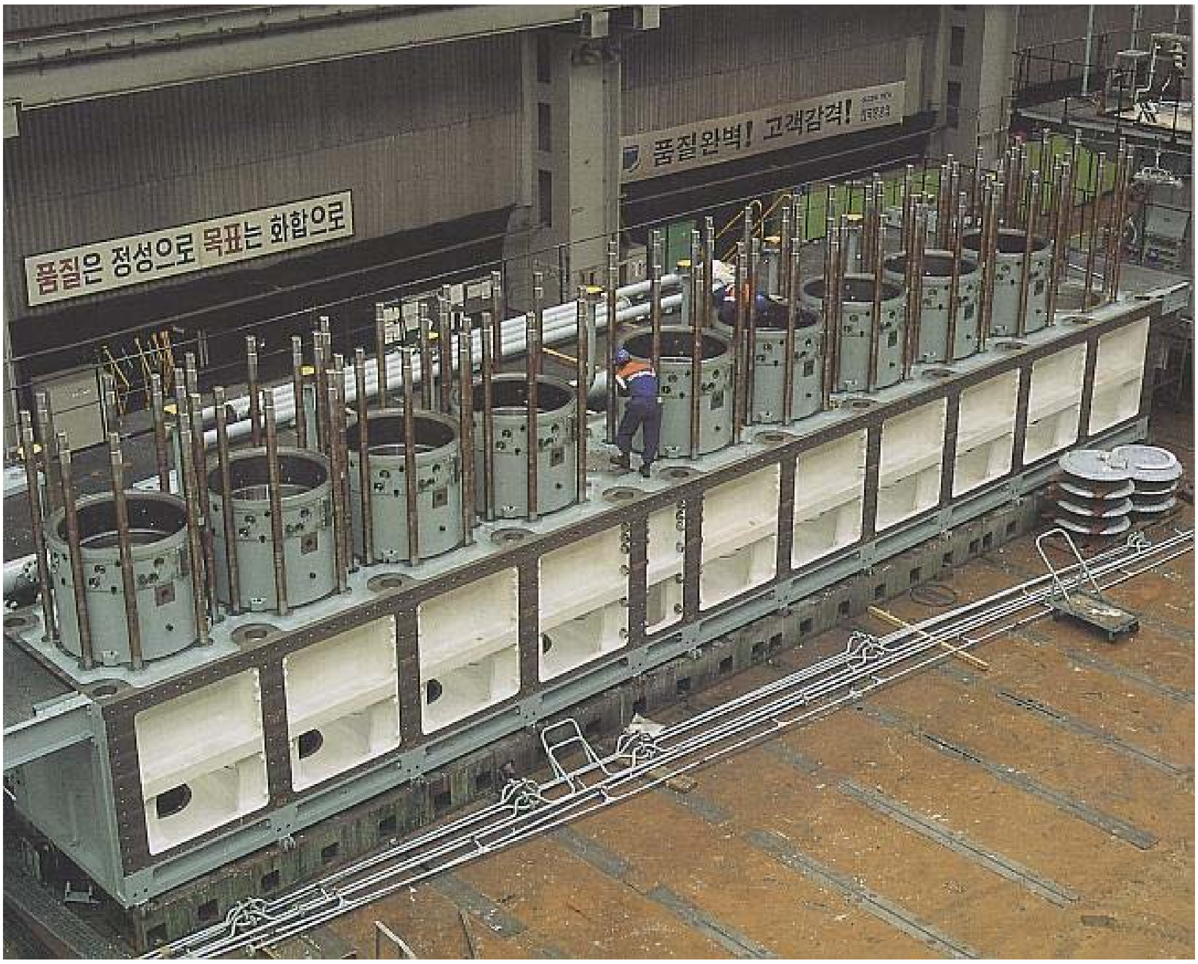
General Notes on Engineering Hardware



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Intended primarily for reference purposes by students in the School
November 2010

For the image above and more images and details of the Wartsila-Sulzer RTA96-c engine, see
http://qualityjunkyard.com/2009/05/27/worlds-biggest-engine-the-wartsila-sulzer-rta96-c/

Preamble

This section of the introductory courses in Mechanical Engineering Design in the School of Mechanical and Manufacturing Engineering at The University of New South Wales deals essentially with engineering hardware. It was originally a hands-on laboratory course, supported by a series of formal lectures, in which students examined actual engineering components and answered a series of questions about certain aspects of those components. However, in the current course, it is presented simply as a very basic familiarisation course in engineering materials, manufacturing processes, and engineering hardware.

The character of the presented material changes as the course proceeds. In the early sections of these notes, the emphasis is on **recognition of basic materials and manufacturing processes**. In the later sections, the student's attention is being directed to **design features and functions** of components and assemblies. It is hoped that an understanding of the basic material will allow students to build a logical framework upon which they can assemble what can otherwise be a mass of disconnected facts into a structured whole.

These notes are set out in the following six parts:

Part 1 – Materials and Processes
Part 2 – Fasteners
Part 3 – Seals, Gaskets and Valves
Part 4 – Springs and Gears
Part 5 – Shafts and Bearings
Part 6 – Power Transmission Elements

A word of caution needs to be given. In a topic as broad as engineering hardware, the material presented must be a superficial view. It is no more than the tip of a very large iceberg. Notwithstanding this restriction, it is hoped that these notes can provide you with an invaluable knowledge of engineering hardware for use in the remainder of your four-year course and a useful start in your engineering career.

Part 1 of 6:

ENGINEERING MATERIALS AND MANUFACTURING PROCESSES

Table of Contents

1 Introduction 3
1.1 Civil Engineering 3
1.2 Electrical Engineering 3
1.2.1 Metals 3
1.2.2 Non-metals 3
1.2.3 Semi-conductors 4
1.3 Mechanical Engineering 4
1.3.1 Metals 4
1.3.2 Plastics (Polymers) 4
2 Ferrous Metals 5
2.1 Production of iron 6
2.2 Production of steel 7
2.3 Characteristics of mild steel 9
2.3.1 Shapes and sizes 9
2.3.2 Material properties 9
2.3.3 Recognising mild steel 10
2.4 Production of sand castings 10
2.5 Characteristics of sand castings 12
2.5.1 Shapes and sizes 12
2.5.2 Material properties 13
2.5.3 Recognising cast iron 13
2.6 Other processes for ferrous materials 14
2.6.1 Steel castings 14
2.6.2 Investment casting 15
2.6.3 Forgings 15
2.7 Forming 21
2.7.1 Bending and folding 21
2.7.2 Roll forming 22
2.8 Spinning 23
2.9 Shearing 24
2.10 Swaging 25
3 Aluminium and its Alloys 26
3.1 Production processes for aluminium 27
3.1.1 Pressure die casting 27
3.1.2 Extrusion 30

3.1.3 Spider dies 33
3.1.4 Drawing 33
3.2 Characteristics of aluminium and its alloys 34
3.2.1 Shapes and sizes 34
3.2.2 Material properties 34
3.2.3 Recognising aluminium 35
4 Stainless Steel 35
4.1 Production processes 36
4.1.1 Rolling 36
4.1.2 Forming 36
4.1.3 Machining 36
4.1.4 Casting 36
4.2 Material properties 36
4.3 Recognising stainless steels 37
5 Copper and its Alloys 37
5.1 Copper alloys and their uses 37
5.1.1 Pure copper 37
5.1.2 Brasses 37
5.1.3 Bronzes 37
6 Zinc 38
7 Magnesium 38
8 Titanium 39
9 Other Metals 39
10 Polymers 39
11 Adhesives 41
11.1 Synthetic adhesives 41
11.2 Drying adhesives 41
11.3 Contact adhesives 41
11.4 Hot adhesives 41
11.5 Emulsion adhesives 42
11.6 UV and light curing adhesives 42
11.7 Pressure sensitive adhesives 42
11.8 Mechanisms of adhesion 42
12 Machining Operations 43
12.1 Drilling 43
12.2 Lathe work – turning 44
12.3 Milling 47
12.3.1 Milling machines 47
12.3.2 Milling cutters 48
12.3.3 Use of milling machines 49
12.4 Grinding 50
12.4.1 Surface Grinding 50
12.4.2 Cylindrical grinding 51
12.4.3 Internal grinding 52
13 Closing Remarks 52

1 Introduction

Engineering materials are the basic building blocks for all types of engineering endeavour. There are obvious differences between the materials typically used in the different branches of engineering and it is instructive to compare the type of material used by different branches.

1.1 Civil Engineering

Civil Engineers are typically interested in the design and construction of large buildings and structures, bridges, dams and large earthworks. They frequently use large quantities of structural materials such as:

Earth	Concrete	Glass
Rock	Structural steel	Timber, etc
Bricks	Aluminium	Composites

1.2 Electrical Engineering

Electrical Engineers use many materials in several different categories and for several different purposes. Some examples are:

1.2.1 Metals

As Conductors:

- Copper
- Aluminium
- Silver
- Gold
- Tungsten

As Structural Members:

- Steel
- Aluminium
- Cast iron

1.2.2 Non-metals

As Insulators:

- Rubber
- Ceramics
- Plastics
- Varnish
- Oils

As Structural Members:

- Plastics
- Composite materials

1.2.3 Semi-conductors

These are extremely important, particularly in electronics (computers, radio, television, etc.):

Germanium
Gallium arsenide
Aluminium gallium arsenide
Silicon
Metal oxides

Ultra-pure silica (silicon dioxide) is finding increasing use for optical fibres, also glass-plastic mixes.

1.3 Mechanical Engineering

Mechanical Engineers also use a wide range of engineering materials in many different applications. Some of these are:

1.3.1 Metals

Ferrous materials	Aluminium and alloys	Tungsten
Mild steel	Zinc	Molybdenum
Carbon steel	Magnesium and alloys	Beryllium
Alloy steel	Titanium and alloys	Nickel
Stainless steel	Copper	Chromium
Cast iron	Copper alloys	Vanadium

1.3.2 Plastics (Polymers)

These are readily available in a very wide variety of forms and find many different engineering applications. Some of these are:

Rigid (structural)**:**	Nylon (delrin)	***Flexible*:**	fibres:	Nylon
	Polyethylene			Polyesters
	ABS			Polyethylene
	PVC			Polypropylene, etc.
	Polystyrene			
	Acrylic (perspex)		films or sheets:	PVC
				Polycarbonate
	Acetals			Polyethylene
				Cellulose acetate
				PTFE

Ceramics: Clays (bricks)
Aluminium oxide
Refractory materials
Glasses
Newer ceramics:
Pure and mixed oxide ceramics
Carbide, nitride, boride and silicide compounds

Composite Materials:
Combinations of two or more materials to produce better material properties:
Glass-fibre reinforced plastic
Carbon-fibre reinforced plastic
Metal fibres in polymer matrix
Ceramic fibres in metal matrix

In this course, we are primarily interested in the materials commonly used in mechanical engineering, particularly metals and plastics. For the greater part of the course, attention will be focussed on the processed material and its engineering applications. A study of the molecular structure of materials and its effects on mechanical properties comes later in your course. However, before turning to engineering applications, it is of advantage to understand something about the basic processes by which commonly-used engineering materials are made. This is because the processes used in their manufacture affect the size, shape, form, strength and appearance of the materials we will be considering. It follows that an understanding of the characteristics and limitations of processes can assist significantly in identifying the various materials you will encounter in the world outside the university, and their likely strengths and weaknesses.

2 Ferrous Metals

Probably the group of materials most widely used in mechanical engineering falls within the classification of ferrous materials [1]. All cast irons and all steels fall into this group.

Because ferrous materials are so important to mechanical engineering, they will be the first group of materials to be considered and will be used to introduce several different manufacturing processes, including casting, rolling and forging. However, this is not intended to imply that these processes are used only for ferrous materials. You will see later in these notes that such manufacturing processes are used for many different materials.

[1] From the Latin *ferrum* meaning iron.

2.1 Production of iron

The element iron occurs very commonly in the earth's crust, but always in the form of iron compounds, usually one of the oxides of iron, referred to as iron ore [2], never in the metallic form. The ore must therefore be refined before it can be used in engineering applications.

PIG IRON is produced by processing a mixture of iron ore, coke (for combustion and heating) and limestone (as a flux) in a **BLAST FURNACE** (Fig. 1-1). A "blast" of heated and pressurised air from the base of the furnace (which gives the process its name) increases the combustion rate of the coke, increases the furnace temperature and results in a breakdown (chemically, a reduction) of the iron ore to molten iron. When it flows from the bottom of the blast furnace, the iron typically contains 8-10% carbon plus other impurities, depending on the origin of the iron ore. Some of this material may be allowed to flow into moulds where it solidifies to form blocks known as "pigs" and is known as **PIG IRON**. These pigs are usually further refined and processed to produce various grades of **CAST IRON**, which are used directly in a number of engineering applications.

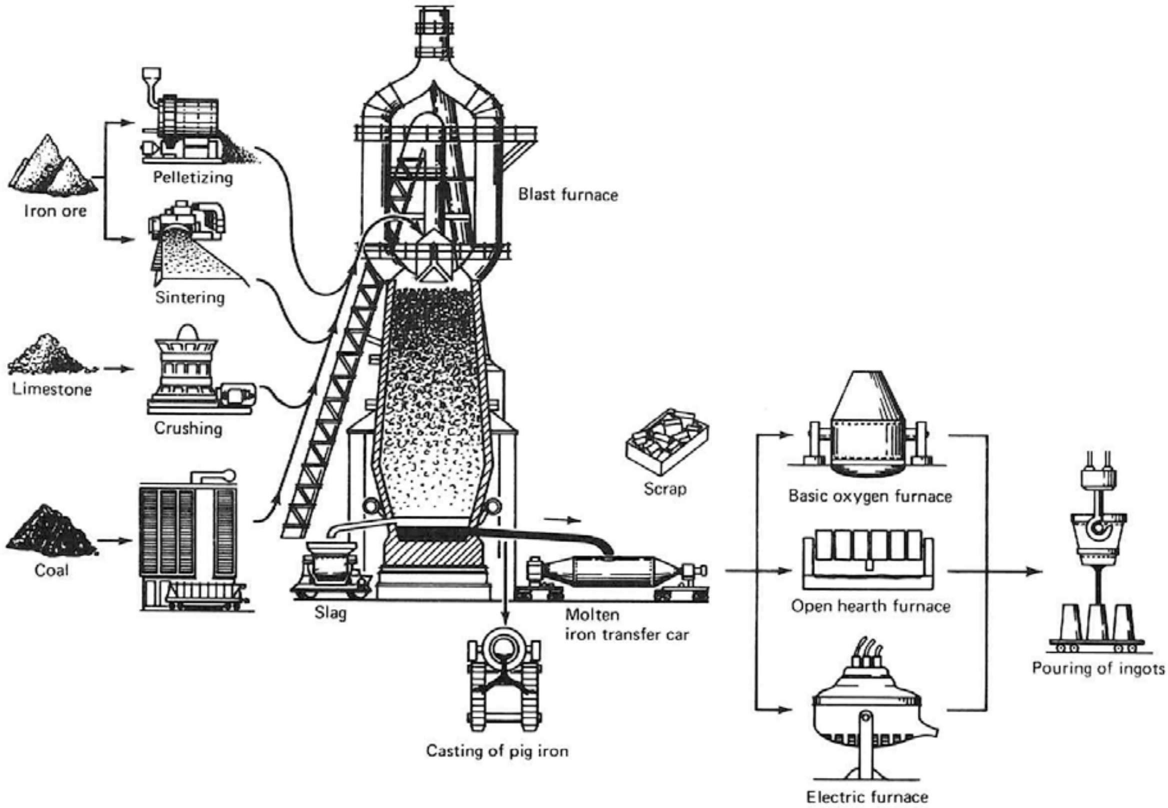

Figure 1-1 Steel-making process.
(From "Steel Making Flow Sheets", © The American Iron & Steel Institute, 1970.)
Reproduced from Kenneth G. Budinski *Engineering Materials*, 3rd Ed., Prentice Hall, 1989, page 216.

[2] Recall that iron rusts readily. You would not expect to find metallic iron after millions of years of exposure to air and water.

2.2 Production of steel

Most of the molten iron from the blast furnace goes directly into the production of steel. Various types of furnace (also known as a converter) have been used over the years to convert pig iron to steel. One of the early steel-making processes was known as the Bessemer converter, in which air was blown into the bottom of the molten iron to burn out impurities such as carbon, sulphur and phosphorus, leaving almost pure iron.

Several different types of furnace are now in common use (Fig 1-2 below). The furnace chosen depends on several factors, including the type of impurities in the pig iron being refined. One type is the open-hearth furnace (Fig. 1-2, centre), which uses jets of pure oxygen to burn out the impurities (mainly carbon) in a controlled fashion, thereby producing **STEEL**. Despite the very large size of furnaces of this type, the steel-making process can be carefully controlled to ensure a precise composition of each steel batch.

In Australia, BHP Billiton makes extensive use of the Basic Oxygen process [3] (BOF) (Fig. 1-2, top), which blows oxygen into the top of a basic-lined Bessemer-type vessel. A third type of furnace, the electric (arc) furnace (also in Fig. 1-2, bottom), is often used where special high quality steel free from impurities (e.g. for ball bearings) is to be produced.

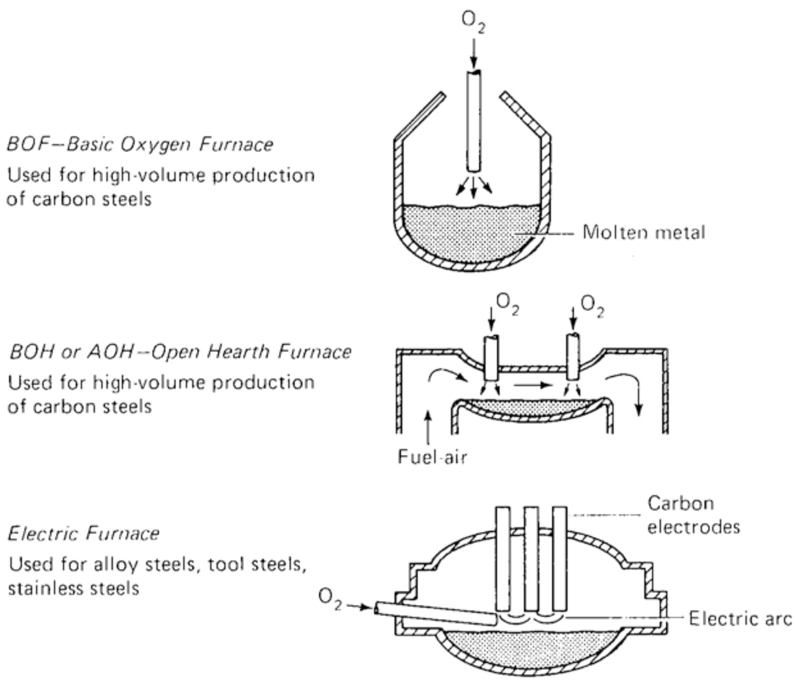

Figure 1-2 Steel-making process.
(From "Steel Making Flow Sheets", © The American Iron & Steel Institute, 1970.)
Reproduced from Kenneth G. Budinski *Engineering Materials*, 3rd Ed., Prentice Hall, 1989, page 219.

[3] "Basic" here refers to the chemical characteristics of the furnace lining. Acidic linings may be used, depending on the impurities in the pig iron being refined.

Most steel produced has a controlled carbon content of 0.18-0.22% (nominal 0.2%) and is called **MILD STEEL**, often abbreviated to **M.S**. Mild steel has no significant content of any metal or element other than iron and carbon. Most of the steel you will see and work with in mechanical engineering will be mild steel. However, you need to be aware that higher percentages of carbon can be used to increase the strength of steel; these are referred to as **CARBON STEELS**. Also, the presence of small quantities (1-3%) of metals such as chromium, nickel, molybdenum, manganese, tungsten (sometimes used in combination and almost always combined with moderate percentages of carbon (0.4-0.5%)) will greatly improve the mechanical properties of steel where such properties are needed for special applications. These are referred to as **ALLOY STEELS** or **HIGH STRENGTH LOW ALLOY (HSLA) STEELS**.

Steel from the open-hearth furnace or other converter is invariably poured into large moulds where it solidifies into ingots (the final stage of Fig. 1-1). When the product is mild steel, the ingot is often processed while the metal is still red hot. The ingot passes through a series of rolling mills (called "roughing" mills, Fig. 1-3) where its thickness is gradually reduced to form different shapes, called

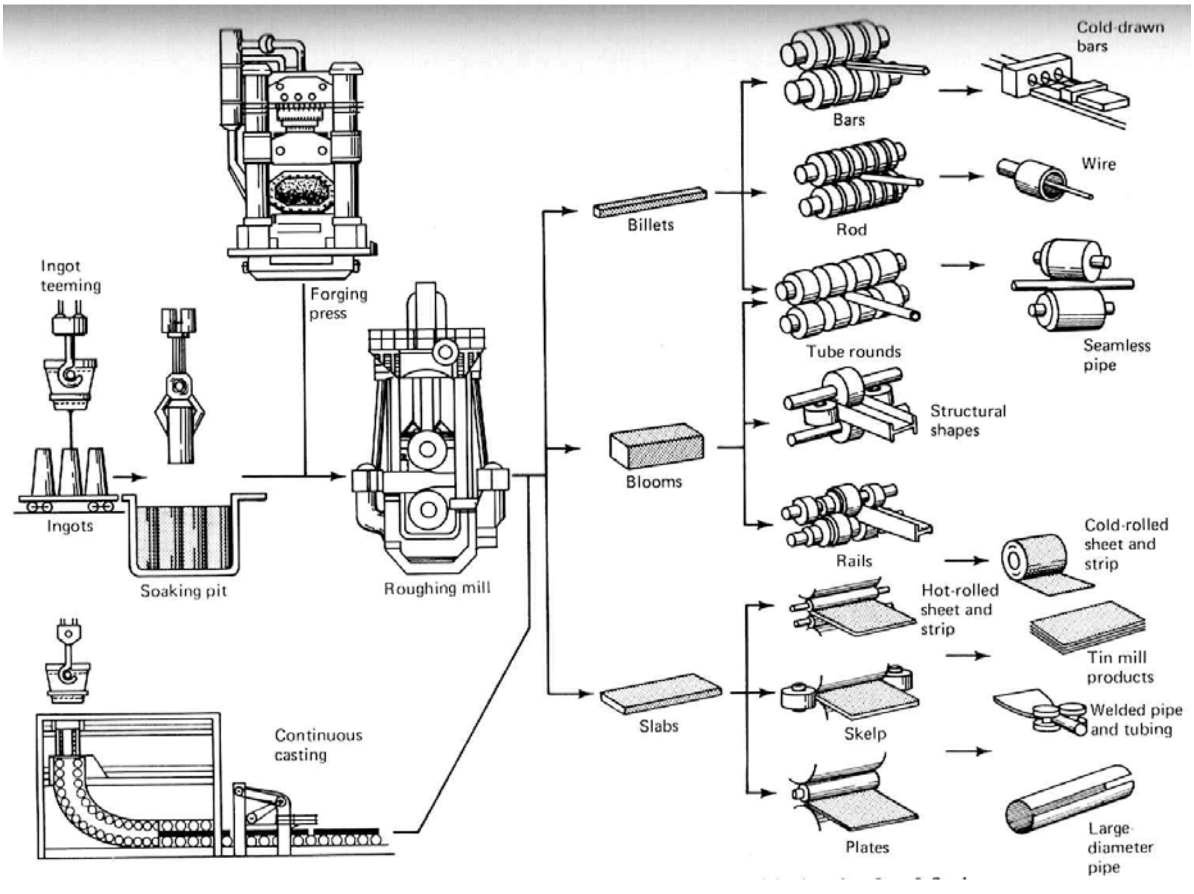

Figure 1-3 Processing of refined steel into products.
(Courtesy of the American Iron & Steel Institute.)
Reproduced from Kenneth G. Budinski *Engineering Materials*, 3rd Ed., Prentice Hall, 1989, page 223.

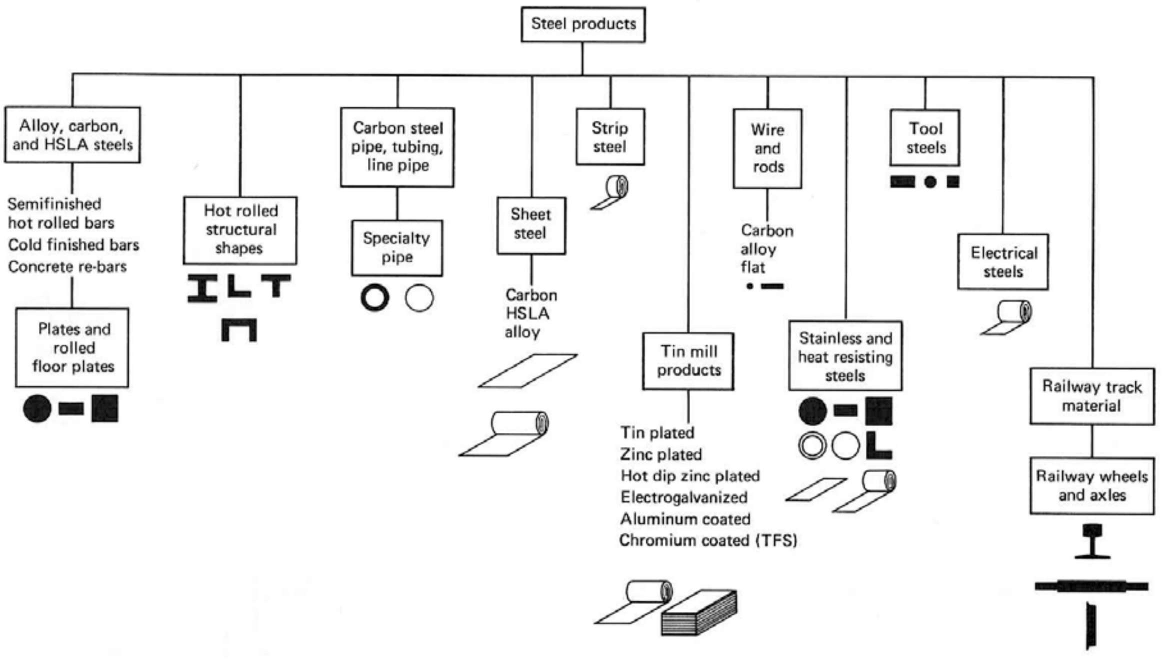

Figure 1-4 Spectrum of steel products.
Reproduced from Kenneth G. Budinski *Engineering Materials*, 3rd Ed., Prentice Hall, 1989, page 224.

blooms, billets, or slabs. These are reheated, then pass through a further series of rolling mills (Fig. 1-3) where they are squeezed into a precise size and shape, determined by the profile and setting of the rolls. The latter rolling mills produce a wide variety of shapes and sizes, including bars, rods, rounds, structural shapes, rails, sheets and strips (Figs 1-3 and 1-4).

2.3 Characteristics of mild steel

2.3.1 Shapes and sizes

- Rolling mills produce long lengths of uniform cross section.
- The mills produce the same size sections day after day (with small size variations, i.e. with small tolerances).
- Only a few discrete sizes are available.
- Standard shapes or "sections" are produced (Fig. 1-3). Intermediate sizes are not available, unless by special order and then only for very large quantities, since that requires special rolls to be made and set up.

2.3.2 Material properties

Mild steel has the following properties:

- It is ductile. If overloaded, it stretches significantly before breaking.

- It has a high Elastic (Young's) Modulus. This means that its deflection under load is less than other common engineering materials.
- It has good tensile and compressive strength. It can carry heavy loads (high stresses) without permanent deformation.
- It corrodes in air in the presence of moisture. Rusting is one of steel's major shortcomings.
- Mild steel is relatively cheap and is readily available (in standard sizes and sections).

2.3.3 Recognising mild steel

Some characteristics which may help you recognise mild steel are:

- Surfaces which have not been machined after hot rolling have a typical hot-rolled surface which is reasonably uniform but slightly rough and usually dark bluish in colour, often referred to as “mill scale”.
- It comes in long lengths of uniform cross section. This is typical of the output of rolling mills.
- It is heavy.
- It is silvery-white when freshly cut but rapidly develops a film of rust.
- It is ferro-magnetic (i.e. attracted by magnets).

2.4 Production of sand castings

Return now to the pig iron produced by the blast furnace (Fig 1-1). This pig iron is refined to reduce its carbon content to 2-4% and eliminate other impurities. Various elements may be added during the refining process to produce the different grades and qualities of **CAST IRON**. This material is intended to be remelted later in the foundry [4], as detailed below.

The process of sand casting begins with the manufacture of a pattern, usually made from wood, of the required component. This pattern (Fig. 1-5 and 1-6) must have the precise shape of the component. The wooden pattern is then used to produce a sand mould (Fig. 1-5 and 1-6), where the sand mould has a cavity which is the size and shape of the pattern. Since the molten metal which will be poured into the mould will shrink appreciably as it cools, the pattern must be made slightly larger in all dimensions than the required component. This is referred to as the shrinkage allowance and varies from metal to metal.

Clearly, if the pattern has to be removed in order to create the cavity, the sand mould has to be made in (at least) two parts which must then be fitted back together. Details of how this is achieved may be seen in Figs 1-5 and 1-6.

[4] By definition, a foundry is a workshop or factory in which **CASTINGS** are produced.

The cavity in the sand mould is then filled by pouring in molten cast iron, through the sprue, seen on the right-hand side of Fig 1-6 which, together with the gate, allows molten metal to flow into every detail of the cavity.

The sand mould must be destroyed in order to get the casting out and a new mould must be made for each casting required, but the pattern is re-usable. The slightly imperfect joint between the mould sections shows up as a parting line on the resulting casting. The presence of a parting line is one of the means of identifying a sand casting. Also, the surface of the casting is influenced by its contact with the sand of the mould, so its slightly granular appearance again forms a useful means of identification.

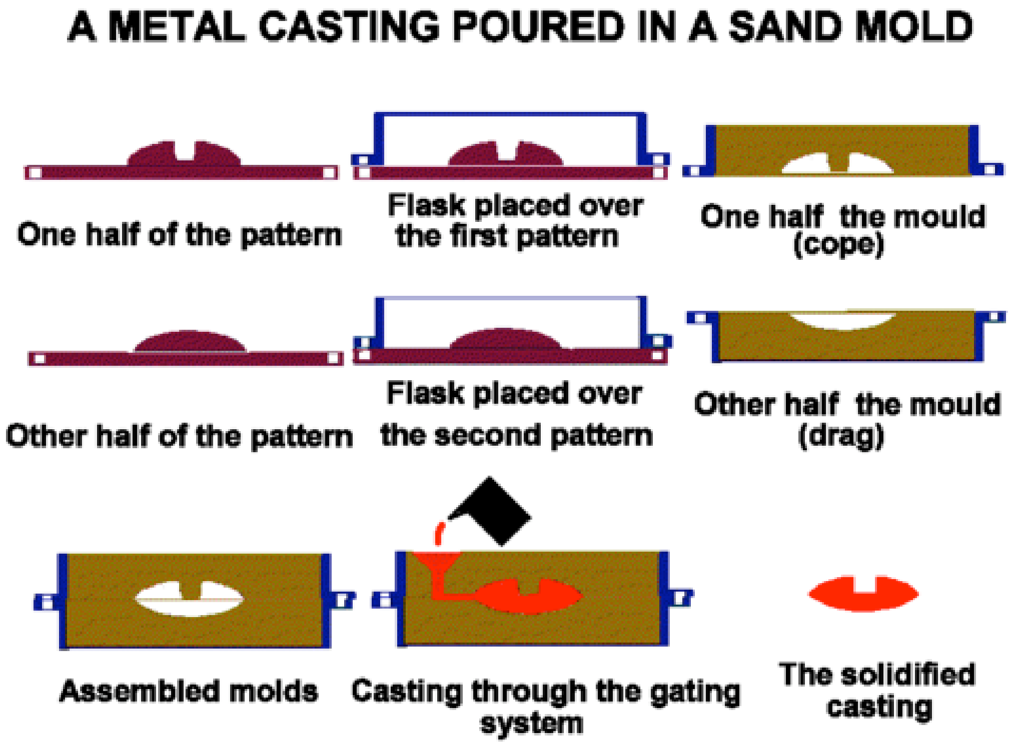

Figure 1-5 A simple schematic illustration of the sand casting process. The brown material shown in the third, sixth, seventh and eighth steps represents the sand of the mould. See also Fig 1-6.
http://en.wikipedia.org/wiki/Sand_casting [December 2009]

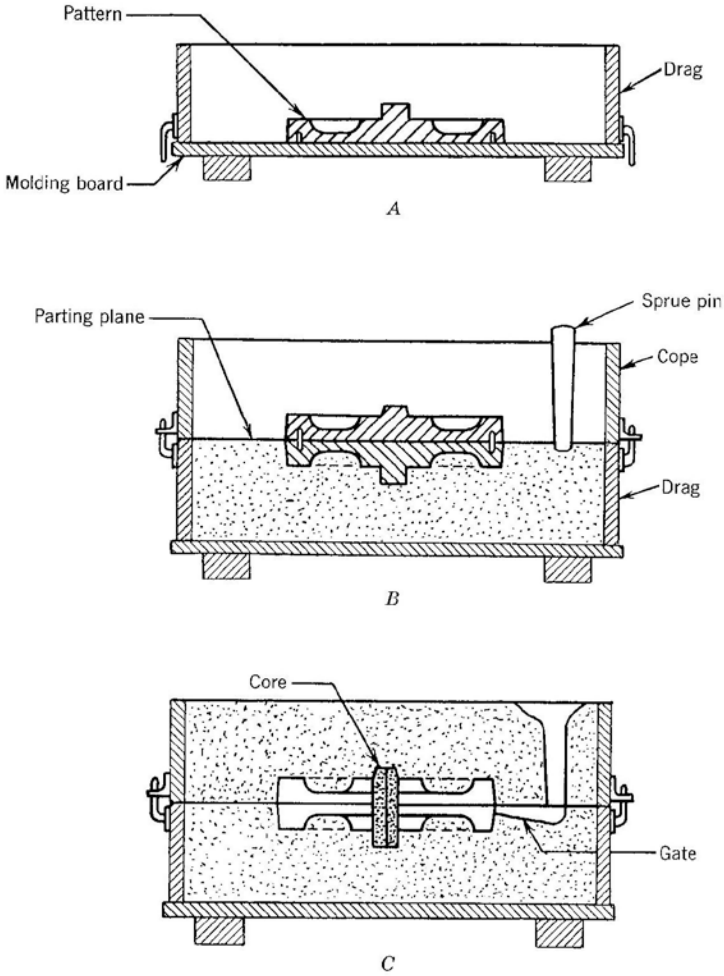

Figure 1-6 More details of the procedure for making green-sand moulds.

A: Bottom half of pattern on moulding board ready to ram up drag.

B: Drag rolled over and pattern assembled ready to ram cope.

C: Mould complete with dry-sand **CORE** in place. The core creates a hole through the casting which reduces machining costs and, by making the casting sections more uniform, achieves more uniform cooling. This helps to avoid porosity. This diagram also shows the passages in the sand through which molten metal is poured in to form the casting.

Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons.

2.5 Characteristics of sand castings

2.5.1 Shapes and sizes

- Sand casting gives freedom to the designer to place metal where it is needed, so additional features e.g. a lifting handle or a reinforcing rib, can be incorporated.
- Casting employs molten (i.e. melted) metal which flows in to fill the shapes formed in the sand mould.

- Casting shapes are therefore often irregular and intricate.
- Castings from a few grams up to tens, hundreds or even thousands of kilograms (i.e. several tonnes) can be produced.
- It takes some time and may involve considerable cost to make a pattern and make a sand mould before the metal casting can be produced.
- Since sand casting also requires re-melting of the cast iron, it may be a relatively costly way to buy metal. However, the costs can often be offset by designing more features into the casting. Costs can also be amortised [5] if several units of the cast component are required.
- Since sand casting requires individual sand moulds and is labour intensive, it tends to be used where relatively small numbers of components are required, rather than for large scale mass production (cf. rolling mills). Nevertheless, there are items such as engine blocks which can only be made by sand casting and are produced in large numbers.

2.5.2 Material properties

- Cast iron in the molten state flows readily and fills intricate details in the sand mould.
- Most cast irons are brittle (break without significant stretching).
- Most cast irons have relatively low tensile strength. However special grades and types of cast iron have good tensile strength and are also ductile. Refer to ductile irons or SG (spheroidal graphite) irons for more details.
- Cast irons have good compressive strength.
- Cast irons do not generally corrode as readily as steel.

2.5.3 Recognising cast iron

Some characteristics which will help you to recognise cast iron are:

- It is invariably in the form of sand castings.
- Unmachined surfaces on the casting have a typical sand-grain texture and either dark grey or rusty reddish surfaces.
- Sand castings allow intricate and non-uniform shapes to be produced (cf. uniform sections from rolling mills).
- Parting lines are usually visible on the surface of the casting.
- The material is heavy, only slightly less dense than steel.

[5] The cost of the pattern, for example, can be spread over all the components produced.

- Machined surfaces oxidise to take on a dull grey colour.

2.6 Other processes for ferrous materials

Not all the steel from the converter goes to the rolling mills. Some goes through other processes to be made into a wide range of alloy steels for special purposes. Some will be produced as medium or high carbon steel where there is a need for a material harder or stronger (or both harder and stronger) than mild steel.

2.6.1 Steel castings

Some of these special steels may finish up as **STEEL CASTINGS**, using a sand mould similar to that used for cast iron (refer to Figs. 1-5 and 1-6). Although molten steel does not flow as easily as cast iron, and is therefore more difficult to cast, the better mechanical properties of steel make this a useful process when strength is required in complex components, e.g. the railway bogie in Fig 1-7. The characteristics and appearance of steel castings are generally similar to cast iron, although the finish is sometimes not as good or as detailed as cast iron.

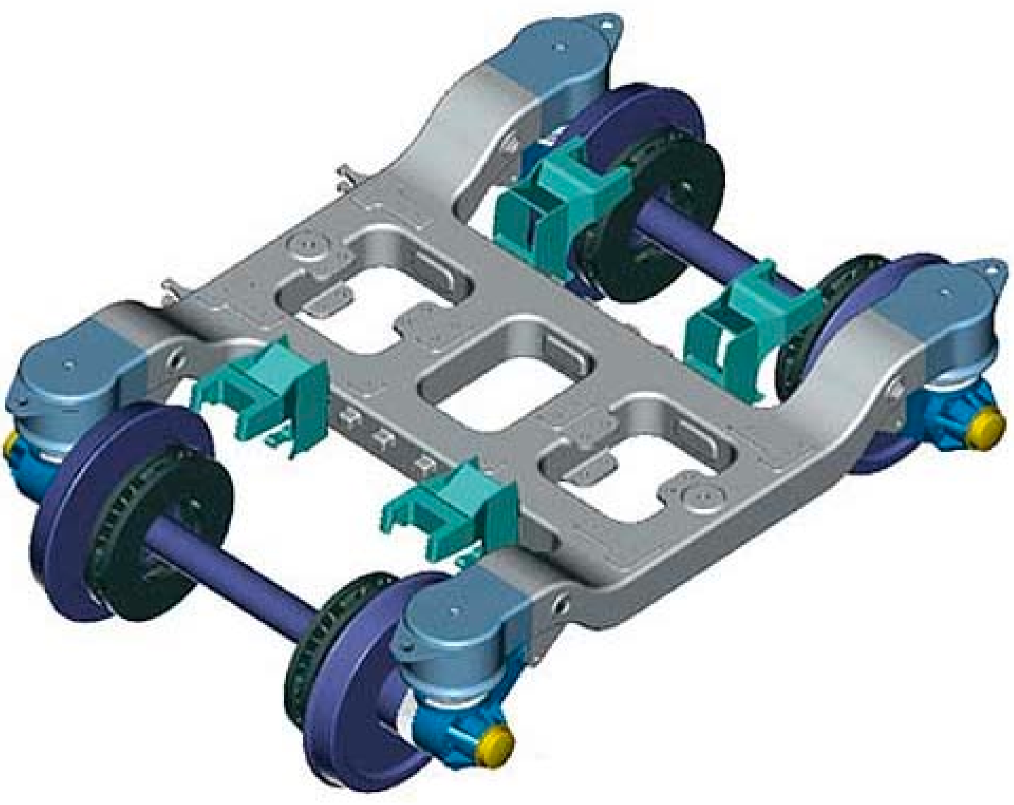

Figure 1-7 The grey frame is an example of a cast-steel railway bogie.
http://www.railway-technology.com/contractors/brakes/william_cook/william_cook1.html
[December 2009]

FOR KEEN STUDENTS

2.6.2 Investment casting

In some cases, there is a need to make a casting which, by reason of its "re-entrant" shape would be difficult if not impossible to cast using a normal pattern. The difficulty is to get the pattern out of the mould. A way around this is to make a pattern from a material, traditionally wax, which melts at low temperature then, after forming the mould, melt the wax, leaving a cavity of the required shape in the mould. The process is often referred to as "lost wax" casting. Every component produced needs its own pattern, but the method is convenient for one-off items. (Dental bridges and crowns and small jewellery are usually made in this way, generally using gold or silver or other alloys rather than ferrous materials.)

A development of the investment casting process is the use of plastic patterns from material such as polystyrene. The mould is formed around the pattern in the usual way. The polystyrene melts and completely disintegrates as hot metal is poured in and the casting takes up the shape of the mould. This is economical for larger components.

2.6.3 Forgings

2.6.3.1 Hot forging

The blacksmith used an anvil and hammer to transform a bar of red-hot steel into items such as tools or horseshoes. This was called hammer forging and required considerable skill and physical strength on the part of the blacksmith.
A more modern, more efficient and more powerful process uses **DIES** mounted in a large press to squeeze the red-hot metal into the required shape (Figs 1-8 to 1-11).

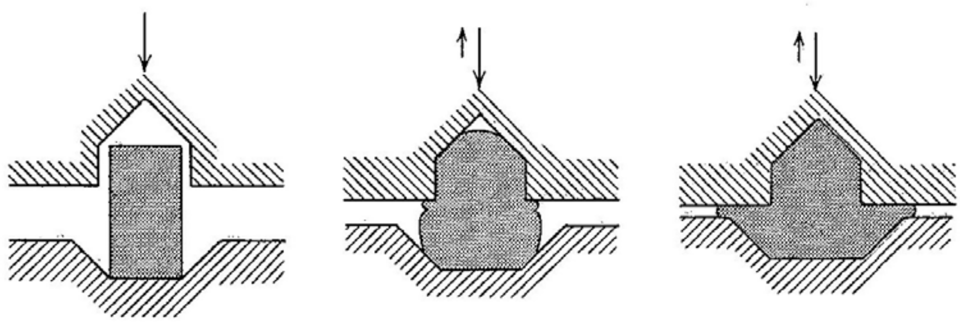

Figure 1-8 Drop forging with closed dies.
Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons, page 340.

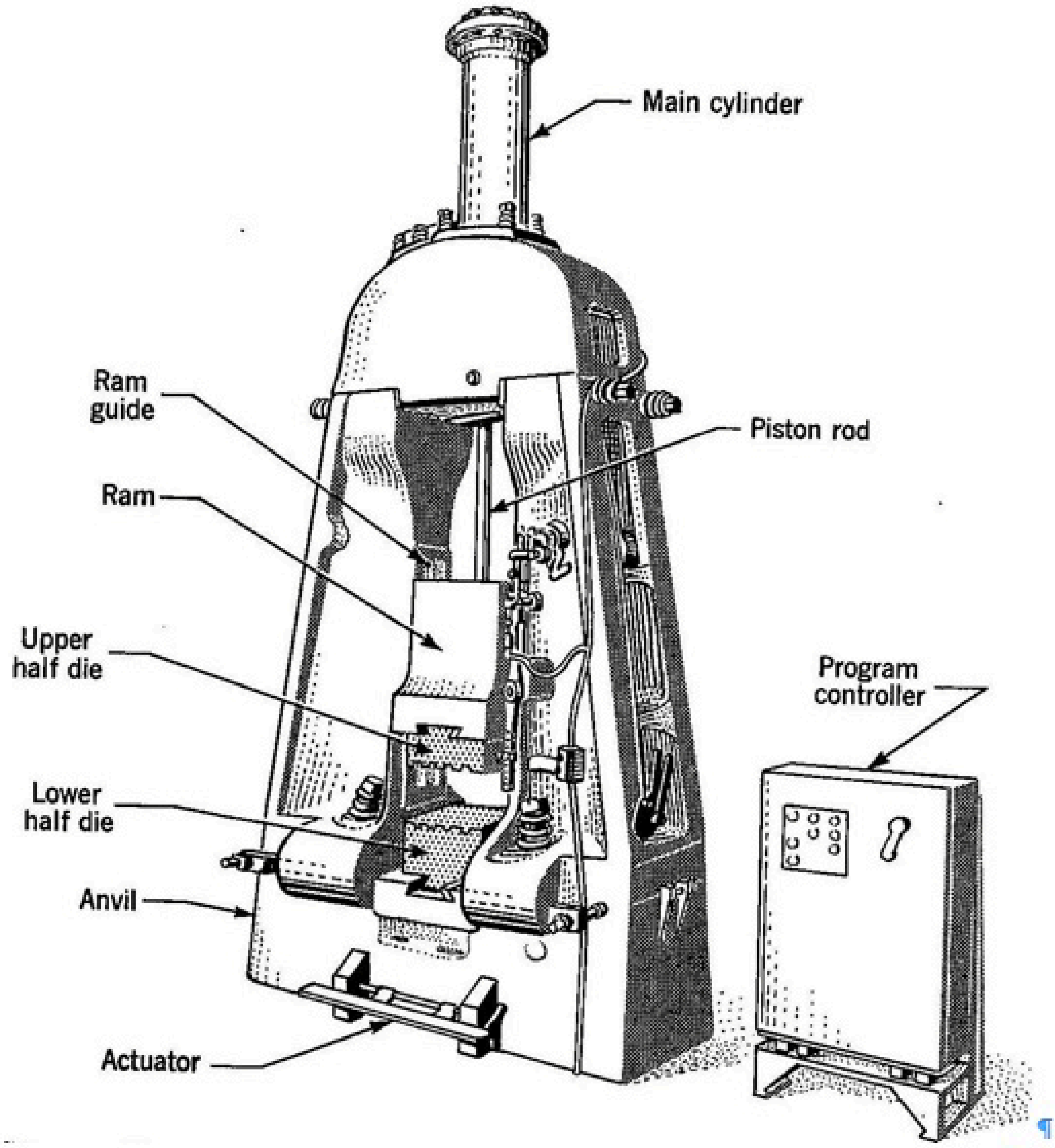

Figure 1-9 A forging press based on a piston-lift gravity-drop hammer. Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes,* 7th Ed., John Wiley & Sons, page 341.

The dies are large blocks of hardened steel into which the required shapes have been machined [6]. The lower-half die is fixed in position in a large machine such as a press or drop hammer (see Fig 1.9) while the upper-half die is able to be raised and lowered by some means. The press or drop hammer forces the two halves of the die to come together. At that stage, there is some resemblance to the casting process, since the metal completely fills the enclosed cavity. The basic difference is that

[6] Machining is the process of metal removal, generally using sharp cutting tools driven by a lathe, milling machine or CNC machine. Machining is described in more detail later in this document.

casting uses molten metal to flow, often by gravity, into the cavity, whereas forging uses pressure to force the heated (but still solid) metal to take the shape of the cavity.

In Fig. 1-8, the workpiece is formed either by prolonged squeezing in a hydraulic press of large capacity, or by repeated blows from a steam- or drop-hammer such as that shown in Fig 1-9. In either case, the whole process takes place in the same set of dies. It is worth noting that, in Fig 1-8, it can be seen that there is slightly more metal in the workpiece than needed to fill the die. The extra material is provided to ensure that the die will always be completely filled, with no gaps or imperfections in the forged component. The additional material finished up in the small "wings" on each side of the finished component on the right of Fig 1-8 and is called flash. Flash must be removed by shearing it off the finished forging.

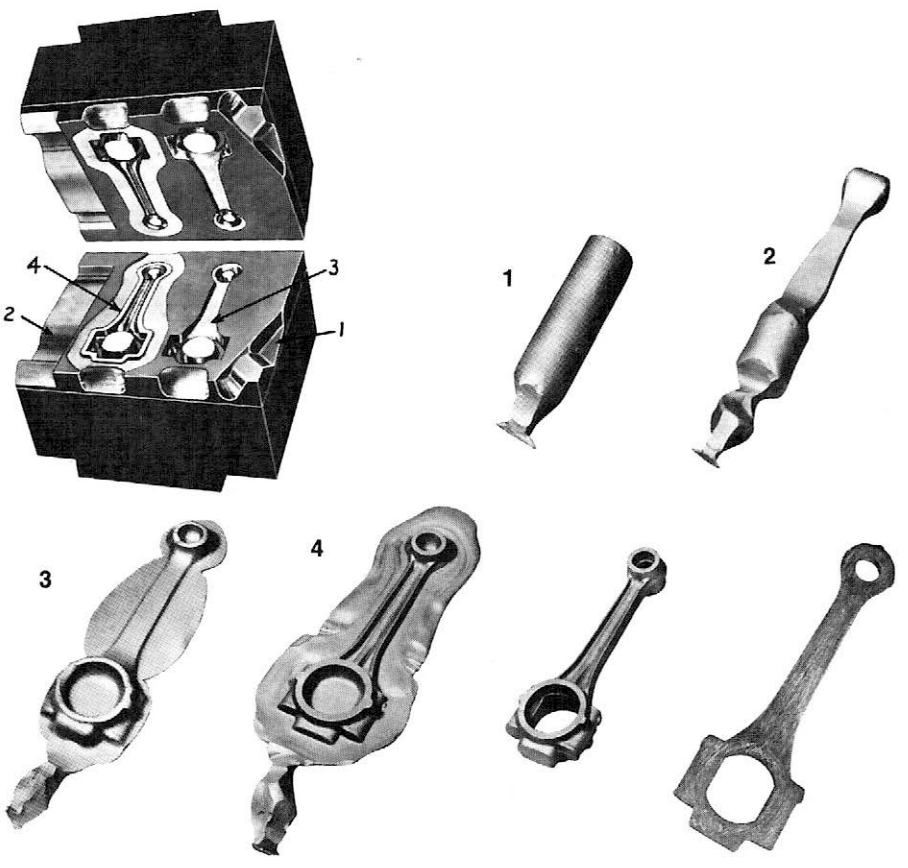

Figure 1-10 Impression drop-forging dies for an engine **CONNECTING ROD**, and the product resulting from each impression. The flash is trimmed from the finished connecting rod in a separate trimming die. Although it is difficult to see in this reproduction, the sectional view on the right shows the grain fibre resulting from the forging process. See Fig 1-12 for a clearer example of grain flow.
(Courtesy Drop Forging Association.)
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 367.

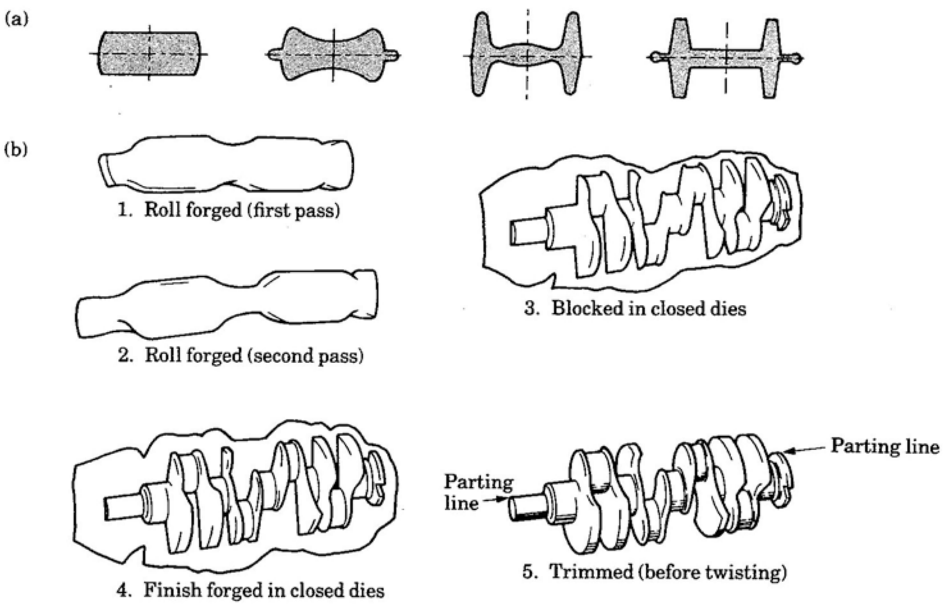

Figure 1-11 Intermediate stages in forging two different parts. (a) H-section. (b) Crankshaft. These intermediate stages are important for distributing the material and filling the die cavities properly.
Reproduced from S. Kalpakjian, *Manufacturing Processes for Engineering Materials*, 1984, Addison Wesley, page 311.

In Fig 1-9, the die halves which form the forged shape are shown mounted in the press with the lower half die fastened to the press frame and the top half die fastened to the ram. The ram is free to move up and down and, in this particular press, it and the upper half die are lifted up by air pressure acting on the piston at the top of the press, then released to fall by gravity, with each drop cycle and impact further deforming the workpiece into the desired shape.

However, in an alternative method shown in Figs 1-10 and 1-11, the workpiece is moved sequentially through a series of die sets to achieve the desired shape. In Fig 1-10, the box-like die halves are mounted in the press as was the case in Fig 1-9. Each blank (i.e. workpiece) is heated to red heat and is moved progressively through positions 1 to 4 to form the connecting rod. The flash visible at stage 4 is then sheared off in a separate trimming die to produce a component ready for machining.

Fig 1-11 gives further illustrations of hot drop-forging. The H-section (a) is produced by sequential deformation in successive dies. Note the flash on the final stage, which needs to be trimmed off in a separate operation.

For the crankshaft (b) in Fig 11, the first two stages of deformation of the blank are by roll forging, followed by two stages of forging in closed dies, roughly similar to the process in Fig 1-10, then trimmed to remove the flash.

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The crankshaft in Fig 1-11(b) is for a four-cylinder engine and has five main bearings. The forging process is carried out “two-dimensionally” (remember the forging die can only move vertically), which is a simple process for a four-cylinder engine where the crankpins are at 180°. In the case of say a six-cylinder crankshaft where the crankpins are at 120°, the final three-dimensional shape of the crankshaft is achieved by twisting portions of the shaft about the main bearings after forging has been completed.

Die forging (or impression drop-forging) produces relatively smooth surfaces on the finished product. As previously noted, there must always be a slight "overflow" from the die as the two halves close together, in order to ensure that there will always be enough material to fill the die completely. The overflow metal spreads out in a thin sheet called **FLASH** (Figs 1-10, 1-11) which is later trimmed from the main component. It is often possible to see the marks of trimming on forgings and this provides a means of identifying a forging. There are, however, some similarities between parting lines on castings and trimming lines on forgings, so some care is needed before drawing conclusions.

In hot forging, the cost of heating and reheating the workpiece adds to the cost of the finished part. However, the forging process produces a beneficial grain structure within the metal. Fig. 1-12 shows how the fibre-like flow lines closely follow the contours of the part. Such a grain structure (which is not present in castings) is found to add considerably to the working strength of the component. The forging process is therefore a valuable one where heavy-duty components are to be made.

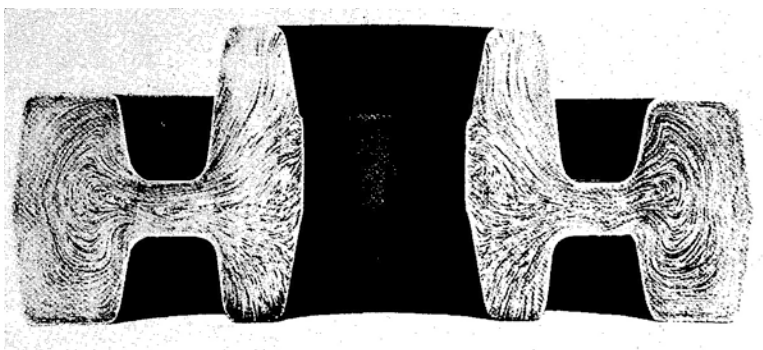

Figure 1-12 An example of grain flow lines in a forged gear blank, visible after sectioning.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 357.

2.6.3.2 Cold forging

Where smaller components (bolts, for example, as in Fig 1-13) are to be made, sufficient force is often available to use **COLD FORGING**. This saves the time and cost of heating the part. It also produces a better surface finish, avoiding the surface oxidation which occurs at high temperatures. In addition, the manufacturing tolerances tend to be lower (i.e. parts are more accurate) and cold working is found to improve the tensile strength of the finished product.

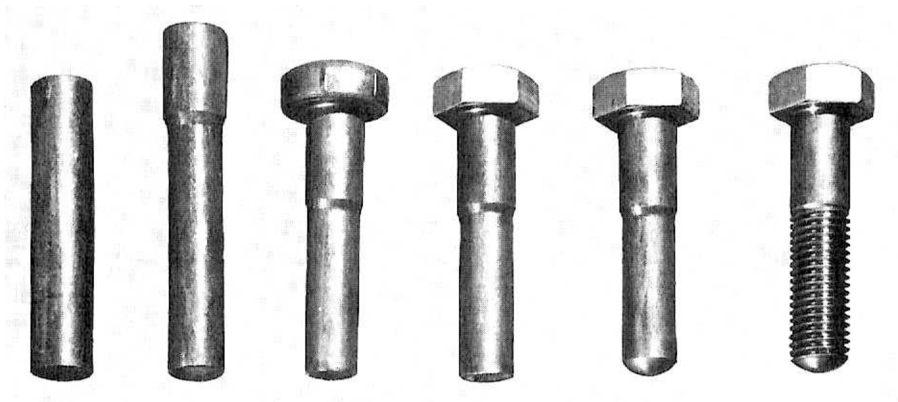

Figure 1-13 Steps in cold-forging a bolt by extrusion, cold heading, and thread rolling.
(Courtesy The National Machinery Company.)
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 398.

Fig. 1-13 shows six stages in cold forming a bolt. The process begins with a carefully sized piece of round bar. Note how the diameter of the shank is reduced over the length to be threaded and how metal is provided to form the hexagonal head. Forming and finishing the hexagonal head requires several stages. The thread on this bolt has been produced by **THREAD ROLLING**, a process whereby metal is displaced from the "valleys" of the thread to form the "crests". The fact that the diameter of the finished thread is slightly greater than the diameter of the shank onto which it was formed demonstrates that it was produced by rolling, not by thread cutting.

Fig. 1-14 gives some further explanation of the methods used to form such features as a hexagonal head on the end of a round bar, using a series of punches to gradually shape the hexagonal head.

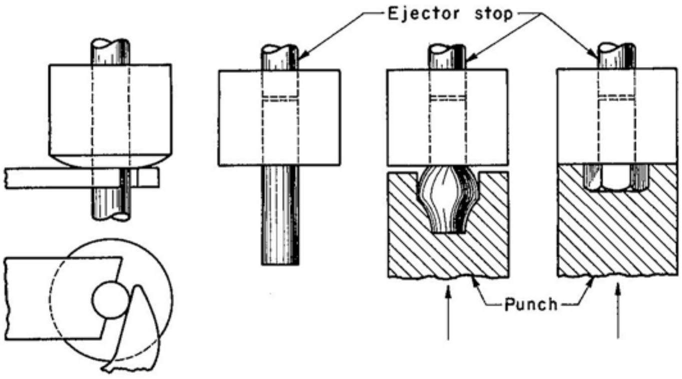

Figure 1-14 Steps in a cold heading operation, illustrating how the head is formed from the original rod.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 395.

2.7 Forming

Forming is a method of deforming metals, often cold, by the application of force, usually in a press. Some forming methods are described below. The processes of drawing and extrusion described later in this document under the heading **Aluminium and its Alloys** are also examples of forming processes.

2.7.1 Bending and folding

In bending and folding, the material is bent by means of a punch, which forces the material into the shape of a die (Fig. 1-15). Using this method, only relatively short lengths of material can be handled, say 1-2 metres long. Sometimes the workpiece may be quite small, e.g. bending a flat steel strip say 25 or 50 mm wide for a bracket. The process does not require severe working of the metal and is done cold.

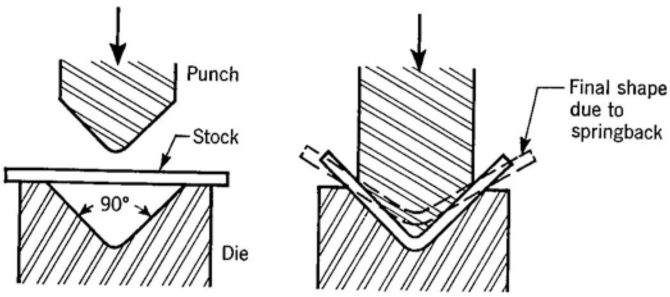

Figure 1-15 Bending a piece of flat material using a punch and die. The length of the workpiece is limited by practical limitations in the length of the die and punch. The figure shows how the workpiece ***springs back*** after bending.
Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons.

2.7.2 Roll forming

Where long lengths of material are required, a roll-forming process is used to form coiled strip material into the desired shape or section. A common example is the way in which roofing contractors roll-form aluminium guttering on-site from a compact coil of aluminium strip. This method allows them to avoid the need to join short lengths of guttering or, alternatively, the difficulty of transporting long lengths of already-formed guttering to different sites.

Fig. 1-16 shows just how useful the roll-forming method can be in producing a wide range of structural and architectural products. The right-hand side of the figure shows the stages in roll forming a flat strip of material into a long length of window-screen section.

Fig 1-17 is a schematic representation of the top/bottom and side rolls used to produce cold-rolled stock.

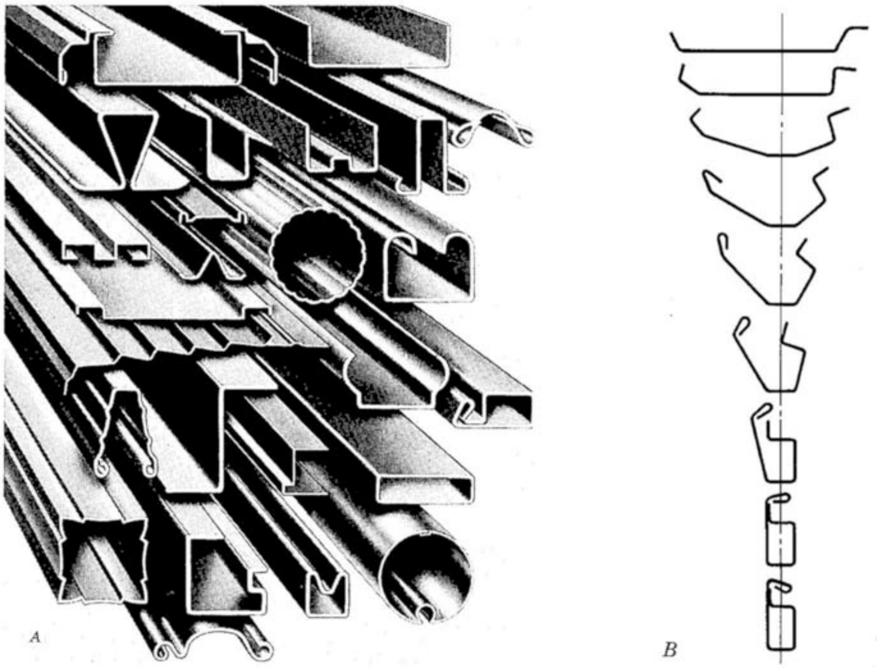

Figure 1-16 Cold-rolled-formed parts. *A*: Miscellaneous parts formed from coiled strip. *B*: Sequence of forming operation for window-screen section.
Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons, page 380.

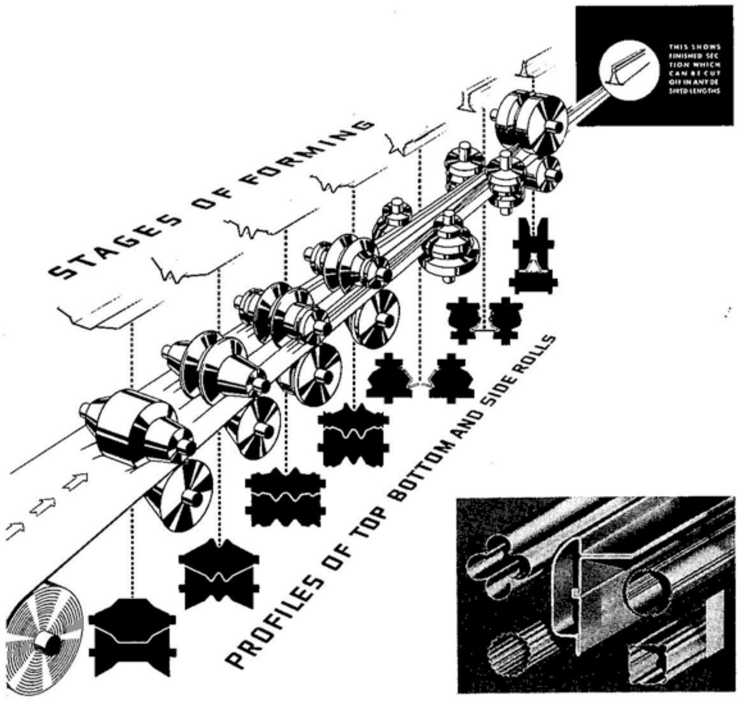

Figure 1-17 A schematic representation of the cold-roll forming process, also showing typical shapes formed by this process.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5E, Macmillan, p 409.

2.8 Spinning

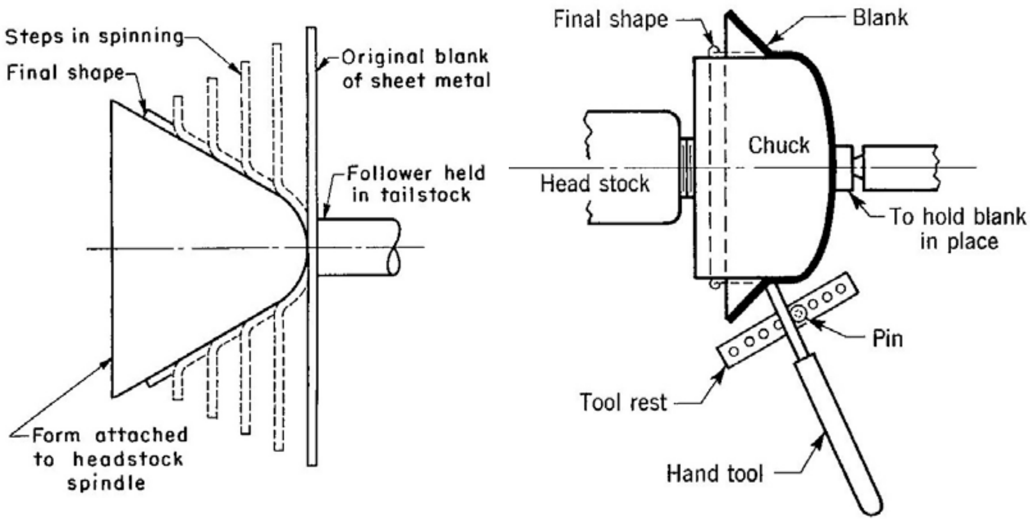

Figure 1-18 Diagrammatic representations of the spinning process.
Left: Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 426. *Right:* Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons page 368.

The spinning process typically begins with a flat disc of a malleable material such as mild steel, brass or aluminium (Fig 1-18 left). The disc is pressed into contact with a form, which has the shape of the component to be manufactured. The form is attached to the headstock of a lathe and the lathe set to run at high speed, so the workpiece also rotates at high speed. A hand tool (Fig 1-18 right) is pressed against the rotating disc with sufficient force to deform the metal into the shape of the form. By progressively moving the hand tool, the flat disc is transformed through stages such as those shown in Fig 1-18 left, being gradually pushed into the final shape.

Quite complex shapes can be made by the spinning process (e.g. Fig 1-18 right). The process is often used for the manufacture of cooking utensils such as saucepans and cooking bowls.

2.9 Shearing

Shearing in general is used to cut sheet-metal parts to shape by a process similar to the action of a pair of scissors. Shearing can be used to cut large sheets or coils of stock material into smaller pieces which can be more easily handled, or into pieces which will form individual components. The word "shearing" is usually reserved for processes where straight-line cuts are made. Where workpieces are cut from a continuous strip or coil, the process is usually called "blanking", i.e. it produces a series of discrete workpieces of basically circular or rectangular or irregular shape, which are called **BLANKS**. In this case, what is left of the continuous strip is waste.

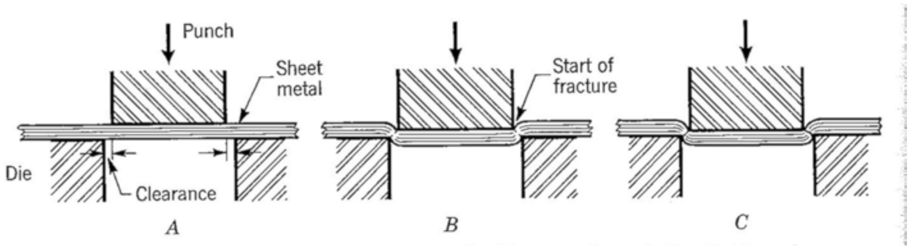

Figure 1-19 Process of shearing metal with punch and die.
A: Punch contacting metal. *B*: Plastic deformation. *C*: Fracture complete.
Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons, page 410.

Fig. 1-19 shows the basic arrangement of a punch and die set for shearing a **BLANK** from a continuous strip of sheet metal. After the blank has been punched (or sheared) out, the punch is withdrawn, the strip is moved along an appropriate distance and the punch is again forced down to shear another blank. The process is set up to run automatically with high production rates.

The shearing process described here is similar in many respects to cutting material with a pair of scissors (or shears). It involves applying two equal and opposite forces (stresses, to be more precise) which exceed the shear strength of the material.

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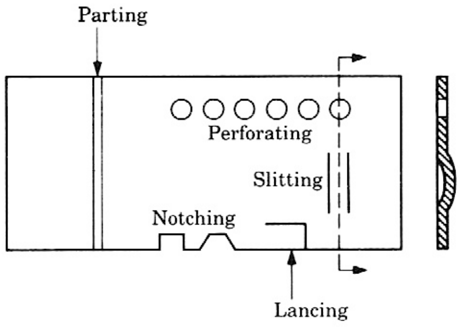

Figure 1-20 Other shearing operations are:

- **PIERCING,** or **PERFORATING,** which produces holes of regular or irregular shape and size in blanks. The piece cut out is scrap.
- **NOTCHING,** which removes material from the edge of the workpiece.
- **LANCING,** where a piece of material is sheared and bent in order to make tabs, vents, or louvres.
- **SLITTING,** which allows small raised sections of the workpiece to be created.

2.10 Swaging

Swaging is a method of forming metals. It usually applies to changing the diameter of short sections of basically cylindrical components. Fig. 1-21 shows the process applied to forming a reduced end on a thick-walled cylinder. In this case, the process is carried out with the workpiece hot and several dies are used in sequence to hammer or force the metal inwards to form the neck of the tube. In general, the swaging process uses repeated hammer-like blows by shaped dies to deform the metal to the desired shape and size.

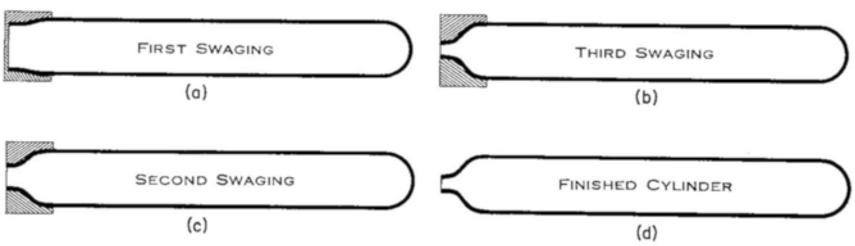

Figure 1-21 Steps in hot swaging a tube to form the neck of a steel cylinder.
(Courtesy United States Steel Corporation.)
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 374.

Fig. 1-22 illustrates some of the many applications of swaging carried out with the workpiece cold.

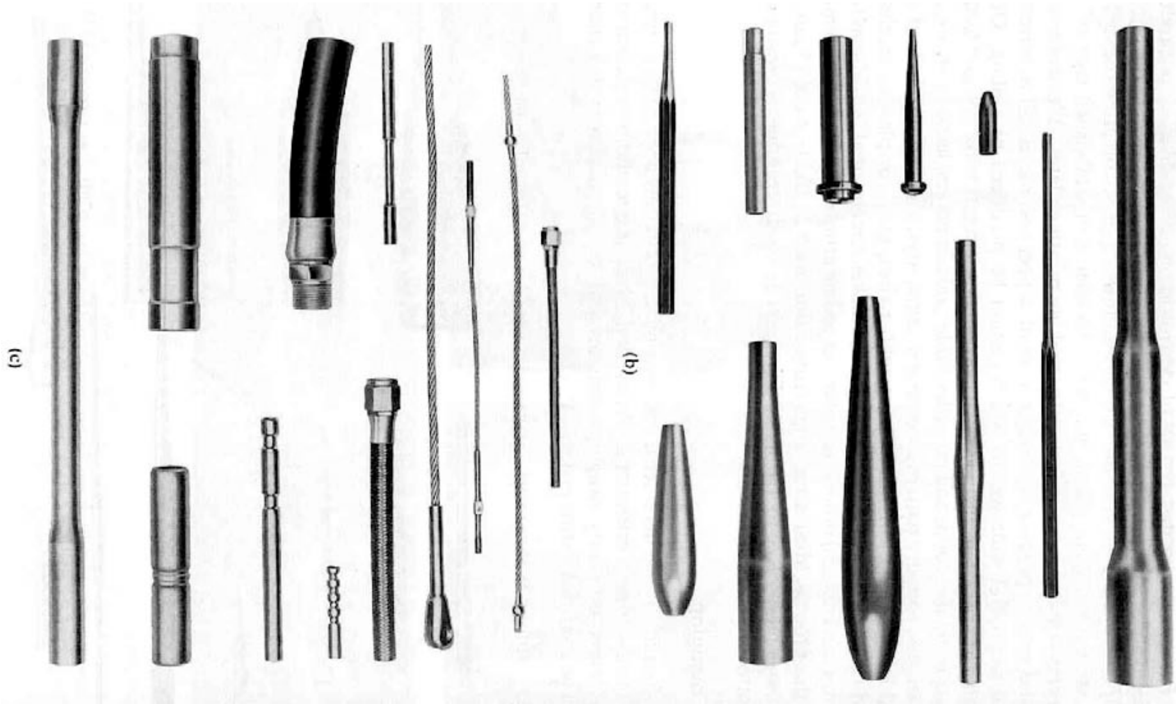

Figure 1-22 Examples of the range of the cold swaging process.
Reproduced from H.W. Yankee, *Manufacturing Processes*, Prentice Hall, 1979, page 540.

Some common examples of cold swaging visible in Fig 1-22 include the swaged end fittings on rubber hoses typically used on hydraulic equipment and the swaged end fittings on steel wire cables used on boats and winches.

3 Aluminium and its Alloys

Turn now to engineering materials other than the ferrous materials which have been the focus so far.

Aluminium is a light-weight metal which is used extensively in industries such as transport and food. The pure metal is soft and has low strength, but by combining aluminium with a few percent of alloying materials, hardness and strength are greatly increased. The main alloying materials are:

- Copper
- Silicon
- Magnesium
- Manganese

Aluminium products may be produced by a wide variety of processes, some of which are:

- Sand casting
- Forging
- Rolling
- Pressure die casting
- Extrusion
- Drawing

3.1 Production processes for aluminium

Sand casting, forging and rolling have already been described in the section on **Ferrous Materials** and similar remarks, advantages and restrictions apply when they are used for aluminium. Processes such as extrusion and drawing, introduced below, are commonly applied to steel as well as to aluminium but pressure die casting cannot be used for ferrous materials.

3.1.1 Pressure die casting

Pressure die casting is again a casting process, using molten metal to fill a cavity of the desired shape and size. In this case, the cavity or is formed by machining recesses into blocks of high quality tool steel, known as **DIES**, which give the process its name. In die-casting, the dies are used over and over again, hundreds of thousands of times. This is in contrast with sand casting, in which the **MOULD** is broken up in order to extract the casting. In order to re-use the dies, methods must be found to open up the dies to allow extraction the cast component.

The molten metal is forced into the die cavity under high pressure, so that very intricate detail can be cast, e.g. threads, very small lettering, etc. The surface of the die cavity is generally smoothly machined, so that the surface of the finished product is also smooth (cf. the rough finish of sand casting), although a textured surface is sometimes used for appearance or function, e.g. to provide a good grip for a lever or control knob.

It is important to understand that pressure die casting using tool-steel dies cannot be used for ferrous materials because the temperature of the molten steel is similar to the temperature which would melt the dies, and the molten steel would simply weld itself to the dies.

Fig 1-23 comprises simplified line diagrams of a **COLD-CHAMBER DIECASTING MACHINE** (left) and a **HOT-CHAMBER DIECASTING MACHINE** (right).

In the cold-chamber type (left), the metal to be cast is heated and melted before being poured into the chamber of the machine. A piston then forces the molten metal into the die. After cooling, part of the die is moved aside and the diecast component removed. The external heating allows metals of higher melting point to be used in the machine, e.g. aluminium, magnesium, copper and its alloys.

The hot-chamber type (right) has a continuous supply of molten metal within its own hot chamber and in principle can cycle more quickly that the cold-chamber type, but tends to be limited in the maximum melting point of the material being diecast, e.g. lead, tin and zinc.

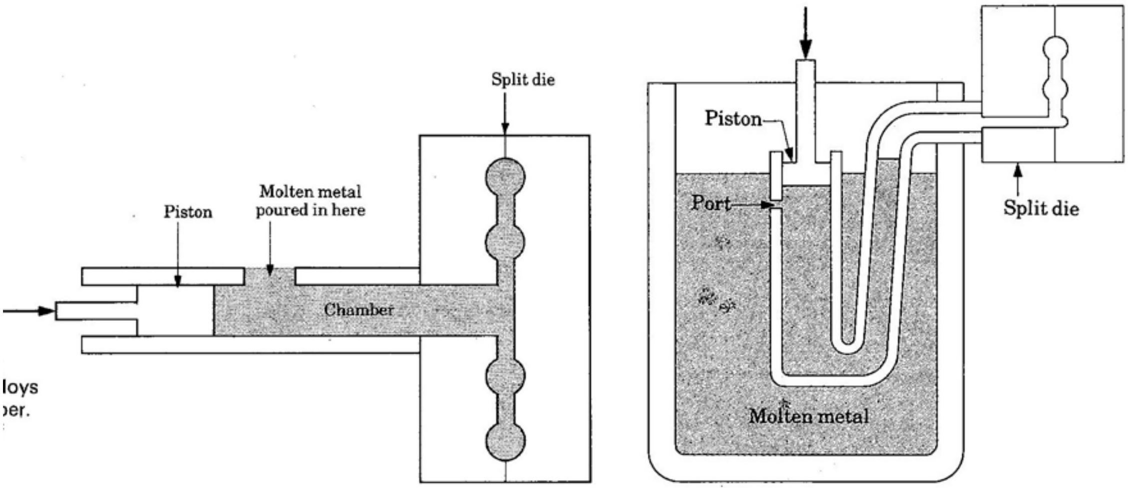

Figure 1-23 Schematic diagrams: *Left:* A cold-chamber die casting machine. *Right:* A hot-chamber die casting machine.
Reproduced from S. Kalpakjian, *Manufacturing Processes for Engineering Materials*, 1984, Addison Wesley, page 269.

In Fig 1-24 (below), the cycle starts at A, with the dies closed, the two **CORES** in position and molten metal from an external source (i.e. a cold-chamber machine) about to be poured into the chamber. At B, with the metal poured into the chamber, the plunger is forced to the left, forcing metal into the cavity in the dies. The black object represents the cast component. At C, the metal has been allowed to solidify (the dies are usually water-cooled), the two cores have moved vertically up and down respectively and the moveable section of the die is then free to move to the left, pushed by the plunger. At D, the moveable die has moved further to the left and an **EJECTOR PIN** pushes the casting clear of the moveable die and it falls clear, allowing the machine to be set up for the next component.

On complex diecastings, several ejector pins are often needed. Each ejector pin leaves a characteristic circular mark on the casting and the presence of such marks is a useful means of identifying diecast components.

An example of a large aluminium die casting is the transmission housing shown in Fig. 1-25. However, die casting is often used to make much smaller objects, commonly the housings for consumer appliances. One source suggests that the small individual hooks on zip fasteners were originally zinc die cast in dies having multiple cavities, so that large numbers were produced at every stroke of the dies.

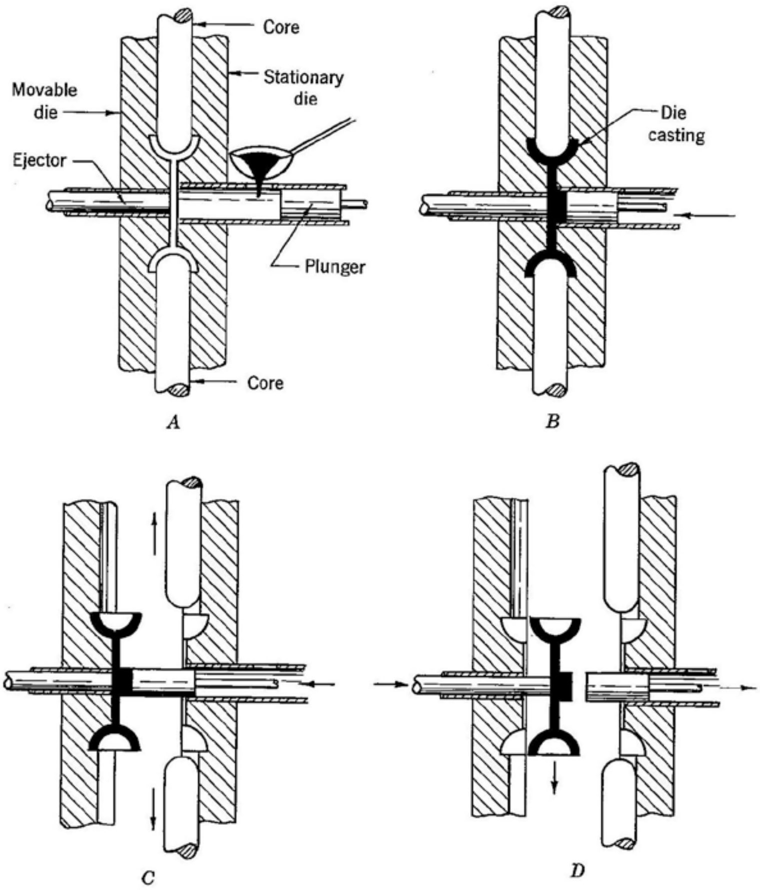

Figure 1-24 Another simplified diagram illustrating more of the principles of a diecasting machine, in this case a cold-chamber machine.
Reproduced from Amstead, Ostwald & Begeman, *Manufacturing Processes*, 7th Ed., John Wiley & Sons, page 133

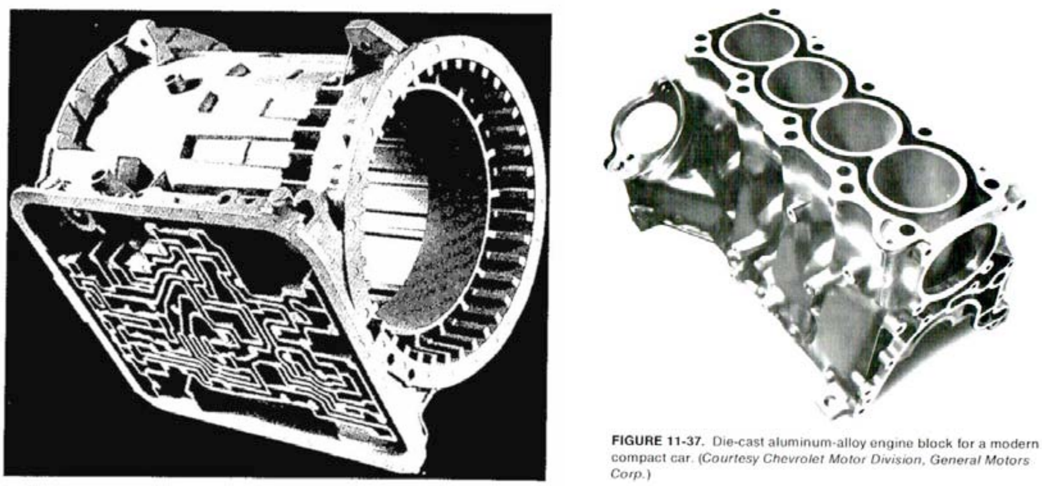

Figure 1-25 *Left:* A diecast aluminium transmission case or housing, weighing approximately 30 kg. (Courtesy Doehler-Jarvis, Division of National Lead Company.) Reproduced from H.W. Yankee, *Manufacturing Processes*, Prentice Hall, 1979, page 105.
Right: A diecast aluminium cylinder block from General Motors Chevrolet Division. Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 290.

3.1.2 Extrusion

The action of squeezing toothpaste from a tube is essentially **EXTRUSION**. Pressure applied to the bulk of the toothpaste in the tube forces some of the toothpaste through the small hole at the end of the tube. Metals may be extruded in a similar way, as illustrated in Fig 1-26, using very high forces. The shape and size of the cross-section of metal issuing from the extrusion die is determined by the design of the die.

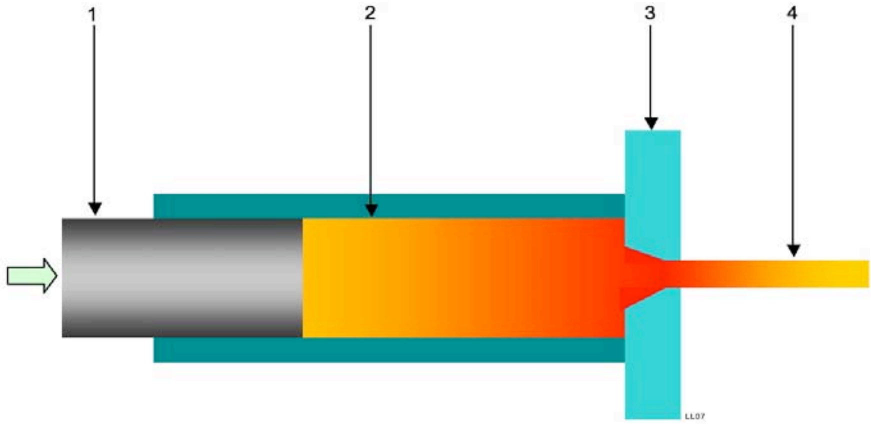

Figure 1-26 Schematic of the extrusion process.
1. Piston which applies pressure to the heated metal;
2. Heated metal being extruded;
3. The extrusion die, which determines the shape of the extruded section;
4. The extruded section.
http://commons.wikimedia.org/wiki/File:Extrusion_process_2.png February 2010

By suitable design of the extrusion die, it is possible to produce extremely complex shapes. Hollow sections can be produced and the process is often used to make tubes. Fig. 1-27 shows two ways in which tubes may be produced by extrusion, the top figure showing a **MANDREL** which is forced through the **BILLET** and into the **DIE** . The heated metal is then forced to flow into the annular space between the mandrel and the die. The second method is similar, but the mandrel is actually part of the ram.

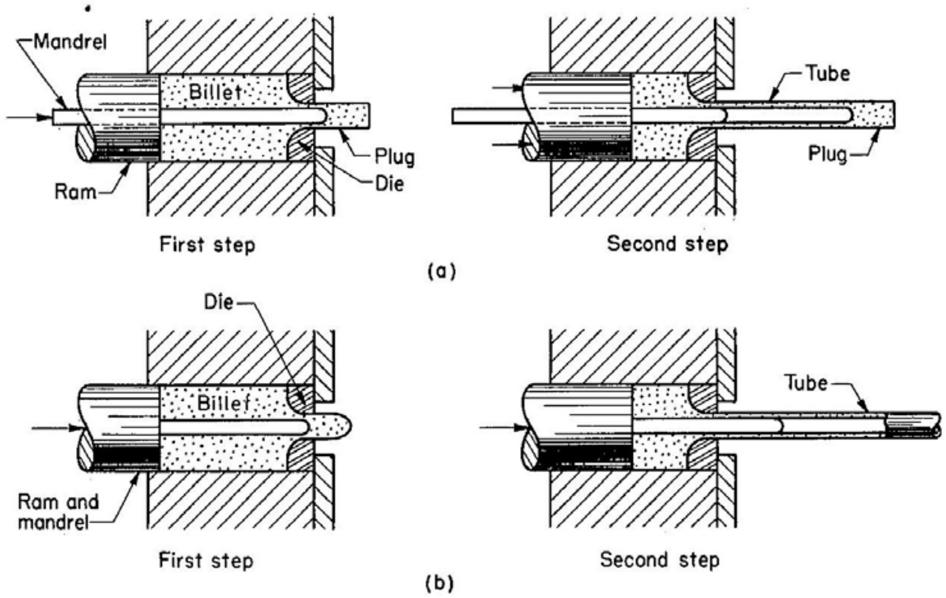

Figure 1-27 Two methods of producing extruded tubes.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 279

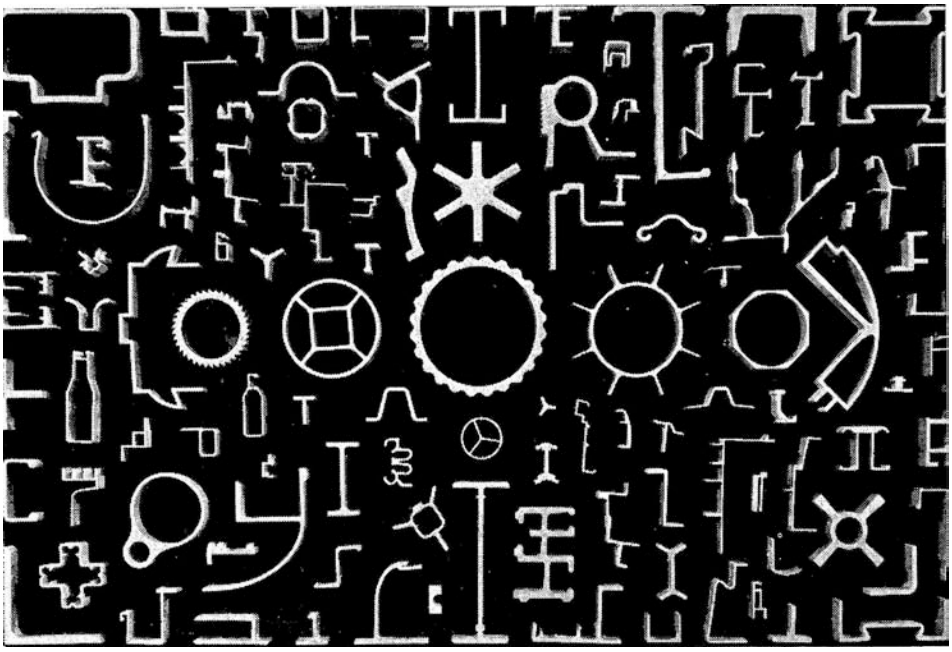

Figure 1-28 Some extruded aluminium sections which have been produced. Many are used in architecture.
Reproduced from Deutschman, Michels and Wilson, *Machine Design - Theory and Practice*, Macmillan, 1975, page 165

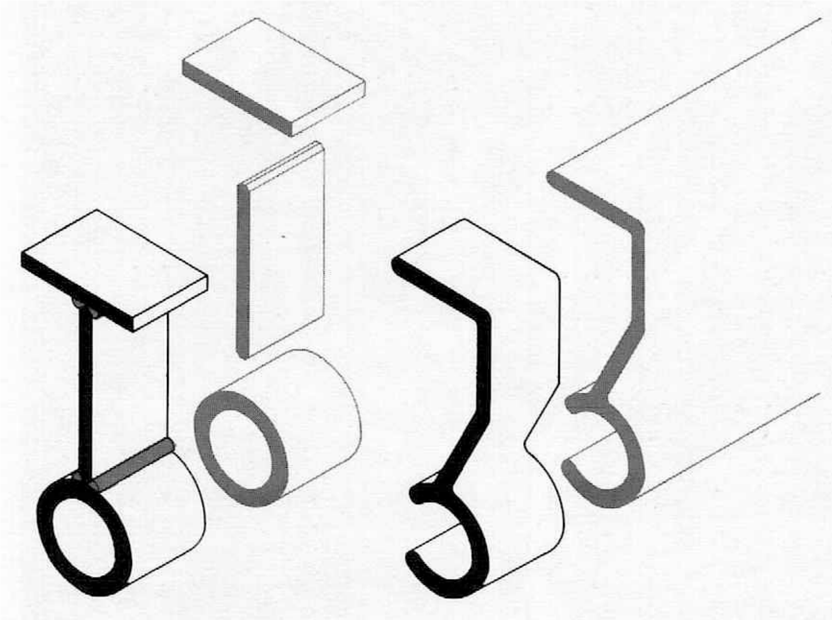

Figure 1-29 The component illustrated can be made by **FABRICATION**, i.e. welding together a number of standard sections such as tubes and flats (left), or an equivalent part can sometimes be made more simply and at lower cost by cutting off short lengths of an extruded section (right). Source not known.

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3.1.3 Spider dies

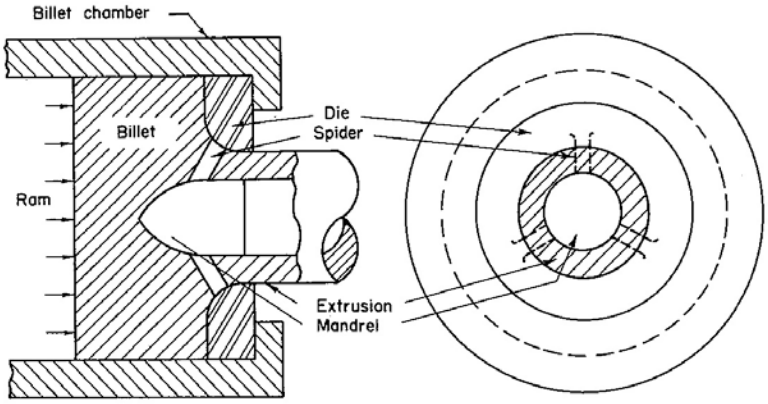

Figure 1-30 Schematic of a **SPIDER DIE** for extruding hollow sections of complex or irregular shape.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 379

Hollow cavities of irregular shape or multiple cavities within extruded material cannot be produced using simple flat two-dimensional extrusion dies of the type shown in Figs 1-26 and 1-27, because there is no way to support the centre “mandrel” of the die. The method adopted is to mount the mandrel centrally within the die orifice by means of several thin “legs”, as seen in Fig 1-30. Viewed from the entry to the die, the mandrel looks somewhat like a spider with body and legs and the die is known as a **SPIDER DIE**. The internal shape of the die gradually changes downstream from the spider and the separate metal streams created by the spider legs can be welded by heat and pressure back into one stream. Fig 1-30 produces a cylindrical tube, but a different shape in the downstream part of the spider die could produce any of the square, rectangular, multi-cavity or other cross-sectional shapes shown in Fig 1-28.

3.1.4 Drawing

In the drawing process, a flat piece of the material (often of circular shape) is forced (or "**DRAWN**") through a die to take on a cup-like or cylindrical shape (Fig. 1-31).

Successive drawing operations on the same piece of material can be used to produce long cylinders of small diameter. The workpieces shown as dotted outlines in Fig. 1-31 are the result of successive drawing operations.

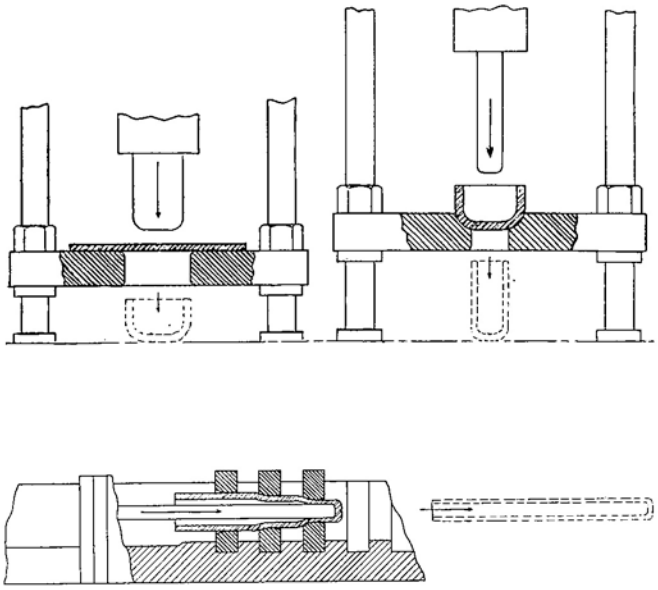

Figure 1-31 Methods of cupping or hot drawing by the use of single and multiple dies.
(Courtesy United States Steel Corporation.)
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 381.

3.2 Characteristics of aluminium and its alloys

3.2.1 Shapes and sizes

- May be sand or die cast or rolled, but is very often extruded into long lengths of uniform cross-section.
- A very wide range of extruded sections is available:
  Sheets, flats, rounds, angles, channels, beams, tubes, rectangular hollow section, plus a very wide range of specialised sections for architecture and the transport industry.

3.2.2 Material properties

- Pure aluminium is soft with low tensile strength
- Aluminium is light, about one third the density of steel.
- The elastic modulus of aluminium and aluminium alloys is roughly one third that of steel.
- Large increases in strength and hardness are possible by correct choice of alloying elements (e.g. copper, manganese, silicon, magnesium) and heat treatment.
- Aluminium does not corrode readily in air or water. The thin film of aluminium oxide which forms rapidly provides a protective coating.

- Aluminium is non-magnetic.
- The metal is white in colour. The surface is often anodised to provide a decorative finish in a wide range of colours.
- Aluminium generally costs more than steel.

3.2.3 Recognising aluminium

- Pure aluminium and the aluminium alloys described above have a very similar appearance. Metallurgical testing is required to determine which alloying elements, if any, are present.
- Light weight is a good indicator that the material is aluminium. The white colour is also characteristic.
- Sand cast components have the typical sand texture and complex shape of this production method. Parting lines are usually evident.
- Die cast components have complex shapes with very smooth surfaces and very fine detail, e.g. threads and lettering may be directly produced by die casting.
- Rolled material has a uniform cross-section. It usually has a better surface finish than similar rolled steel products.
- Extruded products are of uniform cross-section. Hollow sections are usually, but not always, extrusions. Extrusions may have readily visible longitudinal scratches resulting from passage through the extrusion die.
- An anodised finish (e.g. on architectural sections) is characteristic of aluminium.

4 Stainless Steel

Stainless steels are available in a very wide range of alloys, used for many different purposes. In general, they contain relatively large proportions of **CHROMIUM AND NICKEL**. One typical alloy, for example, contains 18% chromium and 8% nickel.

The outstanding characteristic of stainless steels is their corrosion resistance. However, experience has shown that these alloys can be subject to quite severe stress corrosion under certain conditions, e.g. when exposed to sea water. Detailed knowledge of the operating conditions and the properties of the various alloys is essential before rational design choices can be made.

Stainless steels are often of bright silvery appearance. However some alloys may be distinctly bluish in colour. The surface usually retains its lustre and is for that reason often used to make decorative components, e.g. trim strips, bezels, and grille components for cars, stoves, washing machines, etc. In addition to such uses in the automotive and appliance industries, stainless steels have a wide range of applications in the food/beverage and chemical industries in the form of pipes, tanks, etc. They are also widely used to make cutlery and tools, as well as structural members and mechanical components such as springs.

4.1 Production processes

4.1.1 Rolling

Rolled stainless steel sections are available in many of the shapes that are available in carbon steel (see Fig. 1-3):

Bars, plates, strips, tubes, etc.

Various rolling mill finishes are available, from hot-rolled to cold-rolled to mill-polished, to suit various applications.

4.1.2 Forming

Stainless steels may be drawn into cylindrical shapes, as shown in Fig 1-31, or bent into reasonably sharp corners.

4.1.3 Machining

Most stainless steel alloys can be machined with some difficulty. Some alloys work harden very readily, making the machining process more critical.

4.1.4 Casting

Some alloys can be cast. Small items such as dental crowns are often made of stainless steel by the investment casting process.

4.2 Material properties

- The density of stainless steel is approximately the same as carbon steel.
- Stainless steels are poor conductors of heat and electricity.
- Stainless steels resist corrosion. Generally, a thin oxide layer forms on the surface and acts to prevent any further surface deterioration.
- There are wide variations in hardness and wear resistance. Some alloys are soft and have low yield strength. Others are hard, strong and wear resistant.

4.3 Recognising stainless steels

- The characteristic bright surface finish present on many components is one of the best means of recognising this material. However, hot-rolled bar, for example, may have quite a rough surface, lacking any of the lustrous qualities of the polished material.
- It is heavy - approximately the same density as steel.
- Most alloys are not ferro-magnetic, but some are ferro-magnetic.
- Its application sometimes gives an indication that a material is likely to be stainless steel, e.g. to cooking utensils, food preparation equipment or other items where corrosion must be eliminated.

5 Copper and its Alloys

These are often referred to as the "yellow metals". Whilst the colour can vary from yellowish to reddish brown, there is a very good chance that any metal having a colour in this range will be a copper alloy.

There is significant confusion and lack of precision in the description of many copper alloys. The list below makes very simple distinctions which gloss over many of the difficulties which occur in practice.

5.1 Copper alloys and their uses

5.1.1 Pure copper

Distinctly reddish hue. Soft metal which work hardens. Very good electrical conductor. Very good heat conductor. Often in the form of wire, bar, sheet, tube, produced by drawing, rolling or extrusion.

5.1.2 Brasses

COPPER-ZINC ALLOYS are generally classified as brasses. Alloys with 5-20% zinc have a reddish colour, while those with 20-36% zinc are yellow in colour.

Brasses resist corrosion and are often used in applications requiring corrosion resistance, e.g. taps, water pipe fittings and valves, etc. Brasses generally machine very readily.

Brass products may be produced by sand casting, die casting, forging, rolling and extrusion.

5.1.3 Bronzes

COPPER-TIN ALLOYS have traditionally been described as bronzes. There is a wide range of properties, depending on the amount of tin present. Alloys with 8-12% tin are used for gears, machine parts, marine applications. Alloys with 12-20% tin are frequently used for bearings and bushings.

Many materials which are still referred to as bronzes contain other alloying elements and have significantly different properties, e.g. phosphor bronze, leaded bronze, aluminium bronze. Bronzes generally resist corrosion. They machine very readily.

Bronze products may be produced in several ways, e.g. sand and die casting, rolling and forging.

6 Zinc

Zinc is a soft metal with a white or slightly bluish colour. It has a density slightly less than steel. As previously mentioned, zinc is an important alloying component in many brasses.

Zinc is extensively used in die castings. **DIE CASTING ZINC ALLOYS** use about 4% aluminium, a little copper and a trace of magnesium. These alloys are cast at a low temperature (382°C) which allows a very long life to be obtained from the die in a hot-chamber machine. Zinc die castings can therefore be very inexpensive and are often used where intricate detail is required and strength is not a major consideration, e.g. automotive fuel pumps and carburettors in early model cars.

Zinc die castings may be recognised by their typical die-cast appearance (complex shapes, smooth surfaces and intricate detail) plus the fact that the component is too heavy to be aluminium.

The second main use of zinc is as a protective corrosion-resistant coating for steel. The electro-chemistry is such that the zinc is sacrificially corroded rather than the steel. The zinc coating may be applied by hot-dip galvanising (where the component is immersed in a bath of molten zinc) or by zinc plating (usually small parts). Galvanised steel sheets often exhibit a surface characteristic having the appearance of a large overlapping crystalline structure known as "**SPANGLE**".

7 Magnesium

Used when extreme lightness is required, e.g. aircraft and road transport components as well as for consumer items such as mobile phones, laptop computers, cameras, etc. It is about one-quarter the density of steel.

Magnesium is often alloyed with other metals, particularly aluminium, as well as zinc and manganese.

Components may be produced by casting or rolling.

8 Titanium

Titanium is now finding increasing use in many applications.

In the form of titanium dioxide, it is widely used as a white pigment.

Titanium can be alloyed with iron, aluminium, vanadium, molybdenum, among other elements, to produce strong lightweight alloys for aerospace, industrial process (chemicals and petro-chemicals, including desalination plants, pulp, and paper), automotive, agri-food, medical prostheses, sporting goods, jewellery, mobile phones, and other applications.

Useful properties of the metal are corrosion resistance and the highest strength-to-weight ratio of any metal. In its unalloyed condition, titanium is as strong as some steels, but 45% lighter.

[http://en.wikipedia.org/wiki/Titanium] December 2009

9 Other Metals

Many other metals have important applications in engineering materials, many of them as alloying elements. Consideration of these metals is beyond the scope of this course.

10 Polymers

Since the mid 20th Century, engineers have made increasing use of polymers or plastics. It is very difficult to recognise these materials on the basis of appearance. Colouring material may be present or absent, fillers may or may not be used, and plasticisers may transform a rigid polymer into a flexible form.

The following list gives some characteristics of just a few of the more commonly used thermoplastic polymers.

Polyethylene	Resists acids and bases. Reasonably strong.	Films, insulation, bottles, surgical implants.
Polypropylene	Resists acids and bases. Strong.	Ropes, fibres.
Polystyrene	Strong.	Containers, insulating beads, lightweight packaging.
Polyvinyl chloride PVC (Rigid)	Strong.	Floors, pipes, phonograph records.
Polytetrafluoroethylene (PTFE)	Chemical resistant. Low friction.	Seals, bearings, gaskets, pipes, linings.
Acrylonitrile-butadiene-styrene (ABS)	Strong.	Pipes, tubing.
Polyamides (Nylons)	Chemically resistant. Very strong.	Textiles, rope, gears, bearings, machine parts.
Acrylics (Perspex)	Strong.	Aircraft enclosures, lighting fixtures, windows.
Acetals	Very strong.	Appliance parts, hardware, gears, bushings, aerosol bottles.
Poly carbonates	Very strong.	Light globes, machine parts, propellers, lenses, sporting goods.
Polyesters	Resist oils. Strong.	Gears, bearings, valves, pump parts.

11 Adhesives

Adhesives have been known and used almost from the dawn of technology (e.g. resins for holding a spear head to a wooden shaft) and there are still people who remember the hot animal glues (protein adhesive) popularly used in wood-working up to the 1950s.

However, our present interest centres on the newly-developed synthetic resins. These have been developed to the stage where they are used for structural bonding in the aircraft and road transport industries. Literally hundreds of different adhesives of different types are available and the problem is to select the one best suited for the job. In fact, a study of adhesives might well occupy an entire course of lectures, so seek professional advice before making a choice.

Amongst the most frequently used adhesive types are (condensed from Wikipedia encyclopaedia):

11.1 Synthetic adhesives

Elastomers, thermoplastics, Emulsion, and thermosetting adhesives based on polyvinyl acetate, epoxy, polyurethane, cyanoacrylate polymers are examples of synthetic adhesives.

11.2 Drying adhesives

These adhesives are a mixture of ingredients (typically polymers) dissolved in a solvent. White glue and rubber cements are members of the drying adhesive family. As the solvent evaporates, the adhesive hardens. These adhesives are typically weak and are used for household applications.

11.3 Contact adhesives

Contact adhesives must be applied to both surfaces and allowed some time to dry before the two surfaces are pushed together. Natural rubber and polychloroprene (Neoprene) are commonly used contact adhesives. Contact adhesives are used in strong bonds with high shear-resistance like laminates, such as bonding Formica to a wooden counter, and in footwear, such as attaching an outsole to an upper.

11.4 Hot adhesives

Hot adhesives, also known as hot melt adhesives, are simply thermoplastics applied in molten form (in the 65-180 C range) which solidify on cooling to form strong bonds between a wide range of materials. These replaced water-based adhesives that were commonly used in packaging and often failed in humid climates, causing packages to open and become damaged.

11.5 Emulsion adhesives

Milky-white dispersions often based on polyvinyl acetate. Used extensively in the woodworking and packaging industries. Also used with fabrics and fabric-based components, and in engineered products such as loudspeaker cones.

11.6 UV and light curing adhesives

Ultraviolet (UV) light curing adhesives, also known as light curing materials (LCM), have become popular within the manufacturing sector due to their rapid curing time (as little as a second in some formulations) and strong bond strength. They can bond dissimilar substrates (materials) and withstand harsh temperatures and are often used in industrial markets such as electronics, telecommunications, medical, aerospace, glass, and optical.

11.7 Pressure sensitive adhesives

Pressure sensitive adhesives (PSA) including adhesive tape, blu-tack, and gaffer tape form a bond by the application of light pressure to marry the adhesive with the adherend. PSAs are designed for either permanent or removable applications.

FOR KEEN STUDENTS

11.8 Mechanisms of adhesion

Adhesion, the attachment between adhesive and substrate may occur either by mechanical means, in which the adhesive works its way into small pores of the substrate, or by one of several chemical mechanisms. The strength of adhesion depends on many factors, including the means by which it occurs.

In some cases an actual chemical bond occurs between adhesive and substrate. In others electrostatic forces, as in static electricity, hold the substances together. A third mechanism involves the van der Waals forces that develop between molecules. A fourth means involves the moisture-aided diffusion of the glue into the substrate, followed by hardening.

http://en.wikipedia.org/wiki/Adhesive

12 Machining Operations

The capability of the production processes described earlier in these notes to achieve accurate dimensions varies from process to process and also depends on the quality and maintenance of the production machinery and the skill of the operators. Processes such as die casting produce thousands of components of almost identical size and shape, while in sand casting, in which each component comes from its own sand mould, components may vary in size by several millimetres. Where factors such as precise size or flatness, or precise relationship between adjacent features, are important, it is often necessary to **MACHINE** the component. It may also be necessary to carry out machining in order to create features on the component which could not be produced by the production process or are specific to the particular application, e.g. drilling holes for attaching bolts in rolled steel sections.

12.1 Drilling

One of the simplest and most basic machining processes is **DRILLING**. You may well have some experience in using an electrically driven hand drill, or perhaps a bench drill such as that shown in Fig 1-32.

Figure 1-32 An example of a light duty bench drill.
http://www.lowes.com/lowes/lkn?action=howTo&p=BuyGuide/ChsDrlPrs.html

Some important principles of machining operations may be seen from a simple drilling process. The essence of machining is to remove selected material from a given component. This is done, in the case of drilling, by forcing a rotating cutting tool (the **DRILL BIT**) into the surface of the component. The **DRILL BIT** is gripped in a **CHUCK** which is attached to a rotating **SPINDLE** driven by an electric motor. As the drill rotates, material is cut (**SHEARED**) from the component, coming away as a series of chips, or sometimes as a long spiral coil, called **SWARF**.

It is found that for cutting tools (in this case the drill bit) to cut efficiently, the **CUTTING SPEED** needs to be within certain limits. The cutting speed is simply the distance the cutting edge moves across the component in unit time, say in m/s. Hence if a small diameter drill bit is being used, the rotational speed needs to be high while, for a large drill bit, the rotational speed needs to be low. Most bench drills make provision for changing speed by the use of a belt drive with **CONE PULLEYS** but heavier-duty drilling machines frequently use a multi-speed gearbox.

12.2 Lathe work –turning

In machining in a lathe, it is usual for the **WORKPIECE** or component to be rotated or **TURNED** and to **FEED** the cutting tool slowly into or across the workpiece to remove material where desired.

In Fig 1-33, the cylindrical workpiece is gripped in a **CHUCK** and the chuck and workpiece together are caused to rotate by a motor (within the housing at the left-hand end of the lathe). The end of a long workpiece is usually supported by the **TAILSTOCK,** as is done in this illustration. The cutting tool is set to dig into the outer surface of the workpiece and is made to move slowly along the length of the workpiece, shearing off material as it does so. An animation of the cutting process may be seen on http://www.mini-lathe.com/Mini_lathe/Introduction/introduction.htm [December 2009].

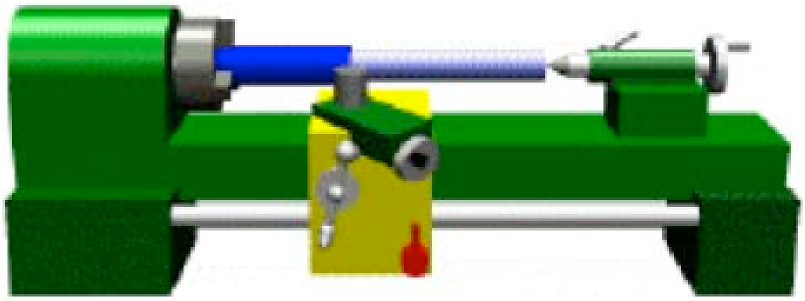

Figure 1-33 A simple schematic of a **LATHE** set up to reduce the diameter of a cylindrical workpiece. http://www.mini-lathe.com [December 2009].

The lathe is used mainly to produce basically axisymmetric components such as those shown in Fig 1-34, but can be used for other purposes, e.g. cutting threads or keyways. The cross-drilled holes visible in some of the components would not have been made in the lathe.

Figure 1-34 Examples of components produced by **TURNING** in a lathe.

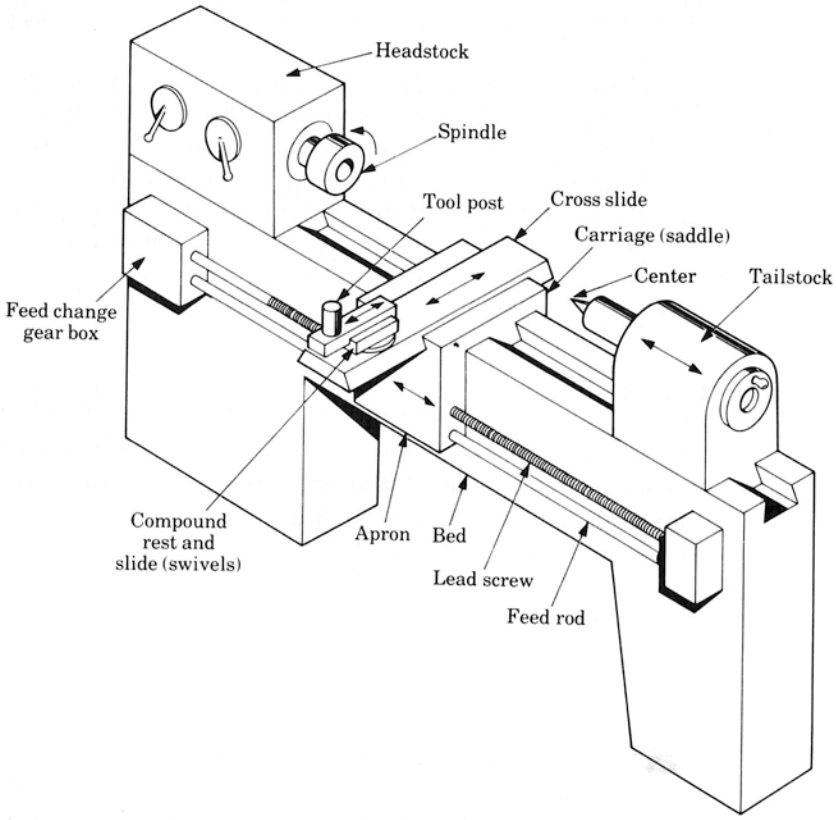

Figure 1-35 Schematic of a lathe indicating various features including the longitudinal and cross **SLIDES** which allow the tool to remove metal from different surfaces of the workpiece.

Reproduced from S. Kalpakjian, *Manufacturing Processes for Engineering Materials*, 1984, Addison Wesley, page 544.

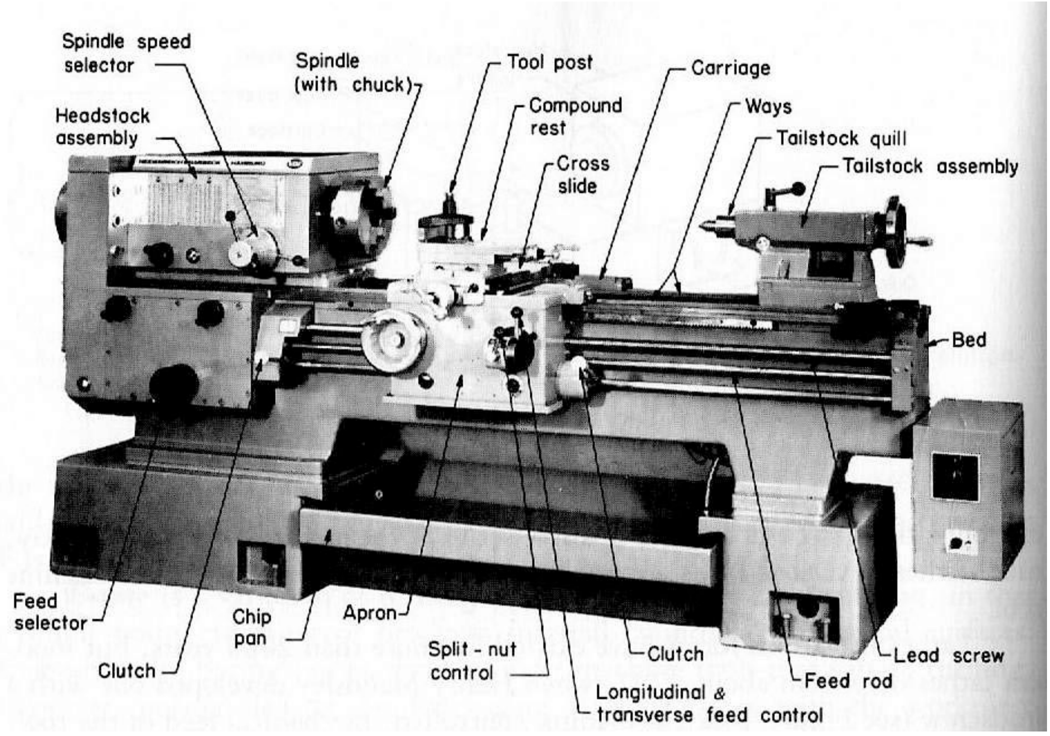

Figure 1-36 A photograph of an actual lathe with the main features named.
Reproduced from E.P. DeGarmo, *Materials & Processes in Manufacturing*, 5th Ed., Macmillan, page 586.

Figure 1-37 *Left:* Photograph of machining the outer diameter of a cylindrical workpiece held in a **THREE-JAW SELF-CENTREING CHUCK**. Note the **SWARF** which has been sheared off, partly as chips, partly as short "coils". *Right:* In this photograph, a large drill is being used to **BORE** a hole in the rotating cylindrical workpiece. Compare with the drilling process in Fig 1-33, in which the drill was rotating and the workpiece stationary.
http://tantel.ca/Images/Lathe/Lathe%20trial_3.jpg [January 2010]

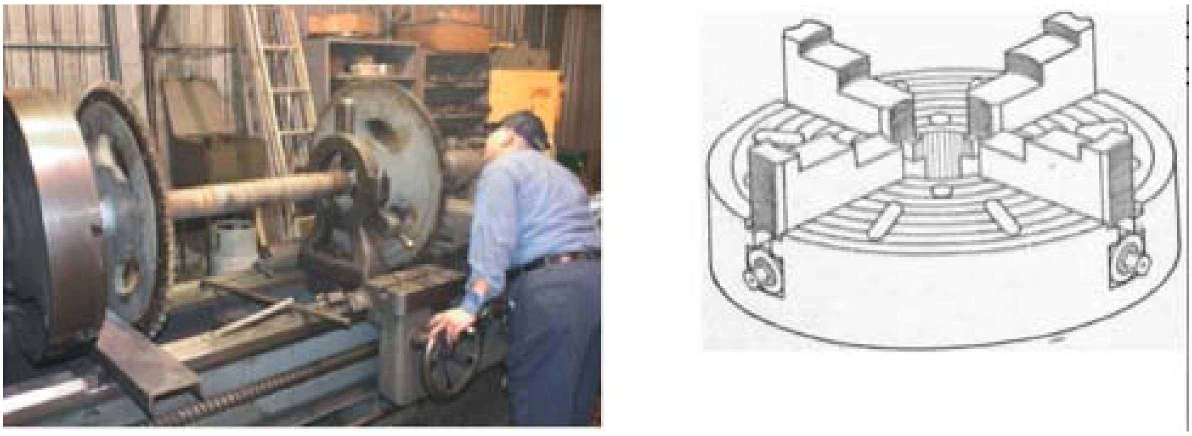

Figure 1.38: *Left:* A large lathe set up for what appears to be repair of a shaft and sprockets from some sort of industrial machinery. The left-hand end of the shaft appears to be driven not by a chuck, but from a **FACE PLATE**, and the right-hand end is mounted in a **STEADY BEARING**. *Right:* A **FOUR-JAW CHUCK**, which allows the positions of the four jaws to be adjusted independently to allow turning of objects of irregular shape.

12.3 Milling

12.3.1 Milling machines

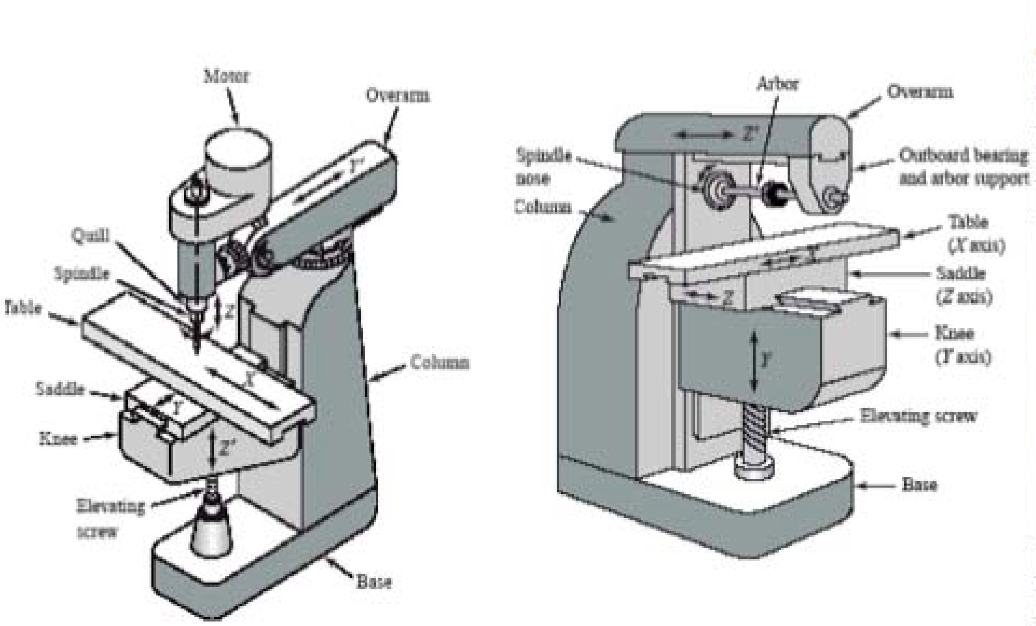

Figure 1-39(a): *Left:* Schematic of a **VERTICAL MILLING MACHINE** showing the vertical spindle and the available x, y, and z movements of **TABLE, SADDLE AND QUILL** respectively which enable machining operations to be carried out.
Right: Schematic of a **HORIZONTAL MILLING MACHINE** showing the horizontal spindle or **ARBOR** and the available movements of **KNEE**, **SADDLE** and **TABLE**.

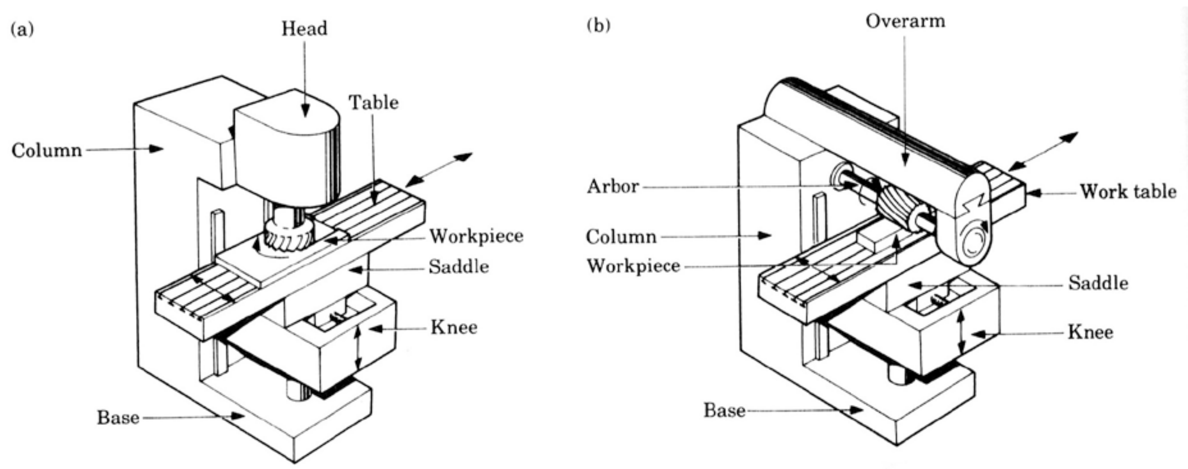

Figure 1-39(b): Vertical and horizontal milling machines similar to Fig 1-39(a) but more diagrammatic so that the machine components are more clearly visible. Reproduced from S. Kalpakjian, *Manufacturing Processes for Engineering Materials*, 1984, Addison Wesley, page 546.

12.3.2 Milling cutters

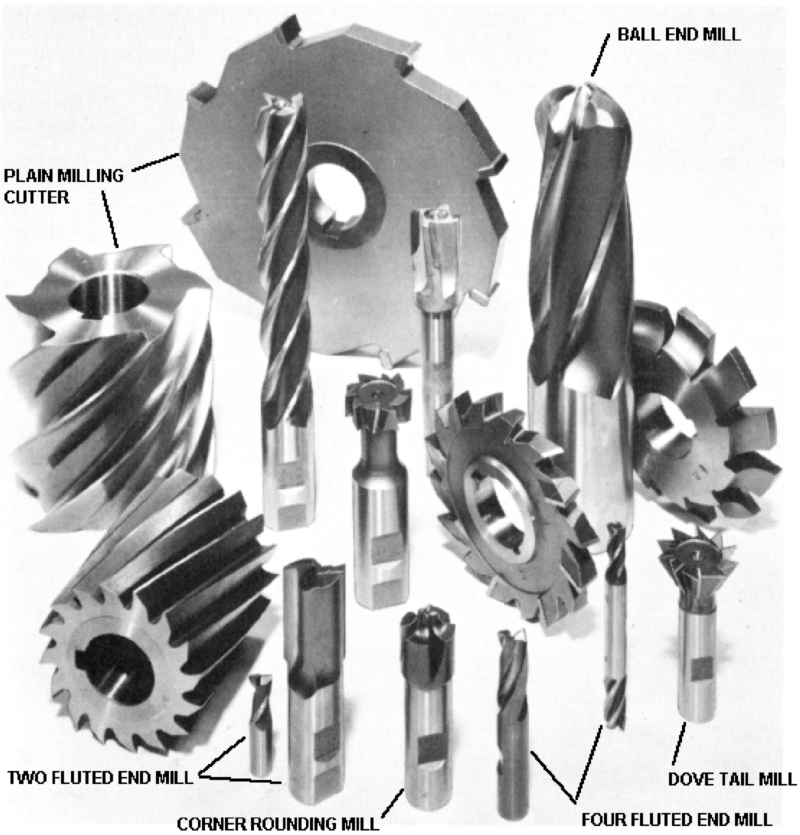

Figure 1-40: Examples of milling cutters used for various milling operations. The drill-like (shank type) cutters are for use in vertical mills, the wider cutters (all those with **KEYWAYS**) for use on the arbor of a horizontal mill.
http://electron.mit.edu/~gsteele/mirrors/www.nmis.org/EducationTraining/machineshop/mill/intro.html

12.3.3 Use of milling machines

Whilst a lathe is a versatile machine tool which is capable of many machining tasks, there are some operations which would be slow and difficult to carry out, and might not achieve the required level of accuracy in a lathe. This is particularly the case when machining is required on several different planes on the component, or when a number of features (e.g. holes or slots) need to be machined in a precise relationship. Milling machines have been developed for such purposes, with versatility a key factor.

As the name implies, the vertical milling machine has a vertical shaft equipped to carry the rotating cutting tool – a **MILLING CUTTER**. The machine is set up so that, for example, the **TABLE** on which the workpiece is mounted can be moved in x and y directions so that the rotating tool can be used to machine a slot in the workpiece. The depth of the slot can be varied by raising or lowering the table (z direction) or by raising or lowering the cutter.

On the other hand, the horizontal milling machine is equipped with a horizontal shaft, called the **ARBOR** which facilitates certain operations, such as using a wide **PLAIN CUTTER** (see Fig 1-40) to produce flat surfaces.

Not surprisingly, universal mills have been developed, combining the features of vertical and horizontal milling machines.

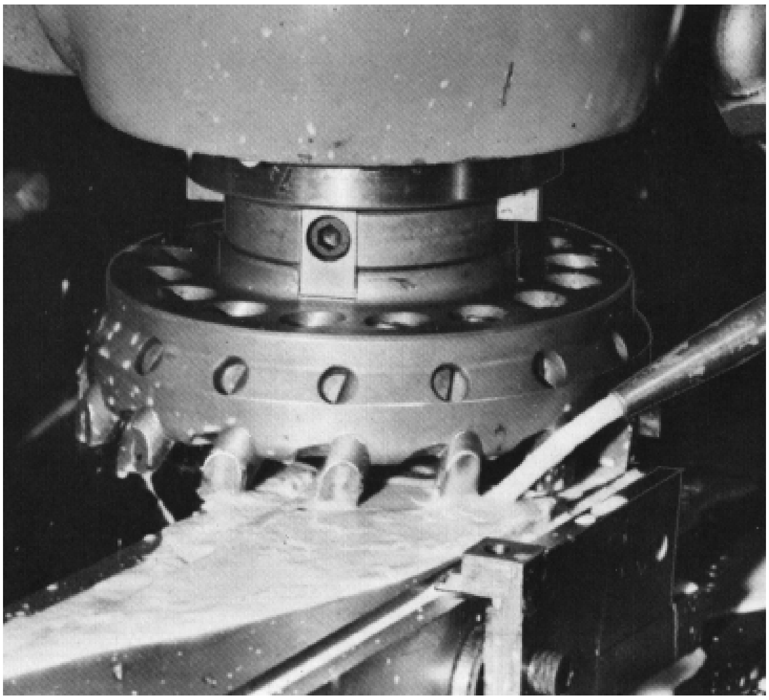

Figure 1-41 Face milling in a vertical-spindle machine. When it is necessary to create a flat face on a large part, this can be done best with a facing cutter. A cutter about 25 mm wider than the workpiece allows the facing can be accomplished in one pass. Note the use of copious quantities of lubricant.
http://electron.mit.edu/~gsteele/mirrors/www.nmis.org/EducationTraining/machineshop/mill/intro.html

12.4 Grinding

12.4.1 Surface Grinding

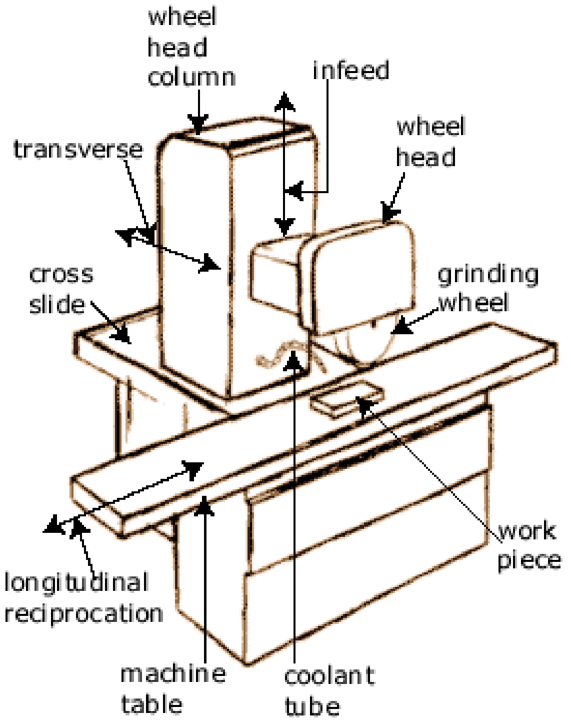

Figure 1-42: *Left:* Schematic of horizontal spindle grinder.
http://www.efunda.com/processes/machining/images/grind/horiz_spindle_grinder_1.gif
Right: A small horizontal-spindle surface grinder in use. The workpiece is typically secured to the machine table by a strong magnetic field.
http://www.surface-grinder.net/2010/05/04/surface-grinder-pictures-2/

The horizontal spindle grinder in Fig 1-42 is of the type frequently used for finish grinding flat surfaces to a high degree of flatness and surface finish. The horizontal spindle or shaft drives a grinding wheel at high speed and the table is arranged to reciprocate longitudinally and progress laterally so that the grinding wheel covers the whole of the surface of the workpiece. The actual cutting process is similar to grinding by pressing a piece of metal onto the grinding wheel of a bench grinder. Only a very small amount of material can be removed with each cut.

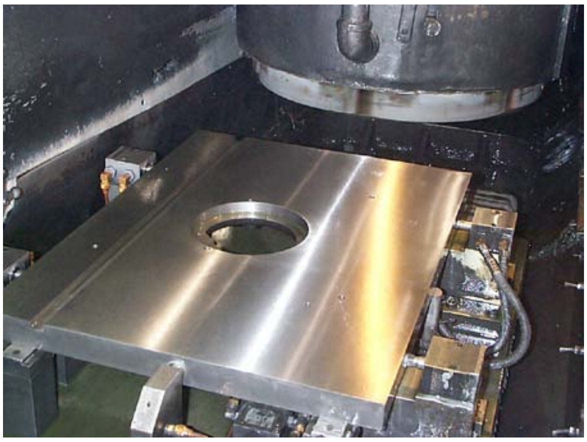

Figure 1-43 *Left:* An example of a large V8 diesel engine on which the top cylinder surfaces (the metallic coloured surface of only one bank of cylinders is visible) is said to have been finished by surface grinding. This factory process would have required a grinding machine dedicated to that particular task. In recent years, finish machining of top cylinder surfaces tends to be done using cutters in a milling style operation, rather than grinding, which is slower and more expensive. See Fig 1-41 above. *Right:* A large steel plate finish-ground on a vertical-spindle grinder.
http://www.qualitygrinding.com/images/DCP00775.jpg&imgrefurl [January 2010]

12.4.2 Cylindrical grinding

Figure 1.44 An example of cylindrical grinding in which the workpiece to be cylindrically ground is mounted in a rotating spindle and the rotating grinding wheel in brought into contact with the surface to be ground. The process is similar to the workpiece being mounted in the chuck on a lathe and its surface machined by a cutting tool.
http://www.wmcinc.com/grinding1.jpg [October 2010]

12.4.3 Internal grinding

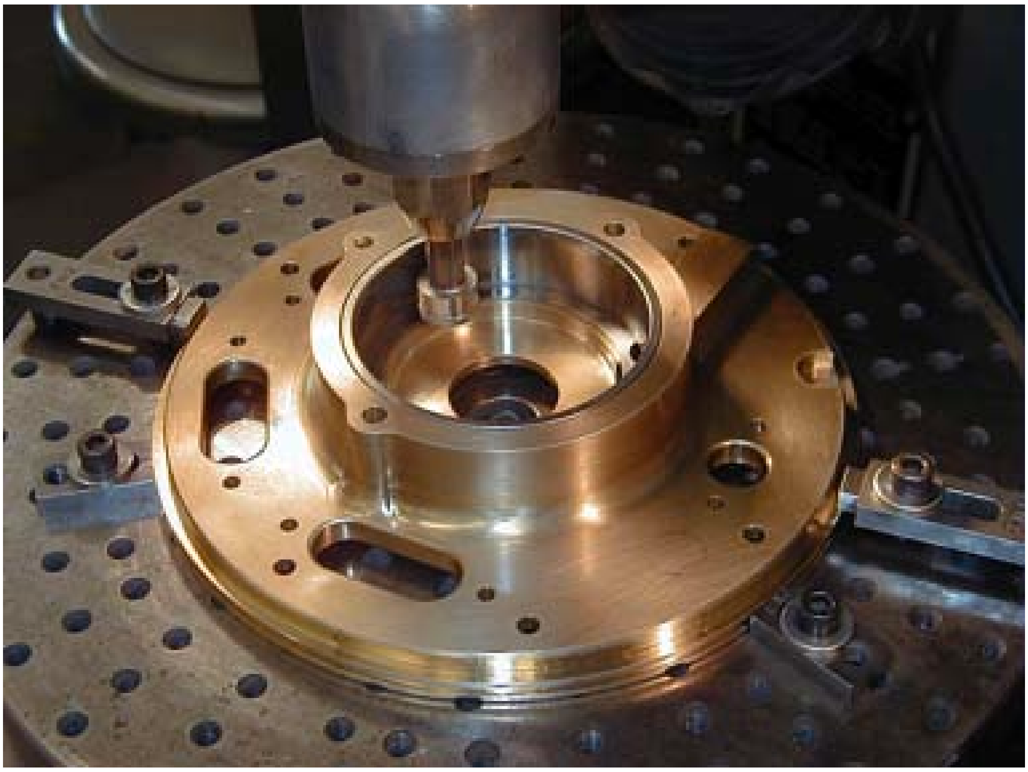

Figure 1-45 Internal grinding. In this photograph, the **INTERNAL GRINDING WHEEL** is the small cylindrical object projecting downwards from the vertical spindle into the internal recess in the workpiece. The workpiece is mounted on a circular table. Depending on the construction of the machine, the table and workpiece may rotate slowly so that the whole of the internal recess is progressively ground by the wheel, or the table might remain stationary with the spindle and wheel moving in an annular path to grind the whole of the internal surface.

13 Closing Remarks

As stated in the Preamble, this document can be no more than a superficial introduction to a very broad and detailed field. The aim has been to attempt to introduce principles, rather than detail and, in doing so, many valuable materials and processes have not even been mentioned. It is hoped that students in Mechanical Engineering generally will use these notes as the basis for further reading, leading to an understanding of an important area of their professional activities.