

FORMING

BENDING STEEL SHEET AND STRIP PRODUCTS

TECHNICAL BULLETIN TB-F4

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This issue supersedes all previous issues

1 BENDING OPERATIONS

Simple straight bending is probably the most common operation used for forming shapes from flat steel sheet. However, the type of bend can range from a single slight deformation to multiple bending of a workpiece in one or more directions.

Types of machinery used are:

- Pan brakes
- Electro Magnetic folders
- Press brakes
- Punch presses
- Automated Bending Systems
- Roll-formers

Using special tools, sheet metal workers can manually produce neat bends in steel sheet in a particularly skillful manner.

The choice of device or method usually depends on quantity and complexity of the work to be done as well as on machinery availability. Given a choice, punch presses are used when close tolerances are to be met, parts are small, quantities are large or when other operations such as notching can be combined. Press brakes are ideal for bending relatively long, narrow parts and for smaller quantity jobs. Pan brakes can be used similarly to press brakes but can achieve selective bending not possible with press brakes.

Forming in a pan brake is a slow, labour intensive process but has very little set-up cost so it is suitable for smaller and single pieces and for small production runs.

Large quantities and long length product will dictate roll-forming (*refer to Technical Bulletin TB-F5 Roll-Forming of Steel Strip*) as the best method of forming.

Details of capacities and capabilities of the various pieces of equipment are readily obtainable from equipment manufacturers or suppliers for calculation of costs to enable a decision on the forming method to be used.

2 FOLDING

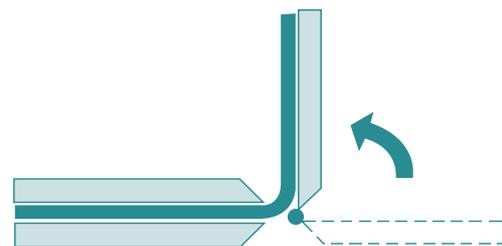
In a folding machine, sheet is clamped along its entire length and a folding apron is manually pivoted to deform the sheet to the required angle (*Figure 1*).

The bending and clamping edges of the equipment can consist of fingers or segments in varying widths to enable bends to be made at right angles to each other for making box or pan shapes. The latter gives the name pan brake to this type of equipment.

A more recent addition to this type of folding equipment are electro magnetic folders. These folders provide great folding flexibility for the jobbing shop, with the profiles achievable being almost infinite. The versatility can be attributed to the fact that the clamp bar is magnetically clamped to the material being folded, hence folding profile depth is unlimited compared to the conventional pan brake folders which are restricted by their mechanical clamping structure.

Clamping may be a problem for close bends and the length of the product is limited to that of the folder. Accuracy of the finished article depends largely on the skill and care of the operator.

Figure 1 - Electro Magnetic folder or Pan brake diagrammatic



3 PRESS-BRAKE FORMING

Press-brake forming is a process in which a blank or workpiece is placed over a straight open die and is deformed down into the die by a punch actuated by a ram. There is probably no more widely used machine in the sheet metal industry than the press brake unless it is the guillotine shears necessary to prepare the feed for it.

The press brake is commonly used for forming relatively long, narrow components that are difficult or impossible to press form, and for applications in which production quantities are too small to warrant contour roll-forming tooling costs.

Press-brake forming normally produces one bend per ram stroke but multiple bends are possible with special tools. The length of product is limited by the machine itself to normally about 4 m but machines have been built for lengths of 10 m. The latter press would typically be of 600 tonnes capacity. It is not uncommon practice to mount two press brakes in tandem, exercising great care in ensuring that they are both accurately aligned.

The versatility of the press brake is demonstrated in that it can be used for producing members with varying cross-section such as tapered members. Cold roll-forming methods can generally only produce components with a constant cross-section.

The main advantages of press brakes are versatility and with computer control, the ease and speed with which they can be changed over to a new set-up.

4 PRESS BENDING

Power presses (*of the inclinable C-type*) are used for bending steel sheet in the manufacture of parts where production quantities are large and where part size is relatively small. Apart from the size and speed of the bending operation and sometimes the orientation of the dies, this process has many similarities to bending in a press brake. The same types of materials are worked and the same allowances made.

There are several basic types of power presses. Equipment suppliers should be consulted for advice on whether hydraulic or mechanical presses are best suited and, if the latter, whether a direct drive or a geared drive is necessary.

5 BENDING METHODS

Bends can be accomplished in a number of ways. In the most common method, a flat sheet is forced by a top tool (*or punch or knife*) into the opening of a bottom tool or die (*Figure 2*). In another method used for producing bends near the edge of a sheet and for forming channels, a blade forces sheet around a radiused bend with a wiping action (*Figure 3*).

Figure 2 - Simple V-bend

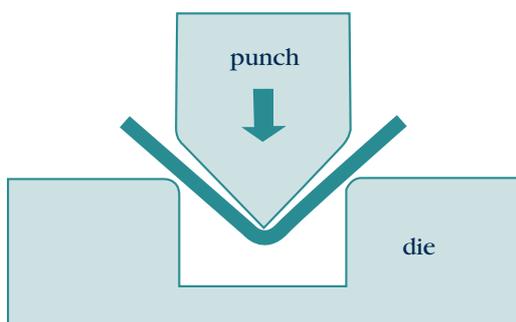
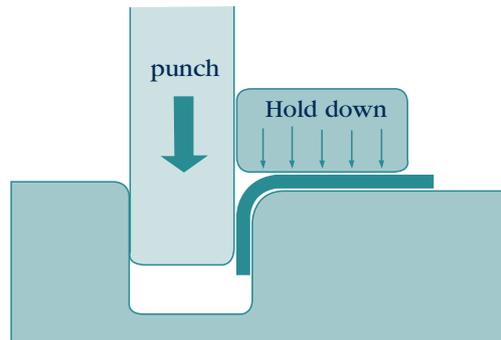


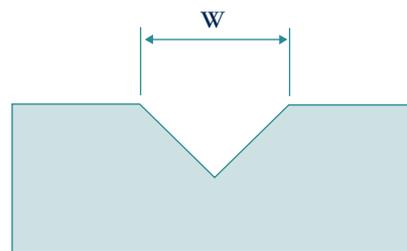
Figure 3 - Wipe bend



5.1 V-Bends

The angle of the bend can be varied by the amount of penetration of the top tool or the size of the opening, W , in the die (*V-notch opening in Figure 4*).

Figure 4 - V-notch opening



The opening, W , must suit the thickness and grade of steel being formed. For normal commercial grades (*with a yield strength of 220-350 MPa*) used in press-brake forming, a practical rule of thumb is:

Equation 1

$$W=12 - 15t$$

Where t = thickness of the sheet being formed.

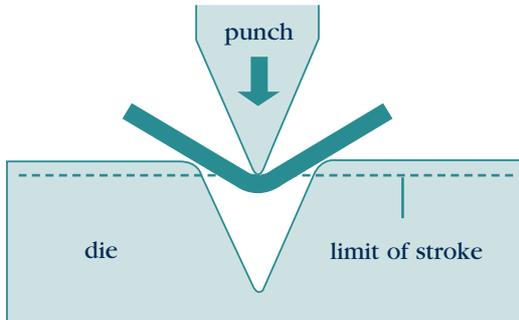
An excessive V-notch opening will give badly shaped bends and a gradual rather than a neat transition from bend into flat surface. Variable spring back is also more likely to occur. Too small a V-notch opening requires a greater bending force and the edge of the opening may mark the workpiece surface or cause excessive edge wear. However, a smaller than usual V-notch opening is sometimes deliberately used to achieve a short lip on the edge of a sheet.

The two most common methods of forming are air bending and hard bottoming. Which method is used depends largely on the nature of the final product and the accuracy required.

5.1.1. AIR BENDING

In air bending, the sheet surface is touched by the tools at three points only (*the punch surface and the corners of the open die*) throughout the whole operation.

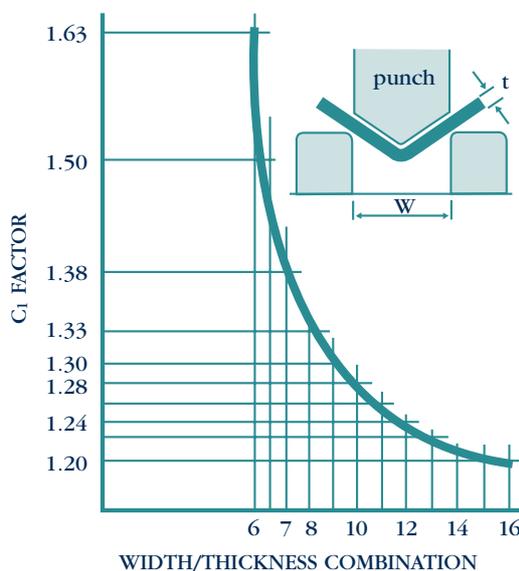
Figure 5 - Air bending in a press brake



The shape and nose radius of the punch are varied to suit the workpiece. The required angle is produced on the workpiece by adjusting the depth to which the punch enters the die opening. This allows the sheet to be bent beyond the design angle to produce the correct profile after spring back.

When the metal is deformed plastically (*that is, the punch force exceeds the yield strength of the steel*) the radius formed bears a definite relation to the opening in the die. A small die opening produces a small radius. The use of a large die opening increases the radius but compensation must be made by overbending for increased spring back. Changing the size of the die opening also changes the amount of force needed to make the bend. As the die opening is increased, less force is required. Conversely, as the die opening decreases, bending leverage is less and thus more force is required.

Figure 6 - Variation of C₁ factor for V-Bends with W/t ratio.



The press size to handle single bending operations can be calculated from Equation 2:

Equation 2

Required capacity

$$F = \frac{C_1 R_m L t^2}{W} \times 10^{-3}$$

- where
- F = bending force, kN
 - C₁ = constant for die width/steel thickness combination (Figure 6)
 - R_m = yield strength of steel, MPa
 - L = bend length, mm
 - t = steel thickness (steel base if coated sheet), mm
 - W = V-notch opening, mm

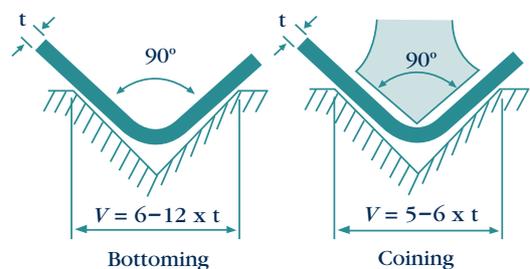
This value is only for air bending in which the required shape is reached without the sheet reaching the bottom of the V-notch. The required angle is obtained by adjusting the depth to which the top tool enters the bottom tool. Air bending is widely used as it can allow for the degree of overbending necessary to compensate for spring back which is inevitable in steel sheet. The degree of spring back must be checked by trial and error on prototypes before production runs commence.

A further advantage of air bending is the ability to produce a great variety of bend angles with fewer tools as the angle on the workpiece, the top tool angle and the V-notch need not be matched.

5.1.2. BOTTOMING AND COINING

Two alternatives to air bending are bottoming and coining in which a top tool, workpiece and V-notch are in solid contact when the bend is completed.

Figure 7 - Bottoming and Coining



Both methods are used for achieving greater bend accuracy than is achievable with air bending. Bottoming is more commonly used as it requires less pressure than coining. The V width for bottoming is 6 - 12t. Coining, which uses high surface and bite by a sharp punch to control springback, uses a V width of 5 - 6t.

These methods produce more accurate bends with consistent spring back and neat transition from bend to flat.

Inherent disadvantages with these techniques restrict their use. These include:

- The top and bottom angle must be accurately matched so more tools are required for the same work range compared to air bending
- Great care must be taken in tool alignment and penetration setting. Insufficient penetration may cause inconsistent shape; excess penetration may damage the press brake
- Steel thickness must be constant. The use of different thicknesses has the same effect as varying penetration settings
- Press capacity is required to be up to five times greater than for air bending.

5.2 Wipe Bending

In wipe bending (*Figure 3*) a wiping die bends the sheet without any kick-back of material in front of the press. Other advantages are better accuracy and safety. Tooling is more expensive and requires adjustment for different thicknesses and types of material.

The bending force required for wipe bending work must take into account punch/sheet surface and punch/die friction. This is estimated to be 20% of the bending force. When a hold down is necessary, the force required is assumed to be 50% of the bending force so the cumulative sum of forces required is 1.7 x bending force.

Equation 3

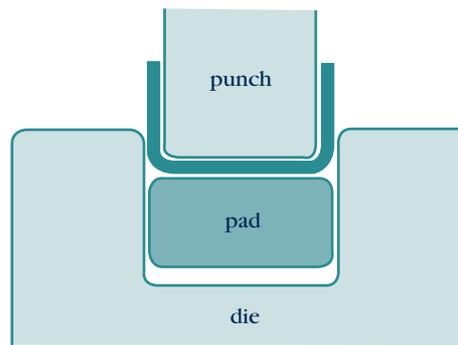
$$F_1 = 0.17 R_m L t \times 10^{-3}$$

$$F_2 = 0.17 F_1$$

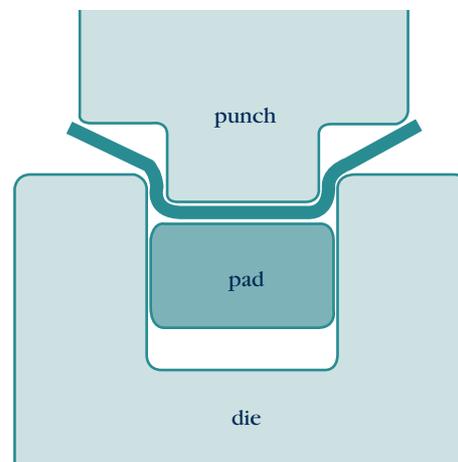
where F_1 = bending force (without allowance for friction), kN
 R_m = tensile strength of sheet, MPa
 L = length of bend, mm
 t = thickness of sheet, mm
 F_2 = total forming force, kN

Examples of tooling for channels are illustrated in *Figure 8* where at least two operations are necessary. A spring actuated pressure pad and ejector are normal for dimensional accuracy and to assist in removal of the formed piece.

Figure 8 - Wiping dies for channels



(a) Simple channel



(b) Winged channel

5.2.1 SIMPLE CHANNEL

The force (F_1) required to form the simple channel in *Figure 8a* has been given as twice that for a single wipe bend. In addition, an allowance (F_2) must be made for friction, taken as 50% of the bending force, plus an allowance (F_3) equal to the total tensile strength of the steel sheet for the stripping pad force (*Equation 4*).

Equation 4

$$F_1 = 0.3 R_m L t \times 10^{-3}$$

$$F_2 = \frac{F_1}{2}$$

$$F_3 = \frac{1.3 R_m L t^2}{W} \times 10^{-3}$$

$$F_4 = F_1 + F_2 + F_3$$

where F_1 = forming force, kN
 R_m = tensile strength, MPa
 L = length of channel, mm
 t = steel thickness, mm
 F_2 = force allowance for friction, kN
 F_3 = force allowance for pressure pad, kN
 W = die width, mm
 F_4 = total force, kN

5.2.2 WINGED CHANNEL

Forming a winged channel requires additional force:

Equation 5

$$F_1 = 2 R_p L t \times 10^{-3}$$

$$F_2 = \frac{F_1}{5}$$

$$F_3 = \frac{2R_p L t^2}{3W} \times 10^{-3}$$

$$F_4 = F_1 + F_2 + F_3$$

where R_p = yield strength of steel sheet, MPa

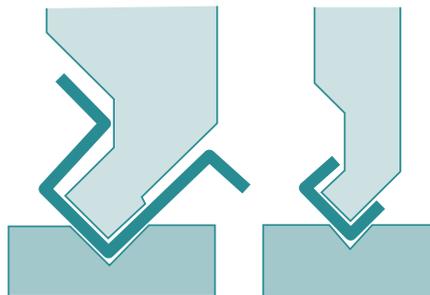
There is a rapid increase in forming force on a winged channel if bottoming of dies is allowed to occur in the flanges. No allowance has been given for this eventuality.

6 DIE DESIGN

A considerable range of standard tools is available and suppliers of press equipment should be consulted for stock designs before special tools are considered.

Off-set or cranked dies enable more complex shapes to be formed. In forming channels with standard tools of the types illustrated in Figure 9, it is necessary that the channel leg be a length equal to at least a half of the die opening.

Figure 9 - Shapes produced with off-set dies



6.1 Special Shapes

Other tools are produced to make special shapes both as single tools or combination tools (Figures 10 and 11).

Figure 10 - Single tool set for hemming

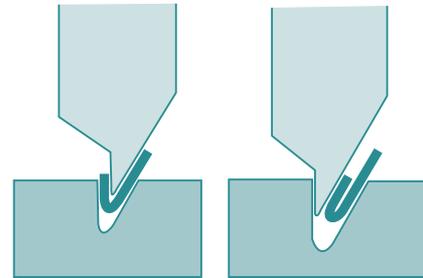
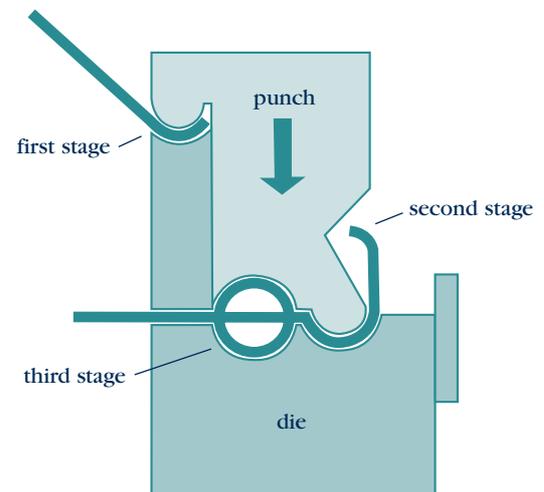


Figure 11 - Combination curling tool

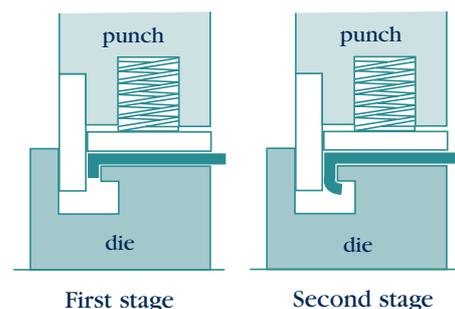


6.2 Combination Tools

Combination tools increase the capacity of a press brake at a cost which must be balanced against the improvement in productivity.

Figure 12 shows a wiping die where right angle and return bends can be made quickly and accurately.

Figure 12 - Wiping the die for return bends



6.3 Tandem Press Brakes

Press brakes can be mounted side by side to enable extra long lengths of bend to be made. Accuracy of alignment is essential to ensure adequate quality of work.

6.4 Flexible Dies

Elastomer type material can replace conventional multiple dies by using a simple underground 50 mm V-block. This deforms under load, matching the shape of the punch (Figure 13 & 14). This versatility eliminates the high cost of the standard multiple die block form and the cost of repeated and sometimes frequent tool changes.

Important advantages with this die material are:

- Extreme accuracy without additional tooling costs since every bend carried out is, in principle, a coining operation (*the material will follow exactly the form of the top tool*)
- Ability to provide formed products free from tool marks
- Production of a short flange with a 90° angle (Figure 15)
- If any part of the die becomes damaged, the damaged section can be cut out and replaced with a new section without impairing bending performance.

Figure 13 - Flexible die

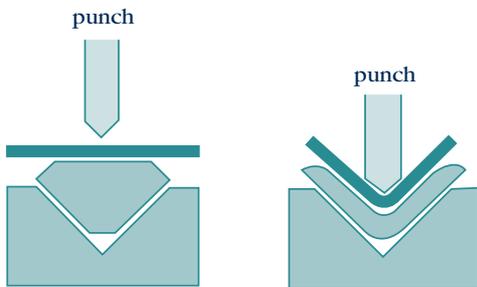


Figure 14 - Varying thickness steel formed using a flexible die

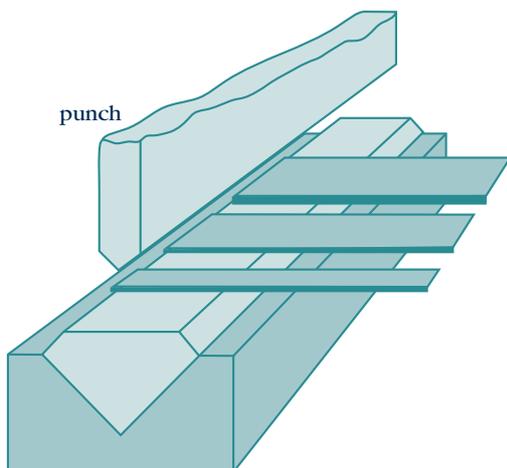
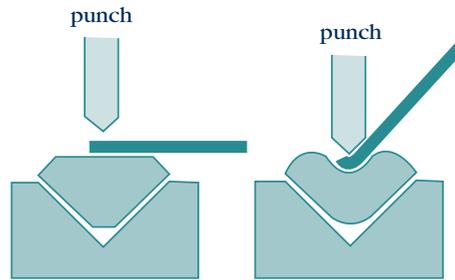


Figure 15 - Short flange produced with flexible die



Disadvantages are:

- Flexible dies are generally expensive but the economics of the whole situation should be discussed with equipment suppliers
- A larger capacity machine is necessary for the same job (*two to three times that for air bending*).

7 PRECAUTIONS

Products from a correctly operated press brake are accurate and consistent provided machines and tools are kept in the best possible condition to maintain close dimensions. General purpose tooling is seldom built for precision work and frequently is given hard usage. Uneven wear aggravates quality of work.

It is general practice for press-brakes to bend the legs of formed sheet upwards when the punch or blade forces the sheet downwards into the die. If a wide sheet is being formed the inertia of the sheet mass causes a kink to form near the bend. This is called kick-back or whip-up, which is undesirable in a panel where surface quality is important. There are several possible remedies:

- Adjust the press-brake folding speed so that the sheet will not swing upwards too quickly.
- Lift the wide leg of the sheet at the moment of deformation to overcome the inertia of the sheet.
- Use a wiping die if a bend is formed near the edge of a sheet, for example, a flange (Figure 12).

8 MATERIAL CHARACTERISTICS AND ALLOWANCES

8.1 Materials

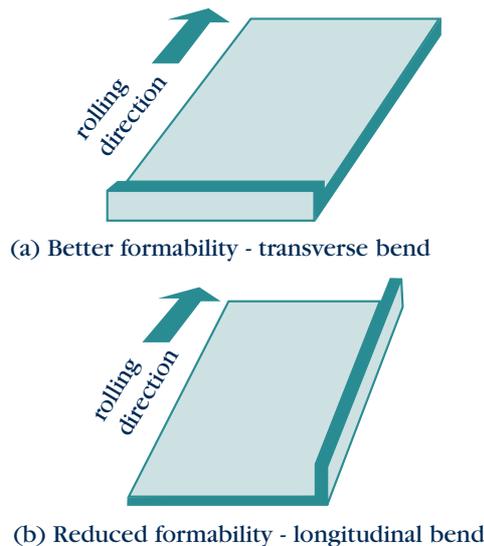
A wide range of sheet steels can be formed in a press-brake. Limitations are the ductility of the metal and the deforming force required. Generally minimum bend radii necessary for a satisfactory bend increase with a larger angle of bend and thicker steels.

Rolling direction and edge condition are among several factors which have an effect on forming characteristics.

8.1.1 ROLLING DIRECTION

The formability of steel sheet varies with the direction for the axis of bend. Sharper bends can usually be made across rather than parallel to the rolling direction (*generally the long dimension*) of the sheet without increasing the probability of cracking. This occurs because of the inherent metallurgical characteristics of steel sheet.

Figure 16 - Orientation of bends



Orientation of bends with respect to the metallurgical grain structure affects not only the severity of the bend that can be made but also the service life of that bend under vibration and fatigue conditions (Figure 16).

This difference is not so evident in BlueScope Steel Limited ductile steels compared to some of the high strength steels.

8.1.2 EDGE CONDITION

Excessive edge burr and work hardening are not conducive to good bending performance of steel sheet. The best solution is the complete removal of distorted steel but if this is not practical the sheet should be turned over so that it is formed with the burr on the inside of the bend. This is necessary as the burr will crack when stretched around the outside of a bend, act as a stress concentration point and initiate failure into the base metal in the bend itself. This effect is worse in thinner sheet, sheet of reduced ductility and in narrow strips less than eight times the sheet thickness in width.

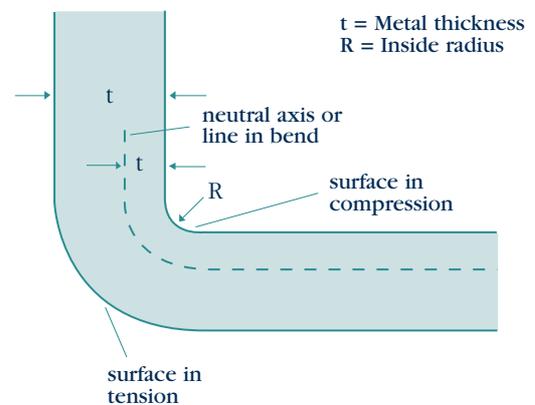
8.2 Bend Allowances (not applicable to stretch bending)

Most modern day fabrication workshops possess CAD (*Computer Aided Drafting*) packages which readily compute blank sizes directly from either 2 or 3 dimensional drawings of sheet metal parts. However, in the

event that a blank size needs to be accurately determined manually, the following approach may be taken.

To determine the size of the blank needed to produce a specified formed part, the blank dimension at 90° to the bend axis can be developed on the basis of the dimension along the neutral axis or line which theoretically does not change its length during the bending operation. As a general guide, this line can be taken at a distance of a from the surface of the inside of to the bend.

Figure 17 - Neutral axis at a distance of a from the inside surface of the bend



Equation 6

$$a = \left[\sqrt{\frac{R}{t} \left(1 + \frac{R}{t}\right)} \right] - \frac{R}{t}$$

where R = inside radius of bend, mm
 t = metal thickness, mm

For values of a for some specific R & t combinations (*expressed as R/t*) see Table 1.

Table 1 Values of a (ratio of distance of neutral axis from the inside bend surface to the metal thickness) for specific R & t combinations.

R/t	0.5	1	2	3	4	5	10	20
a	0.366	0.414	0.449	0.464	0.472	0.477	0.488	0.494

The width of strip required to make a given shape can be determined by adding together the lengths of the straight components and the lengths of each bend.

The length of each bend (L) can be determined from the formula:

Equation 7

$$L = 0.01745 u(R + at)$$

where u = angle of bend, degrees

t = metal thickness, mm

R = inside radius of bend, mm

a = ratio (*refer Equation 6*)

The exact amount of metal required in even a standard bend varies with such factors as its hardness, uniformity of thickness and the speed with which the bend is made. For accurate results the final blank width should be checked by a practical test.

8.3 Allowances for springback (not applicable to stretch bending)

Generally, as the bend radius becomes larger, the allowance for spring back must be more generous, because less of the bent metal has been stressed beyond its yield strength. Very large radii cannot easily be formed by ordinary bending, but must be stretch formed.

Spring back in bending low carbon steel sheet has to be considered only when close dimensional control is needed. It normally ranges from 0.5° to 1.5° and can be controlled by overbending or by bottoming/coining the bend area.

As a general guideline, the spring back in a bending operation can be estimated from Equation 8.

Equation 8

$$\frac{R}{R_1} = \frac{u_1}{u} = 1 - 3f + 4f^3 \text{ for } f < 0.5$$

$$\frac{R}{R_1} = 0 \text{ for } f > 0.5$$

where

$$f = \frac{s_y R}{Et} \times 10^{-3}$$

R = pre-spring back inside bend radius, mm

R₁ = post-spring back inside bend radius, mm

u = pre-spring back angle of bend (angle of former)

u₁ = post-spring back angle of bend

s_y = yield strength of sheet, MPa

E = Young's Modulus of sheet, GPa (200 for steel)

t = thickness of sheet, mm

Alternatively, spring back may be expressed in term of a change in bend radius as follows:

Equation 9

$$\text{Spring back} = \frac{R_1 - R}{R} \times 100\%$$

$$= \left(\frac{1}{1 - 3f + 4f^3} - 1 \right) \times 100\%$$

However, numerous other factors also affect spring back, including angle of bend

(degrees of bend from flat), method of bending (V-bending or wiping) and amount of compression in the bend zone, tool wear and adjustment and power input variations. Because of the number of factors involved the degree of the spring back should be checked by tests after an estimation is made.

9 BENDING ORGANIC FINISHED STEEL

The performance of composite materials is governed by the characteristics of the substrate and the surface layer. The steel base can sometimes limit the performance of the composite while in other cases the coating will set the fabrication parameters.

Organic-finished steel sheet can, in most instances, be formed in the same basic tooling and presses that are used for uncoated steel but methods and tooling may have to be modified to avoid damaging or removing the coating. The performance of the coating during press forming operations is directly equated to the steel substrate hardness (or stiffness). If the substrate is thicker or stronger, a greater pressure is required to carry out forming. This in turn subjects the coating to greater abrasion, surface shear and die pressure. On the credit side the use of organic coatings usually increases tool life and reduces the need for press lubricants.

When straight-line forming organic-finished steels, the coating is required to stretch considerably more than the substrate and creates a situation where coating can be either thin at the outside of the bend or slightly pull back from a sheared edge. This condition in no way impairs the quality of bond between the steel and the coating. To keep the tendency to thin or pull back to a minimum it is recommended that the maximum permissible inside radius be used. When components are being formed with the main surface organic coating on the inside the opposite situation arises as the coating is then under compression and will be required to compress more than the steel substrate.

For press-brake forming it is preferable, where possible, to use dies made from polyurethane rubber or to cover the V of metal dies with polyethylene film tape as this will protect the coating and enable forming of the coated sheet into the most complex shapes without abrasion or damage.

High gloss paint finish films are particularly notable in reducing tool wear. The forming of the high gloss materials often becomes less complicated if tools are used that are designed with the material in mind. The tools should be free from any sharp edges that are likely to damage the coating. The forming edges, where possible, should be highly polished and the tooling and pressings should be handled carefully.

To calculate the correct clearance between punch and die for forming organic-finished steel it is preferable, where possible, to allow for overall thickness (*substrate plus coating*) plus 5%, as the coatings perform better when they are not over compressed. If there is a choice it is a preferable to form organic-finished steels on a slow-acting press. Rapid bending should be discouraged as should the forming of short flanges close to a cut edge.

A clear polyethylene CORSTRIP® film is sometimes applied to the surface of COLORBOND® prepainted strip at the last stage of manufacture. The film is used for protecting the paint surface during forming operations where tool condition is not of adequate standard. It acts as a solid lubricant during forming operations and is designed to be left on high quality surfaces until ready for the ultimate end use. CORSTRIP® strippable coating is easily removed after final fabrication. COLORBOND® steel sheet covered with CORSTRIP® coating should not, however, be left in open sunlight as ultraviolet light may cause adhesion of the film to the paint surface.

10 AUTOMATED BENDING SYSTEMS

There are a number of sophisticated flexible automated bending systems being used by the manufacturing industry. These bending systems may operate in a stand alone mode similar to press brakes, however they are more commonly integrated into computer controlled production lines designed to automatically produce sheet metal components for small to large volume production runs from either sheet or coil feed stocks.

These systems are computer controlled and at the upper end of the spectrum are capable of producing complex sheet metal components generated from CAD drawings. Material is then progressed automatically through punching, shearing, folding and joining operations to completed parts without the requirement for man handling.

Literature relevant to these technologies is extensive and outside the scope of this publication, however, may be readily accessed through the selling agents for flexible manufacturing systems such as Salvagnini, which manufacture parts from sheet stock, or Pivatic flexible manufacturing systems, which manufacture sheet metal components using coil feed.

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