it to your original specification.

Case Studies / Product Analysis

Case	Strategy and Activity
Stadiums of the Beijing 2008 Olympic Games (Re: Topic 1.2)	● Investigate examples of stadiums found in the Beijing 2008 Olympic Games. ● Identify the structures of these stadiums. ● Discuss why such structure is employed to cope with the specific function of each stadium.
Murphy's Law (Re: Topic 2.3)	● Explore the origin of Murphy's Law. ● Study the statements in Murphy's Law. ● Discuss and make notes on the influence of such statements on quality assurance and control.
Earphone (Re: Topic 1.1 & 2.1)	● Examine different parts of an earphone found in the market. ● Identify the materials used in making the earphone. ● Referring to the materials identified, consider the manufacturing processes applied for producing the earphone.

Exercise for Structures and Mechanisms

1. Sketch and describe each of the following, stating whether it is a structure, a mechanism or a combination of both:
   - Bicycle
   - Folding ironing board
   - Piano
   - Sewing machine
   - Tent
   - Umbrella

2. Find an example of each of the following among the items listed in Q.1:
   - Plane frame
   - Space frame
   - Triangulated structure
   - Pin joint
   - Fixed joint
   - Compressive force
   - Tensile force

3. A driving pinion gear which has 15 teeth meshes with a second gear wheel with 45 teeth. A third gear on the same shaft as the second also has 15 teeth and it meshes with a fourth gear with 30 teeth. Assuming 80% efficiency, calculate:
   (a) the total gear ratio for this compound gear train; and
   (b) the MA of the system.

4. Figure 1 shows a simple mechanical winch consisting of a worm attached to a winding crank (radius of 0.3 m), and a 40-toothed wheel attached to a winding drum (diameter of 0.2 m). If an effort of 50 N is needed to raise a load of 800 N, determine:

   (a) the VR of the winch; and
   (b) the efficiency of the mechanism at this load.

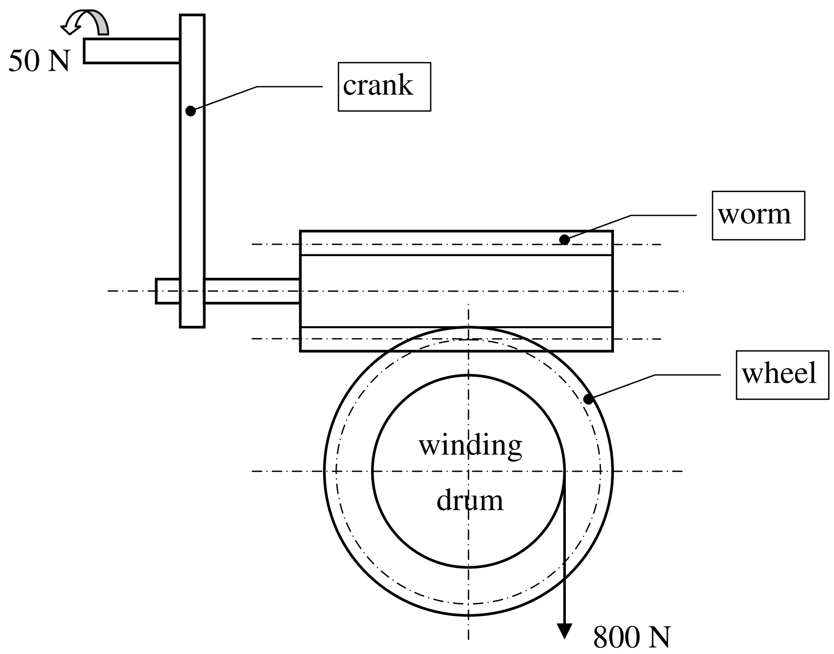


Figure 1

5. Figure 2 shows a motorised winch which has a motor speed of 1800 r.p.m. supplying a torque of 10 Nm. The drum rotates at 200 r.p.m. and has a diameter of 0.2 m. The overall efficiency of the winch is 70%. Determine the following:

(a) the number of teeth on the motor driver gear;
(b) the elevating speed of the load in ms^{-1};
(c) the power input to the winch;
(d) the power output; and
(e) the load being raised.

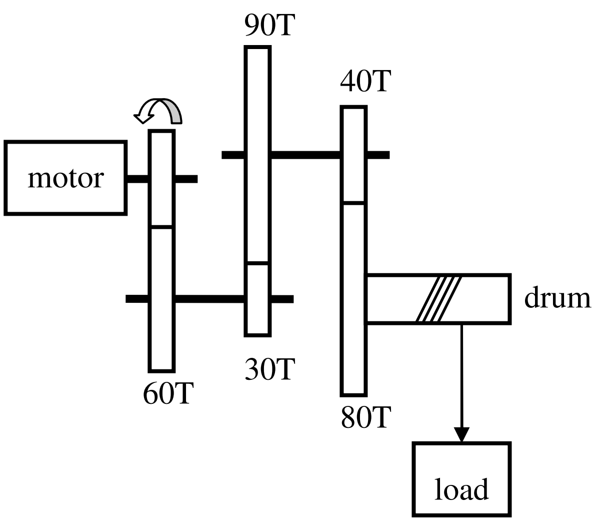


Figure 2

QUIZ

Multiple Choice Questions

1. Which physical properties are significant in the materials used to make metal window frames?

   I. Hardness
   II. Thermal conductivity
   III. Thermal expansion

   A. I and II only
   B. II and III only
   C. I and III only
   D. I, II and III

2. Which combination of manufacturing processes could be used to make a wooden violin body?

   A. Injection Moulding – Joining – Shaping
   B. Laminating – Wasting – Joining
   C. Shaping – Wasting – Extrusion
   D. Wasting – Sintering – Joining

3. Which manufacturing process is most likely to be used to make the case of a MP3 player from thermoplastic?

   A. Extrusion
   B. Injection Moulding
   C. Lamination
   D. Sintering

4. What is the disadvantage of designing complex mechanisms from cut and machined parts?

   A. Assembly requirements
   B. Joining processes
   C. Storage and distribution
   D. Versatility and flexibility

5. In the past, steam engines parts were built using a factor of safety of 8. Why can modern aircraft be constructed using a factor of safety of 1.1?

   I. Manufacturing techniques are more accurate
   II. Quality control of materials is better
   III. Structural forces are better understood

A. I and II only
B. II and III only
C. I and III only
D. I, II and III

Long Questions

1. Explain with the aid of simple drawings or flow chart to describe the process of injection moulding. [3]

   ____

   ____

2. Explain, with graph, how knowledge of Young's modulus affects the choice of materials for particular applications. [8]

   ____

   ____

   ____

   ____

3. Select any manufactured product found in classroom or at home, with which you are familiar and answer the following questions:
   (a) What is the main material from which the product is made? [1]
   (b) Give **two** reasons why the manufacturer select this material for the product. [2]
   (c) Name and briefly describe the main manufacturing process used to make the product. [5]

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

4. Figure 1 shows a passenger lift designed for shopping malls and hotel premises. Both the lift car and the lift enclosure are manufactured from curved laminated glass and steel. The lift is designed to accommodate not more than 10 persons at any time.

Figure 1

(a) Assume that the weight of a person will not exceed 80 kg. What is the normal maximum load for the lift? [1]
(b) Calculate the design load for the lift, which has been designed with a factor of safety of 3 [2]
(c) Explain the need for a factor of safety in the design of the lift. [3]
(d) Outline one way in which steel is finished to make it suitable for internal exposed surfaces in the lift, e.g. the control panel. [2]
(e) Describe how laminated glass responds to impact. [2]
(f) Outline one benefit of designing the lift car from a transparent material, such as laminated glass, apart from aesthetic benefit. [2]

USEFUL WEBSITES

Title	URL	Explanatory Note
Bamboo Scaffolding	http://www.12hk.com/BmbooScaf.html	Website introducing bamboo scaffolding employed in construction
Crocodile Technology	http://www.crocodile-clips.com/croctech/index.htm	Website of technology education with focus on electronics
Design for Manufacturing	http://tds.ic.polyu.edu.hk/dfm_guide/index.htm	Website of design and manufacturing
Design inSite	http://www.designinsite.dk/	The designer's guide to manufacturing
Grand Canyon Skywalk	http://www.grandcanyonskywalk.com/	Official website of the Skywalk at Grand Canyon
HK Brand Development Council	http://www.hkbrand.org/eng_index.html	Website introducing branding activities in HK
How Stuff Works	http://www.howstuffworks.com/	Website introducing the operation of various devices
Kenplas	http://www.kenplas.com	Website introducing the manufacturing process of PET bottles
NASA	http://www.nasa.gov/pdf/58269main_Rockets.Guide.pdf	More information about Newton's Laws and the engineering behind rocket technology
Plasticity	http://www.sciencemuseum.org.uk/visitmuseum/galleries/plasticity.aspx	100 years of making plastics
Popular Mechanics	http://www.popularmechanics.com/	Website introducing new industrial products
RS Components International / Hong Kong	http://www.rs-components.com/index.html http://www.rshongkong.com	Official website of RS Components
The Great Idea Finder	http://www.ideafinder.com/home.htm	Website introducing new inventions
Transformer Toys	http://www.anex.com.hk/~hktf	Website introducing transformer toys
Water Rocket Index	http://ourworld.compuserve.com/homepages/pagrosse/h2oRocketIndex.htm	Website introducing water rockets

Other web sites:

- C R Clarke and Co http://www.crclarke.co.uk/
- EMCO http://www.emco.co.uk/
- Fitchett and Woollacott http://www.fitchetts.co.uk/
- Innovations catalogue http://innovations.co.uk/
- LEGO http://www.lego.com/
- Techsoft http://www.techsoftuk.co.uk/
- TecQuipment http://www.tecquipment.co.uk/
- TEP http://www.tep.org.uk/

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GLOSSARY OF TERMS

Term	Definition
Alloy	A *mixture* that contains at least one metal. This can be a mixture of metals or a mixture of metals and non-metals.
Amorphous material	A solid that is not crystalline.
Batch production	Where the tasks and manufacturing equipment are shared, a team of workers can produce a larger number of an identical product, in less time than if each worker operated on their own.
Beam	A large long (heavy) piece of wood/ metal, especially as used in the framework of a building.
Blow moulding	The process is similar to glass blowing and is used for the production of bottles and containers. There is a tube of hot extruded thermoplastic is gripped at both ends by the mould and air is blown into the tube, which then expands to take on the shape of the mould.
Composite	A mixture composed of two or more substances (materials) with one substance acting as the matrix or glue.
Compound	A substance formed by the combination of elements in fixed proportions. They may be bonded ionically or covalently.
Compression moulding	This process involves placing a measured ‘plug’ of mixed thermoset between the two halves of a split mould. The mould closes under heat and pressure, and the moulding is ‘cured’ for approx. 2 minutes. It is widely used to produce components such as electrical plugs and sockets.
Computer-aided Design (CAD)	CAD *systems* make it easy to create a picture of a new design, and then to change the way it looks on the screen. This means that new ideas or variations on an idea can be tried out and evaluated much more quickly than if they had to be redrawn each time. Some CAD programs are more concerned with the visual appearance of a product, others with technical detail.
Computer-aided Manufacturing (CAM)	CAM is a term used to describe the process whereby parts of a product are manufactured by equipment which is controlled by a computer.
Computer Integrated Manufacturing (CIM)	This is a totally automated production process with every aspect of manufacture controlled by computer.
Computer Numerical Control (CNC)	CNC machine tools can be independently programmed, but also have the facility to exchange data with other computers. They therefore become part of a complex automated production *system*.

Term	Definition
Continuous production	It is the production process set to make one specific product 24 hours a day, 7 days a week, possibly over periods of many years. This occurs in some areas of food manufacturing (e.g. bread), the production of chemicals, steel, energy, etc., where it would take a long time to stop and re-start the production process.
Cost-effectiveness	The most efficient way of designing and producing a product from the manufacturer's point of view.
Design for manufacture (DfM)	The existing manufacturing capability is the dominant factor of DfM. Designers design specifically for optimum use of this capability.
Ductility	The ability of a material to be drawn or extruded into a wire or other extended shape.
Economy of scale	Generally the larger the volume of production, the more *fixed costs* are balanced by variable costs and the better the unit price.
Efficiency	The efficiency of a system can be calculated using *mechanical advantage* and *velocity ratio*: Efficiency = MA/VR x 100%
Electrical conductivity	This is a measure of a material's ability to conduct electricity. A material with a high conductivity will conduct electricity well.
Extrusion moulding	This process involves forcing a molten thermoplastic through a die and rapidly cooling the resultant shape as it emerges. This is commonly used for making products such as pipes, tubes and guttering.
Fixed costs	The costs that must be paid out before production starts, e.g. machinery. These costs do not change with the level of production.
Flexible manufacturing system (FMS)	Any computer-controlled manufacturing *system* which is capable of dealing with several different products and offers users an opportunity to obtain the benefits of economies of scale in small *batch production*. Manufacturing equipment which can automatically change product tooling and software.
Gantt chart	It is a production schedule telling workers when to prepare, assemble and finish the different components.
Gear ratio	This is the method used to calculate the change in speed of rotation of the gears. It is the ratio of the number of teeth on the driven gear divided by the number of teeth on the driver gear.

Term	Definition
Girder	A strong *beam*, usually of iron or steel, which supports a floor or roof or part of a bridge.
Hardness	The resistance a material offers to penetration or scratching.
Hydraulic systems	They use liquids, usually special oils but sometimes water, to transfer large forces.
Injection moulding	This process involves injecting molten thermoplastic into a mould under great pressure. The moulds can be very complicated and are often made in several pieces to allow the item to be removed.
Ion	A positively or negatively charged atom or molecule caused by the loss or gain of electrons from an atom or atoms.
Just-in-case (JIC)	A situation where a company keeps a small stock of rare components (or complete items) or ones that take a long time to make, just in case of a rush order.
Just-in-time (JIT)	It is a production control system which ensures the correct materials and components arrive at the production line at exactly the right time and place.
Lamination	Building up a thick layer of material using thin layers of the material joined with adhesives.
Life cycle analysis	The assessment of the effect a product has on the environment from the initial concept to disposal.
Mass customisation	A sophisticated *CIM* system which manufactures products to individual customer orders. The benefits of *economy of scale* are gained whether the order is for a single item or for thousands.
Mass production	If a number of workers are organised in the workplace on a production line then they will be able to make identical products very quickly, 8 or more hours a day for weeks or months on end.
Mechanical advantage	It is the ratio between the load to be moved and the effort needed.
Mechanical systems	They make use of devices such as gears, cams and levers. They can also be *pneumatic, hydraulic* or electro-mechanical.
Mixture	A substance made of two or more substances that can be separated by physical means, i.e. not chemically bonded together.
Newton's Laws of Motion	The First Law The first law of motion states that if the sum of the forces acting on an object is zero, then the object will remain at rest or remain moving at constant velocity.

Term	Definition
	The Second Law The acceleration of an object will be proportional to the size of the force and be in the same direction as the force. If the force on an object of mass m is F, then the acceleration a is defined by: $F = m a$ The Third Law Every action has an equal and opposite reaction. Thus if two bodies collide, both bodies will experience the same force, but in opposite directions.
One-off production	It might take several days or even weeks for a craftsperson to produce a single item. This is costly in terms of labour and materials, although it does result in a very high quality product.
Optical fibre (Fibre-optic)	A cable that can transmit huge quantities of digital information at very high sped in both directions by means of light waves.
Original Equipment Manufacturer (OEM)	An OEM will design and produce a complete component system for a production product. Examples of these systems are systems for cars and other vehicles such as the ignition or alarm system, or a computer control system for banking systems or manufacturing control systems. The OEM will be entirely responsible for the after sales service for the component system.
Planned obsolescence	A conscious act either to ensure a continuing market or to ensure that safety factors and new technologies can be incorporated into later versions of the product.
Plastic deformation	The permanent deformation of a solid subjected to a stress.
Pneumatic systems	They use compressed air to transfer large forces; a wide range of valves and other devices can be used so that pneumatic *systems* can be used in many different control situations.
Product cycle (product life cycle)	This refers to a product's introduction, growth, maturity and decline and to its general pattern of production and profitability.
Product development	The creation of new, modified or updated products aimed mainly at a company's existing customers.
Quality assurance	At various stages in the process, it will be necessary to build in procedures to ensure that a certain quality is achieved, e.g. setting the depth stop on a drill, colour control strips in printing.

Term	Definition
Quality control	This is the process of checking for accuracy throughout the manufacturing process, e.g. size, colour, weight, consistency, fit, etc.
Sand casting	This process involves making a wooden mould (flat or split), called a pattern, which is the same shape as the object to be cast. The pattern is packed in special sand within two steel boxes (cope and drag). These are then split for the pattern to be removed, leaving a perfect impression in the sand. Molten metal is then poured in through preformed holes known as runners and risers which are formed by removable sprue pins.
Seasoning	The process of drying out timber after conversion.
Sintering	The fusing of solid particles together by heat and pressure without completely liquefying the particles.
Software	It is the programs that are used to make computer operate.
Specification	A set of precise limits for the complete range of performance requirements for the design of a product.
Superconductor	A composite material with the unique property of having almost zero resistance at very low temperatures.
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Systems	They have *inputs* and *outputs* and perform a clear function. They can often contain a number of smaller sub-systems each with its own inputs and outputs.
Tensile strength	The ability of a material to withstand pulling forces.
Thermal conductivity	A measure of how fast heat is conducted through a piece of material with a given temperature difference across the piece.
Thermal expansion	A measure of the degree of increase in dimensions when an object is heated. This can be measured by an increase in length, area or volume.
Tolerance	No manufacturing process can produce identical products. The limits within which the product must fall are known as the tolerance and are usually expressed as + or – (plus or minus). This can be applied to any aspect of the specification, e.g. size, weight and colour.
Toughness	The ability of a material to resist the propagation of cracks.
Transmission ratio	It is the mathematical relationship between the *output* of a *system* and the *input*; it can be used to analyse and compare the performance of systems.

Term	Definition
Truss	A framework of *beams* built to support a roof, bridge, etc.
User research	Obtaining users' responses.
User trial	The observation and analysis of comments made by people who have used a particular product.
User-centred design	A design methodology in which designers do not rely on their tacit knowledge of the user or user group but instead use the users as a resource to increase their understanding.
Vacuum forming	A flat sheet of thermoplastic is clamped above a mould and heated until it becomes very flexible. The air is then pumped out from below the sheet allowing it to be drawn down over the mould (mainly due to atmospheric pressure), thus taking up its shape.
Value for money	A concept that takes account of the relation between what something, e.g. a product, is worth and the cash amount spent on it.
Variable costs	Costs that vary with output, e.g. fuel or raw materials.
Velocity ratio	It is the ratio of the distance moved by the effort divided by the distance moved by the load.
Wasting	The process by which hand tools and machines are used to fabricate materials by the removal of waste.
Yield stress	The stress at which plastic deformation begins.
Young's modulus	The stiffness of a material.

APPENDICES – TABLES OF MATERIAL PROPERTIES

APPENDIX A: PHYSICAL PROPERTIES OF METALLIC ELEMENTS

Element	Mass Density Specific Gravity [kg/l]	Melting point [°C]	Boiling point [°C]	Thermal conductivity W/m [°C]	Coefficient of Expansion [10-6/°C]	Electrical Resistivity [nΩm]	Main uses
Aluminium	2.7	660	2400	205	23	27	Electric Wire
Copper	6.96	1083	2580	390	178	16.8	Electric Wire
Gold	19.3	1063	2660	310	14	23	Jewellery/ Electrical Contacts
Iron	7.9	1535	2900	76	12	97	Castings
Lead	11.3	327	1750	35	29	206	Pipes
Nickel	8.9	1453	2820	91	13	68	Plating
Platinum	21.5	1769	3800	69	9	106	Jewellery/ Electrical Contacts
Silver	10.5	961	2180	418	19	16	Jewellery/ Photographic emulsions
Tantalum	16.6	3000	5300	54	6	135	Capacitors
Tin	7.3	232	2500	64	23	120	Surface coating
Titanium	4.5	1680	3300	17	9	550	Aircraft parts
Tungsten	19.5	3380	6000	190	4.5	55	Light Bulb Elements
Zinc	7.1	420	907	113	31	59	Surface coating

APPENDIX B: PHYSICAL PROPERTIES OF ALLOYS

Alloy	Mass Density Specific Gravity [kg/liter]	Melting point [°C]	Thermal conductivity [W/m°C]	Coefficient of Expansion [10-6/°C]	Electrical Resistivity [nΩm]	Main uses
Brass	8.45	927	120	20	69	marine fittings
Constantan (60/40)	8.9	1320	22	-	490	thermocouples
Dural (44% Cu)	2.8	640	150	23	52	cladding of vehicles aircraft
Manganin (84% Cu)	8.5	-	22	-	440	castings
Nichrome (80/20)	8.36	-	13	12.5	1030	resistance wire
Phosphor-bronze	8.92	1050	75	18	115	marine parts,bearings
Steel (mild)	7.85	-	50	11	120	structures

APPENDIX C: PHYSICAL PROPERTIES OF NON-METALS

Material	Mass Density Specific Gravity [kg/liter]	Melting point [°C]	Thermal Conductivity	Coefficient of Expansion [10-6/°C]	Electrical Resistivity [nΩm]	Main uses
Aluminia	3.9	2050	21	8	$10?10^8$	high temperature linings etc
Brick	14.4-2.2	-	0.4-0.8	3-9	1-2	structure/cladding in buildings
Concrete	2.4	-	1.0-1.5	10-14	-	structure/cladding in buildings
Dry ground	1.6	-	-	-	0.01-0.1	all sorts
Glass	2.4- 3.5	1100	0.4-1.1	3-10	$5.10?10^8$	containers, windows, insulation
Granite	2.7	-	2.4	6-9	-	cladding, work surfaces
Mica	2.8	-	0.5	-	$10?10^8$	insulation
Nylon	1.14	200-220	0.25-0.33	80-130	10^4-10^7	textiles, engineering parts
Paper (dry)	1.0	-	0.06	-	10^4	newspapers, magazines, books
Perspex	1.2	85-115	0.19-0.23	50-80	-	models, construction
Polystyrene	1.06	80-105	0.8-0.2	60-80	10^{19}	engineering parts, packaging
Polythrene	0.93	65-130	0.25-0.5	110-220	10^6	engineering parts, packaging
PTFE	2.2	-	0.23-0.27	90-130	10^9	non-stick surfaces
PVC (plasticised)	1.7	70-80	0.16-0.19	50-250	10^4-10^7	component protection, clothing
Porcelain	2.4	1550	0.8-1.85	2.2	10^4-10^7	containers, insulation
Quartz (crystal)	2.65	-	5-9	7.5-13.7	10^5-$2x10^8$	crystal oscillators
Rubber (natural)	1.1-1.2	125	0.15	200	10^7	tyres, insulation heat
Sandstone	2.4	-	1.1-2.3	5-12	-	structure/cladding in buildings
Timber (along grain)	0.4-0.8	-	0.15	3-5	-	all sorts

APPENDIX D: MECHANICAL PROPERTIES OF METALS

Metallic elements	σ_f	σ_y	E	G	V
Aluminium	60-160	30-140	70	26	0.34
Copper	200-350	47-320	124	46	0.35
Gold	110-230	0-210	80	28	0.42
Iron (wrought)	350	160	195	76	0.29
Iron (cast)	140-320	-	115	45	0.25
Lead	15-18	-	16	6	0.44
Nickel	480-730	140-660	205	79	0.31
Platinum	125-200	15-180	168	61	0.38
Silver	140-380	55-300	76	28	0.37
Tantalum	340-930	-	186	-	-
Tin	15-200	9-14	47	17	0.36
Titanium	250-700	200-500	110	41	0.34
Tungsten	1000-4000	-	360	140	-
Zinc	110-200	-	97	36	0.35

APPENDIX E: MECHANICAL PROPERTIES OF ALLOYS

Alloys	σ_f	σ_y	E	G	V
Brass (65/35)	330-530	62-430	105	38	0.35
Constantan (60/40)	400-570	200-440	163	61	0.33
Dural (4.4% Cu)	230-500	125-450	70	27	0.33
Manganin (84% Cu)	465	-	124	47	-
Mumetal (77% Ni)	540-910	-	220	-	-
Nichrome (80/20)	170-900	-	186	-	-
Phosphor-bronze	330-750	110-870	100	-	0.38
Steel mild	480	240	210	81	0.30
Steel high yield	600	450	210	81	0.30

APPENDIX F: MECHANICAL PROPERTIES OF NON-METALS

Non-metals	E	V	$\sigma_{f\ (tension)}$	$\sigma_{y\ (compression)}$
Alumina	200-400	0.24	140-200	1000-2500
Brick	10-50	-	-	69-140
Concrete	10-17	0.1-0.21	-	27-55
Glass	50-80	0.2-0.27	30-90	-
Granite	40-70	-		90-235
Nylon 6	1-2.5	-	70-85	50-100
Perspex	2.7-3.5	-	50-75	80-140
Polystyrene	2.5-4.0	-	35-60	80-110
Polythrene	0.1-1.0	-	7-38	15-20
PTFE	0.4-0.6	-	17-28	5-12
PVC (plasticized)	0.3	-	14-40	75-100
Rubber (natural)	0.001-1	0.46-0.49	14-40	-
Sandstone	14-55	-		30-135
Timber (along grain)	8-13	-	20-110	50-100

APPENDIX G: SAFE STRESSES IN STRUCTURAL TIMBERS (N MM^{-2})

Timber	Bending			Compression			
	stress in extreme fibre		horizontal shear stress	stress parallel to grain		stress perpendicular to grain	
	outside location	dry location	all locations	outside location	dry location	outside location	dry location
Oak	8.3	9.7	0.9	6.0	6.9	1.6	3.5
Douglas fir	7.6	9.0	0.6	6.0	6.9	1.6	2.1
Norway spuce	6.9	7.6	0.6	5.5	5.5	1.2	2.1

APPENDIX H: MECHANICAL PROPERTIES OF SOME TIMBERS

Wood	Moisture (%)	Density, ρ(kgm^{-3})	Fibre stress at elastic limit (N mm^{-2})	Modulus of elasticity E (N mm^{-2})	Modulus of rupture (N mm^{-2})	Compressive strength parallel to grain (N mm^{-2})	Shear strength (N mm^{-2})
Ash	15	657	60	10070	103	48	10
Beech	-	740	60-110	10350	-	27-54	8.3-14
Birch	9-10	710	85-90	15170	130-135	67-74	13-18.5
English elm	-	560	40-54	11790	-	17-32	8-11.3
Fir, Douglas	6-9	530	45-73	10340-15170	71-79	49-74	7.4-8.8
Mahogany	15	545	60	8890	80	45	6.0
Oak	-	740	58-87	14550	-	27-50	8-12
Scots pine	-	530	41-83	8550-10340	-	21-42	5.2-9.7
Poplar	-	450	40-43	7240	-	20	4.8
Spruce	-	430	36-62	7380-8620	-	18-39	4.3-8
Sycamore	-	625	62-106	8970-13450	-	26-46	8.8-15

APPENDIX I: STIFFNESS OF SECTIONS

All of the sections shown here have an equal cross-sectional area:

BENDING	
I section	most stiff
Channel section	
Square section tube	
Round section tube	
L section	
Rectangular section	
⊥ section	
Round section tube	
Square section tube	
Round section tube	least stiff

TORSION	
Round section tube	most stiff
Square section tube	
Round section tube	
Round section tube	
Square section tube	
Rectangular section	
⊥ section	
L section	
Channel section	
I section	least stiff

APPENDIX J : SPECIAL PROPERTIES

High temp metals
Chromium
Heat-resisting alloy steels
High speed steel
Nichrome
Nimonic alloys
Stainless steel
Stellite
Tantalum
Titanium
Tungsten
Vanadium

Good heat conductors
Aluminium
Bronze
Copper
Duralumin
Silver
Zinc

Good heat insulators
Cotton wool
Expanded poly styrene
Felt
Glass fibre and foam
Glass wool
Hardboard
Mineral wool
Plywood
Polyurethane foam
Rubber
Sawdust
Wood

High strength to weight ratio materials
Fibre reinforced plastics
Duralumin
Glass reinforced plastics
Magnesium alloys
Nylon
Polycarbonate
Spruce
Titanium
Titanium alloys

Corrosion resistant metals
Cupronickel
Lead
Monel metal
Nickel
Pure aluminium
Stainless steel
Tin
Titanium and alloys

Good electrical conductors
Aluminium
Beryllium copper
Brass
Copper
Gold
Magnesium
Phosphor bronze
Silver

Good electrical insulators
Ceramics
Ebonite
Gases
Glass
Insulating papers
Mica
Shellac
Silicone rubber
Natural rubber
Thermoplastics
Thermosetting plastics
Tufnol

Coating metals
Brass
Bronze
Cadmium
Chromium
Copper
Gold
Lead
Nickel
Platinum
Silver
Tin
Zinc

APPENDIX K : PHYSICAL PROPERTIES OF PLASTICS

(A) PHYSICAL PROPERTIES OF THERMOPLASTICS

BHN = Brinell Hardness Number E = Young's modulus

Properties of thermoplastics	Density, ρ(Kg m^{-3})	Tensile strength (N mm^{-2})	Elongation (%)	E (GN m^{-2})	Impact resistance	BHN	Machinability
PVC rigid	1330	48	200	3.4	good	20	v.good
Polystyrene	1300	48	3	3.4	average	25	average
PTFE	2100	13	100	0.3	v.good	-	v.good
Polypropylene	1200	27	200-700	1.3	v.good	10	v.good
Nylon	1160	60	90	2.4	good	10	v.good
Cellulose nitrate	1350	48	40	1.4	average	10	v.good
Cellulose acetate	1300	40	10-60	1.4	average	12	v.good
Acrylic (Perspex)	1190	74	6	3.0	poor	34	v.good
Polythene (high density)	1450	20-30	20-100	0.7	average	2	v.good

(B) PHYSICAL PROPERTIES OF THERMOSETTING PLASTICS

BHN = Brinell Hardness Number E = Young's modulus

Properties of thermoplastics	Density, ρ(Kg m^{-3})	Tensile strength (N mm^{-2})	Elongation (%)	E (GN m^{-2})	Impact resistance	BHN	Machinability
Epoxy resin (glass filled)	1600-2000	68-200	4	20	v.good	38	good
Melamine formaldehyde (fabric filled)	1800-2000	60-90	-	7	v.good	38	average
Urea formaldehyde (cellulose filled)	1500	38-90	1	7-10	v.good	51	average
Phenol formaldehyde (mica filled)	1600-1900	38-50	0.5	17-35	v.good	36	good
Acetals (glass filled)	1600	58-75	2-7	7	v.good	27	good

APPENDIX L : DENSITY OF METALS

In the following table, densities are given for normal pressure and temperature:

Metal	ρ(Kg m⁻³)
Aluminium	2700
Aluminium bronze (90% Cu,10% Al)	7700
Antimony	6690
Beryllium	1829
Bismuth	9750
Brass (60% Cu, 40% Zn)	8520
Cadmium	8650
Chromium	7190
Cobalt	8900
Constantan	8920
Copper	8930
Gold	19320
Inconel	8510
iron:pure cast	7870-7270
Lead	11350
Magnesium	1740
Manganese	7430
Mercury	13546
Molybdenum	10200
Monel	18900
Nickel	8900
Nimonic (average)	8100
Palladium	12160
Phosphor bronze (typical)	8900
Platinum	21370
Sodium	971
Steel:mild stainless	7830-8000
Tin:grey rhombic tetragonal	5750-6550-7310
Titanium	4540
Tungsten	19300
Uranium	18680
Vanadium	5960
Zinc	7140

APPENDIX M : COMPARATIVE TENSILE STRENGTHS OF MATERIALS

The following table gives approximate tensile strengths for a range of materials, for purposes of comparison:

Material	MN/m^2
steel piano wire	3000
high tensile steel	1500
titanium alloys	700-1400
mild steel	400
aluminium alloys	140-550
traditional wrought iron	140-280
modern cast iron	140-280
copper	140
pure cast aluminium	120-400
brasses	70
flax	700
cotton	350
silk	350
spider's thread	240
bone	140
wood (along grain)	100
tendon (muscle)	100
hemp rope	80
leather	40
glass window or wine glass	30-170
ordinary brick	5
cement and concrete	4
wood (across grain)	3

APPENDIX N : TYPICAL BRINELL HARDNESS NUMBERS

The following chart shows typical Brinell hardness numbers (BHN) for metals and plastics:

Material	BHN
Soft brass	60
Mild steel	130
Annealed chisel steel	235
White cast iron	415
Nitrided surface	750
PVC rigid	20
Polystyrene	25
Acrylic (perspex)	34
Polythene (high density)	2
Epoxy resin (glass filled)	38

APPENDIX O : DENSITY OF WOODS

In the following table, densities are given for normal pressure and temperature for various woods at 15% moisture:

Wood	ρ(Kg m^{-3})
Ash	660
Balsa	100-390
Beech	740
Birch	720
Elm: English	580
Dutch	560
Elm: wych	690
Fir,Douglas	480-550
Mahogany	545
Pine: Parana	550
Pine: pitch	640
Pine: Scots	530
Spruce,Norway	430
Teak	660

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