7

Sheet and plate metalwork

When you have read this chapter, you should understand:

- The principles of forming sheet metal and plate by bending
- The meaning of 'spring-back' and how to compensate for it
- The types and uses of bending (folding) machines
- The principles of bending in press tools
- The use of press brakes and typical press brake operations
- The methods of calculating bend allowance
- The types and uses of roll-bending machines
- The principles of three-dimensional flow-forming
- The techniques and equipment when flow-forming by hand
- The types and use of wheeling machines
- The techniques and tools used when spinning sheet metal
- The principles, need for, and practice of swaging
- The need for operation planning
- The manufacture of typical sheet-metal rectangular and conical circular products
- Making thin sheet-metal edges safe by wiring and folding
- The use of the universal Jennying machine

7.1 Sheet and plate metalwork (introduction)

Sheet metalwork is the manipulation of sheet metal of 3.5 mm in thickness, or less, using mainly hand tools or portable power tools in order to manufacture a range of diverse products. Plate metalwork is the manipulation of metal plate over 3.5 mm in thickness using mainly power tools. The fabricated products for both sheet metalwork and for thin plate metalwork are produced from flat blanks that have been marked out as discussed in Chapter 5 and then cut out (contoured) prior to forming to shape. The forming operations used range from simple bending and rolling operations to more complex flow-forming operations such as spinning and presswork as shown in Fig. 7.1.

7.1.1 Forming by bending (folding)

The terms folding and bending are loosely used in the sheet-metal industry and largely interchangeable in common parlance. To be precise, the term 'folding' refers to sharp corners with a minimum bend radius. The term 'bending' refers to deflections of relatively large corner radii. Folding and bending involve the deformation of material along a straight line in two dimensions only.

When a bending force is applied to a workpiece under free bending conditions, the initial bending is elastic in character. This is because the stresses that are developed in the opposite faces of the material are not sufficiently high to exceed the *yield strength* of the material. The stresses developed on the outside of the bend tend to stretch the metal and are, therefore, *tensile stresses*. The stresses developed on the inside of the bend tend to shorten the metal and are, therefore, *compressive stresses*. The movement or strain which takes place in the metal as a result of the initial bending force is elastic only and, upon removal of the force, the workpiece springs back to its original shape.
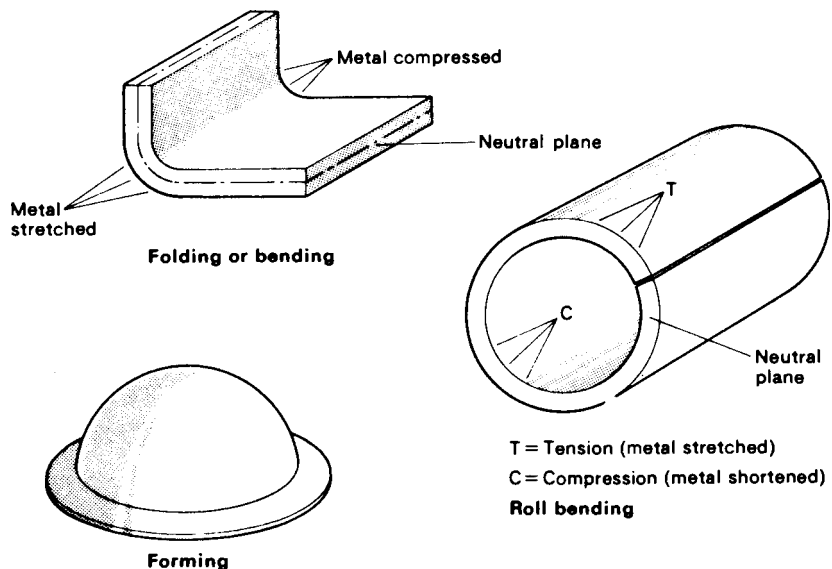

Figure 7.1 Comparison of common cold-forming applications

As the bending force is gradually increased these stresses, both tensile and compressive, produced in the outermost regions of the material, will eventually exceed the yield strength of the material. Once the yield strength of the material has been exceeded, the movement (strain) which occurs in the material becomes *plastic* and the material takes on a *permanent set*. This permanent strain occurs only in the outermost regions furthest from the *neutral plane* (*neutral axis*). The neutral plane is an imaginary plane situated between the tension side and the compression side of the bend of the material where the metal is neither stretched or shortened but maintains its original length. Its position will vary slightly due to the differing properties of different materials, their thickness and their physical condition. Therefore, there is a zone adjacent to the neutral plane where the strain remains elastic.

On release of the bending force the material adjacent to the neutral plane will try to give up its elastic strain energy and straighten the material out. However, the greater portion of the material which has suffered plastic deformation will resist this release of elastic strain energy and the material will remain bent. Nevertheless, there will be some slight recovery of shape and this is known as '*spring-back*'. To allow for this spring-back a degree of '*over-bend*' is required. Figure 7.2 shows the effects of a bending force on a material.

In reality, 'free-bending' conditions rarely, if ever, occur intentionally. Folding or bending usually occurs in press tools (pressure bending) or in folding machines. The principle of pressure bending is shown in Fig. 7.3.
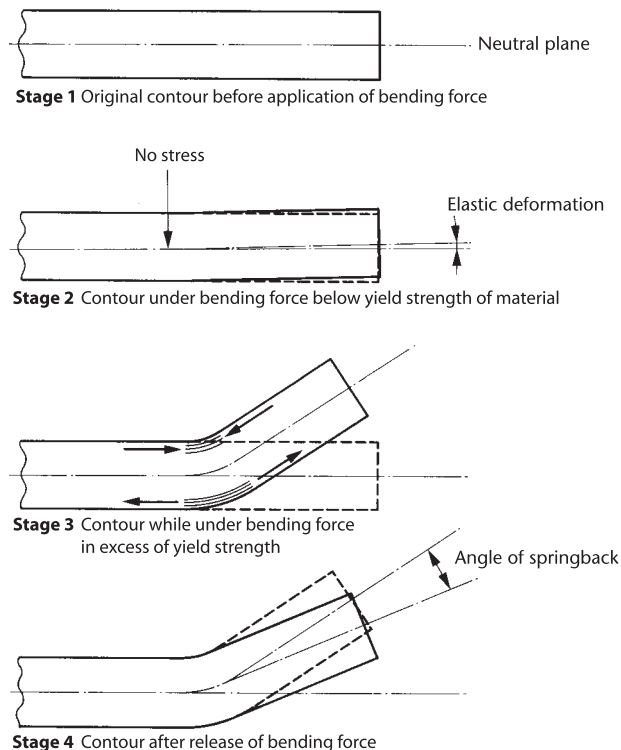

Stage 1 Original contour before application of bending force

Stage 2 Contour under bending force below yield strength of material

Stage 3 Contour while under bending force in excess of yield strength

Stage 4 Contour after release of bending force

Figure 7.2 The effects of a bending force on a material
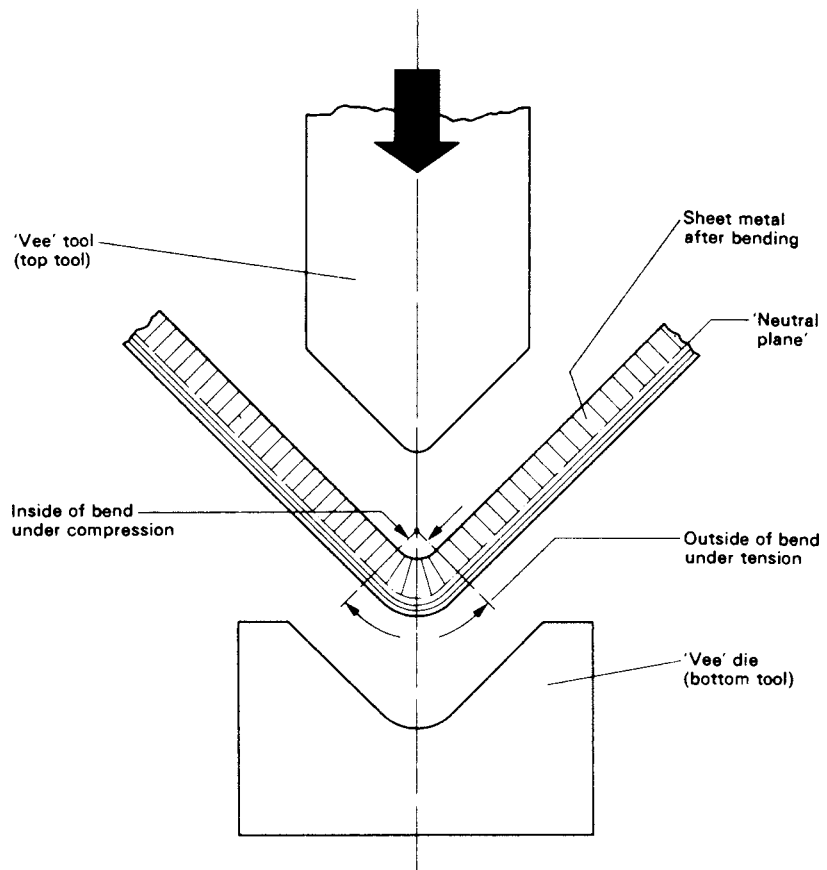
Figure 7.3 Bending action – pressure bending

7.1.2 Spring-back

Spring-back has already been mentioned in the previous section. We will now consider it in more detail. When bending a material an unbalanced system of varying stresses occurs in the region of the bend. When the bending operation is complete and the bending force is removed, this unbalanced system of stresses tends to return to a state of equilibrium. The material tries to spring back and any part of the elastic stress which remains in the material becomes *residual stress* in the bend zone. The amount of spring-back to be expected will vary because of the differing composition and mechanical properties of the materials used in fabrication processes. Some materials, because of their composition, can withstand more severe cold-working than others.

The severity of bending a specific material can withstand without cracking depends upon the *ratio of bend radius to material thickness*.

- A 'tight' (small) radius causes greater cold-deformation than a more generous bend in a material of the same thickness.
- A thicker material develops more strain-hardening (work-hardening) than is experienced in a thinner material bent to the same inside radius.
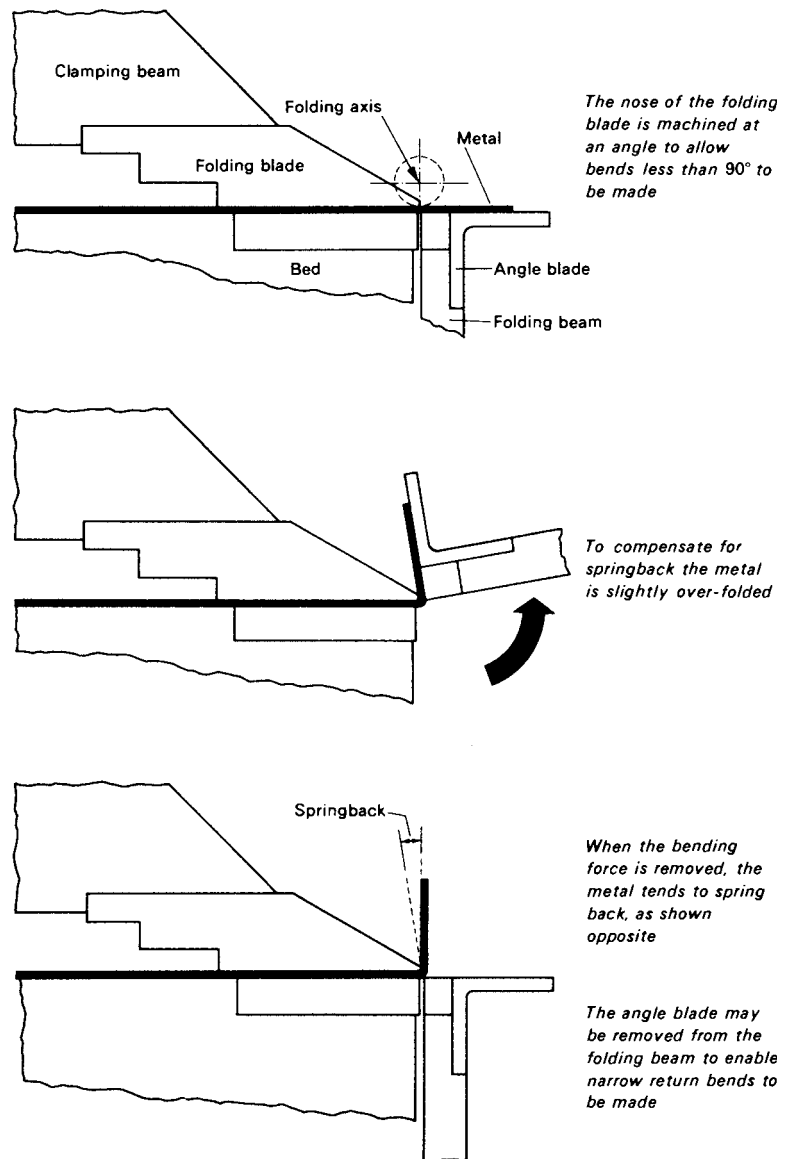
Figure 7.4 Allowing for springback on a folding machine

The '*condition*' of the material being bent will influence the amount of spring-back likely to occur. For example, an aluminium alloy that has been cold-rolled to the *half-hard condition* will exhibit greater spring-back than the same alloy in the *fully annealed condition* for the same degree of bending.

7.1.3 Compensating for spring-back

Figure 7.4 shows how the clamping beam of a folding machine is specifically designed to compensate for spring-back, whilst Fig. 7.5 shows two methods of compensating for spring-back when using a *press-brake* or a 'vee' tool in a fly press.
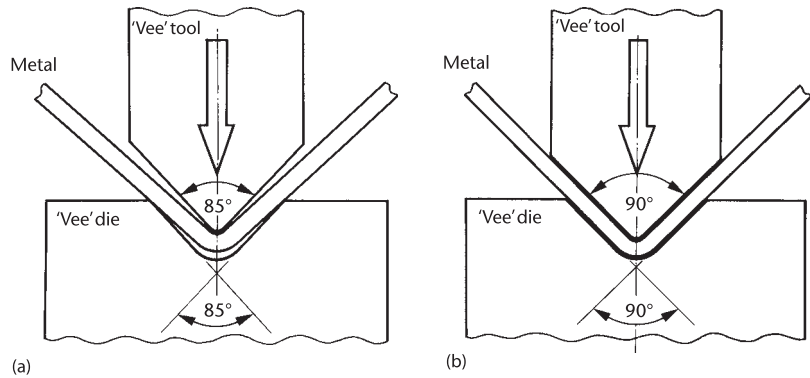
Figure 7.5 Two methods of pressure bending. (a) Air bending; (b) coining

Air-bending

The principle of air-bending is shown in Fig. 7.5(a). This allows for various angles of bend to be achieved by *three-point loading*. These three points are the *two edges* of the 'vee-die' and the *nose* of the 'vee-punch' (top tool). During air-bending, the material retains some of its elasticity. Therefore, the bending angle must be over-closed (over-bend) to compensate for the spring-back that occurs when the tools are opened. The bending tools are designed accordingly, with both the top and bottom tools having 'vees' that are less than 90°, usually about 85°. The advantages of air-bending are:

- A smaller bending force is required for any given material.
- The ability to bend heavy (thick) sheets and plates.
- The ability to form various angles in the same tools.

Coining (pressure bending)

The principle of this method of bending is shown in Fig. 7.5(b). The nose of the vee-punch crushes the natural air-bending radius of the material on the inside of the bend. This compression removes most or all of the elasticity from the bent material, resulting in the bend retaining the exact angles of the bending tools. Therefore, when coining a bend, both the punch and the die have an included angle of 90°.

7.1.4 Folding machines

Manually operated folding machines are usually used for folding tinplate and thin sheet metal up to 1.62 mm in thickness. An example of a manually operated folding machine is shown in Fig. 7.6. The smallest width of bending is 8 to 10 times the material thickness and the minimum inside corner radius of the bend is 1.5 times the metal thickness.

The procedure for bending sheet metal in a folding machine is as follows:

1. *Clamping*. In clamping, the amount of lift of the clamping beam is important. It should be sufficient to allow the fitting and use of special clamping blades (fingers) and to give adequate clearance for previous folds.
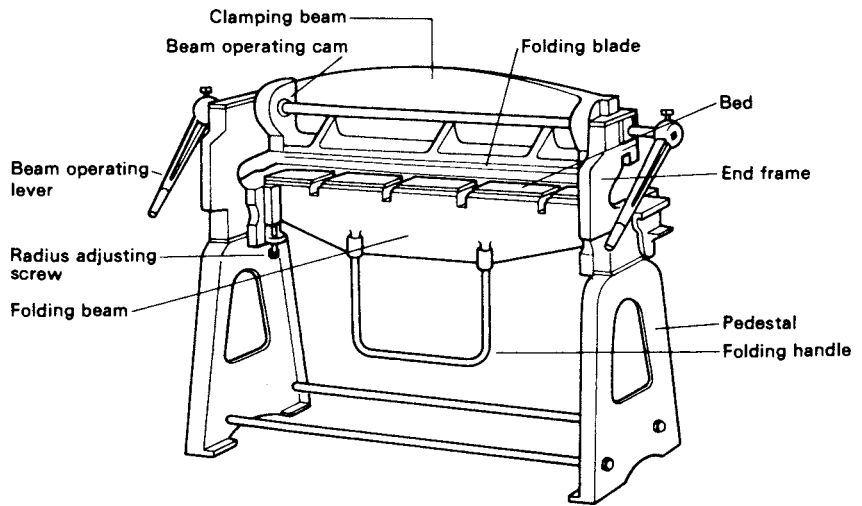
Figure 7.6 Manual folding machine

2. *Folding*. Care must be taken to see that the folding beam will clear the work, particularly when making second or third folds. Some folding machines are designed to fold radii above the minimum, either by fitting a radius bar or by adjustment of the folding beam.

3. *Removal of work*. Care must be taken when folding to ensure that the work can be easily removed on completion of the final bend. The sequence of folding must be carefully planned. The lift of the clamping beam is important when removing the work. Some folding machines, known as *universal folders*, have swing beams. The work may be folded completely around the beam, which is swung out to allow removal of the work.

Some of the above points are shown in Fig. 7.7.

Figure 7.7(a) shows a section through a 'box and pan' folding machine. It is fitted with a standard bed bar and fingers. The sheet metal is shown in position after completion of a right-angle bend when using a standard-angle folding bar.

Figure 7.7(b) shows a small radius bend being made. This time there is a gap between the nose of the folding blade and the face of the folding bar, thus air bending is taking place. This allows a larger radius to be formed.

Figure 7.7(c) shows a series of small return bends being made on this machine using a specially stepped bed bar. Such a bar is very useful for moulded work. The clamping beam lifts high enough to allow that part of the metal on the inside of the beam to be withdrawn over the bar. In this example a narrow blade has been substituted for the standard folding bar. This presents a smaller face width to the folding beam.

Figure 7.7(d) shows the use of radius fingers in conjunction with the standard folding bar. This allows radius bends up to a maximum of 25 mm radius to be made. The radius fingers may be positioned where required on the clamping beam to allow short lengths to be folded.
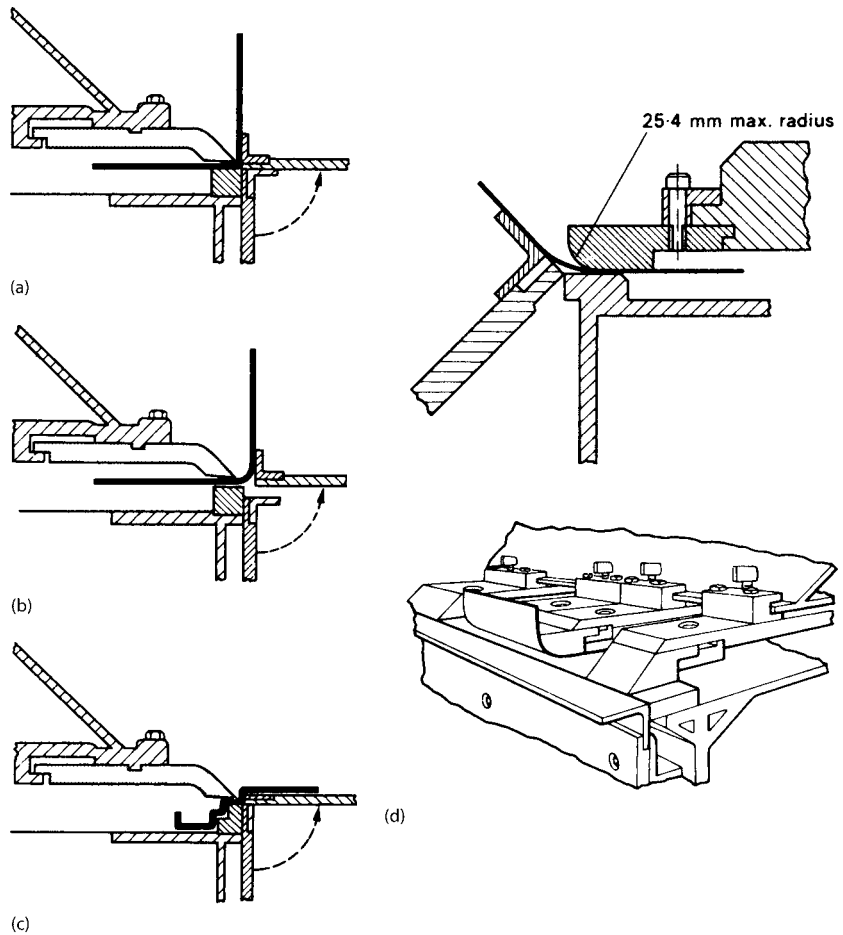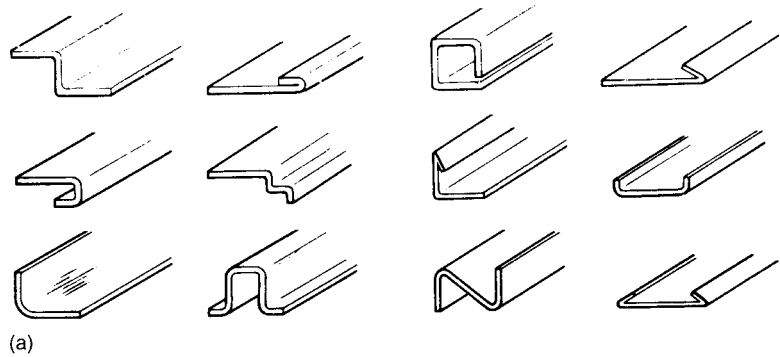
Figure 7.7 Use of folding machines. (a) Folding with standard bed bar; (b) small radius bending; (c) making small reverse bends; (d) use of radius fingers

Figure 7.8(a) shows the variety and combination of bends that can be produced on a standard folding machine, whilst Fig. 7.8(b) shows the use of a mandrel providing the folding machine is fitted with trunnion arms to carry the mandrel. This is only possible if the lift of the clamping beam is adequate. A machine with a clamping beam lift of between 175 and 200 mm will allow a mandrel of 152 mm maximum diameter to be used.

The folding of shallow boxes and pans can also be performed on a universal folding machine, provided there is sufficient lift of the clamping beam to allow an angle clamping blade to be attached to the clamping beam as shown in Fig. 7.8(c).
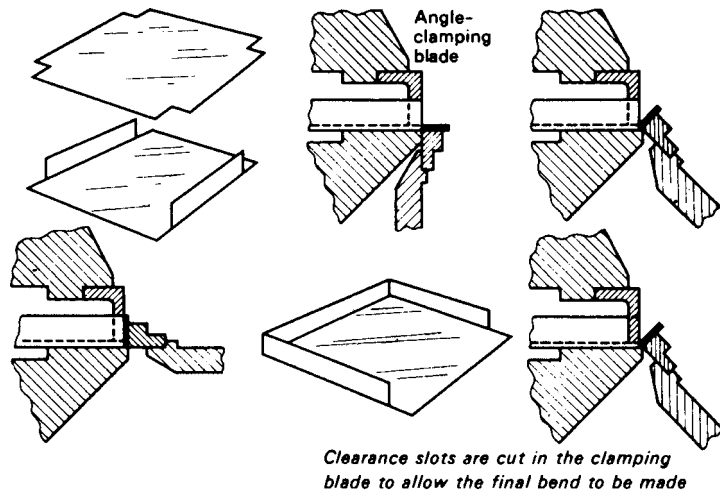
7.1.5 Bending in press tools

Pressure bending (coining) has already been introduced in Section 7.1.3. This is a common presswork operation for the batch production of small clips and brackets.

(a)

(b)

Clearance slots are cut in the clamping
blade to allow the final bend to be made
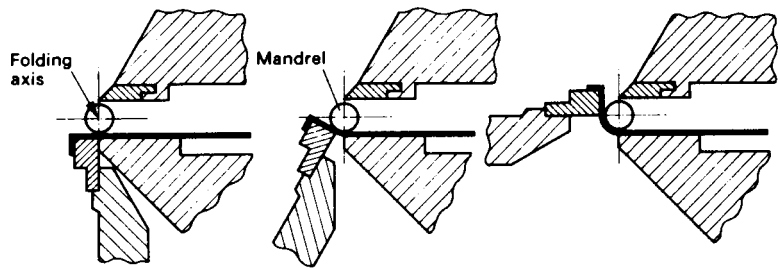
(c)

Figure 7.8 Further examples of the use of folding machines. (a) Examples of
work produced on a folding machine; (b) use of a mandrel in a folding machine;
(c) use of an angel-clamping blade in a folding machine

A typical vee-bending tool suitable for a fly press (hand press) is shown in Fig.
7.9(a) and a typical U-bending tool is shown in Fig. 7.9(b). For larger components
and thicker materials, similar tools can be used in power presses. Dedicated angle
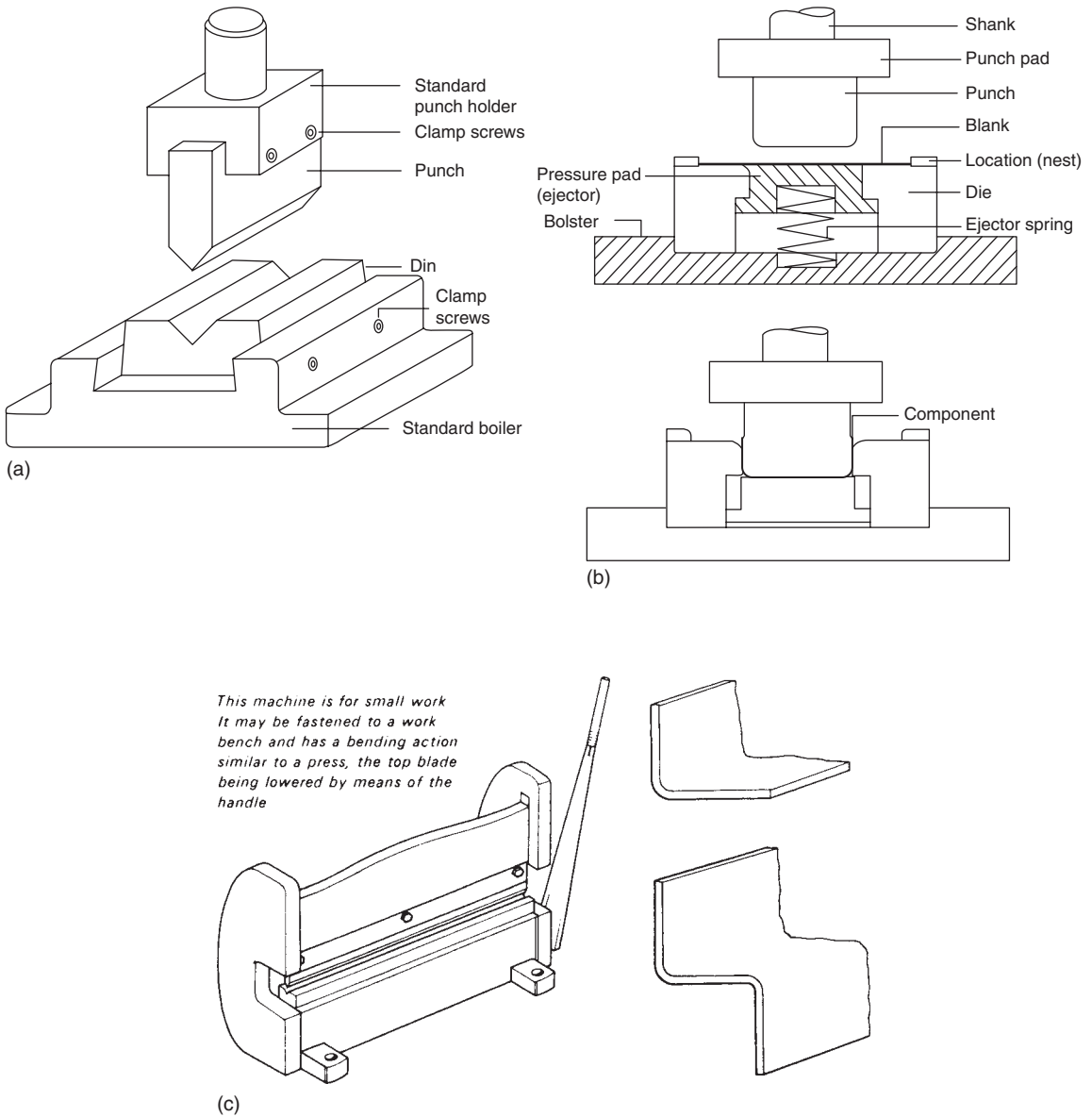bending machines are manufactured and an example is shown in Fig. 7.9(c).

(a)

Standard punch holder
Clamp screws
Punch
Din
Clamp screws
Standard boiler

(b)

Shank
Punch pad
Punch
Blank
Location (nest)
Die
Ejector spring
Pressure pad (ejector)
Bolster
Component

(c)

This machine is for small work
It may be fastened to a work
bench and has a bending action
similar to a press, the top blade
being lowered by means of the
handle

Figure 7.9 Pressure bending. (a) Simple vee-bend tool; (b) U-bending; (c) angle-bending machine

7.1.6 The press-brake

A typical *press-brake* is, in effect, a power press with a very wide but narrow ram and bed. It may be mechanically or hydraulically operated. Press-brakes are designed to bend to a rated *capacity* based on a *die ratio* of 8:1 which is accepted as the ideal bending condition. The meaning of die ratio for a vee-bending tool is explained in Fig. 7.10, whilst Table 7.1 shows the effect of the die ratio on the bending pressure
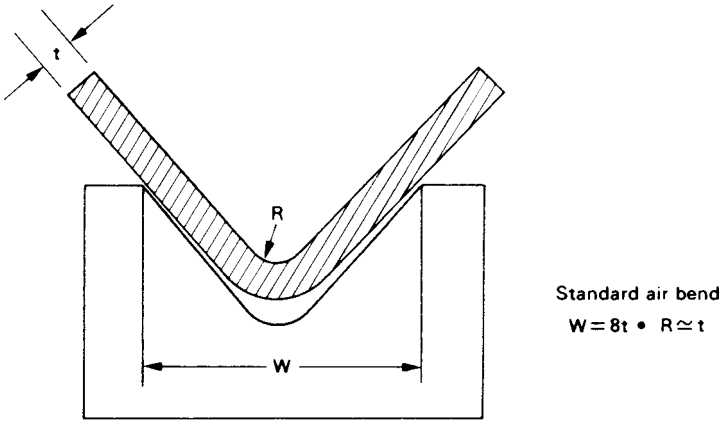
Figure 7.10 Die ratio

Table 7.1 Comparison of 'Vee' die ratios

Metal thickness		Force tonnes/metre (die ratio)*		
s.w.g.	mm	8:1	2:1	16:1
20	0.9	6.8	4.1	3.0
18	1.2	9.1	5.8	4.1
16	1.62	12.2	7.5	5.4
14	2.0	14.9	9.5	6.8
12	2.64	19.6	12.2	8.8
	3.2	23.7	14.6	10.5
	4.8	35.2	22.0	15.9
	6.4	47.4	29.5	21.3
	8.0	58.9	36.6	26.8
	9.5	70.8	44.0	31.8
	11.0	82.6	51.5	37.3
	12.7	94.5	58.9	42.7
	14.3	115.3	66.0	48.1
	15.9	118.2	73.5	53.2
	17.5	129.7	80.9	58.6
	19.0	141.9	88.1	64.0
	20.4	153.5	95.5	69.1
	22.2	165.2	102.6	74.5
	23.8	177.1	110.1	79.9
	25.4	189.3	117.5	85.3

*Required to produce 90° 'air bends' in mild steel (Tensile strength 450 N/m^2 using a die ratio).

required when bending mild steel. Table 7.2 gives the multiplying factors required when bending metals other than mild steel.

For thin material the die ratio may be reduced to 6:1 but the bending pressure will increase. For thick material the die ratio may have to be increased to 10:1 or even 12:1 to keep the bending pressure within the capacity of the machine.
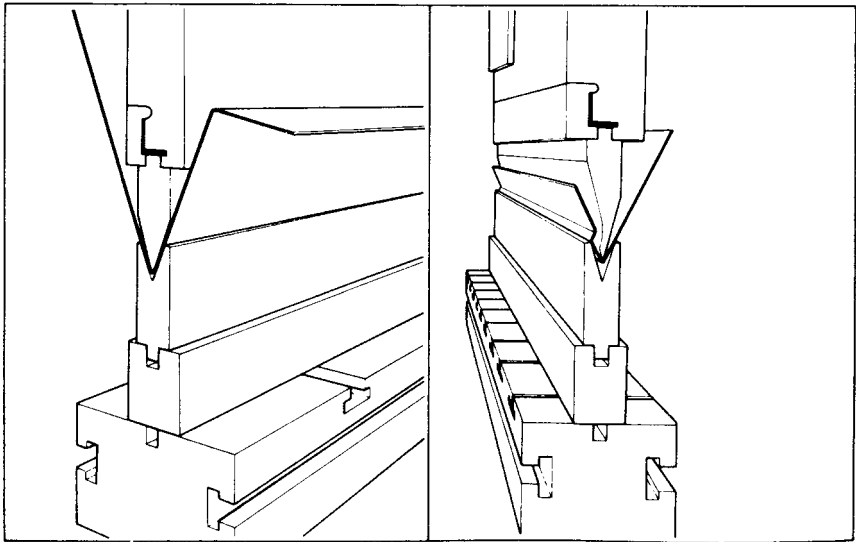
Let's now consider some typical press-brake operations as shown in Fig. 7.11.

Table 7.2 Bending forces required for metals other than mild steel

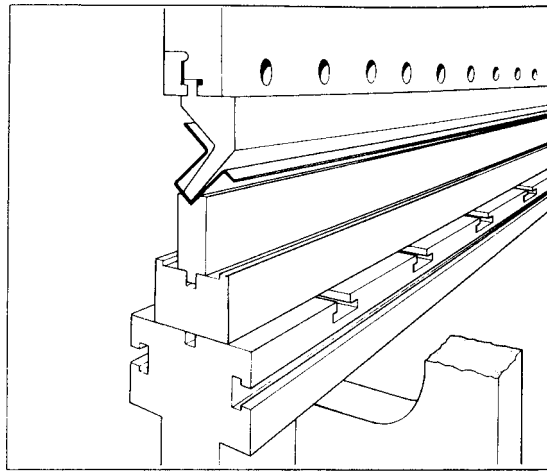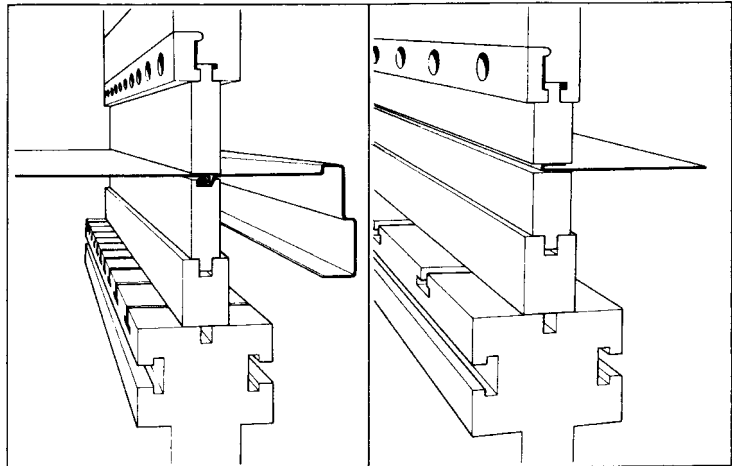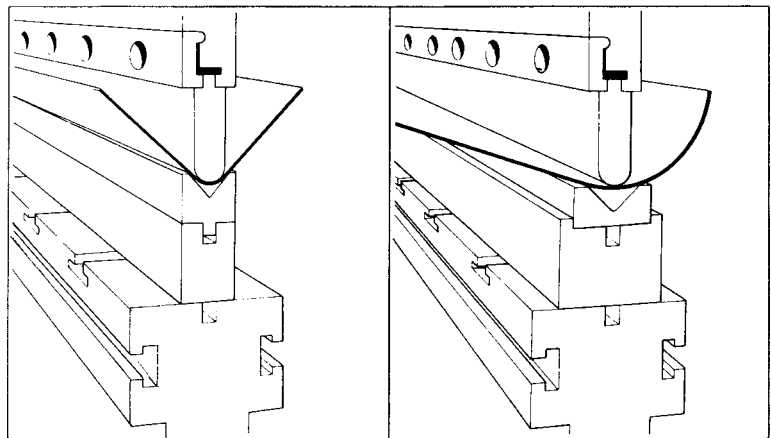| Material	Multiplied by
Stainless steel	1.5
Aluminium – soft temper	0.25
Aluminium – hard temper	0.4
Aluminium alloy – heat treated	1.2
Brass – soft temper	0.8
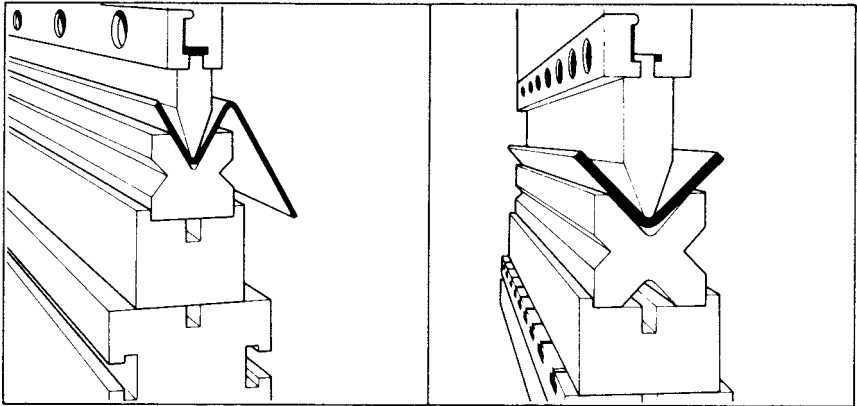
(a)

(b)

Figure 7.11 Versatility of pressure bending. (a) Four-way dies; (b) acute angle tools; (c) goose-neck punches; (d) flattening; (e) radius bending; (f) channel forming; (g) box making; (h) beading (see stiffening of sheet metal)
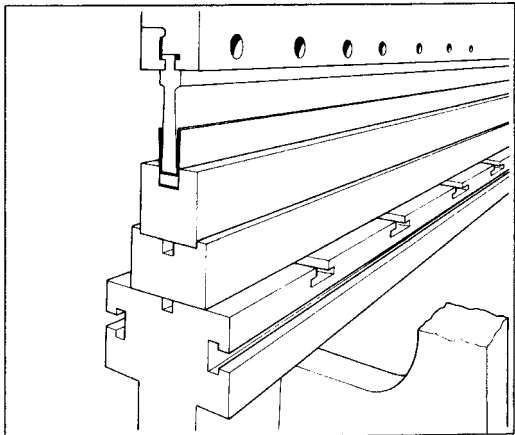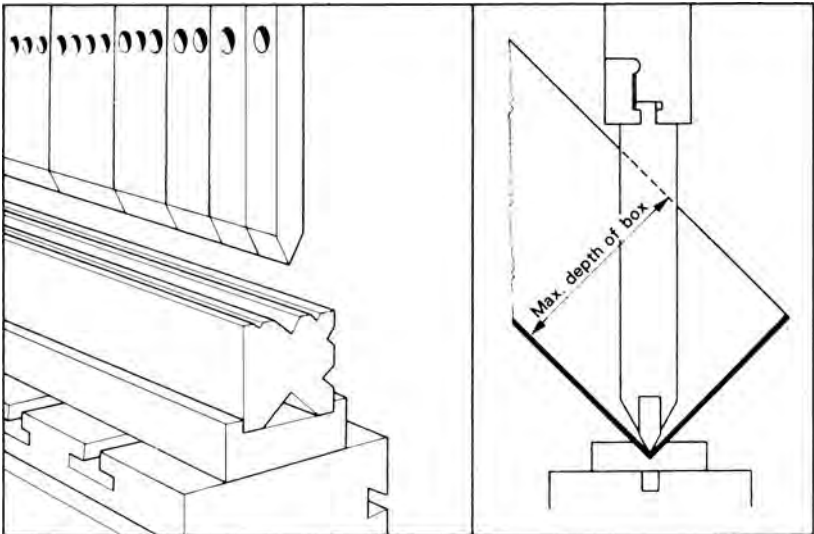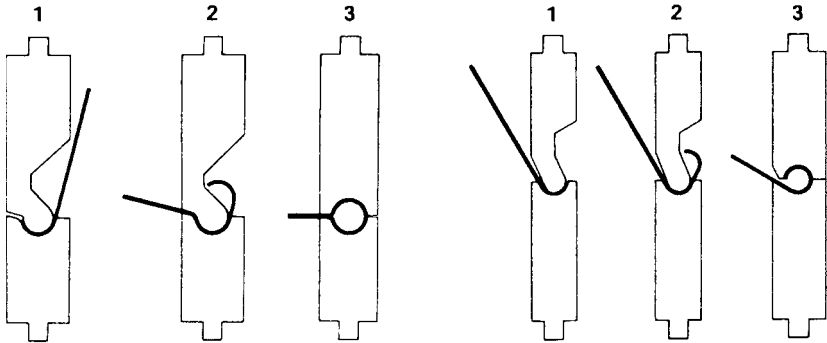
(c)

(d)

(e)

Figure 7.11 (Continued)

(f)

(g)

(h)

Figure 7.11 (Continued)

Interchangeable four-way dies – Figure 7.11(a)

These are used for air-bending medium and heavy plate. The bottom tool (die) has four 'vee' openings depending upon the die ratio required. The 'vee' openings have an included angle of 85° to provide *over-bend* to allow for *spring-back*. The punch for use with four-way dies has an included nose angle of 60°.

Acute-angle dies – Figure 7.11(b)

Acute-angle dies have many uses and, if used in conjunction with flattening dies, a variety of seams and hems may be produced in sheet metal. These tools are available for any angle but if the angle is less than 35° the sheet-metal component tends to stick in the lower tool (die). Acute-angle dies may be set to air-bend a 90° angle by *raising* the ram and punch.

Goose-neck punch – Figure 7.11(c)

When making a number of bends in the same component, clearance for previous bends has to be considered. *Goose-neck* punches are specially designed for this purpose. These tools are very versatile, enabling a variety of sheet-metal sections to be formed.

Flattening (planishing) tools – Figure 7.11(d)

Flattening tools of various forms may be used either in pairs for flattening a returned edge or hem on the edge of sheet metal, or in conjunction with a formed male or female die. Figure 7.11(d) shows a flat male tool (punch) and a formed female tool (die) closing a countersunk seam in a sheet-metal fabrication.

Radius bending – Figure 7.11(e)

A radius bend is best formed in a pair of suitable tools. The radius on the male punch is usually slightly less than that required in order to allow for 'spring-back' in the material. Large radii, particularly in plate, can be produced by simply adjusting the height of the ram and progressively feeding the sheet or plate through the tools.

Channel dies – Figure 7.11(f)

Channel dies are made with *pressure pads* so that the blank material is held against the punch during the forming operation to avoid the blank slipping out of position at the start of the operation. A channel section in heavy-gauge metal is best made in a 'vee' die with a 'goose neck'-type male tool (punch).

Box-making – Figure 7.11(g)

Male punches for box-making must be as deep as possible. Most standard machines are fitted with box tools which can make boxes of any depth up to a maximum of 170 mm deep. For deeper boxes machines with greater die space than standard

are required. For each extra 25 mm of die space (*daylight*) the depth of the box increases by 17 mm. The punches are made in segments of standard widths to suit any size of box.

Beading – Figure 7.11(h)

This shows the three operations required to form a beaded edge. Sheet-metal edges are dangerously sharp and, for safety reasons as well as adding strength and stiffness to the product, have to be beaded, wired (beaded around a wire core) or folded to make them safe. Figure 7.11(h) shows the three operations required to form a beaded edge (hem).

7.1.7 Bend allowance for sheet metal

When sheet metals are bent through an angle, the metal on or adjacent to the outside surfaces becomes *stretched*, whilst the metal on or adjacent to the inside surfaces of the bends becomes *compressed*. It is necessary to make allowance for these effects when developing a template or when marking out a blank sheet prior to bending. The enlarged cross-section of a 90° bend shown in Fig. 7.15 emphasizes the importance of the 'neutral line'.

This neutral line is an imaginary curved line lying somewhere inside the metal in the bend. Its position and length does not alter from the original flat length during bending

Because there is a slight difference between the amount of *compressive strain* and the amount of *tensile strain*, the *neutral line* does not lie on the centre line of the metal but lies in a position nearer to the inside of the bend as shown in Fig. 7.12.

T = Thickness of metal

R = Outside radius of bend

r = Inside radius of bend

x = Distance of neutral line in from compression or inner side of bend

r + x = Radius for neutral line

bc = Arc length of neutral line

L = AB + CD + Calculated length *bc*

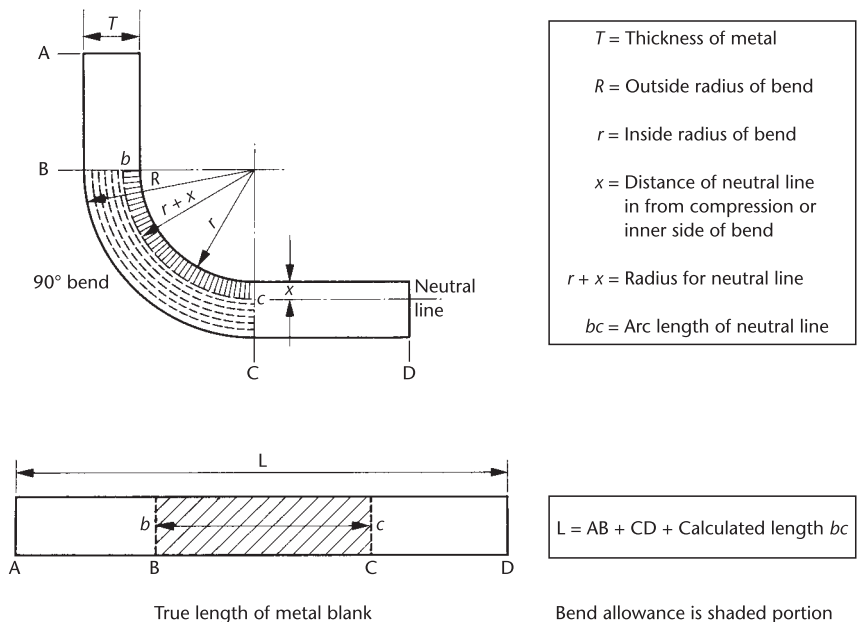True length of metal blank

Bend allowance is shaded portion

Figure 7.12 Bend allowances for sheet metal

For the purpose of calculating the allowance for a bend in sheet metal, the neutral line curve is regarded as the arc of a circle whose radius is equal to the sum of the inside bend radius plus the distance of the neutral line in from the inside of the bend. The precise position of the neutral line inside the bend depends upon a number of factors which include:

- The properties of the metal.
- The thickness of the metal.
- The inside radius of the bend.

Table 7.3 lists the approximate positions of the neutral line for some common materials and should be read in conjunction with Fig. 7.12. For general sheet metalwork the values for the radius of the neutral line may be used (where precision is unimportant). These are shown in Table 7.4.

Generally, the position of the neutral line is 0.4 times the thickness of the metal in from the inside of the bend. Therefore, the radius used for calculating the bend allowance is equal to the sum of the inside bend radius plus 0.4 times the thickness of the metal. Furthermore, the bend radius is rarely less than twice the metal thickness and rarely more than four times the metal thickness. Therefore, for all practical purposes, when calculating the required length of a thin sheet-metal blank when forming cylindrical or part cylindrical work, the mean circumference is used. That is, the neutral line is assumed to be the central axis of the metal thickness. It is only when working with thin plate and thick plate that the neutral line needs to be calculated more accurately. The terminology used when bending metal is as follows:

- *Bend radius* – the inside radius of the bend.
- *Outside bend radius* – the inside radius of the bend plus the metal thickness.
- *Bend allowance* – the length of the metal required to produce only the radius portion of the bend.

Table 7.3 Neutral line data for bending sheet metal

Material	Average value of ratio x/T
Mild steel	0.433
Half-hard aluminium	0.442
Heat-treatable aluminium alloys	0.348
Stainless steel	0.360

Table 7.4

Thickness of material		Approximate value of neutral line radius
s.w.g.	mm	
30 to 19	0.315 to 1.016	One-third metal thickness plus inside bend radius
18 to 11	1.219 to 2.346	Two-fifths metal thickness plus inside bend radius
10 to 1	3.251 to 7.620	One-half metal thickness plus inside bend radius

Example 7.1

Calculation – centre line bend allowance

Calculate the length of the blank required to form the 'U' clip shown in Fig. 7.13. The position of the neutral line $= 0.5T$ (centre line), where $T = 12.7$ mm.
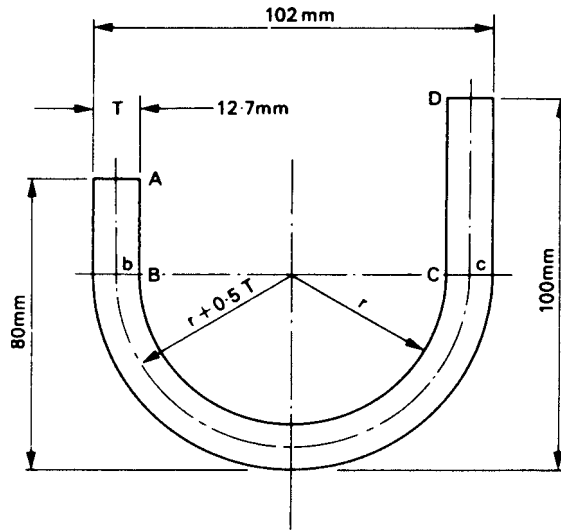
Figure 7.13 Calculation – centre line bend allowance

Solution
The length (L) of the blank is equal to the sum of the straight arm lengths 'AB' and 'CD' plus the mean line (radius) length 'bc'. Thus

$$L = \text{AB} + \text{CD} + bc$$

where bc represents a semi-circular arc whose mean radius R is equal to the inside radius r plus half the metal thickness T.
The outside diameter of the diameter of the semicircle is given as 102 mm.

$$= 49$$

Therefore, the inside diameter of the semicircle $= 102 - (2T)$
$$= 102 - 25.4 = 76.6 \text{ mm}$$

Therefore, the inside radius $r = (76.6)/2 = \textbf{38.3 mm}$
And the mean radius $R = 38.3 + (0.5 \times 12.7)$
$$= 38.3 + 6.35 = \textbf{44.65 mm}$$

Length of arms:

$$AB = 80 - (102)/2 = 80 - 51 = \mathbf{29\,mm}$$
$$CD = 100 - (102)/2 = 100 - 51 = \mathbf{49\,mm}$$

Bend allowance:

$$bc = \pi R = 3.142 \times 44.65 = \mathbf{140.3\,mm}$$

Total length of blank:

$$AB + CD + bc = 29 + 49 + 140.3 = \mathbf{218.3\,mm}$$

Example 7.2

Calculation – neutral line bend allowance

Calculate the length of the blank required to form the bracket shown in Fig. 7.14, using the neutral line value of $0.4T$ from the inside bend radius, and given that the metal thickness $(T) = 6.35\,mm$ and the inside bend radius $(r) = 2T$.
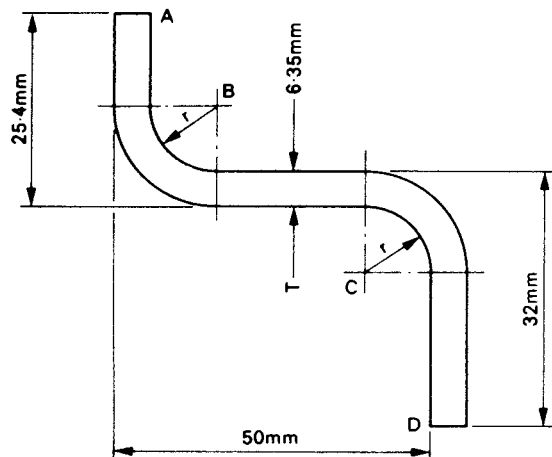

Figure 7.14 Calculation – neutral line bend allowance

Solution
Length of flats:

$$AB = 25.4 - (r + T) = 25.4 - (2T + T)$$
$$= 25.4 - 3T$$
$$= 25.4 - (3 \times 6.35)$$
$$= 25.4 - 19.05 = \mathbf{6.35\,mm}$$

Similarly:

$$CD = 32 - 3T = 32 - 19.05 = \mathbf{12.95\,mm}$$

But

$$\begin{aligned}
BC &= 50 - (r + T + r) \\
&= 50 - (2r + T) \\
&= 50 - (4T + T) \\
&= 50 - 5T \\
&= 50 - (5 \times 6.35) = \mathbf{18.25\,mm}
\end{aligned}$$

Total length of flats:

$$6.35 + 12.95 + 18.25 = \mathbf{37.55\,mm}$$

The bend allowance radius:

$$\begin{aligned}
R &= r + 0.4T \\
&= 2T + 0.4T \\
&= 2.4T
\end{aligned}$$

Therefore

$$R = 2.4 \times 6.35 = \mathbf{15.24\,mm}$$

Bend allowance for bends B and C (90° + 90° = 180°)
Bend allowance:

$$2\{\theta \times R \times (2\pi/360°)\}$$

where $\theta = 180° - 90° = 90°$

$$= 2 \times 90 \times 15.24 \times 0.0175 \approx \mathbf{48\,mm}$$

Therefore, the total blank length = total length of flats + total bend allowance
$$= 37.55 + 48 = \mathbf{85.55\,mm}$$

7.2 Roll-bending sheet metal and plate

Roll-bending sheet metal and plate is used for:

- Producing cylindrical components.
- Producing conical components.
- Wiring cylindrical edges.

7.2.1 Roll-bending machines

Bending rolls for sheet metal and plate are made in a variety of sizes. Those intended for thin sheet metal and wiring beaded edges are usually manually operated, whilst those for plate work are always power-driven. Bending rolls for sheet metal are
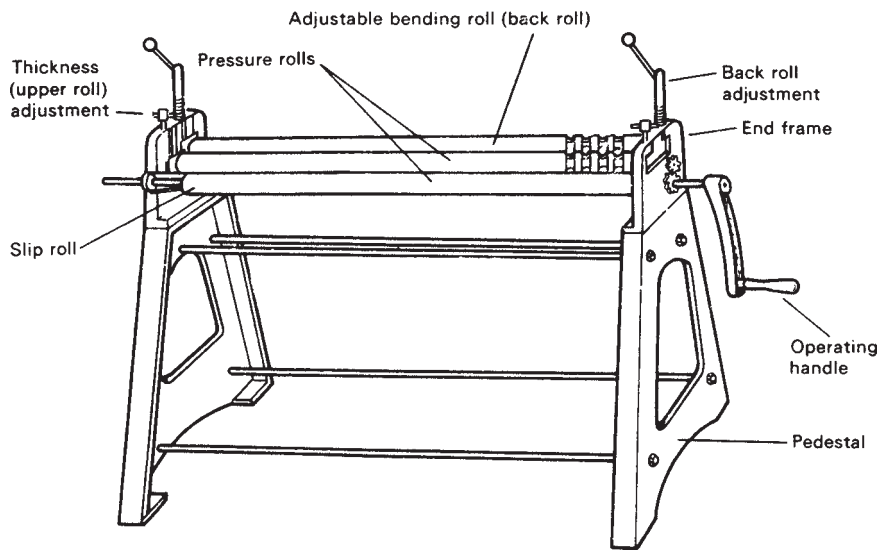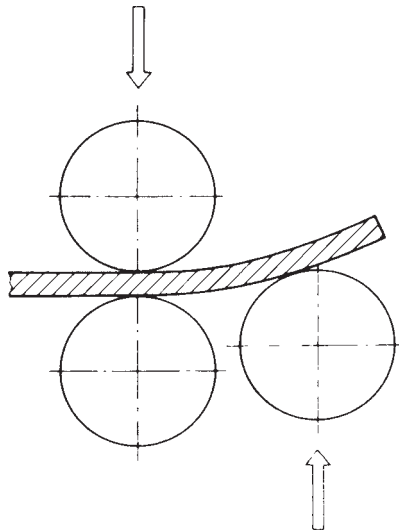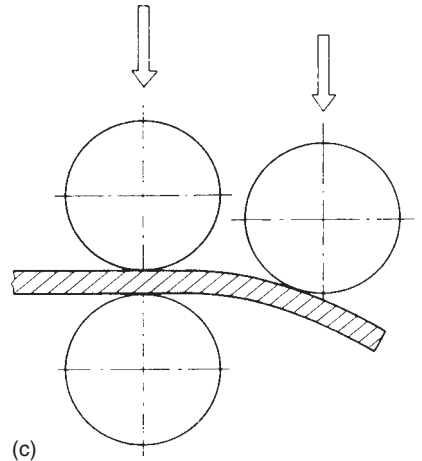
Figure 7.15 Roll bending sheet metal. (a) Sheet-metal bending rolls; (b) roll-up type; (c) roll-down type

known as *pinch-type* machines, whilst those intended for plate work *are pyramid-type* machines. Also available for heavy-duty plate work are universal machines, which may be used for both *pinch* and *pyramid* rolling.

Figure 7.15(a) shows a set of manually operated sheet-metal bending rolls. The grooves at the right-hand end of the rolls are for wire-beading the edges of cylindrical or conical components. This is a *pinch*-type machine. It has two front rollers that are geared together and lightly grip (*pinch*) the sheet, propelling it through the machine.

There is a third 'free' roller at the rear of the machine to 'set' the sheet to the required radius. This third roller may be below the sheet or above the sheet.

Roll-up-type machine

This has the 'free' roller *below* the sheet as shown in Fig. 7.15(b). Roll-up machines have adjustment on the top or bottom pinch roll to compensate for various material thicknesses and adjustment in the upward direction on the back (free) roller to adjust the set of the sheet to the required radius. As a general rule, the minimum diameter that can be rolled on a pinch-type, roll-up machine is about 1.5 to 2 times the diameter of the rear roller.

Roll-down-type machine

This has the free roller *above* the sheet as shown in Fig. 7.15(c). Roll-down machines have adjustment in a vertical direction on the top and bottom pinch rollers to compensate for various material thicknesses and adjustment in a downward direction on the back roller. This type of machine will not roll more curvature than will pass beneath the pedestal frame.

7.2.2 Rolling plate

Rolling machines used for plate work are very much more robust than those used for sheet metal and tin plate. They are always power driven. Whereas heavy-duty, motorized pinch-type rolls are suitable for thin plate work, machines intended for thick plate work are of the *pyramid type*. These have three rolls arranged in a pyramid formation as shown in Fig. 7.16(a).

Most plate-rolling machines are provided with longitudinal grooves along the lower rolls to assist in gripping and driving the plate. These grooves can also be used for the initial alignment of the plate. The top roll is adjustable up or down and may be 'slipped' to allow removal of the work when rolling is complete to form a cylinder (see Section 7.2.3).

Figure 7.19(b) shows the rolls set for 'pinch-bending'. The main advantage of the three-roll pyramid type machine is that for heavy plate the bottom roll centres are wide apart. This reduces the load on the top roller. Since the bottom rollers are mounted in inclined slideways, the bottom roll centres are automatically reduced as the rollers are adjusted upwards for work on thin plate and small diameters.

Figure 7.17(a) shows the layout of a 'four-in-one' universal pyramid/pinch type rolling machine. These machines are capable of performing all the roll-bending operations normally carried out in fabrication workshops. In the hands of a skilled operator it is a universal machine for all types of roll-bending in both thin and thick plate work. Figure 7.17(b) shows the sequence of operations for rolling a section of steel pipeline on a 'four-in-one' rolling machine.

7.2.3 Slip-rolls

When rolling complete cylinders, the finished cylinder is left surrounding the rear roll, so provision has to be made for its removal. Rolls with this provision are referred to as *slip-rolls*. With most sheet-metal rolling machines the roll around

(a)

(b)
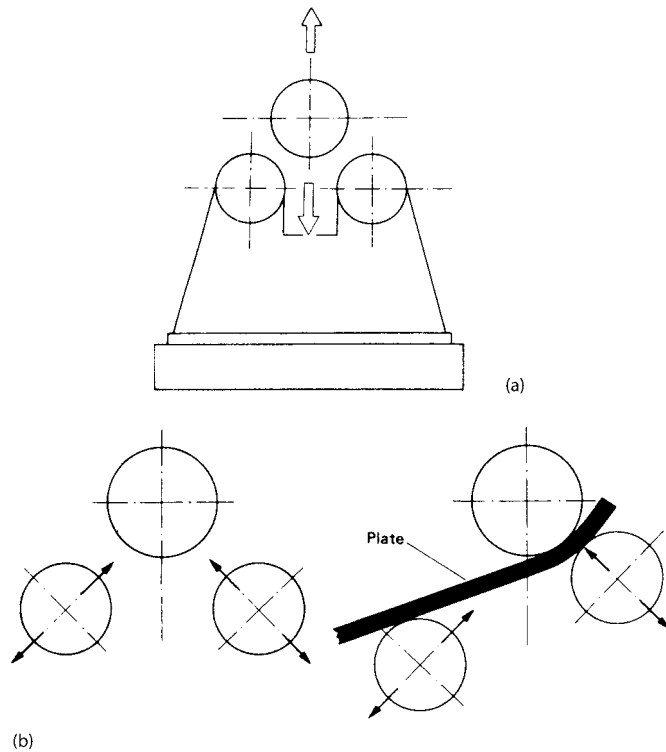
Figure 7.16 Pyramid-type rolling machine. (a) Pyramid-type rolls (standard design); (b) pyramid-type rolls with adjustable bottom rollers

(a)   (b)

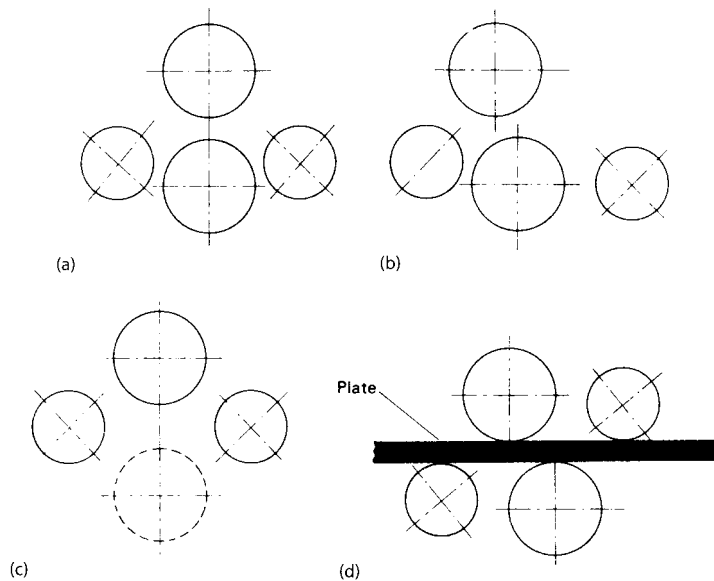(c)   (d)

Figure 7.17 The four-in-one universal pyramid/pinch-type rolling machine showing alternative settings of the rollers. (a) Four-roll pinch; (b) three-roll or offset pinch; (c) inclined-roll pyramid bender; (d) four-roll flattening machine

which the cylinder is formed is made to slip out sideways so that the cylinder can be removed. The slip-roll on heavy-duty, power-driven plate-rolling machines usually slips upwards for removal of the cylinder.

7.2.4 Cone rolling

It is possible to roll conical components on both hand- and power-operated rolling machines providing the included angle of the cone is relatively small. This is done by adjusting the rear (curving) roller so that it is at an angle in the horizontal plane to the pinch rollers or, in the case of pyramid rolling machines, so that the curving roller is at an angle to the other two rolls.

7.2.5 Ring-bending rolls for angle sections

Ring-bending rolls may be hand-operated by suitable gearing or power-operated. They are used for the cold-bending of channel, angle and tee-section stock to produce bar rings. The axes of the rollers may be either horizontal or vertical as shown in Fig. 7.18.

Ring-bending rolling machines consist of three rollers arranged in triangular formation (similar to pyramid rolls). Each roller can be split into two sections to accept the flat flanges of angle sections or channels as they are being bent. When bending an outside ring, the flat flange of the angle lies in the slots between the two bottom rollers. These slots are adjusted so as to prevent the flat flange from puckering during the roll-bending operation. For an inside ring the flat flange of the angle lies in the slot of the single
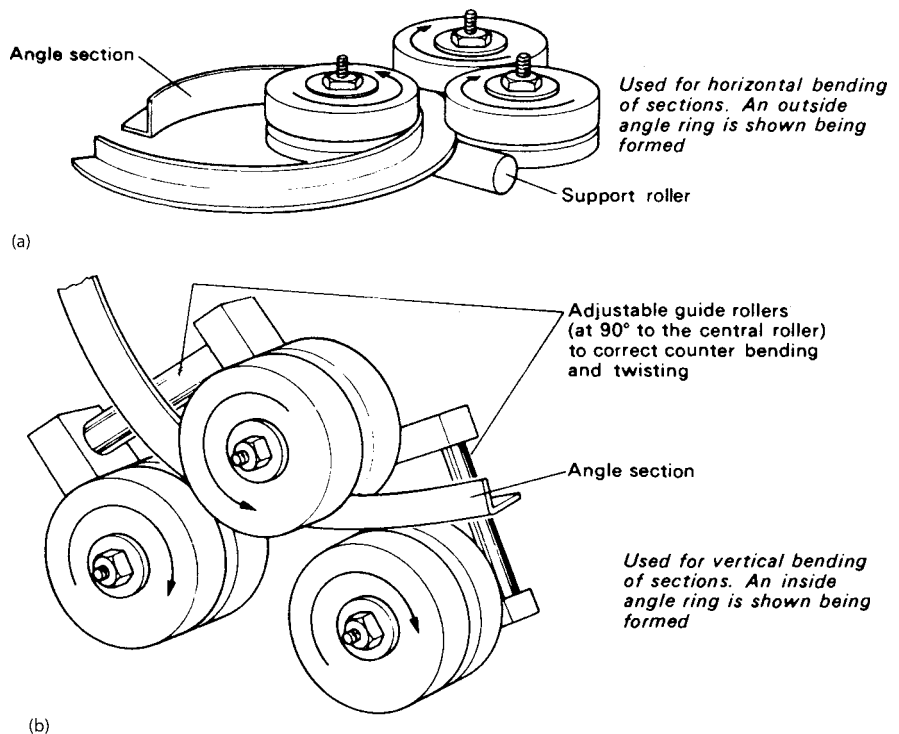

Figure 7.18 Angle ring-bending rolls. (a) Vertical roller arrangement; (b) horizontal roller arrangement

central roller. Pressure is exerted, during the rolling operation, by a screw arrangement which moves the single central roller towards the gap between the other two rollers.

7.3 Flow-forming sheet metal

So far, we have only considered the bending and rolling of sheet metal and plate in two planes. Flow-forming is the shaping or bending of metal in three planes (three-dimensional). This is much more difficult than manipulating metal in two planes since, in three planes, some part of the metal must be *stretched* or *shrunk* or both.

7.3.1 Flanging sheet metal

Let's consider a *flange* that is to be 'thrown' on a curved surface such as a cylinder as shown in Fig. 7.19(a). It can be seen that the edge of the flange, after externally flanging, has a greater circumference than it had before the flange was thrown. In this case the metal has been *stretched.* Now let's consider a flange to be worked up around the edge of a flat metal disc as shown in Fig. 7.19(b). It can be seen that, in this instance, the edge of the disc after flanging has a smaller circumference than it had before flanging. In this case the metal has been *shrunk (compressed)*. Shrinking or compressing the metal will *increase* its thickness.

Stretching the metal will **reduce** its thickness

Figure 7.20 shows how an angle section can be curved by increasing or decreasing the surface area of one flange. In practice metal is not normally removed by the simple expedient of cutting 'vee-slots'. The surface area is reduced by shrinking (compressing) the metal. This is more difficult and requires greater skill than when producing an externally curved flange because it is much easier to stretch metal by thinning it, than to compress metal by thickening it.

(a)
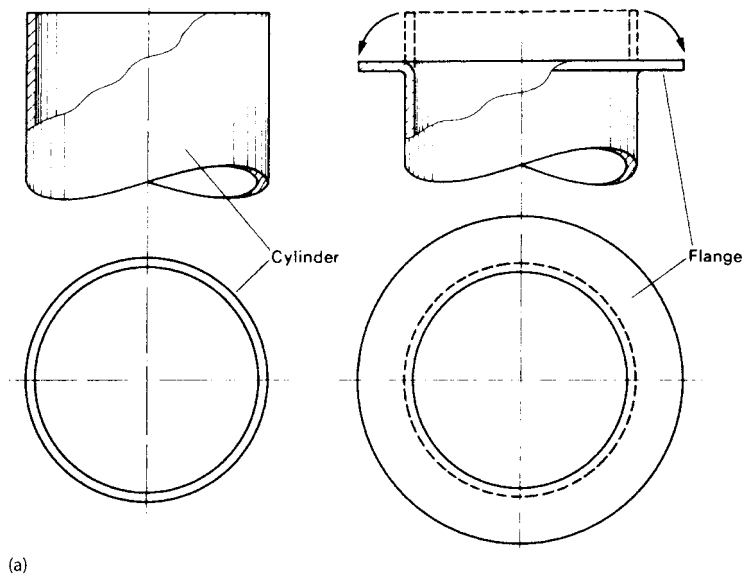
Figure 7.19 Comparison of flanging methods. (a) Left: cylinder before flanging, right: cylinder after flanging; (b) left: disc before flanging, right: disc after flanging

Flat disc

Flange

(b)

Figure 7.19 (Continued)

Stretching hammer

Anvil

(a) **Increased area of metal**
The increased area on one flange causes the other flange to curve inwards

Series of vee-notches

Vees closed

(b) **Decreased area of metal**
The decreased area in one flange causes the other flange to curve outwards

Figure 7.20 The effects of increasing and decreasing the surface area of one flange of an angle strip

7.3.2 The principles of flow-forming sheet metal by hand

A craftsperson needs to posses a thorough knowledge of the properties of the materials which he or she has to use. This enables the craftsperson to understand and even forecast the behaviour of materials which are subjected to applied forces and so be in *control of the desired direction of flow* during flow-forming operations. During

For successful flow-forming the metal must be in the *annealed* (soft) condition

flow-forming the metal will tend to *work-harden*. The degree of work-hardening will depend upon the composition of the metal and the severity of the forming operation to which it is subjected. It may be necessary to re-anneal the work several times during a flow-forming operation to prevent it cracking and splitting.

The techniques used for forming work by hand are similar for most materials. The main differences are concerned with:

1. The *force* with which the metal is struck.
2. *The direction* in which the force (blow) is applied.

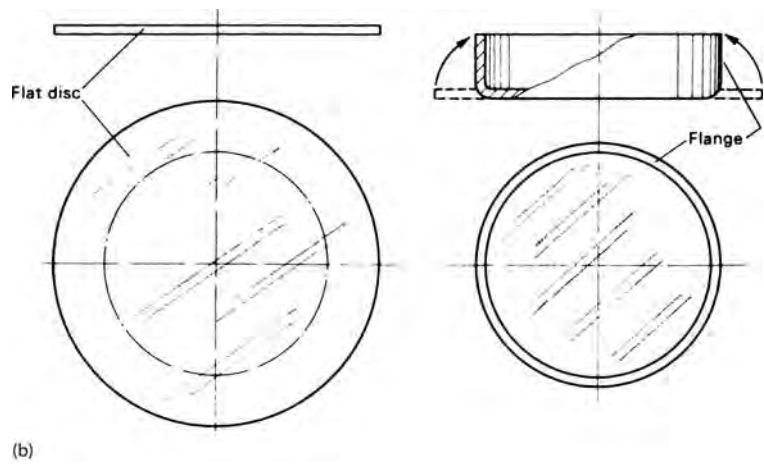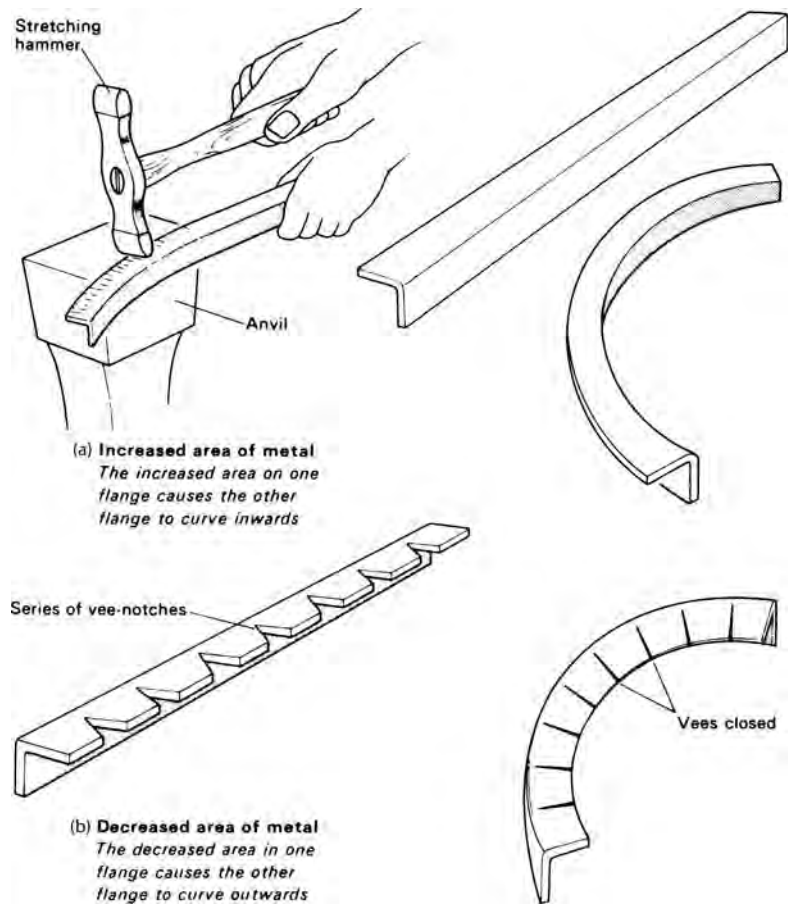If a piece of aluminium sheet and a piece of low-carbon steel sheet of the same thickness are struck with blows of equal force, the aluminium, being the softer and more malleable, will deform to a much greater extent than the steel. Since the flow-forming
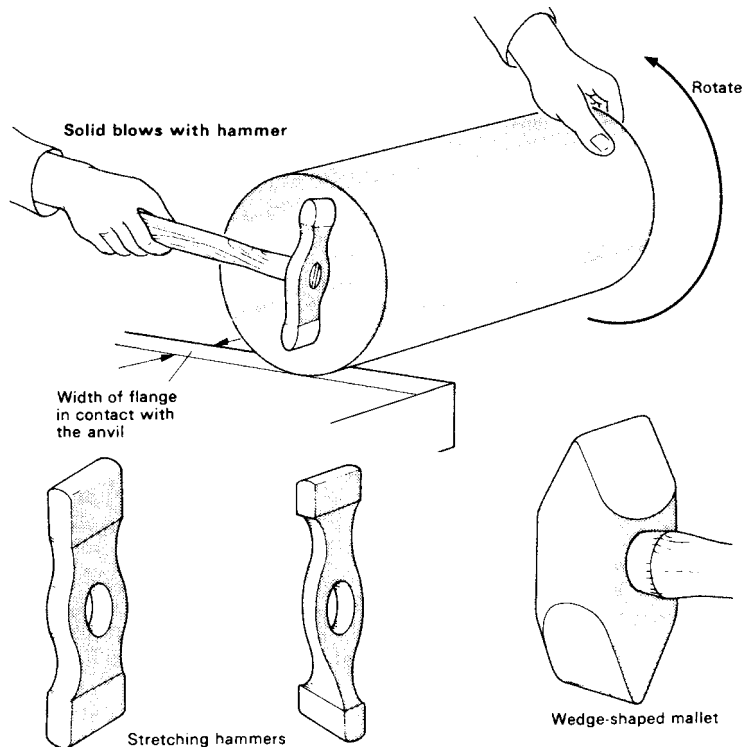
Figure 7.21 Increasing circumference by stretching. (a) Increased area of metal. The increased area on one flange causes the other flange to curve inwards; (b) decreased area of metal. The decreased area in one flange causes the other flange to curve outwards

of sheet metal is essentially a 'hammering' processes, it is most important that we consider the types of blow which can be struck on sheet metal and that each type of blow has its own field of application for any given purpose.

Solid blow

When metal is struck solidly over a steel anvil or 'head', the solid blow will stretch the metal as the typical application in Figs. 7.21 and 7.22 shows. For very soft materials a wooden mallet is less likely to bruise the metal.

Solid blows with hammer

Anvil

1. Stretch   2.Tilt and flare

A ring appears during the initial stretching -- this acts as a guide line for throwing a constant width of flange

3. Stretch   4. Tilt and flare

The material must be stretched before flaring. The cylinder is progressively rotated as the flange is worked over

5. Stretch   6. Tilt and flare

7.Final stretching
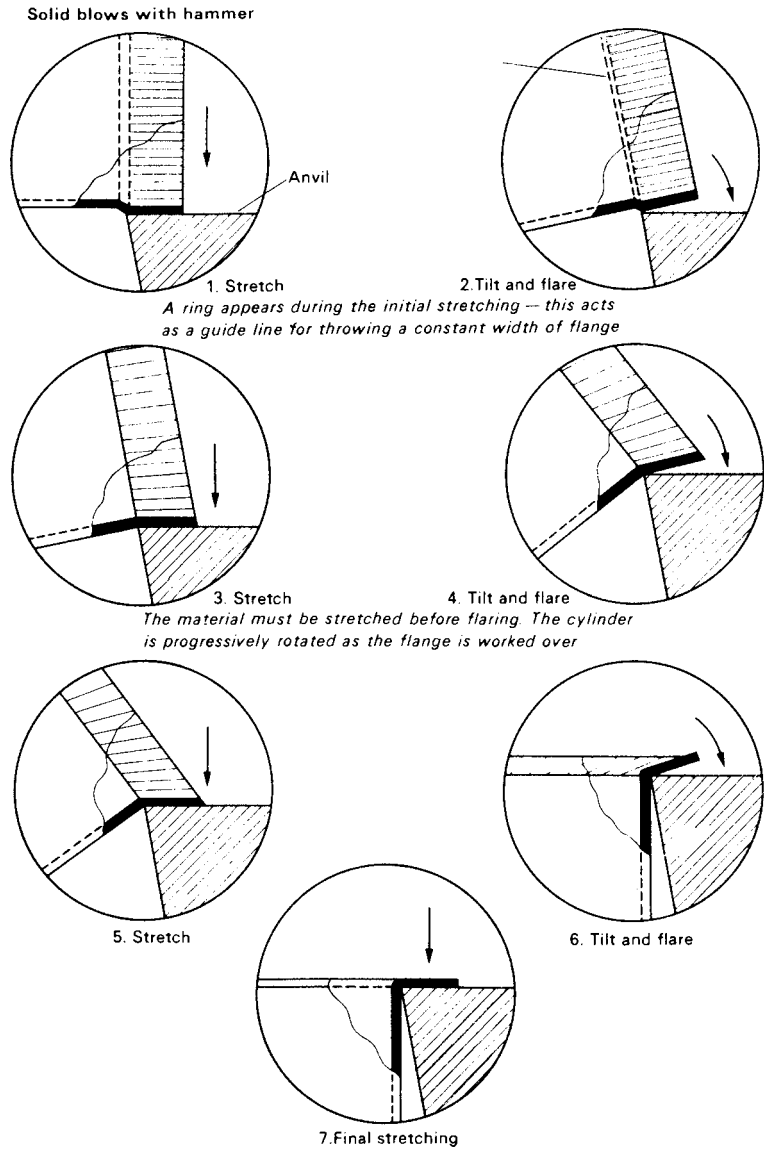
Figure 7.22 Sequence of operations for producing an external flange on a cylindrical body

Elastic blow

Where either the head or the tool (or both) are made of a resilient material such as wood an elastic blow is delivered. An elastic blow will form sheet metal without unduly stretching it and can be used to advantage to thicken the metal when shrinking it. The use of an elastic blow is shown in Fig. 7.23.

Floating blow

Where the head of the anvil is not directly under the hammer a floating blow is delivered. The floating blow is one which is used to control the direction in which the
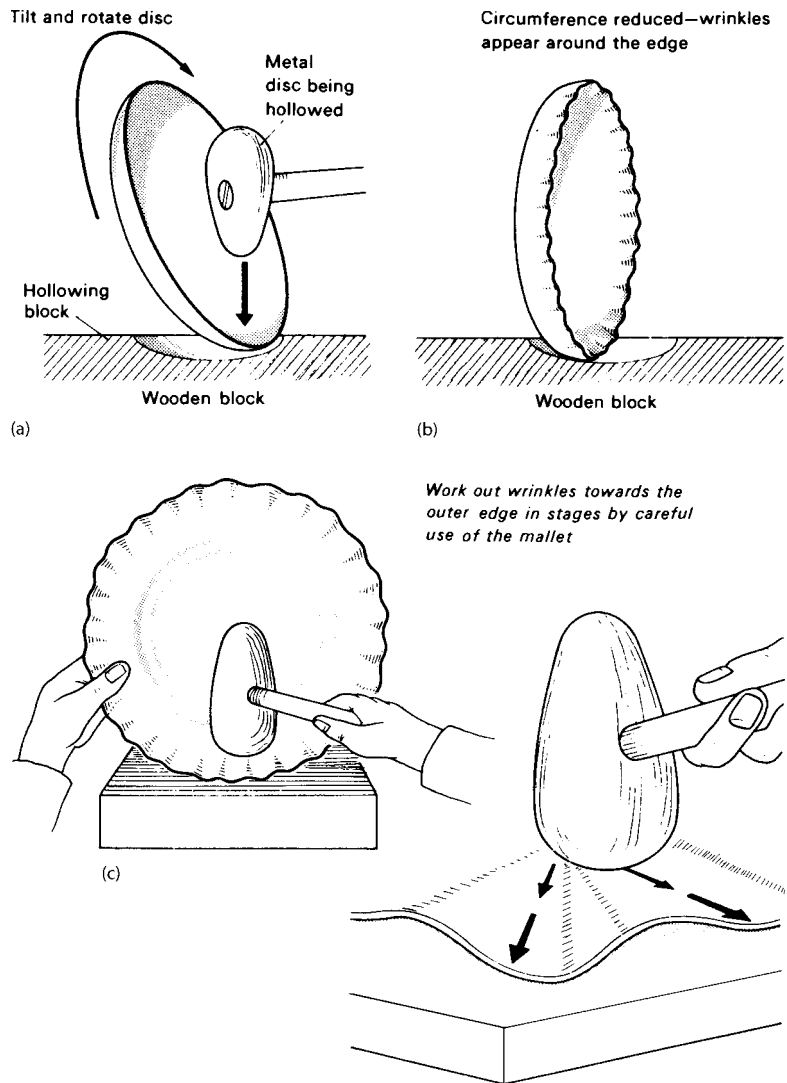
Figure 7.23 Shrinking the edge when hollowing (elastic blows). (a) Tilt to steeper angle; (b) edge caused to wrinkle; (c) use elastic blows
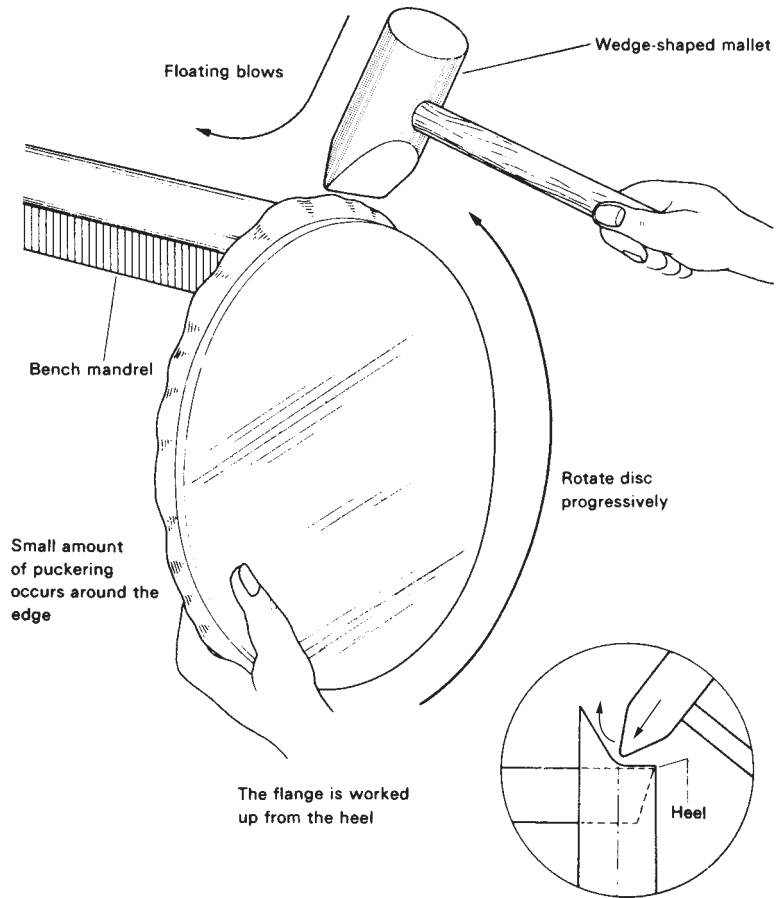
Figure 7.24 Raising a flange on a metal disc

metal is required to flow during the forming process. It is delivered while the metal is held over a suitable head or stake, hitting it 'off the solid' so as to form an indentation at the point of impact. Figure 7.24 shows the use of floating blows.

7.3.3 Use of bench tools for forming sheet metal

Craftpersons frequently find it necessary, when suitable machines are not available, to resort to the use of various types of metal anvils and heads when forming sheet-metal articles. These devices are commonly referred to as 'stakes' and are designed to perform many types of operations for which machines are not readily available or readily adaptable. Good-quality stakes are made from malleable cast iron or cast steel. They are all sold by weight because of their variety of size and shape.

A 'stake' used for sheet metalwork consists basically of a shank supporting a head or horn. The shanks are generally tapered to a standard size and shape at their lower end and are designed to fit into a bench socket. The heads and horns are available in a great variety of shapes and sizes with their working faces machined and polished. Figure 7.25 shows some of the more common types that are available.

Figure 7.25 Typical bench stakes. (a) Hatchet stake; (b) half-moon stake; (c) funnel stake; (d) beak or brick-iron; (e) side stake; (f) pipe stake; (g) extinguisher stake; (h) creasing iron; (j) bench mandrel; (k) planishing anvil; (l) round bottom stake; (m) canister stake; (n) convex-head stakes; (o) horse; (p) long-head stake; (q) round-head stakes; (r) oval-head stake

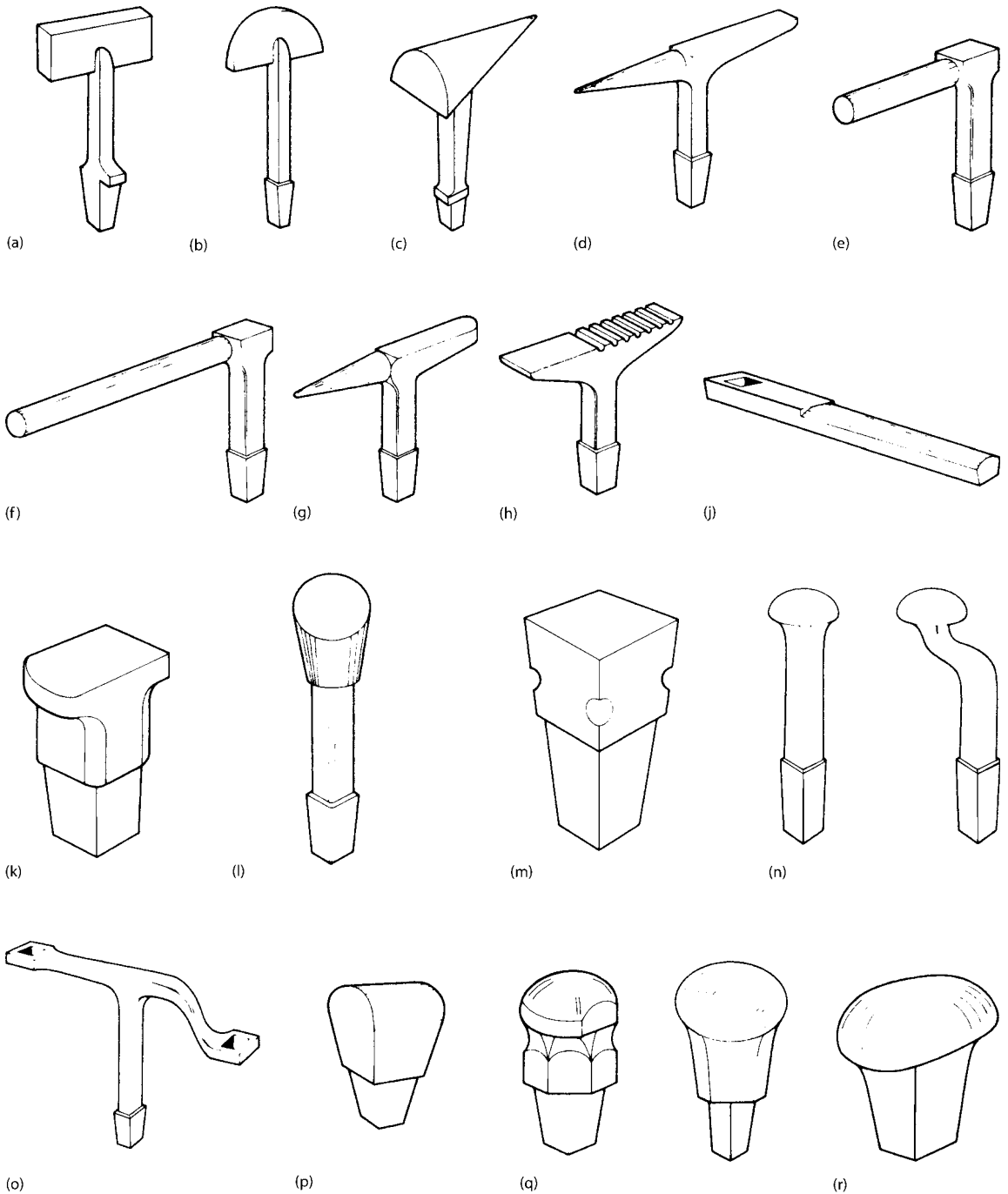- *Hatchet stake* – Fig. 7.25(a). The hatchet stake has a sharp, straight edge bevelled on one side. It is very useful for making sharp bends, folding the edges of sheet metal, forming boxes and pans by hand, and 'tucking-in' wired edges and seaming.
- *Half-moon stake* – Fig. 7.25(b). The half-moon stake has a sharp edge in the form of an arc of a circle bevelled on one side. It is used for throwing up flanges on metal discs, or profiled blanks, preparatory to wiring and seaming. It is also used for 'tucking-in' fired edges on curved work.
- *Funnel stake* – Fig. 7.25(c). As the name implies, this stake is used when shaping and seaming funnels and tapered articles with part conical corners such as 'square-to-round' transformers.
- *Beak- or bick-iron* – Fig. 7.25(d). This stake has two horns, one of which is tapered and the other is a rectangular anvil. The thick, tapered horn or 'beak' is used when making spouts and sharp tapering articles. The anvil may be used for squaring corners, seaming and light riveting.
- *Side stake* – Fig. 7.25(e). A side stake has only one horn which is not tapered. It is more robust than a bick-iron and can withstand considerable hammering. Its main uses are forming, riveting and seaming pipe work. It is also used when forming tapered work of short proportions.
- *Pipe stake* – Fig. 7.25(f). A pipe stake is an elongated version of the side stake and, because of the overhang, is less robust. As its name implies it is used when forming and seaming sheet-metal pipes.
- *Extinguisher stake* – Fig. 7.25(g). This is very similar to a bick-iron. It has a round and tapered horn at one end and a rectangular-shaped horn at the other. Some extinguisher stakes contain a number of grooving slots on the working surface of the rectangular horn. These are useful when creasing metal and bending wire. The tapered horn is used when forming, riveting, or seaming small tapered articles. It is also useful when forming wrinkles or puckers prior to 'raising'.
- *Creasing iron* – Fig. 7.25(h). This has two rectangular shaped horns, one of which is plain. The other horn has a series of grooving slots of various sizes. The grooves are used when 'sinking' a bead on a straight edge of a flat sheet (i.e. reversing wired edges).
- *Bench mandrel* – Fig. 7.25(j). This is firmly fixed to the bench by means of strap clamps which may be quickly released, allowing the mandrel to be reversed or adjusted for length of overhang. The mandrel is double-ended – the rounded end is used for riveting and seaming pipes, whilst the flat end is used for seaming the corners of pans, boxes, square or rectangular ducting and riveting. It also has a square tapered hole in the flat end for receiving the shanks of other stakes and heads. Bench mandrels are available in four sizes ranging from 20 kg to 114 kg.
- *Planishing mandrel* – Fig. 7.25(k). Planishing mandrels are available in a variety of shapes and sizes. The one shown is called a 'Tinsmith's anvil' and is used when planishing flat surfaces in all types of work. The working surface is highly polished.
- *Round bottom stake* – Fig. 7.25(l). These stakes are available in various diameters and have flat working surfaces. They are used when forming the bases of cylindrical work and for squaring knocked-up seams.
- *Canister stake* – Fig. 7.25(m). This stake has square and flat working surfaces. Its main use is for working in the corners and squaring up the seams when working with square or rectangular products.

- *Convex-head stakes* – Fig. 7.25(n). These are used when forming or shaping double-contoured and spherical work. They are usually available in two patterns – with a straight shank and with an off-set (cranked) shank.
- *Horse* – Fig. 7.25(o). This adaptable stake is really a double-ended support. At the end of each arm (one of which is cranked downwards for clearance) there is a square, tapered hole for the reception of a wide variety of heads. Four typical heads will now be shown.
- *Long-head* – Fig. 7.25(p). This is used when making knocked-up joints on cylindrical articles, and also when flanging.
- *Round-heads* – Fig. 7.25(q). Two types of round head are shown and these are used when 'raising'.
- *Oval head* – Fig. 7.25(r). This is oval in shape as shown and has a slightly convex working surface. It sometimes has a straight edge at one end.

The condition of the stake has much to do with the workmanship of the finished articles. Therefore, great care must be taken when using them. If a stake has been roughened by centre-punch marks or is chisel-marked, such marks will be impressed upon the surface of the workpiece and spoil its appearance. Therefore, a stake should never be used to back up work directly when centre-punching or cutting with a cold chisel.

A mallet should be used wherever possible when forming sheet metal. When a hammer has to be used, care must be taken to avoid hitting the metal at an angle so as to leave 'half-moon' impressions on the surface of the stake. Bench tools that have been abused and damaged must be reconditioned immediately. Regular maintenance will avoid marking the surface of the workpiece. Such marks cannot be removed.

7.3.4 'Hollowing' and 'raising'

Hollowing and raising are both methods employed for the purpose of flow-forming sheet metal. Basically:

- *Hollowing* is employed when the desired shape is only slightly domed or hollowed. The sheet metal is beaten into a small indentation; therefore, the metal being formed is stretched and its *original thickness is reduced*.
- *Raising* is always employed where shapes of much greater depth are required. It is a process whereby sheet metal is beaten and induced to flow into the required shape by the application of 'floating' blows struck whilst the metal is slightly off the head or former shape being used. The metal formed by raising is compressed and has its *original thickness increased*.

Figures 7.26 to 7.31 inclusive show the comparison between the two techniques.

7.3.5 Panel beating

Panel beating was originally much in demand when car bodies where built as 'one-offs' by highly skilled coach builders. Nowadays car bodies and sub-frames are integrated fabrications assembled by robots from pressed steel panels. Panel beating is now largely relegated to firms restoring vintage and veteran cars and aircraft, firms producing prototypes, firms rebuilding cars damaged in accidents and similar specialist work.

Bossing mallet

*Sandbags may be supplied
either round or square in
tough buffalo hide*

Hollowing

Blocking

*Hammer heads used for hollowing
and blocking have ball faces*

Tree trunk

Steel ring
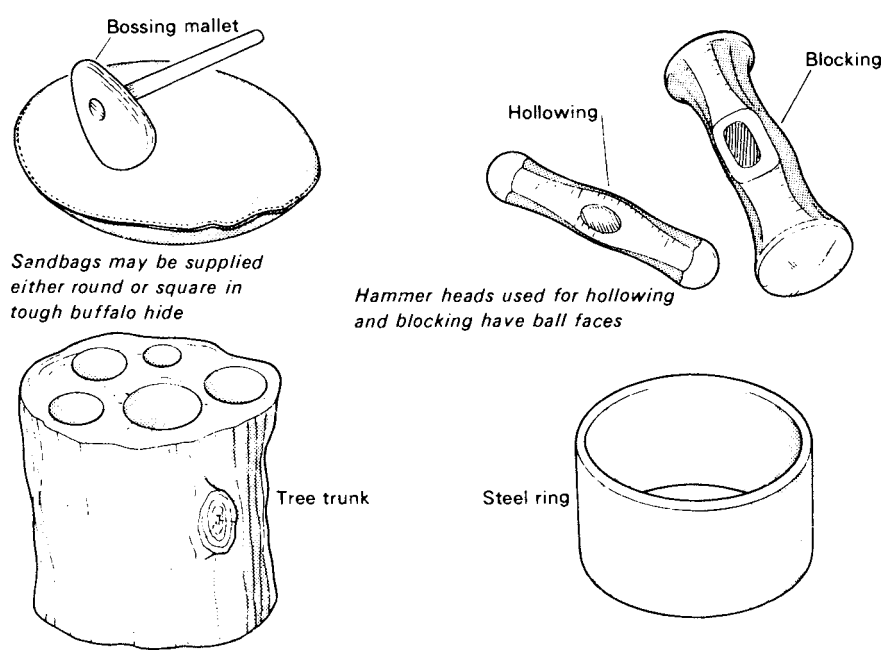
Figure 7.26 The basic tools for hollowing

(a)

(b)

Blocking hammer

(c)
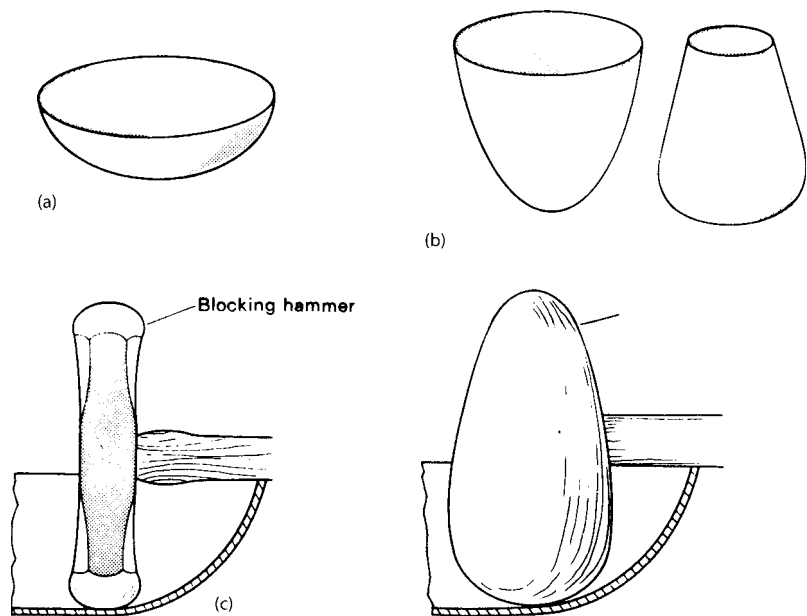
Figure 7.27 Comparison of hollowing and raising. (a) Shallow depth – this
would be formed by hollowing; (b) too deep for hollowing – this would be
formed by raising; (c) depth limitations

(a)   (b)
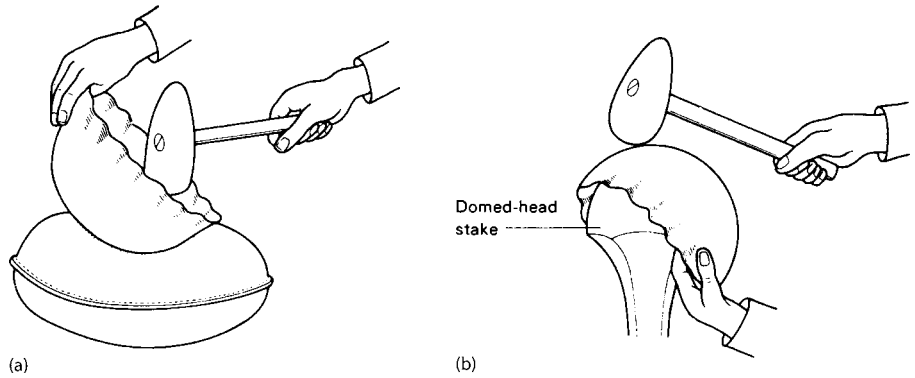
Figure 7.28 The two basic methods of forming a bowl. (a) Hollowing a hemispherical bowl on a sandbag; (b) shaping a hemispherical bowl by raising – the metal is made to flow over a solid steel head

Floating blows off the stake direct the flow of the metal

Rotate disc

Cod-head or domed-shaped stake

Bick iron

Floating blows

Bick iron

Forming puckers around edge of disc

Commencing at the apex, the pucker is gradually malleted out towards the edge
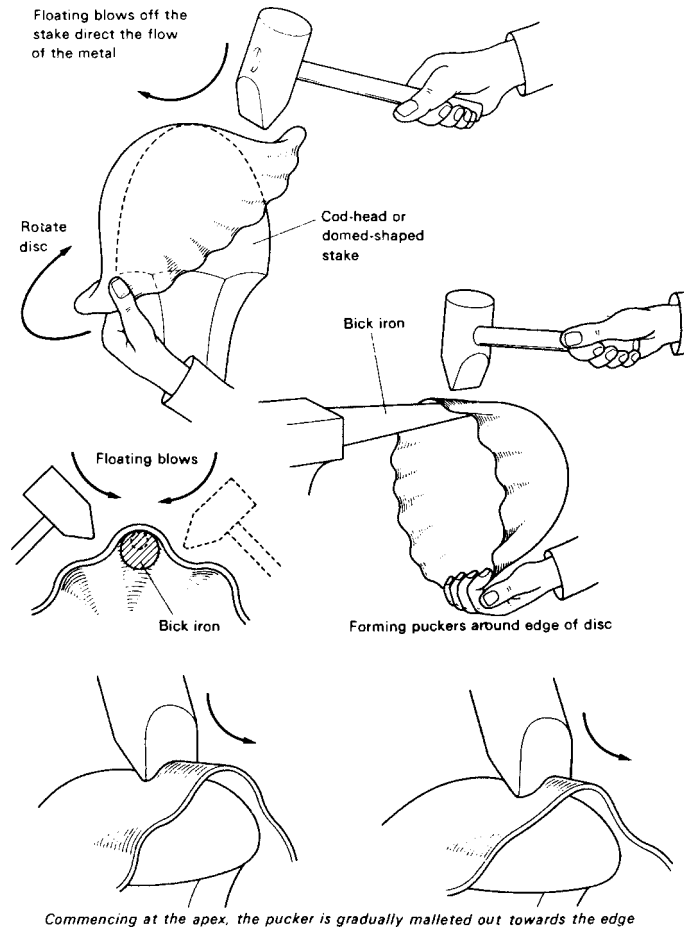
Figure 7.29 Taking in surplus metal when raising

(a) Checked with the aid of inside and outside templates

Standard mallet

Domed-head stake

(b) Produced by either hollowing or raising is placed on a suitable stake and lightly malleted all over in order to remove any high spots on the surface

Planishing hammer

(c) These are made with the planishing hammer directly over the point of contact of the workpiece with the surface of the stake

Figure 7.30 Finishing processes for double curvature work. (a) Checking the contour; (b) double-curvature work; (c) overlapping blows

(a) Made from two cheeks — shaped, planished and welded together

(b)

(c)

Shaping speeded up by means of puckers

Figure 7.31 Pipe bend fabricated from sheet metal. (a) Pipe bend; (b) working up the throat of one cheek; (c) working up the back of one cheek

A pattern is made on a panel jig or hard wood former using brown paper.
The paper is first held off the jig by tension at its edge. To allow the paper to drop on to the contour of the jig, the paper is slit at convenient intervals, the edges then opening out to let it fall in position, indicating that metal is required at the slits.

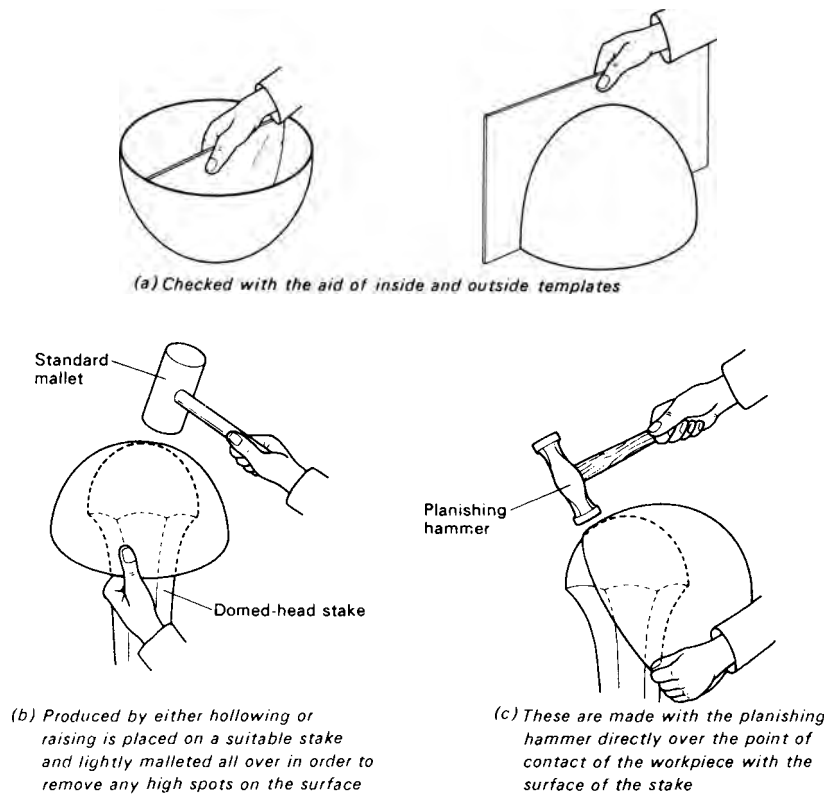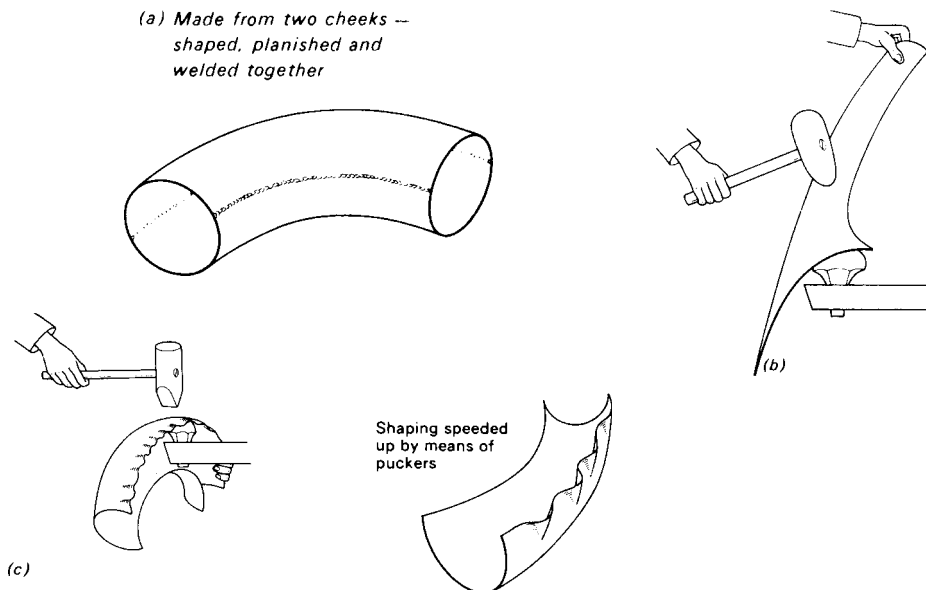Wood formers upon which the beaten shape can be 'offered-up' in order to establish uniformity of shape for each workpiece are used for many jobs.
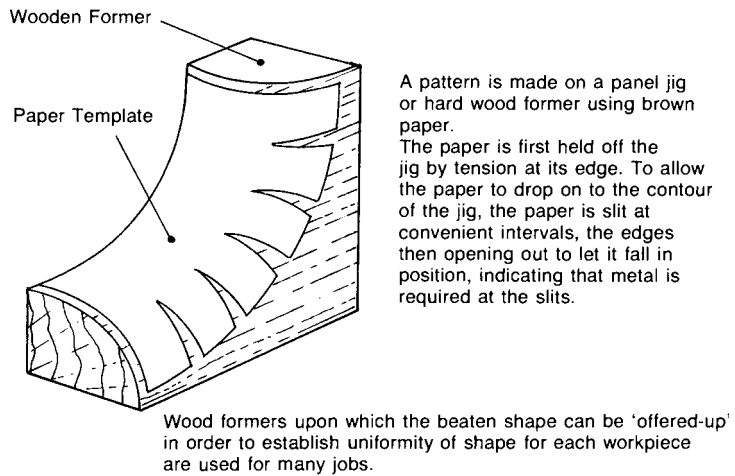
Figure 7.32 Split and weld pattern (panel beating)

The skilled panel beater is a craftsperson who, to a great extent, relies on a good eye for line and form. It is a specialized skill which can only be cultivated by years of experience combined with dexterity in the use of hand tools.

In general, most panel-beating work is carried out on deep-drawing quality steel or aluminium alloy. Although aluminium alloy is softer and more malleable than steel, it is more easily overstretched and great care is required when forming it. Providing they have skills and lightness of touch, many panel beaters prefer working with aluminium alloys which they find responds more readily than steel and is much lighter to handle. Whichever metal is used – steel or aluminium – the techniques used are the same.

Basically, double curvature work is produced by hollowing or raising to the required shape, followed by planishing to achieve a smooth surface finish. In beating certain complex shapes, hollowing and raising are often combined. The planishing operation, which 'fixes' the metal to shape and gives a perfectly smooth surface, demands particularly clean, smooth tools whether a hammer or wheeling is used.

7.3.6 Split and weld method

This process, as shown in Fig. 7.32, is simpler, less laborious and quicker than other methods of panel beating. It is clear from the paper template being fitted over a wooden former that material is required where the slits open out. Stretching the metal at these points is time-consuming and it is often quicker and cheaper to weld in V-shaped metal gussets. Conversely, when beating certain forms of double curvature where 'shrinking' is necessary, it is much quicker to 'lose' the surplus metal by simply cutting V-shaped pieces out of it. The workpiece is beaten to shape so that the cut edges meet and then weld them together. An example is shown in Fig. 7.38.

7.3.7 The wheeling machine

The wheeling machine is used where sheet metal has to be shaped into double curvature forms. Although their most frequent use is to smooth metal panels that have been roughly beaten to shape, they can be used for 'crushing' welded seams and shaping panels of shallow curvature without any preparatory beating.
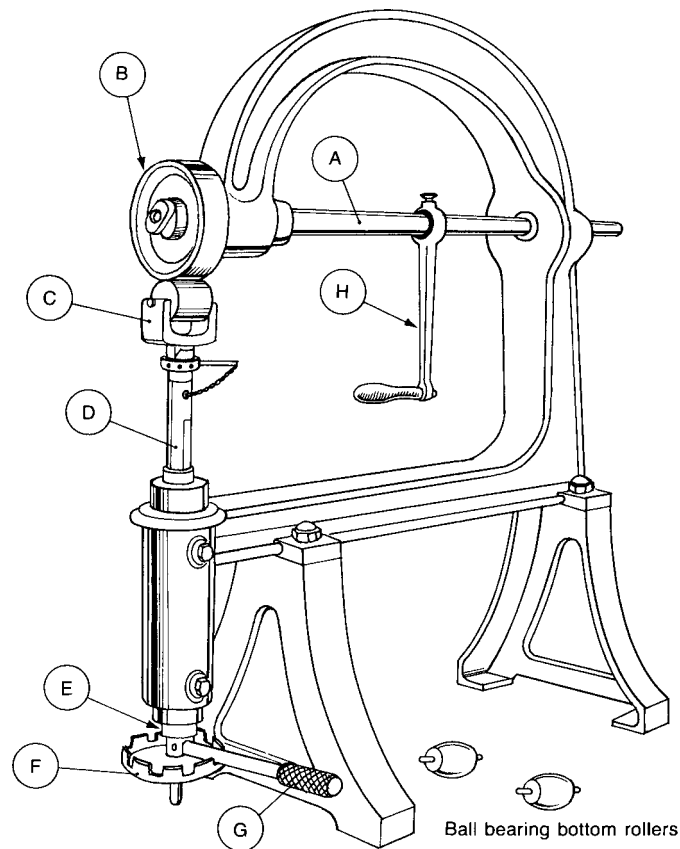
A — Main steel shaft running on ball bearings.
B — Flanged top roller (fixed).
C — Detachable bottom roller supported in carrier that has quick release action.
D — Perpendicular pillar supporting bottom roller.
E — Screwed shaft for pillar adjustment.
F — Flanged turret wheel enabling bottom roller assembly to be raised or
    lowered, during operation, by turning the wheel with the foot lever 'G'.
H — Handle freely rotating on shaft, can, when necessary, be tightened and
    used to rotate top roller when wheeling work of small dimensions.

Figure 7.33 Standard type wheel machine

Figure 7.33 shows a wheeling machine and names its parts. The machine has two wheels or rollers, the upper wheel being almost flat and the lower wheel being convex with both wheels meeting at a common centre. The upper wheel is fixed on its spindle and the lower wheel runs freely and is carried on a vertical pillar which can be adjusted up or down by a screw mechanism to regulate the pressure on the sheet metal. Interchangeable bottom wheels (rollers) are available in a number of shapes to suit work with various curvatures. The wheels (rollers) are made from hardened and tempered steel and polished. They run on anti-friction bearings. A quick-release mechanism is provided for the lower wheel support column to facilitate the insertion and removal of the workpiece without altering the pressure setting. Wheeling machines are available in various sizes, some with additional clearance for large

work such as aircraft cowlings; however, the majority conform to the design shown in Fig. 7.33.

7.3.8 Wheeling processes

The skill in using a wheeling machine lies in acquiring a 'feel' for the work as it passes back and forth between the rollers. Panels of moderate curvature can be produced by wheeling alone. The sheet is placed between the wheels and, depending upon the thickness, temper and composition of the material, the pressure is applied accordingly. Repetition of the passing movement between the wheels in both directions, as shown in Fig. 7.34, stretches the metal so that it takes on a convex curvature. It is very important that each backward and forward movement should be accompanied by alteration of direction so that the wheels make contact with the panel in a different place at each pass while ensuring complete coverage of the entire surface. The panel should not be pinched between the wheels too tightly and, by 'feel', the operator should allow the panel to follow its own shape during wheeling. The movement is varied until the desired shape is obtained, with those parts of the panel which only require a slight curvature receiving less wheeling that those parts that require greater curvature. Wheeling pressure is applied as required by raising the lower wheel (roller) and, after a few passes, the necessary curvature will be accomplished.

When working with soft metals such as aluminium, which is very easily scratched, it is essential that the surfaces of the tools, rollers and workpiece are perfectly clean. Care must be taken not to put excessive pressure on the workpiece because three times as much 'lift' is obtained compared with harder metals such as steel for the same setting. Figure 7.34 shows the basic wheeling process and the means of correcting a common error (corrugation).

Panels of shallow curvature

Panels with very little curvature require the minimum of pressure and should be wheeled to the required shape a gently as possible. Excessive working will result in a fault known as 'corrugating' as shown in Fig. 7.34(c). This type of fault is not easily corrected by wheeling as this tends to make the corrugations worse. It may be necessary to reset the panel using a mallet and panel head. However, slight corrugations can be removed by wheeling across the wheel tracks responsible for the fault as shown in Fig. 7.34(d).

Panels of varying contour

The contours of some panels vary from one point to another, with the result that the curve is greater in some places and less in others. In order to produce this variable curvature it is necessary to wheel over the heavily curved parts more often than the surrounding areas as shown in Fig. 7.34(e). A better finish is obtained by lightly wheeling across the panel in a diagonal direction as indicated by the dotted lines.

Panels of deep curvature

Panels with very full contours can be subjected to considerably greater wheeling pressure without danger of corrugating the surface. When wheeling panels of very full shape, the passage of the wheel over work should be controlled so that the start and

Passage of Wheel

Panel

(a)

The arrows at the corners denote the movement of the panel to alter direction of the wheel track at the end of each pass. The entire surface of the panel must be covered with the narrow track of the bottom wheel during the backwards and forward movement.

(b)

(c)

(d)

Full lines denote the path of the original wheel tracks. Dotted lines denote the diagonal path of the correcting wheel tracks.

Section of Panel

Start   Finish

(e)

Wheeling commences at the spot where the fullness occurs and traverses in the direction of the arrow to the end of the panel. The return is made over the same area already covered. The movement is continued to the other end of the panel.
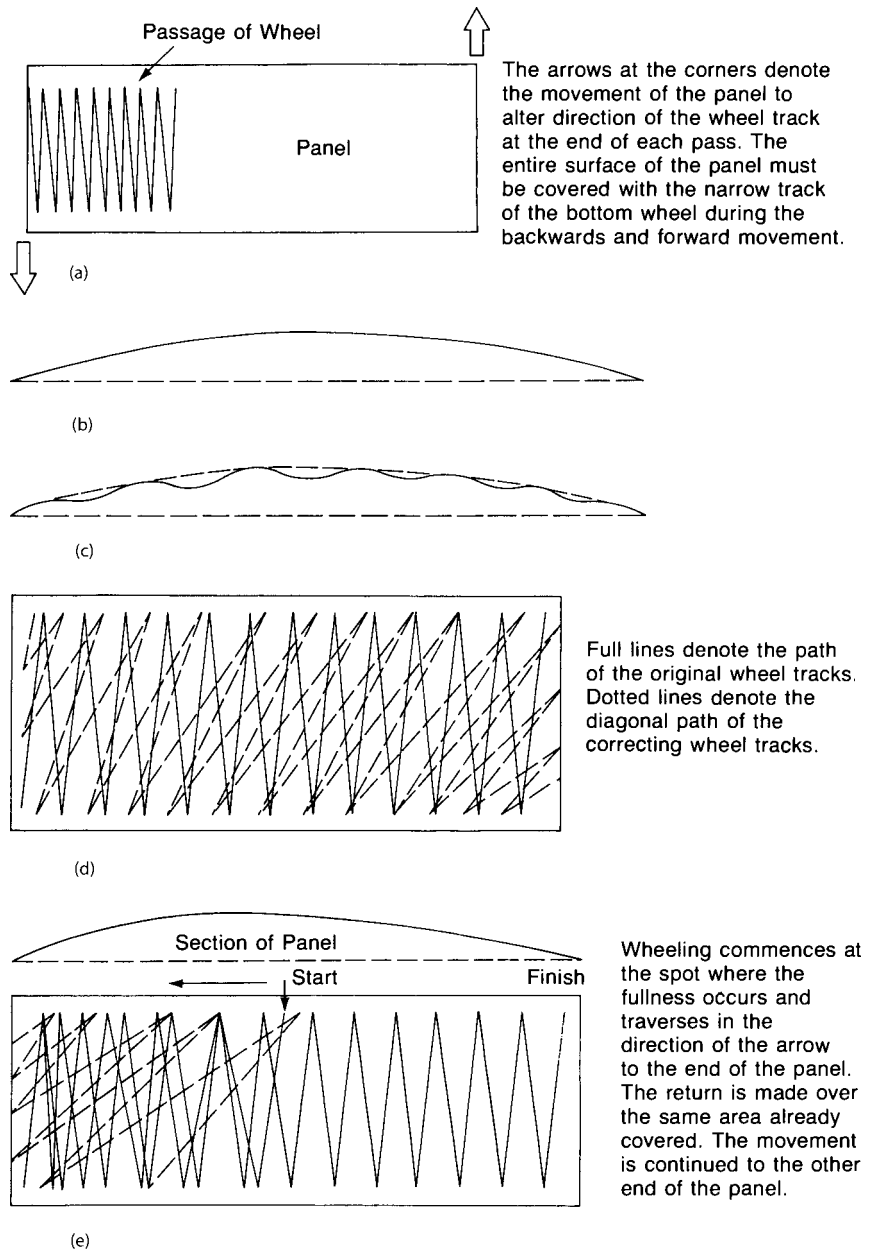
Figure 7.34 The technique of wheeling. (a) Correct method of wheeling; (b) section of a panel with a clean contour; (c) section of a panel with corrugation faults; (d) correcting a corrugated panel; (e) wheeling a panel with a varying contour

finish points of each pass do not occur in the same position, the panel being moved so that the raising of the shape is performed evenly. Sometimes too much shape is wheeled into the panel. This excess shape can be corrected by turning the panel upside down and wheeling the outside edges. With panels of only very slight curvature, this reverse wheeling can be performed over the entire panel.

Large panels

An assistant may be required to hold one side when wheeling large panels. Success when wheeling one panel with two operators depends upon each person doing their own pulling. On no account should either operator push the panel whilst the other operator is pulling. Since no two operators have the same 'pull', it is important that they change sides half-way through the job to avoid giving the panel uneven curvature. Any roughness when pulling or pushing will cause corrugations and unevenness of shape.

As previously stated, wheeling is widely used for finishing panels that have be formed by the 'cut-and-weld' method. The approximate shape and the protrusion of the weld-bead can be smoothed out and brought to the required contour on the wheel after preliminary dressing with a mallet over a suitable panel head. Wheeling not only crushes and smoothes over the weld which will disappear after dressing with a portable sander but, as a result of the cold-working imposed by wheeling, also partially restores the temper of the metal in the weld zone. Metal adjacent to the welded seam will become soft due to the heat of the welding process. Figure 7.35 shows the stages in forming a large roof panel for a prototype motor vehicle.

Shape of Panel in the 'Flat'

(One off each hand)

Right-hand Panel

Panel roughly shaped; edges of V-shape brought together and welded; surface irregularities malleted out.
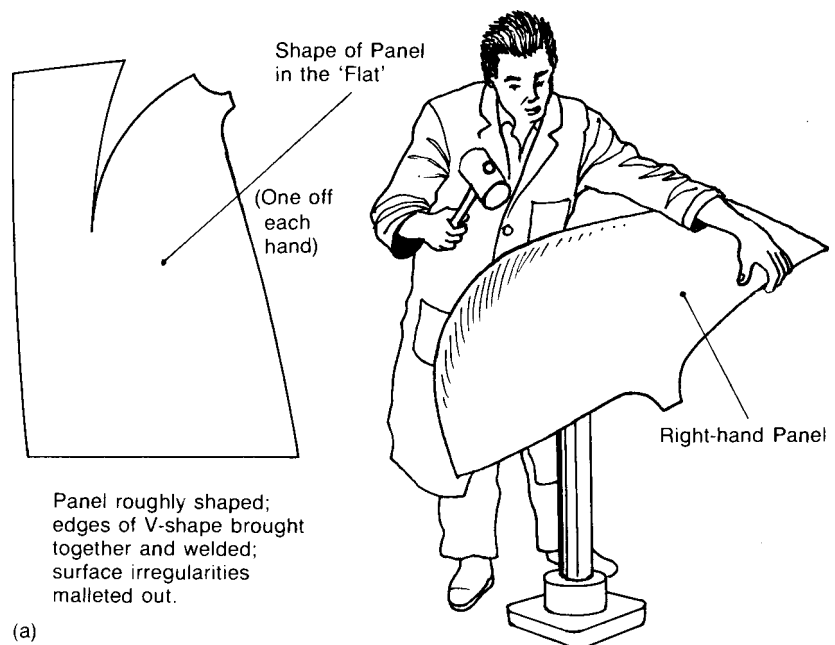
(a)

Figure 7.35 The stages in forming large panels (coach building). (a) Panel shaping; (b) planishing on the wheel; (c) use of a jig

Left-hand Panel

(b)

Panel 'offered-up' for final
fitting and trimming

Jig

Frequent use of jigs during the fabrication of the component
panels, and for final fitting and trimming, ensure the symmetry
of the final composite panel.
The composite panel is fabricated by welding. It consists basically
of a central panel and two end panels. The central panel is shaped
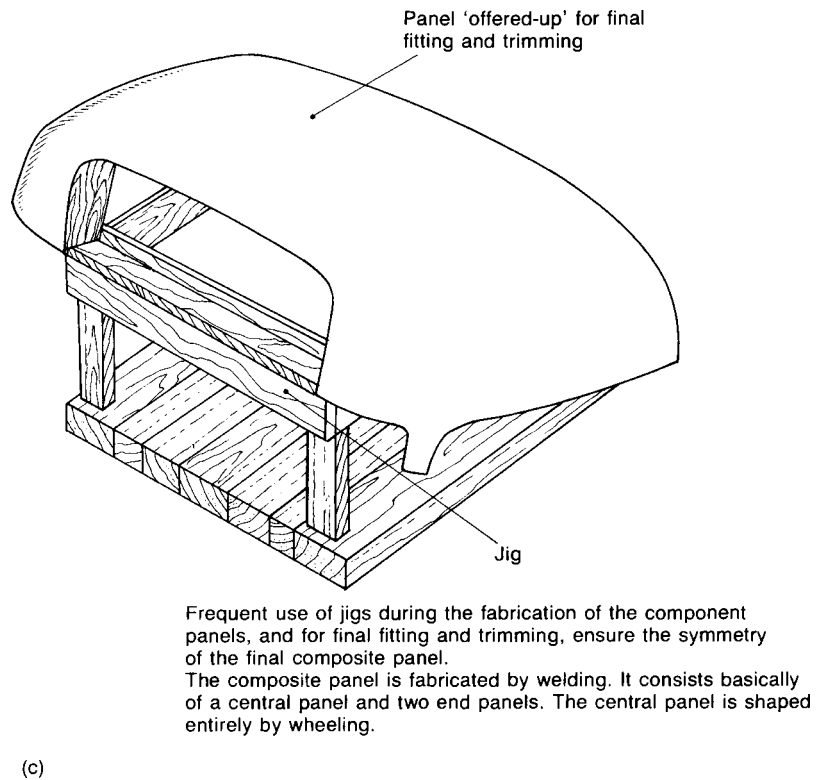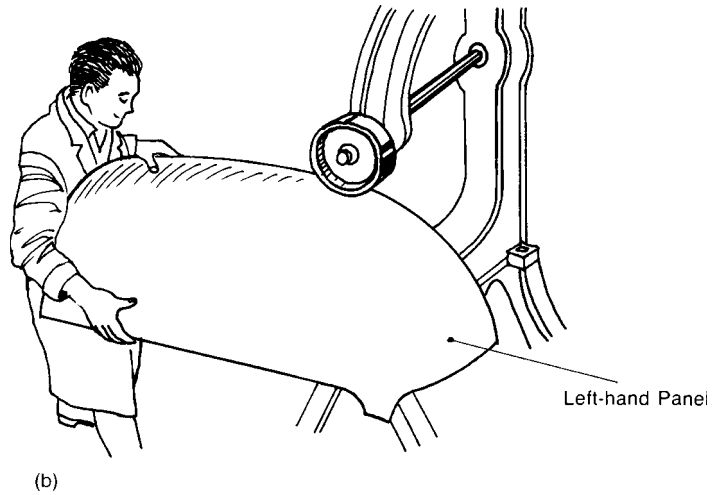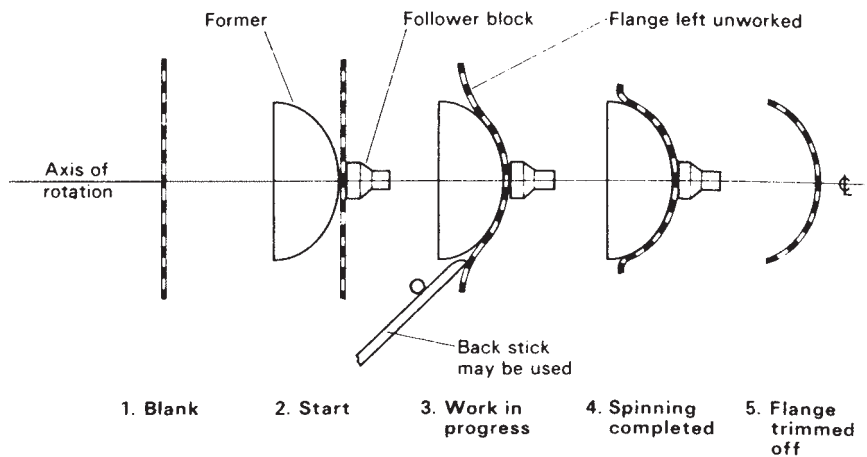entirely by wheeling.

(c)

Figure 7.35 (Continued)

7.4 The principles of metal spinning

Metal spinning is another method of flow-forming suitable for producing surfaces
of revolution. Most sheet metals can be cold-formed by spinning circular blanks in a
spinning lathe and applying pressure to make the circular blank flow over a rotating

Former   Follower block   Flange left unworked

Axis of
rotation   ₵

Back stick
may be used

1. Blank   2. Start   3. Work in   4. Spinning   5. Flange
                            progress   completed   trimmed
                                                             off

(a)   *The successive stages in manual metal spinning showing the*
           spreading or drawing action which is characteristic of the process

Headstock   Barrel   Tailstock   Barrel clamp

A
B
C

D

Lathe spindle   Bed   Tailstock locking clamp
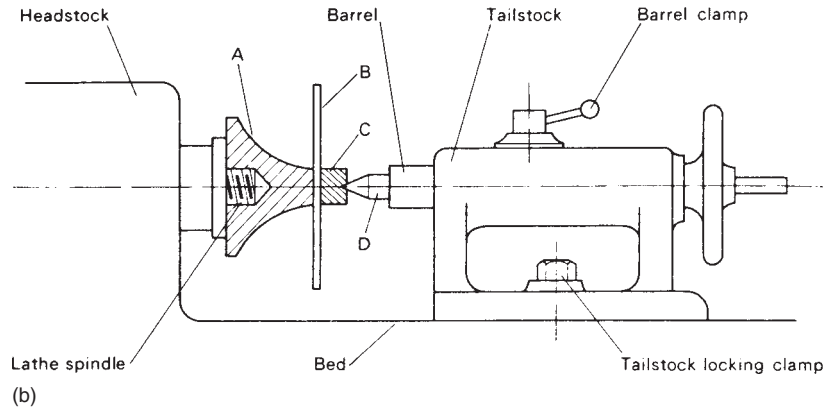(b)

Figure 7.36 The basic principles of metal spinning. (a) Metal spinning; (b) the
basic features of the spinning lathe

former. The flat blank undergoes *plastic flow* during the spinning process and the
pressure is applied manually through the *leverage* of spinning tools. This calls for
considerable skill acquired through training and experience. The ease with which a
metal can be spun depends upon the individual properties of the metal being used.
The way in which the change of shape is accomplished is shown in Fig. 7.36(a). The
spinning tool is not shown, but the 'back-stick' is introduced as a means of prevent-
ing the blank from collapsing.

   The spinning lathe is much simpler than the engineer's centre lathe. It consists of
a headstock with a solid spindle with a screwed nose to carry the former and a tail-
stock with a rotating live centre. The tool is supported on a tee-rest similar to a wood-
turning lathe. The formers are made from hardwood such as *mahogany* or *lignum vitae*
for short runs or steel and cast iron for long runs. The basic features of a spinning
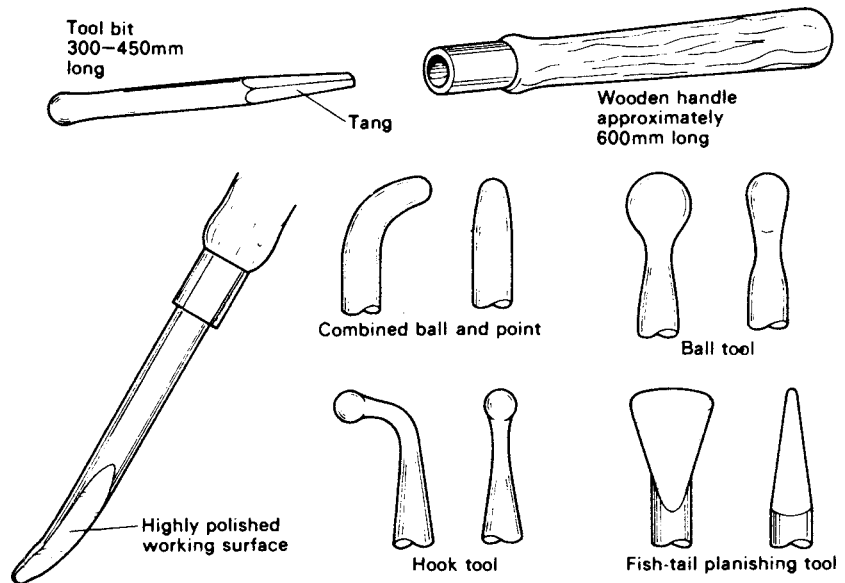lathe are shown in Fig. 7.36(b).

Figure 7.37 Hand forming tools for metal spinning

7.4.1 The spinning process

The hand-spinning process which is most commonly used is performed with the aid of a number of uniquely designed tools whose hardened working surfaces are shaped and polished according to the nature of the work being spun. Some typical hand-spinning tools are shown in Fig. 7.37. The tools are not standardized and many craftpersons choose to make their own tools.

Hand-spinning tools consist of two parts:

- *The tool bit*. This is approximately 300 to 450 mm long and usually forged to shape from high-speed steel round bar hardened and tempered. Opposite the working end is a 'tang' which fits into a long wooden handle.
- *The wooden handle*. This is approximately 600 mm long. The tool bit, when securely fitted, projects from the handle for about 200 mm. Therefore, the average overall length of a hand-spinning tool is between 750 and 850 mm.

The most common spinning tools consist of a combination ball and point. Its range of usefulness is large on account of the variety of shapes that may be utilized by rotating the tool in different directions.

- The *ball tool* is used for finishing curves.
- The *hook tool* is shaped for inside work.
- The *fish-tail planishing tool* is commonly used for finishing work. It can also be used for sharpening any radii in the contour.

The majority of spinning operations involve starting the work and bringing it approximately to the shape of the former, after which 'smoothing' or 'planishing' tools are used to remove the spinning marks imparted during the initial forming and producing a smooth finish. These hand tools are used in conjunction with a *tee-rest*

'B' represents the working portion of the fulcrum pin.
This varies in length between 75 and 100mm.
'C' represents the portion of the pin which is a free
fit in the holes provided in the tee-rest.
It is smaller diameter than 'B' and is approximately
40 to 50mm in length
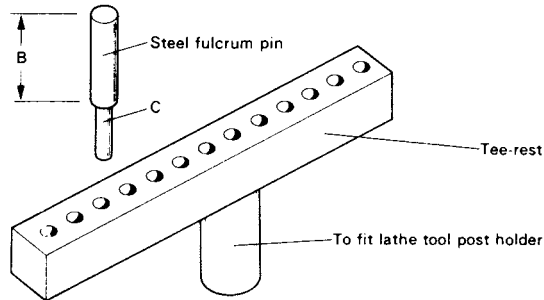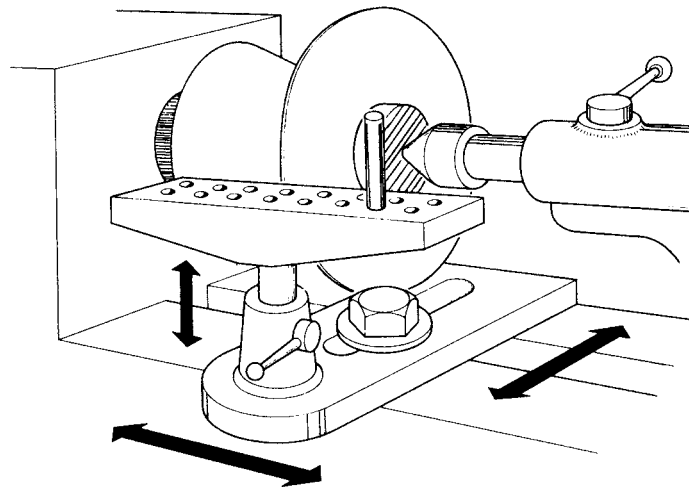

Simple tee-rest and fulcrum pin

Figure 7.38 Adjustment for variations of fulcrum pin position

and *fulcrum pin*. The manner in which the fulcrum pin is advanced as the spinning proceeds is extremely simple and is shown in Figs 7.38 to 7.41 inclusive. The tee-rest is supported in the tool-rest holder, which is clamped to the bed of the lathe. The tool rest provides a wide range of adjustments in six directions and a further fine adjustment can be made by releasing the clamp bolt and swivelling the tee-rest. All these features are shown in Fig. 7.41. The action of the spinning tool is shown in Fig. 7.39.

When commencing spinning operations, the initial strokes are made outwards towards the edge of the circular blank being spun. In order to speed up the process and to avoid thinning the metal unduly, strokes in the opposite direction are also made, i.e. inward strokes. In both cases it is important not to dwell in any one position on the workpiece so as to cause excessive local work-hardening. The tee-rest and the position of the fulcrum pin are reset as the work progresses and both the forming tool and the
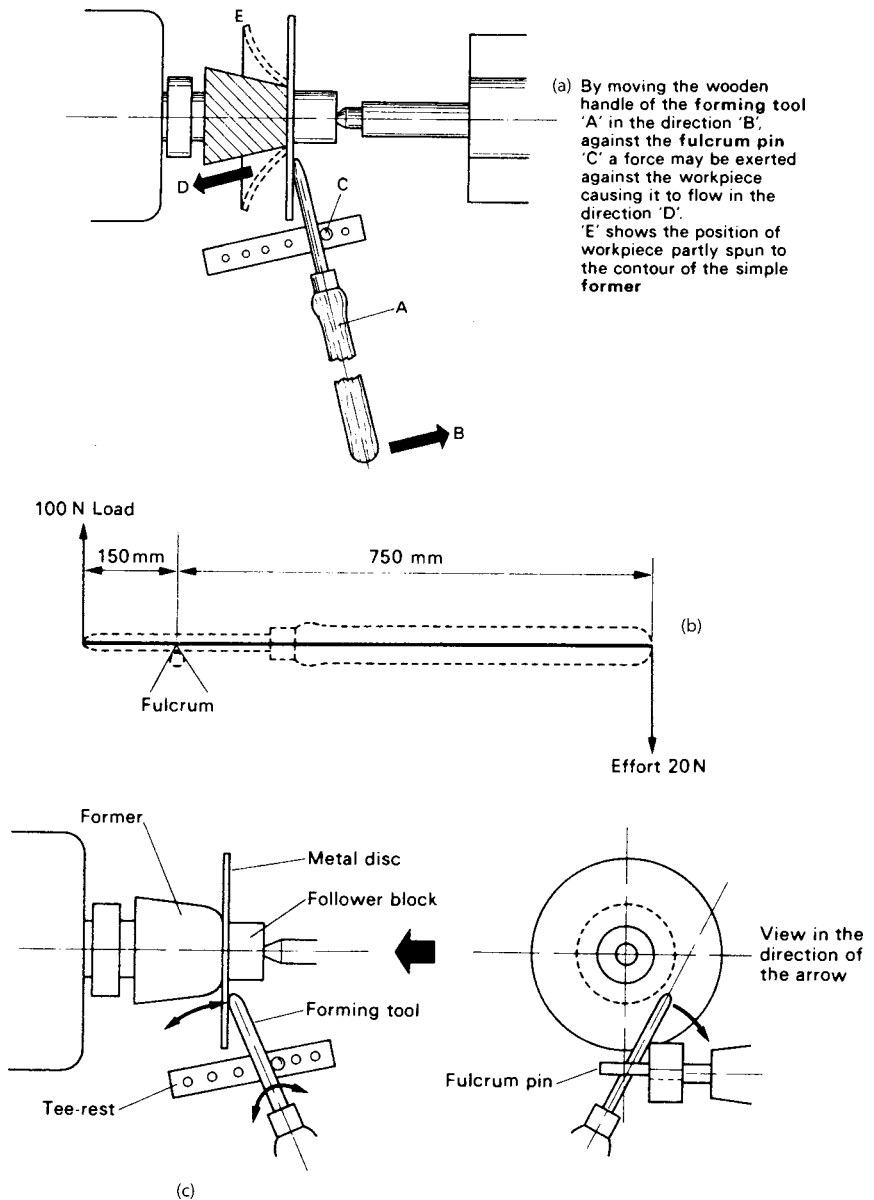
(a) By moving the wooden handle of the forming tool 'A' in the direction 'B', against the fulcrum pin 'C' a force may be exerted against the workpiece causing it to flow in the direction 'D'. 'E' shows the position of workpiece partly spun to the contour of the simple former

Figure 7.39 The action of hand spinning. (a) Exerting a force against a workpiece; (b) moments acting on the spinning tool; (c) three-dimensional movement of the forming tool

outer surface of the metal blank have to be frequently lubricated. Figure 7.40 shows the metal spinning process.

Back-sticks, as their name implies, are always positioned at the back of the blank being spun immediately opposite the forming tool as shown in Fig. 7.41. They are used to prevent wrinkles forming and, in the case of thin metal, they prevent it collapsing. Pressure is applied in the direction indicated and the work revolves between the back-stick and the forming tool, two fulcrum pins being used in this instance.
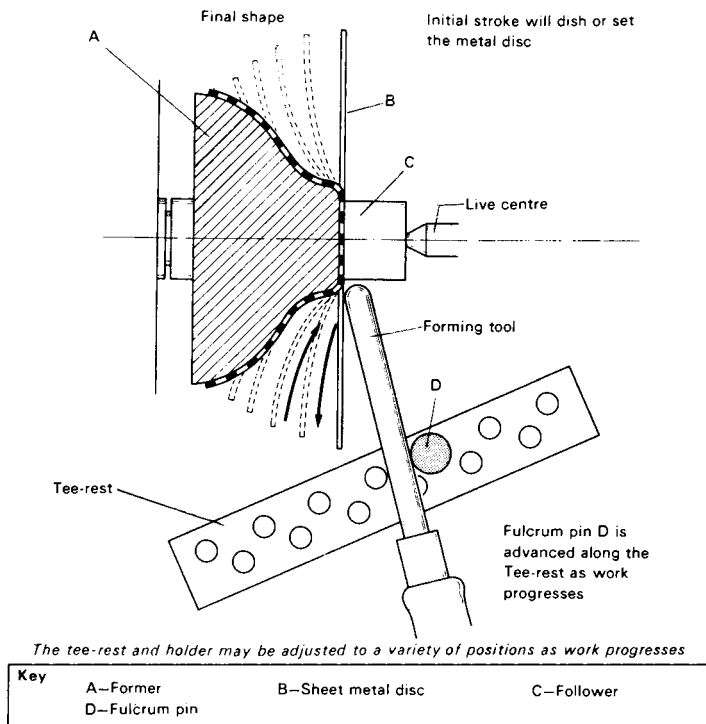
Final shape

A

B

Initial stroke will dish or set
the metal disc

C

Live centre

Forming tool

D

Tee-rest

Fulcrum pin D is
advanced along the
Tee-rest as work
progresses

The tee-rest and holder may be adjusted to a variety of positions as work progresses

Key
A—Former   B—Sheet metal disc   C—Follower
D—Fulcrum pin

Figure 7.40 The metal spinning process

Back-sticks are made from
hardwood and are approximately
300 mm long

Former

Partly spun disc

Fulcrum Pin

Forming tool

Fulcrum pin

Back-stick

Thrust   Pull

The forces exerted on the forming tool and back-stick are counter balanced
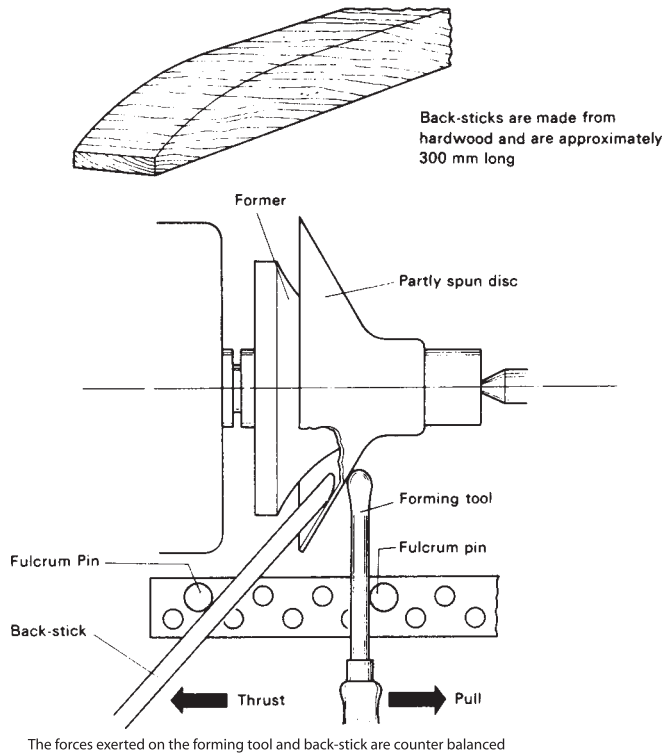
Figure 7.41 The use of the back-stick

7.4.2 Lubrication for spinning

Lubrication is essential in order to minimize the friction between the work and the tool to prevent excessive heating, scratching of the work or damage to the tool. A lubricant must be applied frequently to the surface of the work and tools during the spinning operation. It is important to use the correct type of lubricant. It should adhere to the metal blank and not be thrown off by the high rotational speed involved. For hand spinning, *tallow* or *industrial soap* or a *mixture of both* are used as lubricants.

7.4.3 Spindle speeds for spinning

Spindle speeds for metal spinning are fairly critical, and they will depend upon:

- The ductility of the metal being spun.
- Whether the metal is ferrous (hard to spin) or non-ferrous (easy to spin).
- The diameter of the blank being spun (the larger the diameter, the higher the surface speed).
- The thickness of the metal being spun.
- The shape of the former.
- The shape of the spinning tool used.

The drive to the spindle is usually via a two-speed electric motor and a three-step cone pulley, giving six possible speeds. As a general rule:

- Mild steel requires the slowest spindle speed.
- Brass requires about twice the speed of mild steel.
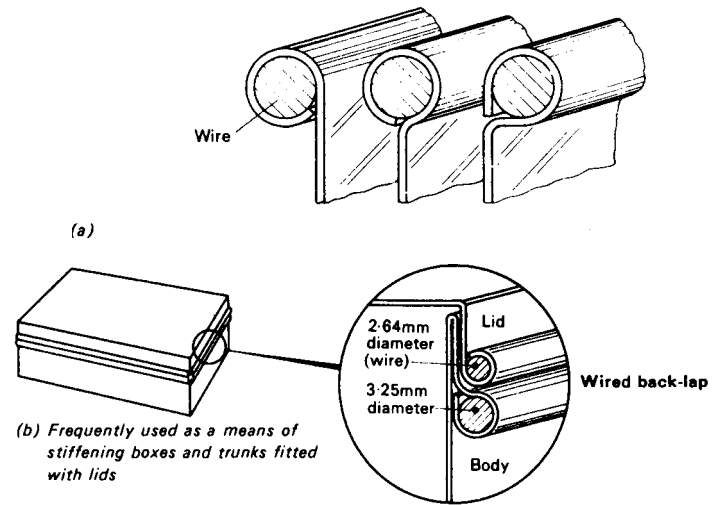- Copper and aluminium requires a speed only slightly higher than brass.

7.5 Swaging sheet metal

Swaging is an operation that is used to raise a moulding (*swage*) on the surface of a sheet-metal component. A swage is produced by means of a pair of special contoured rollers. Swaging rolls are available in a large variety of contours to fit a swaging machine, which may be hand- or power-operated.

The wired edges can also be made using simple bench tools primarily to make the sharp, raw edges of a sheet-metal article safe and also to add strength and stiffness to the article. Although swaging has many similar functions to that of wired beads, it is not just confined to stiffening edges but may be used some distance from the edge of the sheet. The projecting shape of the swage above the surface imparts considerable strength to sheet-metal articles.

Wiring sheet metal not only makes the edges of sheet metal articles rigid and safe, but also provides a pleasing appearance. Wiring or 'beading' is a process for forming a sheet metal fold around a wire of suitable diameter. Much of the strength of this type of edge is provided by the wire. Additional strength is obtained from the stressed metal that closely follows the exact contour of the wire. The allowance to be added to the sheet metal is 2.5 times the diameter of the wire. In addition to 'true' wired edges, there are also 'false' wired edges which may be one of two types:

1. *Applied*. The applied type is used when the position or metal thickness is unsuitable for normal 'true' wiring. Applied wired edges are attached and fastened in position by a return flange, riveting, spot-welding or soldering.
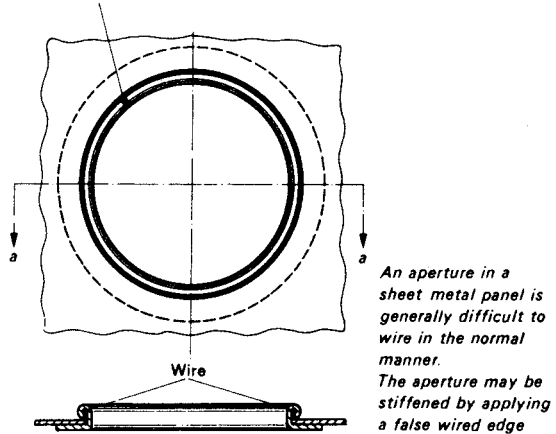
(a)

(b) Frequently used as a means of
stiffening boxes and trunks fitted
with lids

2·64mm
diameter
(wire)

3·25mm
diameter

Lid

Wired back-lap

Body

This method of stiffening combines:
   (i) The strength of a wired edge
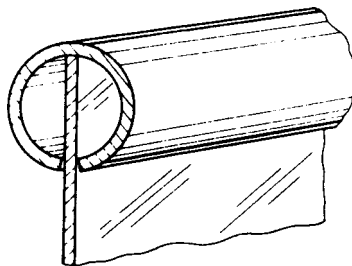   (ii) A safe edge to the body
   (iii) Location for the lid

Wire of a smaller diameter than
that for the body is used for the lid.
This ensures a perfect fit when the
lid is closed

The edge of the metal is hidden on the inside in the case of the 'back-lapped wired edge'

False wired edge applied to acircular aperture

An aperture in a
sheet metal panel is
generally difficult to
wire in the normal
manner.
The aperture may be
stiffened by applying
a false wired edge

Wire

(c)

(d) This type of false wiring consists basically
of split tubing. It may be rolled to required
contour and slipped over the raw edge of
the sheet-metal article and soldered into
position.
Split beading is mainly used for decorative
purposes

Figure 7.42 Types of wired edge; (a) three common types of wired edges;
(b) back-lapped wired edges; (c) cross-section a – a of applied false wired edge;
(d) split beading

2. *Hollow*. This type of 'hollow bead' is usually produced by folding the edges around a wire core that is then withdrawn. Although hollow beads are rigid due their shape and the work-hardening that the process induces in the metal, because hollow edges do not contain a wire they will not withstand an impact blow and are relatively easily damaged. Figure 7.42 shows some types of wired edges, whilst Figure 7.43 shows how a hollow bead may be produced on a spinning lathe.

7.5.1 Further swaging operations

The 'ogee', or return curve swage, is frequently used to strengthen the centre portions of cylindrical containers and drums because of its high resistance to internally
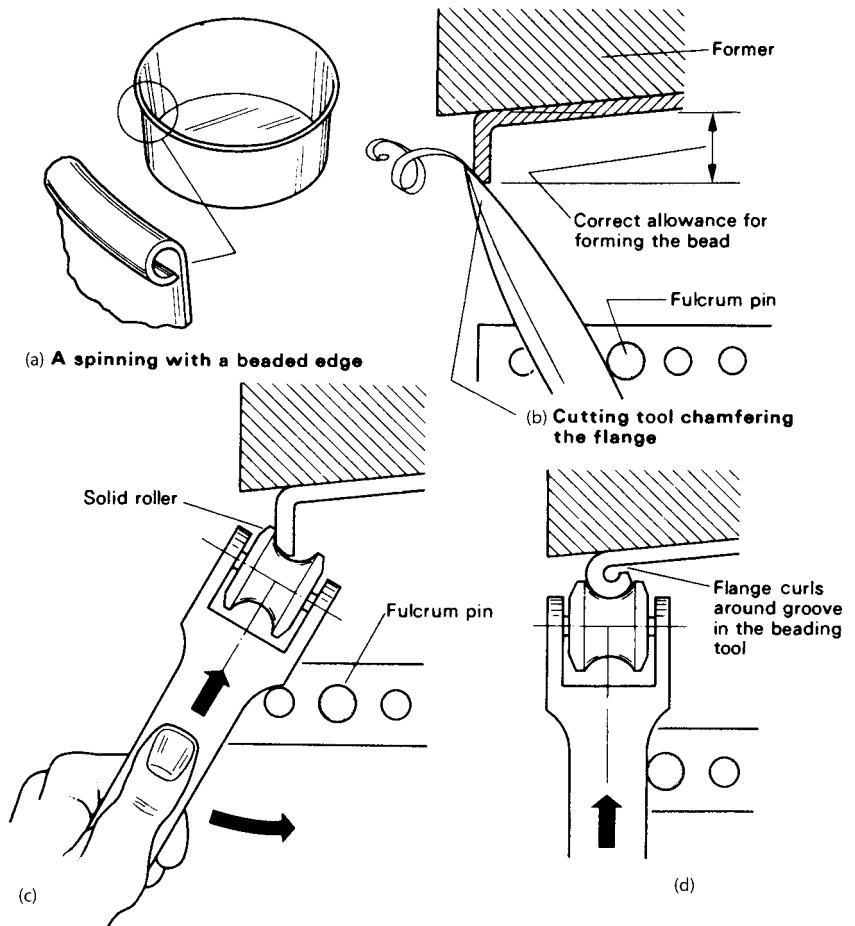

(a) **A spinning with a beaded edge**

(b) **Cutting tool chamfering the flange**

(c)

(d)

Figure 7.43 Forming a hollow bead on a spinning lathe. (a) A spinning with a beaded edge; (b) cutting tool chamfering the flange; (c) beading wheel advanced at an angle and then gradually brought square; (d) to the spinning axis for final closing of the bead

and externally applied forces in service. Examples of the combination of strength and decoration associated with swaging are to be found in the design of circular sheet-metal objects such as drums, dustbins, waste-paper baskets, buckets and water tanks. The maximum thickness of sheet metal that can be swaged is 1.62 mm. Figure 7.44 shows some aspects of swaging.

The swage is a very important part of the automobile industry to add strength and stiffness to large body panels and also to prevent them 'drumming', thus reducing the noise level in the passenger compartment. The body panels are formed in
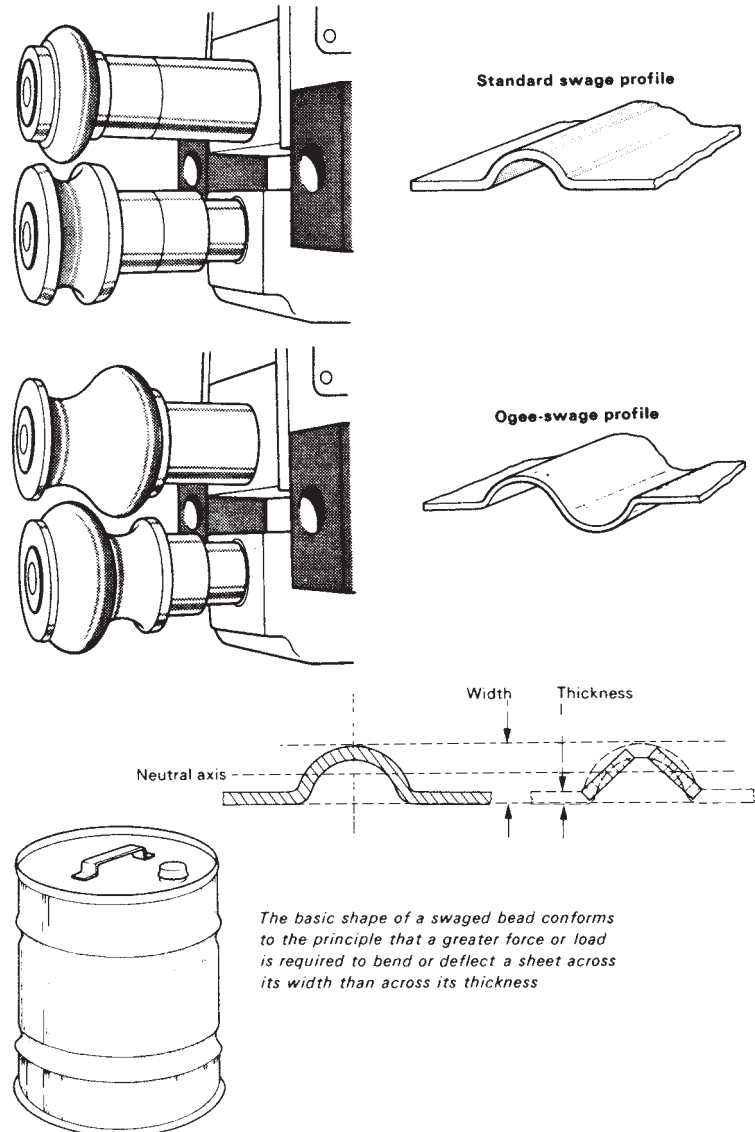

Standard swage profile

Ogee-swage profile

Width   Thickness

Neutral axis

The basic shape of a swaged bead conforms to the principle that a greater force or load is required to bend or deflect a sheet across its width than across its thickness

Figure 7.44 The swaging of sheet metal

large power presses, and the correct contour and the swage is formed at the same time as an integral part of the pressing operation.

7.5.2 The use of stiffeners

Large panels may be reinforced by the application of stiffeners. Usually panels are stiffened by the fact that they are fastened to some sort of rigid framework. These frameworks are usually fabricated from metal sections that are inherently strong and rigid because of their form. Sheet-metal sections may be roll-formed for the purpose of providing internal and external stiffening of large components of cylindrical or circular shape.

The edges of fabrications constructed in sheet metal which is too thick to wire or hem can be stiffened by the use of a flat bar or D-shaped section. It may be attached by spot-welding, manual welding, brazing or riveting. One of the more common methods of achieving strength and stiffness is the use of 'angle-section frames'. Figure 7.45 shows various methods of stiffening large panels. All four edges are made rigid by folding. A 'top-hat' section is used to stiffen the centre section of the panel and is usually secured in position by spot-welding.

Another method of stiffening large sheet fabrications, also shown in Fig. 7.48, is to attach them to a rigid framework. The welded section is fabricated from a 'P-section', which has a very high strength/weight ratio for a sheet-metal section. All four edges of the panel are folded at 90° to a suitable width. The panel is then placed in position
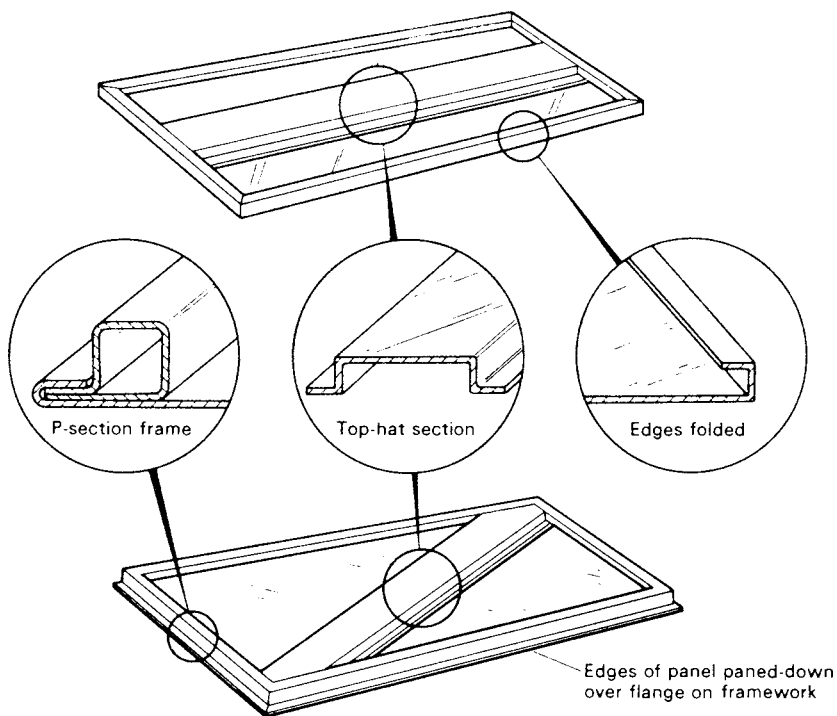

Figure 7.45 Methods of stiffening large panels

over the frame and the edges are paned down over the flange of the 'P-section'. The centre of the panel can be stiffened by means of a diagonal 'top-hat' section.

Figure 7.46 shows the use of angle stiffeners. Welded angle frames are widely used as a means of stiffening and supporting rectangular ducting for high-velocity systems. They also serve as a jointing media when assembling sections together by bolting as shown in Fig. 7.46(a). The angle section is riveted to the duct and sections of duct are then bolted together – flange to flange – with a suitable gasket between the angle flanges. The large sizes of square or rectangular ducting tend to 'drum' as a result of turbulence in the air passing through them. To overcome this drumming it is advisable
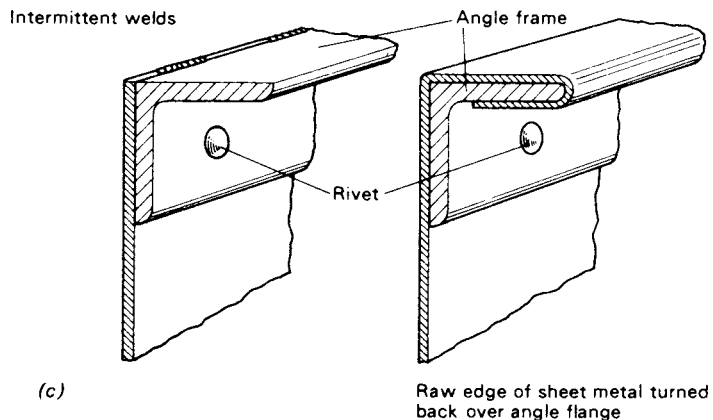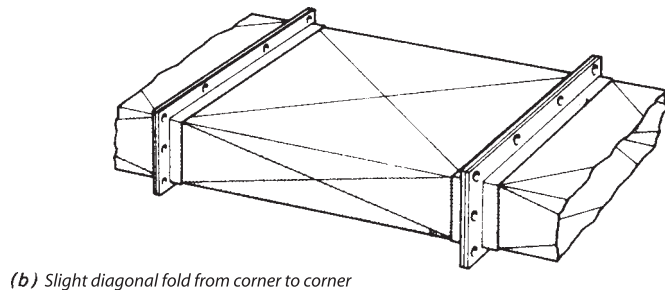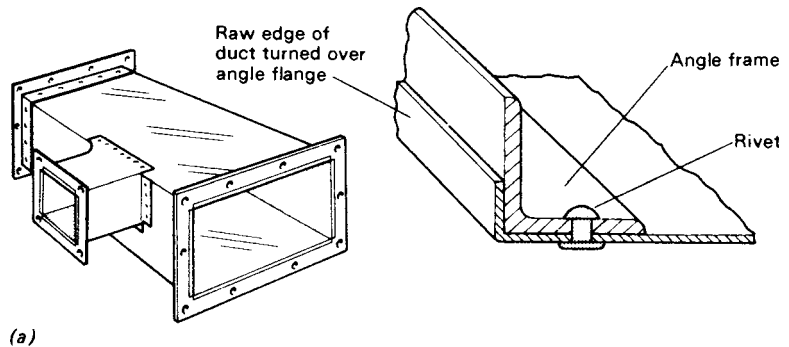
(a)

(b) Slight diagonal fold from corner to corner

(c)

Figure 7.46 The use of angle stiffeners. (a) Section of rectangular ductwork; (b) diamond-break stiffening of duct walls; (c) welded or riveted

to provide adequate stiffening to the walls of the duct. This may be achieved by the use of swaging, but more often a diamond break is used as shown in Fig. 7.46(b).

Simple welded angle frames may be used as a means of supporting and stiffening the open ends of tanks or bins fabricated from sheet metal. Two methods of attaching angle frame stiffeners are shown in Fig. 7.46(c).

7.6 Basic fabrication procedure

The production of fabricated components and structures involves five principal operational stages:

1. Measuring, marking out and the production of templates (see Chapter 5).
2. Cutting and preparing blanks from stock material (see Chapter 6).
3. Forming blanks to make the required article (see Chapter 7).
4. Joining and assembly (see Chapters 10, 11 and 12).
5. Surface finishing – galvanizing, electroplating and polishing, vitreous enamelling and painting. These topics are beyond the scope of this book.

7.6.1 The need for planning the sequence of operations

Sheet-metal articles may be made from one or more pieces of metal by the use of hand tools, machine tools or a combination of both. Most components and assembles involve a sequence of operations that must be planned in order to produce the finished article as economically as possible. The sequence of operations may vary slightly between individual craftpersons and the equipment available in the fabrication workshop. If a sheet-metal article requires a number of joints to be made during the course of its fabrication, the sequence of operations must be planned to ensure that access is possible.
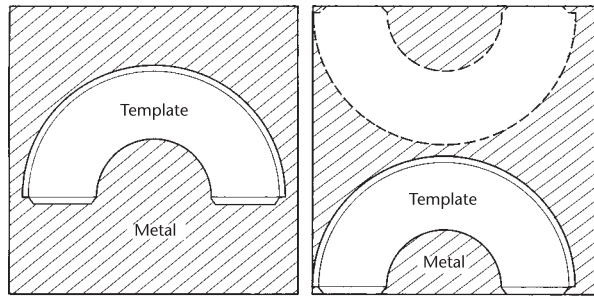
Usually, operations on sheet metal and plate commence with cutting out the blank. This often involves the use of a guillotine shear. It is considered good practice to make a 'trim cut' on standard sized sheets or plates to ensure one straight edge is available to use as a datum or service edge from which other measurements and cuts are made.

Economy in the use of materials should be the prime consideration of all craftpersons engaged in fabrication
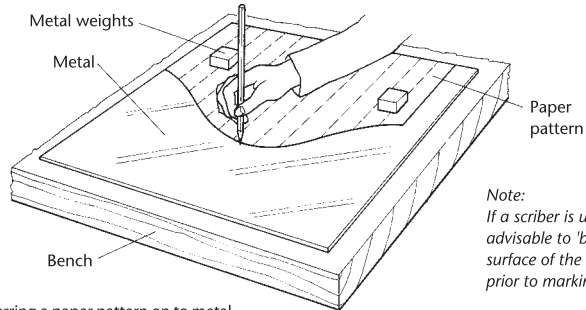
This reduces the size of the flat material, usually in length, and this must be taken into consideration when marking out blank sizes for cutting to ensure maximum yield and minimum waste. Intelligent marking-out on the flat material is essential in order to avoid unnecessary waste in the form of 'off-cut material' or 'scrap'.

7.6.2 Transferring paper or metal templates onto sheet metal

The first operation is to transfer the pattern or template outline onto the sheet metal. When using patterns or templates it is important to position them in the proper manner on the stock sheet in order to avoid unnecessary scrap. Templates must be held in position in order to restrain any tendency to move during the marking-out operation. This initial marking-out operation is shown in Figure 7.47.

Incorrect positioning   Correct positioning

(*a*) Positioning of template or material to avoid unnecessary waste

Note:
If a scriber is used it is
advisable to 'blue' the
surface of the sheet metal
prior to marking out

(*b*) Transferring a paper pattern on to metal

(i)   Place the sheet of metal to be used on the surface of the bench and position the paper to avoid waste
(ii) To prevent the paper from creeping hold it in position with metal weights
(iii) With a hard sharp pencil or scriber scribe the outline of the pattern on the sheet metal
(iv) Remove the weights and the pattern and cut the metal to the outline scribed upon it using universal hand shears removing all burrs with a suitable file
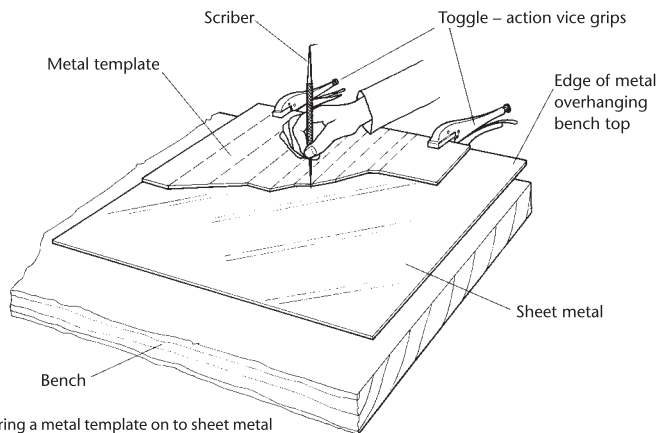
(*c*) Transferring a metal template on to sheet metal

(i)   Place the sheet of metal to be used on the bench with one of its squared sides slightly overhanging
(ii) Position the metal template in position as shown, and clamp it securely with vice grips to restrain any movement
(iii) Scribe the outline of the template on the sheet metal, using a sharp scriber
(iv) Release vice grips to remove template and cut the sheet metal to the outline scribed upon it with a suitable pair of hand shears. Remove all burrs with a file

Figure 7.47 Methods of transferring patterns to metal

7.6.3 Use of notched corners in sheet-metal work

A common requirement for light sheet-metal fabrications is the *notched corner*, as used in the making of simple folded trays and boxes. Notching is an essential operation where thin gauge fabrications include wired edges, self-secured joints, lap joints and welded corner seams. The term 'notching' is used to describe, in simple form, the removal of metal from the edges and/or corners of sheet-metal blanks or patterns prior to carrying out any forming operations in order to facilitate such operations.

Considerable thought must be given to marking out for notching since good notching is of prime importance where the finished article is to have a neat appearance. There is nothing more unsightly than overlaps, bulges and gaps resulting from not allowing for notching, or resulting from bad notching, on the initial blank. It is advisable to make rough sketches of junctions that require notching before starting to mark out the pattern. This simple exercise will enable the craftsperson to determine where metal removal (notching) is necessary to make the article.

Usually, the notching of corners on sheet-metal blanks that are to be formed into boxes is controlled by the depth of the box. Unfortunately, a large amount of scrap often results from this notching operation. For example:

- A rectangular tray is required to be made by square notching the corners, folding the sides up square and welding the vertical corner seams. The depth of the notch is 20 mm. **Area removed by notching** $= 4 \times 20 \times 20 = 1600\,\text{mm}^2$.
- A rectangular box made in the same way but 140 mm deep will have a **total area removed by notching** $= 4 \times 140 \times 140 = 78400\,\text{mm}^2$. By comparison, it can be seen that although the box is only seven times deeper than the tray the amount of scrap metal produced by notching is 49 times greater.

7.6.4 Fabricating a sheet-metal pan with wired edges and riveted corners

Figure 7.48 shows the details and blank layout for making the sheet-metal pan from thin-gauge sheet metal. Table 7.5 lists the tools and equipment required.

The following sequence of operations is required to make the pan:

Remember that handling freshly cut sheet-metal can be dangerous so always remove sharp edges and burrs after any cutting operation

1. Mark out the overall dimensions for the blank on a suitable sheet of metal of the correct thickness. If a standard size sheet is used, square the sheet by making a trim-cut on the guillotine shear and, using this cut edge as a datum edge, mark out the overall length and width of the required blank. Check the rectangular outline for squareness by measuring the diagonals.
2. Cut out the blank on the guillotine and remove all sharp edges or burrs with a suitable file.
3. Mark off the allowances for the riveted flanges. These are normally positioned on each end of the long sides of the pan.
4. Mark the centre lines for the rivets. *Operations 3 and 4 may be performed after square notching the corners if preferred*.
5. Notch the corners. Care must be taken, when cutting with snips, not to 'over cut' the corners. The notching of corners can be performed much quicker and more conveniently on a notching machine. Most machines are capable of making square notches up to 102 mm in depth in sheet metal up to 1.6 mm thick.
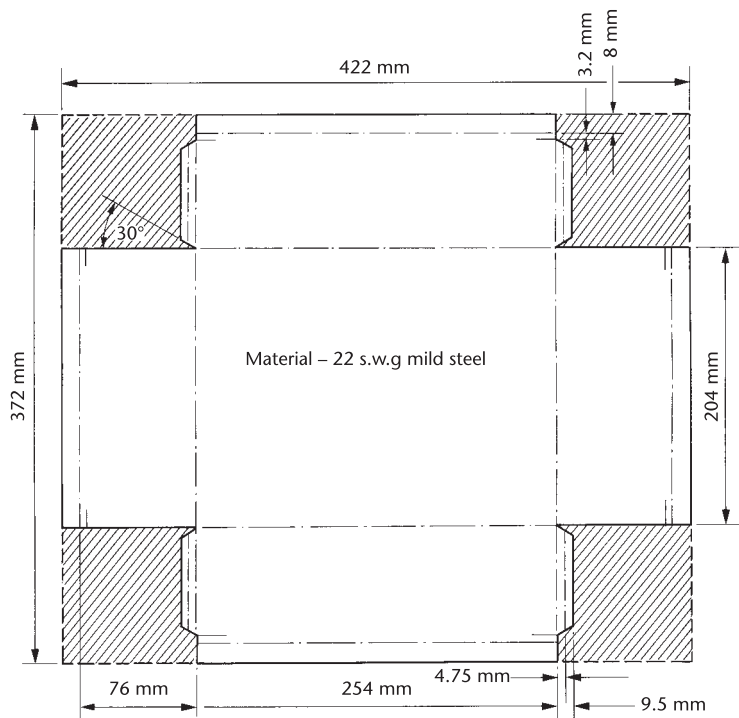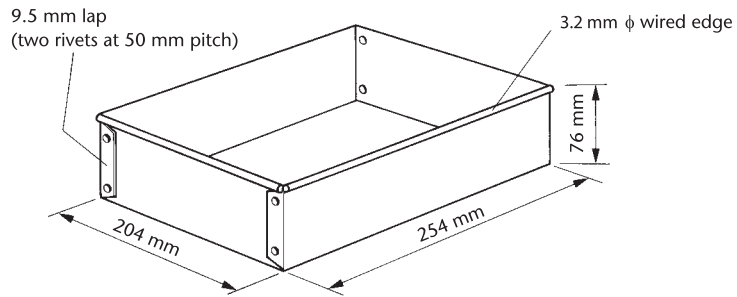
Figure 7.48 Layout for forming a pan

6. Mark out the clearance notches at the end of the rivet flanges. These are normally made at an angle of 30° as shown in Fig. 7.48, and may be marked with the aid of a bevel gauge.
7. Mark the positions for the rivets on the flanges and centre punch.
8. Drill or punch the rivet holes. Figure 7.49 shows a 'tinman's hand lever punch', which is used for punching holes in thin sheet metal. Note the conical nipple for aligning the punch in the centre punch mark.
9. Bend the long sides up first in a folding machine to an angle of about 45° and flatten back as shown in Fig. 7.50(a). This provides a crease line for final bending by hand over a hatchet stake after the short sides (ends) have been folded up.

Table 7.5 Tools and equipment required to make a rectangular pan

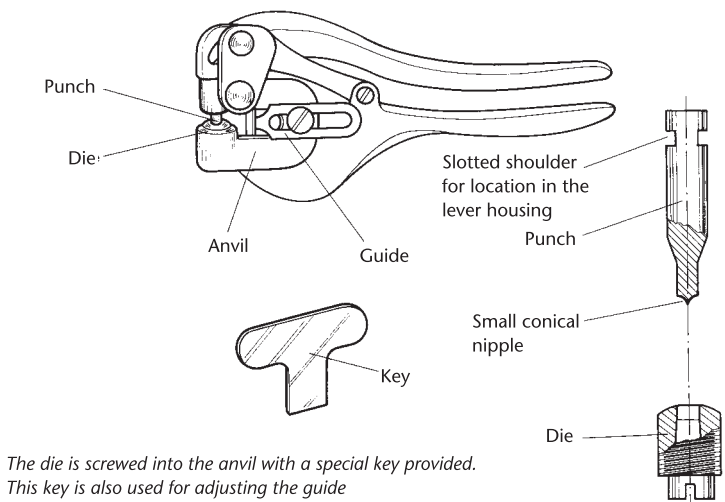| Tools and equipment required	Remarks
Steel rule Straight edge Flat steel square Dividers Jenny odd-legs Bevel Scriber	These are used for marking-out the blank
Centre punch Nipple punch Hammer	Required for marking the positions of the rivet holes. The hammer is also used for riveting
Guillotine Universal snips	For cutting out the blank and notching the corners
Rivet set	For the riveting operation
Folding machine	For bending up the sides
Bench stakes Mallet	These are required for completing the bending operations by hand and for wiring the edge
Cutting pliers	For cutting the wire and holding it in position during the wiring operation
Bench vice	For bending the wire if a frame is used, and for holding the hatched stake when throwing the flange off for the wired edge
Tinman's hand-lever punch	May be used for punching the rivet holes in the corner flanges on the blank
Drilling machine or portable drill	For drilling the rivet holes on assembly

Punch

Die

Slotted shoulder for location in the lever housing

Punch

Anvil

Guide

Small conical nipple

Key

Die

The die is screwed into the anvil with a special key provided. This key is also used for adjusting the guide

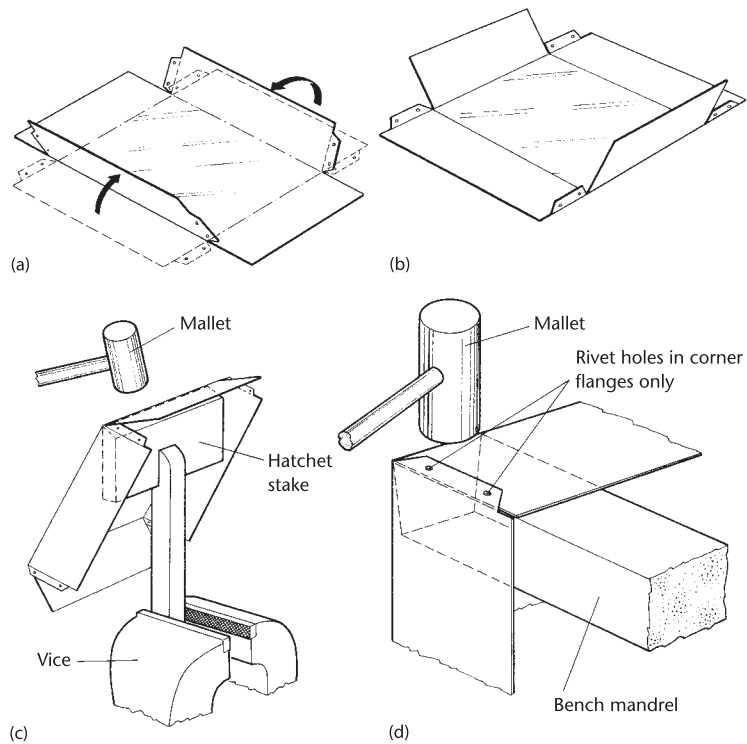**Figure 7.49** Tinman's hand-lever punch

Figure 7.50 Bending the sides of the pan. (a) First bend; (b) second bend; (c) final bend; (d) bending the laps

10. Bend up the ends in the folding machine to 90°. This operation will also bend up the rivet flanges as shown in Fig. 7.50(b).
11. Complete the bending operations over a hatchet stake as shown in Fig. 7.50(c).
12. During operation 11, the flanges have to be knocked back slightly to accommodate the ends. This is rectified by bending the laps over a suitable stake with a mallet as shown in Fig. 7.50(d).
13. Support each corner, in turn, on a suitable anvil or bench stake and mark the centres of the rivet holes through the holes in the flanges with a suitable size nipple punch.
14. Drill or punch the top hole in each corner first and insert a rivet to maintain alignment before drilling or punching the bottom holes.
15. Deburr the holes ready for riveting.
16. The corners are riveted as shown in Fig. 7.51. Further information on making riveted joints is given in Chapter 9.
17. To wire the edge, bend the wire frame in a bench vice and apply it to the pan. Tuck in the bead using a chisel stake and mallet as shown in Fig. 7.51.

Typical faults that can occur when wiring a straight edge are shown in Fig. 7.52.
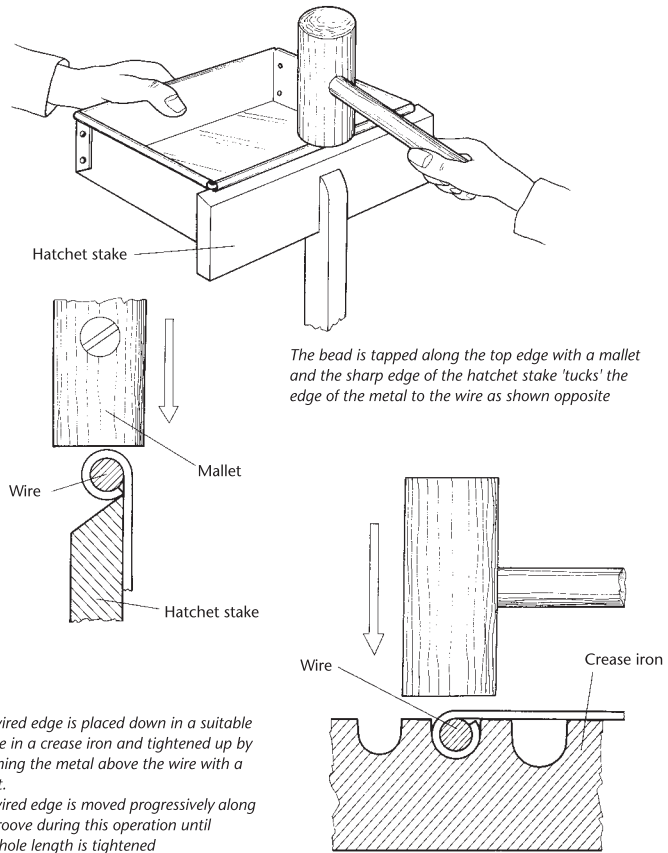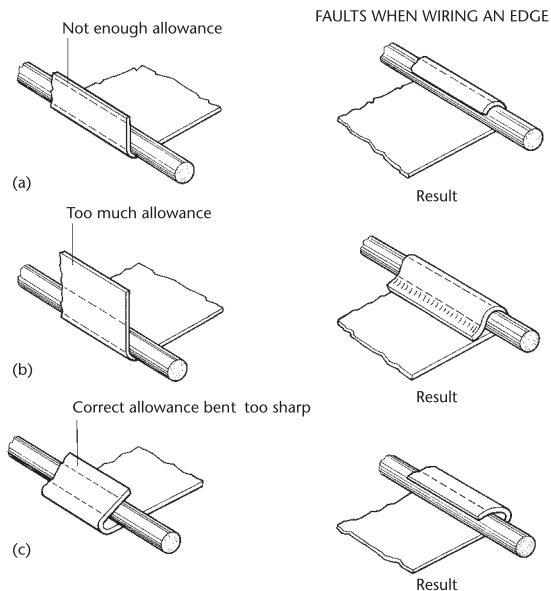
Hatchet stake

The bead is tapped along the top edge with a mallet and the sharp edge of the hatchet stake 'tucks' the edge of the metal to the wire as shown opposite

Mallet

Wire

Hatchet stake

Wire

Crease iron

The wired edge is placed down in a suitable groove in a crease iron and tightened up by flattening the metal above the wire with a mallet.
The wired edge is moved progressively along the groove during this operation until the whole length is tightened

Figure 7.51 Wiring the edge of the pan

FAULTS WHEN WIRING AN EDGE

Not enough allowance

(a)

Result

Too much allowance

(b)

Result

Correct allowance bent too sharp

(c)

Result

Figure 7.52 Typical faults when wiring as straight edge

Groove allowance bent up

Extended wire

Slip roll

Back roll moved progressively upwards for each successive pass through rollers

Pinch rolls

Groove allowance bent down

Short length of wire withdrawn on completion of rolling operation

Back roll moved progressively downwards for each successive pass through rollers

Back roll adjusting screw

Pinch roll adjusting screw

Guard over gear wheels

Slip roll

Figure 7.53 Rolling after wiring in the flat

### 7.6.5 Wiring cylinders and cones

There are two methods of wiring the edge of a curved surface:

- Wiring in the flat *before* forming by rolling.
- Wiring the edge *after* forming by rolling.

Wiring before rolling

Figure 7.53 shows how a cylinder is rolled after it has been wired in the flat. *Slip-rolls* are used for rolling cylinders after wiring. The cylinder is rolled over the *slip-roll* so that the cylinder can be removed after rolling is complete. Before inserting the metal, care must be taken to ensure that:

- The wired edge rests in the correct groove in one of the 'pinch rolls'.
- The machine is checked to determine whether it 'rolls-up' or 'rolls-down'.
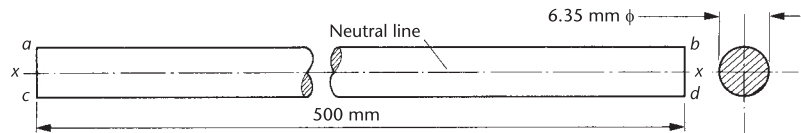
If a piece of 6.35 mm diameter wire 500 mm in length is rolled to form a ring it will have a mean diameter of 159 mm. Likewise, when sheet of 1.6 mm thick metal of the same length is rolled to form a cylinder, it will have a mean diameter of 159 mm
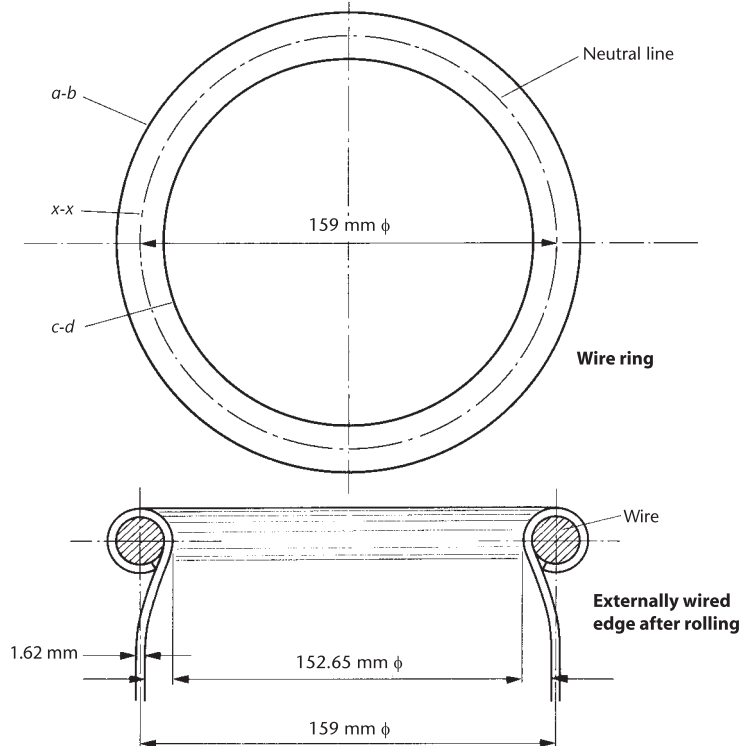
If the sheet is wired along on edge (i.e. the 500 mm length) and then rolled to form a cylinder, the above effect will result. It will be seen that both sheet metal and wire forms assume a common **mean diameter** thus causing a considerable constriction as illustrated above

Figure 7.54 The effect of wiring before rolling

The rolling operation reduces the internal diameter of the cylinder in the vicinity of the wired edge as shown in Fig. 7.54 if the edge is wired before rolling.

The rolling operation

On *internally* wired edges, rolling after wiring produces the *opposite effect* to that obtained on *externally* wired cylinders. The wired edge tends to become slightly larger in diameter than that of the cylinder.

Wiring after rolling

Figure 7.55 shows the sequence of operations for wiring the edge of a cylinder after it has been rolled. Rolling can be employed as a final operation to true up the wired edge.
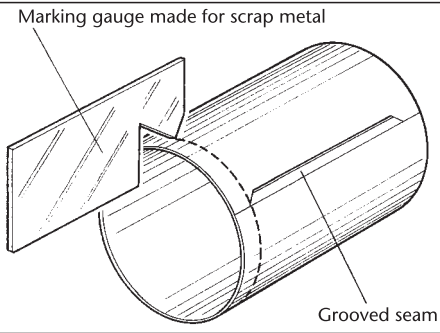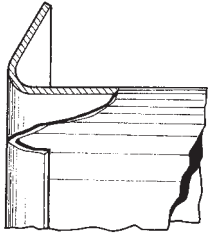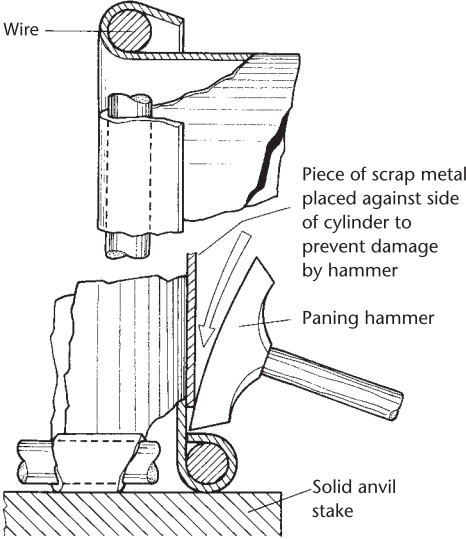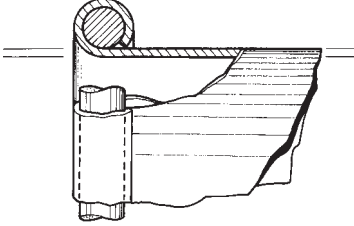
Marking gauge made for scrap metal	After rolling to shape and fastening the seam the wiring allowance is marked off
Grooved seam	
	The edge may be flanged off by hand by the method described in Fig. 7.19
	An alternative method is to 'jenny' the flange
Wire	The wire may be cut to required length and rolled into hoop by placing it in a suitable groove on the rolls.
Piece of scrap metal placed against side of cylinder to prevent damage by hammer	An alternative is to wire straight from the coil.
Paning hammer	The metal flange is formed over the wire with a mallet, taking care that the ends of the wire are positioned away from the grooved seam.
	The bead may be tucked in on a hatchet stake or by placing the edge on a suitable stake and tucking in with a paning hammer as shown opposite.
Solid anvil stake	An alternative method is to tuck the edge in on a 'jennying' machine
	The diagram opposite shows that wiring after rolling produces a constant diameter throughout the length of the cylinder

Figure 7.55 Wiring a cylinder after rolling

7.6.6 Fabricating a domestic tin-plate funnel

The funnel shown in Fig. 7.56 is made from tin plate in two parts, a *body* and a *thimble*. Both are frustums of right cones and their patterns are developed by the radial line method previously described in Section 4.15.2. Bend lines are marked out in pencil to avoid damaging the tin plating and allowing the funnel to rust in service. Lines showing where the metal is to be cut can be scribed as usual. The developments for both the body and the thimble are quadrants with the appropriate allowances for the seams and for notching made as usual.

Breaking the grain

Before commencing work on the sheet of tin plate the first operation should be to '*break the grain*' of the metal in order to prevent ridges forming in the metal. This is done by rolling the piece of metal backwards and forwards a few times though bending rolls set to impart a shallow curvature. The direction of bending is reversed each time. This will ensure that the parts of the funnel will have a smooth surface, free from ridges, when they are formed. Breaking the grain is always sound practice prior to rolling, particularly on metals that have been cold-reduced. Once the breaking operation is complete, the metal should be rolled out flat by suitable adjustment of the rolls in readiness for cutting out the blank and forming to shape.
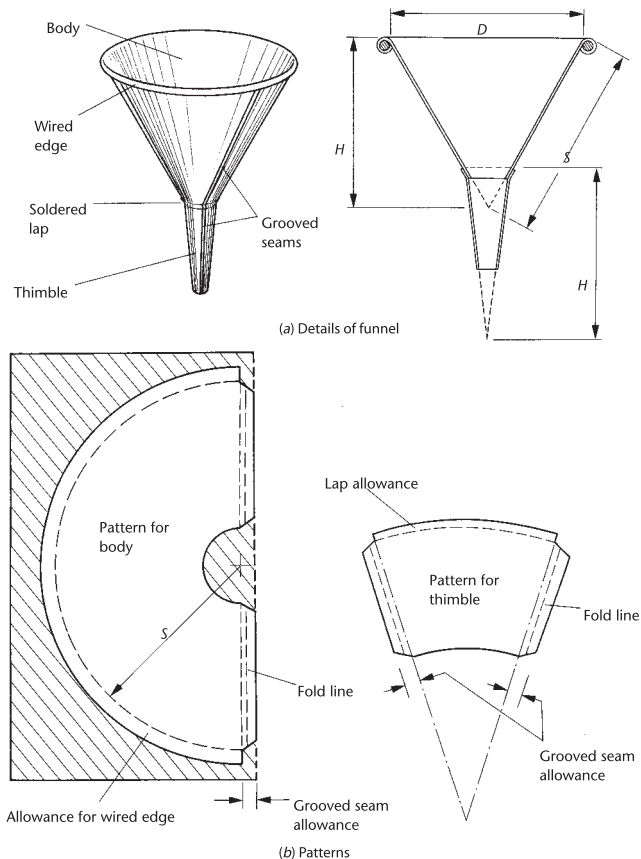

(a) Details of funnel

(b) Patterns

Figure 7.56 Details and patterns for fabricating a domestic funnel

Making the funnel

Table 7.6 lists the tools and equipment needed to make the funnel, whilst Fig. 7.57 shows some of the operations involved.

1. Cut out the blanks from tin plate that has had its grain broken, as previously described, using bench shears and snips.
2. Fold the locks for the grooved seam, one up and one down as shown at A and B in Fig. 7.57(a) on both the body and the thimble using a bench folding machine.
3. The body may be formed to shape over a funnel stake. This operation consists of bending the body of the funnel by hand with a sliding motion over the stake. A mallet is used for final forming to shape after grooving the seams as shown in Fig. 7.57(b). For further information on making self-secured grooved joints see Section 9.4.
4. The thimble is formed in a similar manner over a long tapering bick-iron as shown in Fig. 7.60(c). It is formed roughly to shape, the grooved seams are inter-locked, and the thimble is driven hard onto the bick-iron to hold the seam tight until it is completed by grooving.
5. The body and thimble are joined by soft-soldering as shown in Fig. 7.60(d). For further information on soldering see Section 10.1. The grooved seams are sealed by soldering on the inside.

Table 7.6 Tools and equipment required to make a funnel

| Tools and equipment required	Remarks
Steel rule Scriber Divider	These are used for marking out
Guillotine Bench shears Universal snips	For cutting out the blanks and developed shapes. Straight snips may be used for straight line and external curve cutting, but bent pattern snips will be required for cutting internal curves. Universal snips will perform both these operations
Rolling machine	for BREAKING-IN the TINPLATE
Flat bed folding machine	For forming the locks for the grooved seams. An alternative method of performing this operation is to throw the edges over a hatchet stake using a mallet
Funnel stake Bick iron Mallet Stretching hammer	Used for forming the body of the funnel Used for forming the thimble For stretching lap circumference of thimble
Grooving tool Hammer	For fastening the seams
Soldering stove Soldering iron	For soft soldering the inside of the seams and the lap joint between body and thimble
Cutting pliers	For cutting wire for the wired edge
Jennying machine	Two operations are required: 1. Turning the wire allowance 2. 'Tucking' the edge over the wire
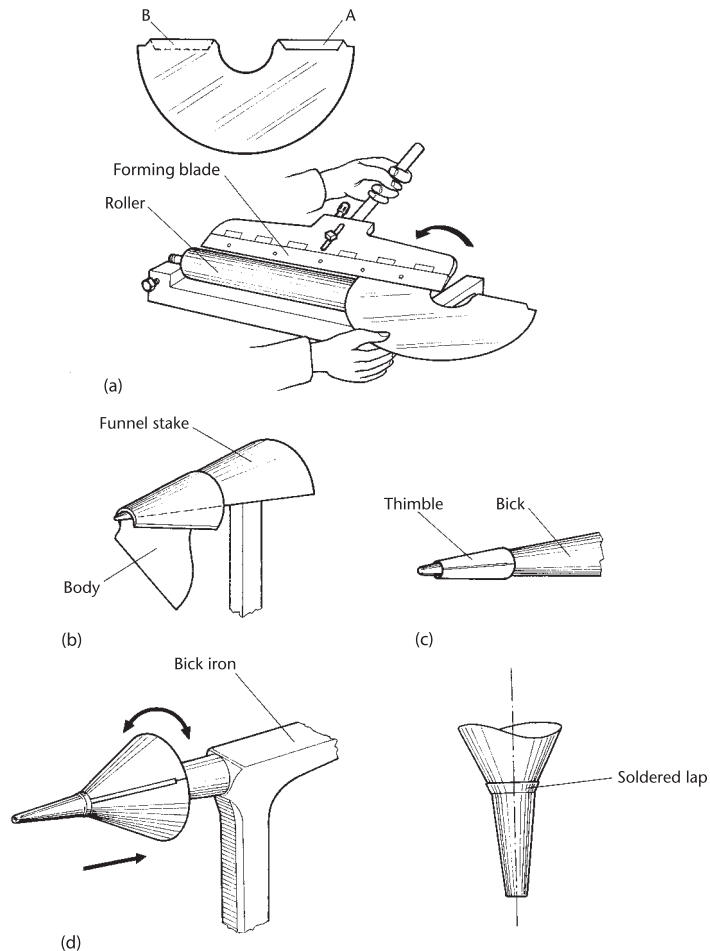
Figure 7.57 Operations for forming a funnel. (a) Folding the locks; (b) forming the body; (c) forming the thimble; (d) finishing the funnel

6. Finally the top edge of the body has to be wired. Cut a length of wire and roll it into a hoop on the bending rolls. The wire allowance is flanged up on a jennying machine (see Section 7.5.5). The wire is fitted in place and the metal is closed over the wire with a suitable pair of rolls on the jenny, making sure that the butt joint of the hoop is positioned away from the grooved seam of the body.

7.6.7 Forming operations using a universal jennying machine

Figure 7.58 shows some examples of the types of wheels or rolls that are used on a universal jennying machine together with the various operations which they perform.

Figure 7.59 shows some typical operations using a universal jennying machine for preparing edges.

■ Figure 7.59(a) shows how the rolls can be used to turn up a narrow edge on circular and irregular components ready for wiring.
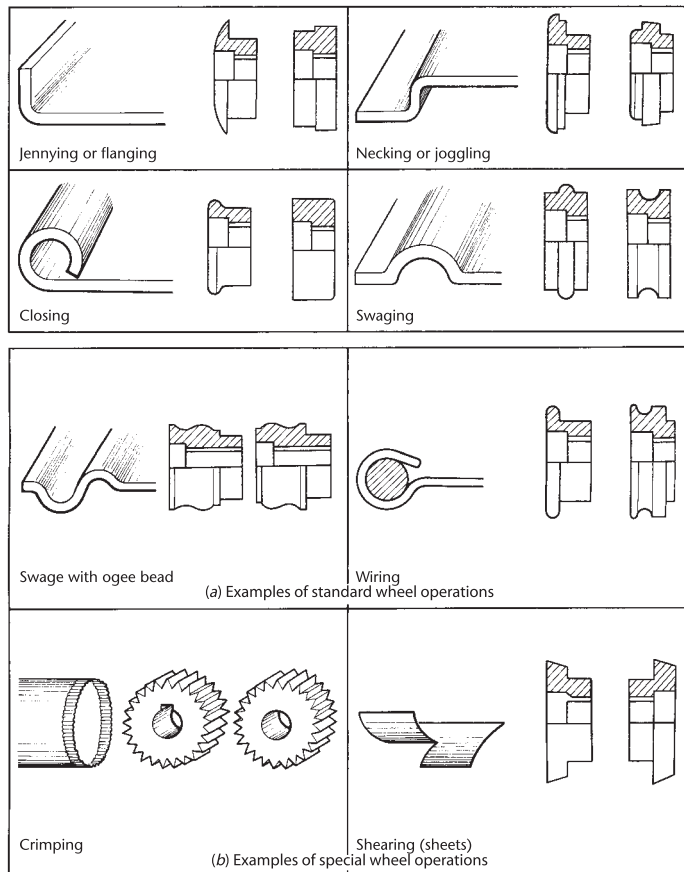
Figure 7.58 Wheels and rollers for jennying machines

- Figure 7.59(b) shows how the sharp edge of the upper roll can be used for tucking-in wired edges and also for turning single edges on curved work and discs.
- The vee-shaped rolls shown in Fig. 7.59(c) are ideal for turning up a double edge on elbows for paned-down or knocked-up seams.
- For a wired edge the allowance must equal 2.5 times the diameter of the wire. This measurement is taken from the face of the 'gauge' to the centre of the upper roll as shown in Fig. 7.59(d). The gauge is adjusted, usually by a knurled screw, at the side of the machine. After setting to the required measurement the gauge is locked in position.

Caution: When using sharp edged rolls for flanging operations, do not over-tighten the top roll. If the top roll is too tight the metal will be sheared. The top roll should be adjusted so as to afford only a light grip on the metal between the rolls.

When flanging a disc, a small piece of thin, scrap metal folded as shown Fig. 7.60 should be used to prevent injury to the operator's hand. As an extra precaution remove all burrs from the metal blank before commencing the operation.
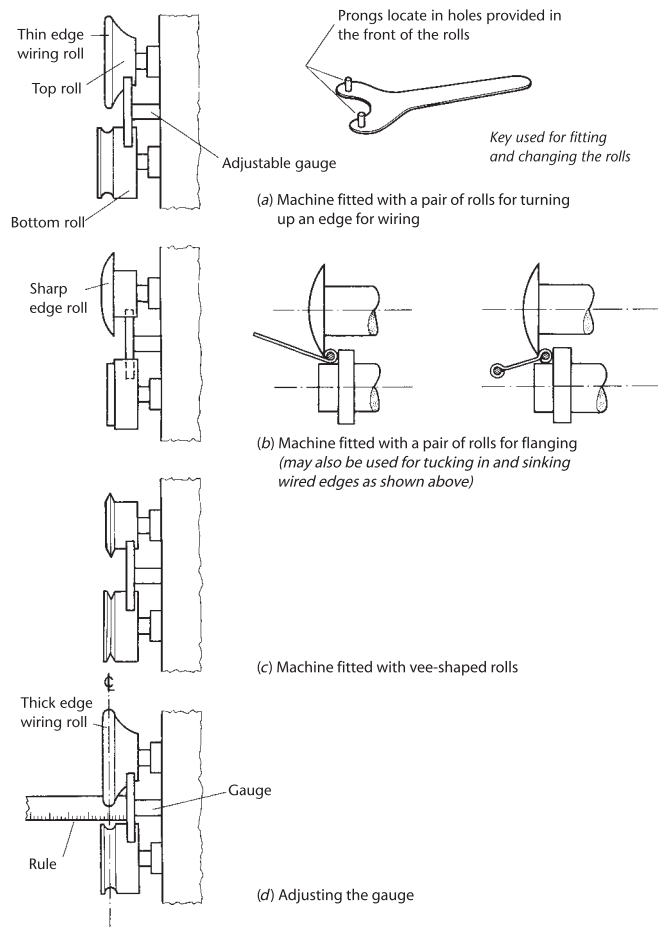
Thin edge
wiring roll

Top roll

Adjustable gauge

Bottom roll

Prongs locate in holes provided in
the front of the rolls

*Key used for fitting
and changing the rolls*

(*a*) Machine fitted with a pair of rolls for turning
up an edge for wiring

Sharp
edge roll

(*b*) Machine fitted with a pair of rolls for flanging
(*may also be used for tucking in and sinking
wired edges as shown above*)

(c) Machine fitted with vee-shaped rolls

Thick edge
wiring roll

Gauge

Rule

(*d*) Adjusting the gauge

Figure 7.59 Edge preparation on a jennying machine

Rotation

Adjustable gauge

Top roll

Metal disc

Disc

Hand shield made from scrap material
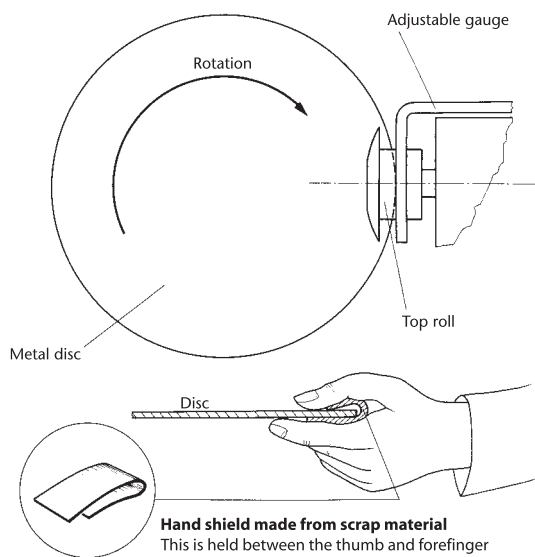This is held between the thumb and forefinger

Figure 7.60 Safety precaution when flanging a disc with the jenny

Exercises

7.1 Forming sheet metal and thin plate by folding and bending

   a) Explain what is meant by 'spring-back' and explain how this effect may be overcome.

   b) With the aid of sketches explain the difference between 'air-bending' and 'pressure-bending'.

   c) With the aid of sketches illustrate the principle of operation of a manually operated folding machine.

   d) Sketch a typical U-bending tool suitable for use in a fly press and label its principal parts.

   e) Describe in what ways a press-brake differs from a power press and show a typical example of its use.

   f) With the aid of sketches explain what is meant by 'the neutral line' when bending sheet metal and thin plate, and explain the difference between neutral line allowance and centre line allowance when calculating the sized of a blank.

   g) For the component shown in Fig. 7.61, calculate:

     i) The neutral line blank length

     ii) The centre line blank length.

7.2 Roll-bending sheet metal and plate

   a) With the aid of sketches explain the difference between 'pinch rolls' and 'pyramid rolls'.

   b) With the aid of sketches explain the difference between 'roll-up'-type machines and 'roll-down'-type machines.

   c) Explain:

     i) the purpose of 'slip-rolls'

     ii) the difference between cylinder rolling and cone rolling.

   d) Describe what is meant by the 'flow-forming' of sheet metal.

   e) With the aid of sketches show how a flange may be 'thrown' on the end of a sheet-metal cylinder.

   f) When using a hammer or a mallet, describe the differences between:

     i) a solid blow

     ii) an elastic blow

     iii) a floating blow.

   g) With the aid of sketches explain how a hemisphere 75 mm diameter can be raised from a flat copper blank 1.00 mm thick using hand tools only. List the tools required and describe any inter-stage heat treatment that may be necessary as the metal work-hardens.

   h) Describe the difference between 'hollowing' and 'raising'.

   **i)** Briefly describe why the 'split and weld' technique is used when panel beating.

   j) Describe the essential requirements of a wheeling machine and the purpose of its use.

7.3 Metal spinning

   a) Describe the essential differences between an engineer's centre lathe and a sheet metalworker's spinning lathe.

   b) With the aid of sketches explain the basic principles of metal spinning.

   c) Explain what is meant by a 'back stick', why it is required and how it is used.

Material: Mild steel 20 mm wide strip
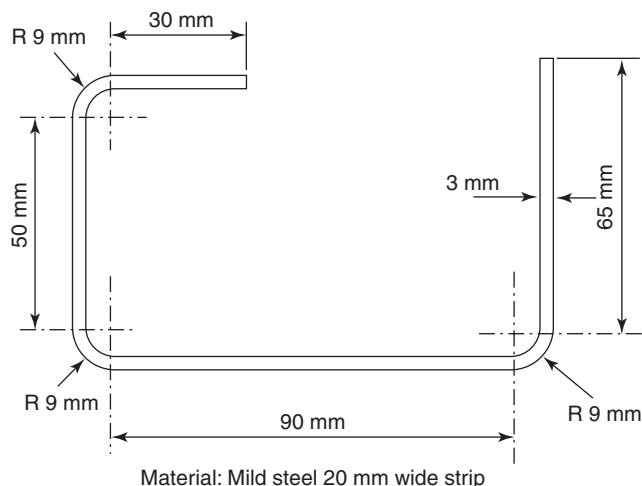
Figure 7.61

d) Why must the blank be lubricated when spinning and what special property must the lubricant possess?

7.4 Swaging and stiffening processes
   a) With the aid of sketches describe the essential principles of swaging and why this process is often required in sheet metalwork.
   b) State the reasons for wiring the edge of a sheet-metal component and, with the aid of sketches, show how a straight edge may be wired.
   c) With the aid of sketches show how the ends of a cylindrical sheet-metal component may be wired.
   d) Explain why stiffening is required for large sheet-metal surfaces and, with the aid of sketches, show TWO examples of applied stiffeners.

7.5 Fabrication planning and procedures
   a) Describe how the outline of a template may be transferred to the sheet-metal stock from which a blank is to be cut.
   b) Explain why notched corners are often required when making sheet-metal products.
   c) Sketch a blank layout and write out a planning sheet and a list of tools required to make the box shown in Fig. 7.62.
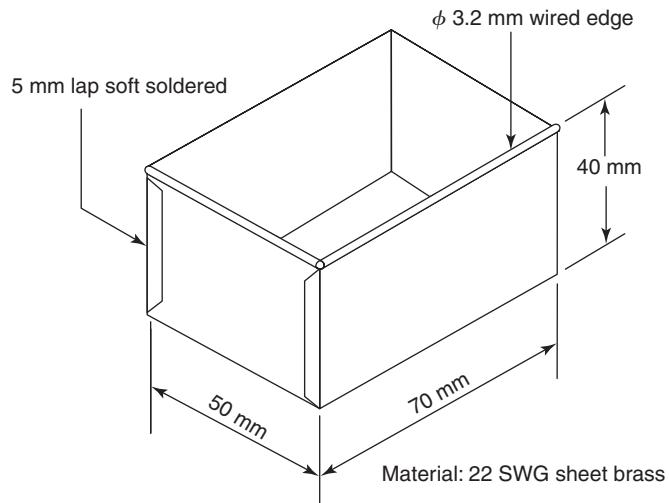   d) Describe the procedure for making the box shown in Fig. 7.62.

Figure 7.62