Production Technology

Processes, materials and planning

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Preface

This book has been written to present an overview and appraisal:

- of the manufacturing processes used with metals and polymers, so that an informed *choice of process* can be made, taking into account the various alternatives.
- of the materials used in engineering—metals both ferrous and non-ferrous, polymers, ceramics and composites—so that an informed *choice of material* can be made, taking into account the properties that are required.
- of production planning and cost accounting, so that choice of process and material can be *related to quantity, quality and cost requirements*, with an appreciation of the planning needed in the design of work tasks.

The level of discussion of these subjects is about that of HNC/HND for mechanical and production engineering technicians. The book caters for a range of BTEC HNC/HND units—manufacturing technology, engineering materials and associated materials units, production planning and control, and various aspects of other units. The aim has been to produce a text covering the core of most mechanical and production engineering courses at this level.

Parts of this book have been taken from other texts, also published by Heinemann, that I have written for specific BTEC units. Acknowledgements are due to the large number of companies that supplied me with information, also to other publishers for permission to reproduce from their publications. I am indebted to the Controller of HMSO for permission to quote from the Health and Safety of Work Act 1974. Extracts from PD 6470: 1981 are reproduced by permission of BSI; complete copies can be obtained from them at Linford Wood, Milton Keynes MK14 6LE. Every effort has been made to acknowledge sources of material used—if at any time I have not made full acknowledgement I hope that my apologies will be accepted.

PART ONE

Manufacturing Processes

This part of the book consists of four chapters concerning the range of manufacturing processes, their characteristics and suitability for particular types of components.

Chapter 1 Forming processes – metals

Casting processes, hot and cold manipulative processes, powder techniques, cutting and grinding, metal removal by electrochemical, electrical discharge and chemical means, and surface finishing are described in outline. The main emphasis is placed on the characteristics of the processes and their suitability for particular types of operation.

Chapter 2 Forming processes – polymers

Following a preliminary discussion of the characteristics of polymer materials, the forming processes of casting, moulding, extrusion, calendering, forming and machining are described. Consideration is then given to the choice of such processes and the design constraints involved when using polymers.

Chapter 3 Assembly operations

Assembly processes are described and their characteristics considered: for metals – adhesives, soldering, brazing, welding and the use of fastening systems; for plastics – welding, adhesives, riveting, press and snap fits and thread systems. Finally, there is a discussion of the combination of such processes for an entire component, with consideration of limits and fits.

Chapter 4 Automation

This chapter presents an introductory discussion of numerical control of machining, and of robotics, in the automation of manufacturing methods.

1

Forming processes – metals

1.1 Introduction

With metals, the range of forming processes possible for component production can be divided into four main categories:

Casting: shaping of a material by pouring the liquid material into a mould.
Manipulative processes: shaping of materials by plastic deformation methods.
Powder techniques: production of a shape by compacting a powder.
Cutting: production of a shape by metal removal.

In this chapter each of the above types of process will be considered in more detail so that comparisons can be made as to the suitability of a particular process for the manufacture of a component.

One factor that will be referred to is surface roughness. Roughness is defined as the irregularities in the surface texture which are inherent in the production process but excluding waviness and errors of form. Waviness may arise from such factors as machine or work deflections, vibrations, heat treatment or warping strains.

One measure of roughness is the arithmetical mean deviation, denoted by the symbol R_a. This is the arithmetical average value of the variation of the profile above and below a reference line throughout the prescribed sampling length. The reference line may be the centre line, this being a line chosen so

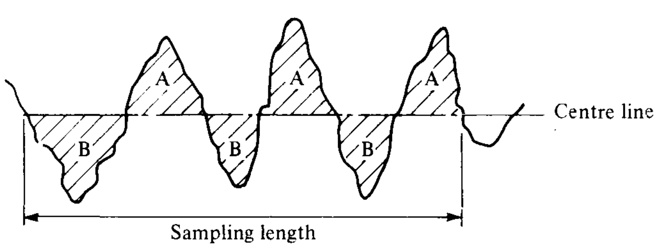

Figure 1.1 The centre line. The sum of the areas marked A equals the sum of those marked B

Table 1.1 *Typical R_a values*

Surface texture	R_a *(μm)*
Very rough	50
Rough	25
Semi-rough	12.5
Medium	6.3
Semi fine	3.2
Fine	1.6
Coarse-ground	0.8
Medium-ground	0.4
Fine-ground	0.2
Super-fine	0.1

that the sums of the areas contained between it and those parts of the surface profile which lie on either side of it are equal (Figure 1.1). Table 1.1 indicates the significance of R_a values.

Another factor in making comparisons between processes is the tolerance possible. Tolerance is the difference between the maximum limit of size and the minimum limit of size. It is the amount by which deviation may occur from a desired dimension.

1.2 Casting

Essentially, casting consists of pouring a liquid metal into a suitable mould and then permitting it to solidify, thereby producing a solid of the required shape. The products fall into two main categories, those for which the solid shape is just a convenient form for further processing, and those for which the component produced requires only some machining or finishing to give the final product.

Where the products are produced for further processing simple, regular geometrical shapes are generally used, the products being known as ingots, billets, pigs, slabs, or by other descriptive terms. The shape adopted depends on the processes that are to follow.

Where the casting is used to produce the product in almost finished state, a mould is used which has the appropriate internal shape and form. The mould has, however, to be designed in such a way that the liquid metal can easily and quickly flow to all parts. This has implications for the finished casting in that sharp corners and re-entrant sections have to be avoided and gradually tapered changes in section used. Account has also to be taken of the fact that the dimensions of the finished casting will be less than those of the mould, because shrinkage occurs when the metal cools from the liquid state to room temperature.

A number of casting methods are available, the choice of method depending on:

size of casting required;
number of castings required;
complexity of the casting;
mechanical properties required for the casting;
surface finish required;
dimensional accuracy required;
metal to be used;
cost per casting.

Sand casting

This involves using a mould made of a mixture of sand and clay. The mixture is packed around a pattern of the required casting to give the mould, which is usually made in two main parts so that the pattern can be extracted (Figure 1.2). The mould must be designed so that when the liquid metal is introduced into the mould, all air or gases can escape and the mould can be completely filled. After the casting has solidified the mould is broken open, the moulds only being used for the one casting. Some machining is always necessary with the casting, such as the trimming off of the metal in the feeder and riser.

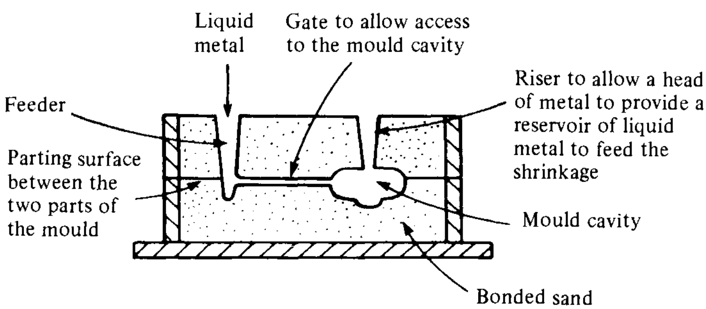

Figure 1.2 Sand casting

Sand casting can be used for a wide range of casting sizes and for simple or complex shapes. Holes and inserts are possible. However, the mechanical properties, surface finish and dimensional accuracy of the casting are limited. Roughness values (R_a) of the order of 12.5 to 25 μm are produced. A wide range of alloys can be used. The cost of the mould is relatively cheap, at least in comparison with metal moulds, but the cost of the mould has to be defrayed against just one casting as it is broken up after being used only once. For small number production, sand casting is the cheapest casting process.

Die casting

This involves the use of a metal mould. With *gravity die casting* the liquid metal is poured into the mould, gravity being responsible for causing the metal to flow into all parts of the mould. With *pressure die casting* the liquid metal is injected into the mould under pressure. This enables the metal to be forced into all parts of the mould and enables very complex shapes with high dimensional accuracy to be produced.

There are limitations to the size of casting that can be produced with pressure die casting, the mass of the casting generally being less than about 5 kg. Gravity die casting can, however, be used for larger castings. Because the metal mould is expensive, compared with, for example, a sand mould, this process is generally uneconomic for one-off castings or small runs. The mould can be used for many castings and thus the cost defrayed over the larger number of castings. The castings produced by this method have very good mechanical properties, dimensional accuracy and finish, good enough to reduce or even eliminate machining or other finishing processes. Roughness values (R_a) of the order of 0.8 to 1.6 μm are produced. The metals used with this casting method are limited to aluminium, copper, magnesium and zinc alloys.

The main cost factor is the cost of the metal mould. If the cost per casting is to be reasonable, there needs to be a large number production from a particular mould. The metal mould does, however, mean that, with little further machining or finishing necessary, the cost element for such operations is reduced.

Cetrifugal casting

This method involves rotating either consumable or metal moulds, using the forces set up during rotation of the mould to force the liquid metal to cling to the inside surface (Figure 1.3). This enables hollow objects to be produced without the use of an inner core in the mould. This method is used for simple geometrical shapes, e.g. large diameter pipes.

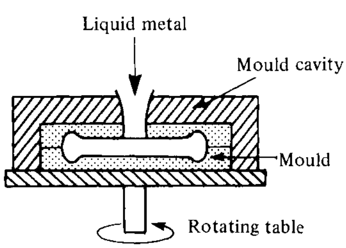

Figure 1.3 Centrifugal casting

Investment casting

This method, sometimes known as *lost wax casting*, can be used with metals that have to withstand very high temperatures and so have high melting points, and for which high dimensional accuracy is required—aero engine blades are a typical product.

With this method the required shape is made from wax or a similar material. The wax pattern is then coated with a ceramic paste. When this coated wax pattern is heated the ceramic hardens, the wax melts and runs out to leave a mould cavity. Liquid metal is injected into the hot mould. After cooling, the ceramic is broken away to leave the casting.

The size of casting that can be produced by this method is not as great as that possible with sand casting. The method does, however, give high dimensional accuracy and a good surface finish. Roughness values (R_a) of the order of 1.6 to 3.2 μm are produced. For large number production it is a more expensive method than die casting, but it is cheaper for small number production.

Choosing a casting process

The following factors largely determine the type of casting process used:

Large, heavy casting. Sand casting can be used for very large castings.
Complex design. Sand casting is the most flexible method and can be used for very complex castings.
Thin walls. Investment casting or pressure die casting can cope with walls as thin as 1 mm. Sand casting cannot cope with such thin walls.
Small castings. Investment casting or die casting. Sand casting is not suitable for very small castings.
Good reproduction of detail. Pressure die casting or investment casting, sand casting being the worst.
Good surface finish. Pressure die casting or investment casting, sand casting being the worst.
High melting point alloys. Sand casting or investment casting.
Tooling cost. This is highest with pressure die casting. Sand casting is cheapest. However, with large number production the tooling costs for the metal mould can be defrayed over a large number of castings, whereas the cost of the mould for sand casting is the same no matter how many castings are made because a new mould is required for each casting.

Design considerations when using casting

Rounded corners, no abrupt changes in section, gradually sloping surfaces are all necessary with casting if there is to be a proper flow of metal and a complete filling up of the mould. During the casting gas bubbles escape from the liquid metal, so corners in which the gas could collect have to be eliminated. Thus for example in Figure 1.4a the design in (ii) is to be preferred to that in (i).

Shrinkage occurs during the cooling and solidification of a casting. The amount of shrinkage depends on the metal being used and so the pattern used for the casting must be designed to take this into account, the pattern being larger than the required casting by an amount depending on the metal concerned. During the solidification the outer surfaces of the metal cool more

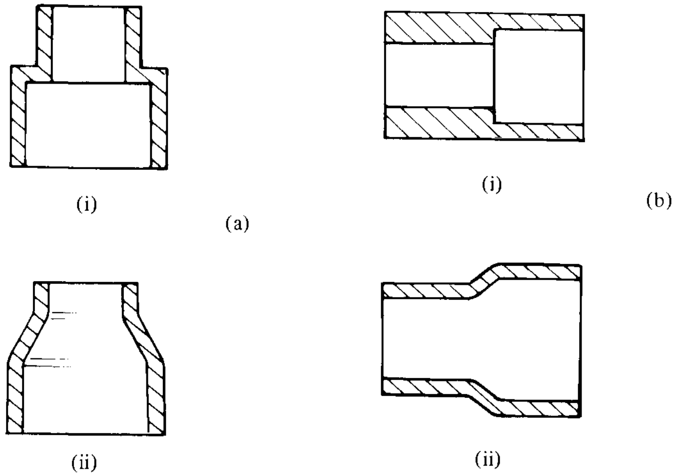

Figure 1.4 (a) The need for no sharp corners in casting means (ii) is preferred to (i) (b) The need for uniform thickness sections in casting means (ii) is preferred to (i)

rapidly than the inside of the metal. This can result in the outer layers solidifying while the inside is still liquid. When this liquid then contracts and solidifies, cavities can be caused if the solidifying inner liquid metal cannot 'pull in' the outer solidified metal. The production of cavities due to this effect is markedly increased where the section thickness shows abrupt changes. Ideally, a section of uniform thickness should be used; however, if this is not feasible a gradual change in thickness should occur rather than an abrupt change (Figure 1.4b).

When to use casting

Casting is likely to be the optimum method for product production under the following circumstances.

1 *The part has a large internal cavity.* There would be a considerable amount of metal to be removed if machining were used. Casting removes this need.
2 *The part has a complex internal cavity.* Machining might be impossible; by casting, however, very complex internal cavities can be produced.
3 *The part is made of a material which is difficult to machine.*
4 *The metal used is expensive and so there is to be little waste.*
5 *The directional properties of a material are to be minimised.* Metals subject to a manipulative process often have properties which differ in different directions.
6 *The component has a complex shape.* Casting may be more economical than assembling a number of individual parts.

Casting is not likely to be the optimum method for parts that are simple enough to be extruded or deep drawn.

1.3 Manipulative processes

Manipulative processes involve the shaping of a material by means of plastic deformation processes. Where the deformation takes place at a temperature in excess of the recrystallisation temperature of the metal the process is said to be *hot working*. Where the deformation is at a temperature below the recrystallisation temperature the process is said to be *cold working*.

When compared with hot working, cold working has the following advantages:

Better surface finish.
Improved strength.
Better dimensional control.
Better reproducibility.
Directional properties can be imparted to the material.
Contamination is minimised.
No heating is required.

Cold working has, however, the following disadvantages when compared with hot working:

Higher forces are needed for plastic deformation.
More energy is needed for plastic deformation.
Work hardening occurs.
The resulting material has less ductility and toughness.
The directional properties given to the material may be detrimental.
The metal used must be clean and scale-free.

Hot working

The main hot-working processes are rolling, forging and extruding. The following notes involve a closer look at these and related processes.

1 *Rolling*

This is the shaping of the metal by passing it, hot, between rollers. With nominally parallel cylinder rolls, flat sheet or strip can be produced in long lengths. If contoured rollers are used, channel sections, rails, etc can be produced.

Hot rolling is usually done in a number of stages. This could be either a series of passes through one set of rollers or a continuous process with the material passing through a sequence of sets of rollers. Figure 1.5a shows the type of rolling sequence that is adopted in rolling a structural beam section.

Darlington and Simpson Rolling Mills Ltd in their catalogue state that over six hundred different rolled shapes are available ranging from 1 kg to 10 kg per metre length. Figure 1.5b shows some of their rolled sections. Roughness values (R_a) of the order of 12.5 to 25 μm are produced.

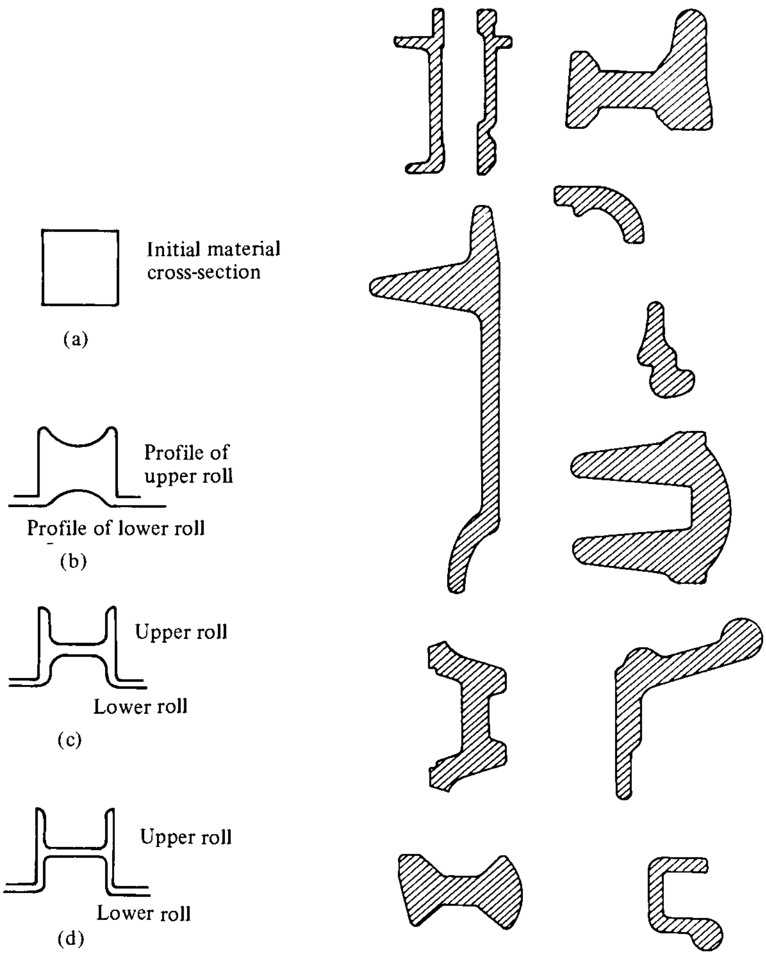

Figure 1.5 (a) The type of rolling sequence used for a structural beam section (b), (c), (d) Examples of rolled sections

2 *Forging*

Forging is a squeezing process, the hot metal being squeezed by pressing or hammering between a pair of dies. *Heavy smith's forging or open die forging* involves the metal being hammered by a vertically moving tool against a stationary tool, or anvil. Such forgings are fairly crude in form and generally are only the first stage in the forming operation. *Closed die forging* involves the hot metal being squeezed between two shaped dies which effectively form a complete mould (Figure 1.6). The metal in the cavity is squeezed under pressure in the cavity, flowing under the pressure and filling the cavity. In order to fill the cavity completely, a small excess of metal is allowed and this is squeezed outwards to form a flash which is later trimmed away. *Drop forging* is one form of closed die forging and uses the impact of a hammer to cause the metal billet to flow and fill the die cavity. The term *machine forging* (or *press forging*) is used for the closed die forging process where a press is used to squeeze the metal billet slowly between the dies.

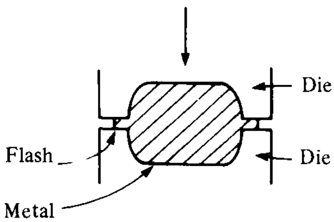

Figure 1.6 Closed die forging

The cost of forging is high for small number production because of the cost of the dies. Large number production is necessary to reduce the die cost per unit product produced. For example, with an aluminium alloy being forged, increasing the production run from 100 units to 1000 units can result in the cost per unit decreasing by 50% to 75%. An indication of the factors, and their relative costings, involved in producing a forging is given by the following costs for a drop forging (Iron and Steel Institute, ISI publication No. 138, 1971):

	Percentage of total production cost
Material	52
Direct overheads	15
Direct labour	10
Dies	8
Maintenance	4
Stock heating	3
Other	8

Forging results in a product superior in toughness and impact strength to that given by casting. The process also results in the welding up of shrinkage cavities in the cast ingot used for the forging. The process can be used to give a fibre structure within the material, a directionality of properties, which minimises the chances of crack formation and enhances the properties in service of the product. Roughness values (R_a) of the order of 3.2 to 12.5 μm are produced.

There are few limits to the shape of component that can be forged with a