Sheet metal operations - Bending and related processes

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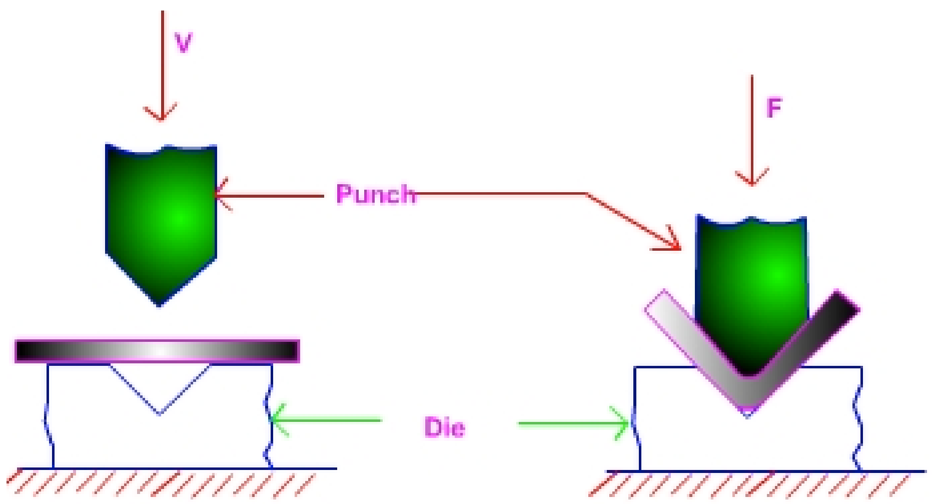
1.Bending and related processes:

1.1 Sheet metal bending

Bending of sheets and plates is widely used in forming parts such as corrugations, flanges, etc. Bending is a forming operation in which a sheet metal is subjected to bending stress thereby a flat straight sheet is made into a curved sheet. The sheet gets plastically deformed without change in thickness. Die and punch are used for bending. If a v shaped die and punch are used, the bending is called v-bending. If the sheet is bent on the edge using a wiping die it is called edge bending. In this process, one end of the sheet is held like a cantilever using a pressure pad and the other end is deformed by a punch which moves vertically down, bending the sheet. Usually, edge bending is done in order to obtain an angle of 90^o.

During bending of a strip, the material outward of the neutral axis is subjected to tensile stress. Material inside is subjected to compressive stress. Bend radius R is the radius of curvature of the bent sheet inside the bending. The neutral axis remains at the center of the thickness of the sheet for elastic bending. For plastic bending, however, the neutral axis shifts towards the inside of the bend. The rate of elongation of outer fibers is greater than the rate of contraction of inner fibers. Therefore, there is a thickness reduction at the bend section.



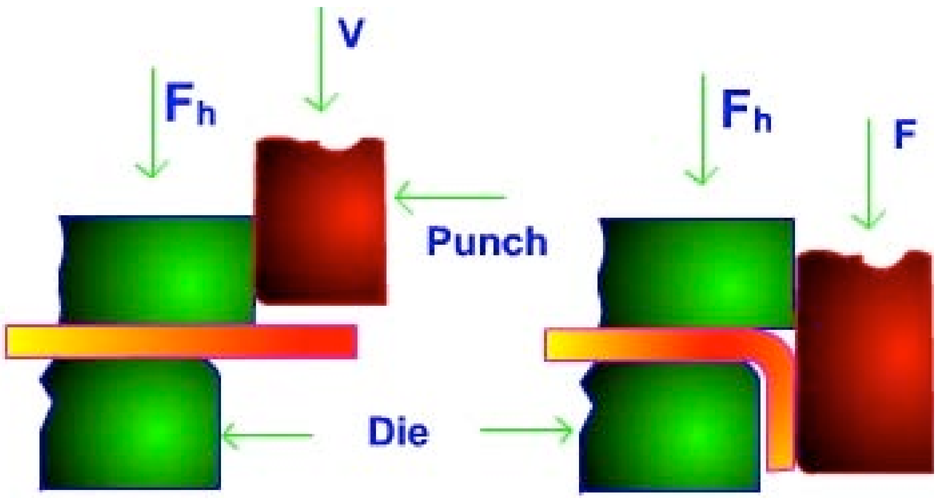


Fig. 2.1.1: V-bending and edge bending operations

U-Bending.swf **V-Bending.swf**

Fig. 1.1.1A: U bending and V bending animations

1.2 Theory of bending:

In plastic bending, we ignore the thickness reduction. Therefore, we assume that the neutral axis remains at the center of the sheet thickness. Consider a sheet of thickness t, subjected to bending so that it is bent to a radius of curvature of R. We can ignore strain along the width direction. Let α be the bend angle.
Bend allowance is the arc length of the neutral axis in the bend area. It is an important design parameter. It is given by:

$L_b = \alpha(R+kt)$, where k is a constant which is equal to 0.5 for ideal bending- neutral axis remains at center. K = 0.33 to 0.5 for R<2t or R>2t. respectively.

We can write the strain on outer fiber or inner fiber as (both are equal):

$$e = \frac{1}{(\frac{2R}{t})+1}$$

In actual bending, the outer fibers stretch more than the inner fibers getting shrunk. This difference in strain between outer and inner fibers increases with decrease in radius of bending or decrease in R/t. Beyond a certain minimum R/t the tensile strain on outer fiber may reach so high a value that the material outside starts cracking. The particular radius at which cracks appear on the outer surface of the bent sheet is called minimum bend radius. It is usually given in terms of the sheet thickness, t.

The following table gives minimum radius for some materials:

Table 1.2.1: Minimum radius for bending

Material	Soft	Hardened
Aluminium alloys	0	6t
Low carbon steel	0.5t	4t
Titanium alloys	2.5t	4t

Note, that a minimum bend radius of zero means that the sheet can be bent on itself.
In order to obtain an expression for minimum bend radius, the true strain of a material during uniaxial tensile test at fracture can be equated to the strain in bending.

$\ln(Ao/Af) = \ln(1+e) = \ln(1+\frac{1}{(\frac{2R}{t})+1})$

From this, we obtain:

R/t minimum = $\frac{1}{2r} - 1$, where r is reduction in area of the sheet during bending.

Or, $R_{min}/t = 50/r - 1$, in which r is expressed as percent area reduction. This expression is applicable for reduction in area less than 0.2.

For 50% area reduction, R=0 which means the material can be folded on itself.

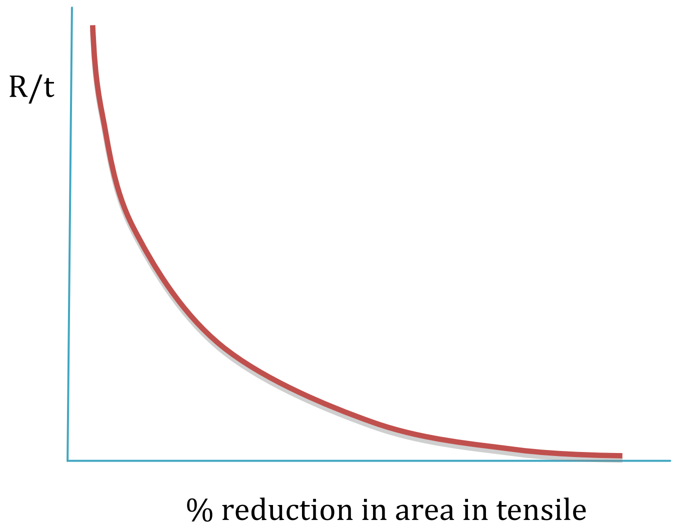


Fig. 1.2.1: Minimum bend radius versus percent area reduction

The above graph shows the variation of minimum bend radius with respect to percent area reduction.

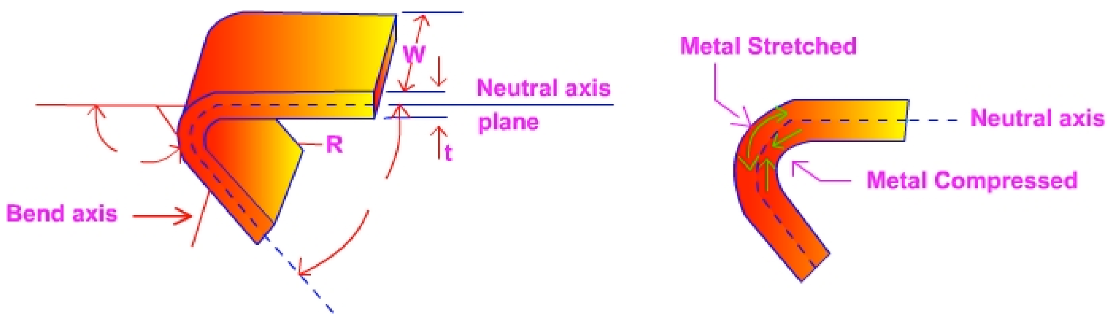


Fig. 1.2.2: Bending – terminology and geometry

In bending the ductility of the sheet metal plays very important role. If the ductility is lower, the minimum bend radius is larger. Similarly, a state of biaxial stress in bend region may also reduce ductility on outer fibers. For larger values of width to thickness ratio (w/t) of the sheet, the state of biaxial stress can be expected. State of biaxiality reaches when w/t reaches a value of 8. Larger w/t ratios reduce the critical strain required for fracture. As a result the bend radius will be higher. Narrow sheets undergo crack at the edge because the state of stress along edge is more biaxial than at center. Wider sheets, when subjected to larger radius of bend, undergo crack at center because the center is subjected to more biaxial state of stress. In order to increase the minimum radius, sheets are polished or ground.

Ability to undergo bending, called bendability can be improved by subjecting the material to hydrostatic stress. This improves the ductility (percent area reduction). Inducing compressive stress on outer fibers may also increase the bendability. Rough edges of the sheet reduces bendability because the rough edges can easily crack during bending. Cold working of the edges can also lead to cracking. Edge cracking may also happen due to inclusions or anisotropy of the material due to operations such as rolling having been cariedout on it.

1.3 Springback:

Elastic recovery of the sheet after the bend load is removed is called springback. Even after plastic deformation, small elastic recovery may happen in ductile materials, after removal of load. In bending springback reduces the bend angle. Similarly, the bend radius after springback is larger. Springback will be larger for materials having lower elastic modulus and higher yield strength. Springback increases for a sheet with higher width to thickness ratio as the stress state is biaxial or plane stress.
After releasing the load during bending, the bend radius changes. However, the bend allowance does not change. Therefore, we have:

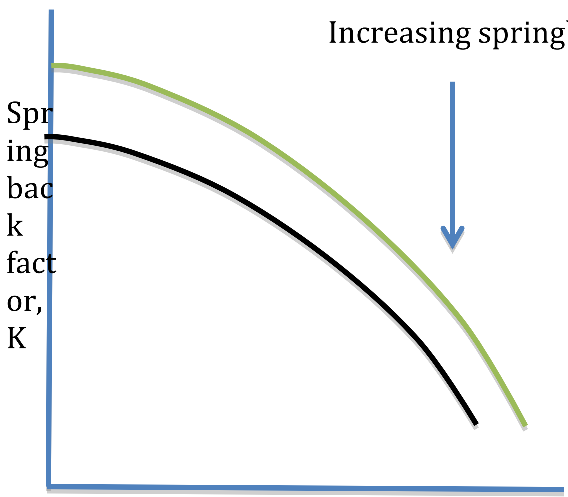
$L_b = \alpha i(Ri+t/2) = \alpha f(Rf+t/2)$

Or, $K = \alpha f / \alpha i = \frac{(\frac{2Ri}{t}+1)}{(\frac{2Rf}{t}+1)}$

K is springback factor, Ri is initial radius of curvature before releasing the load, Rf is radius of curvature of bend after releasing the load.

K = 1 indicates that there is no springback. K=0 means there is total elastic recovery as in springs.

Springback depends on R/t ratio. As the ratio increases, the spring back also increases, as indicated by decreasing K value from the graph below.



R/t

Fig. 1.3.1: Springback factor versus bend radius

Negative springback is a situation in which the bend angle becomes larger after removal of load. Negative spring back happens in v-bending. The material bends inward after the load removal due to large strains.
Another expression for springback in terms of bend radius is:

$\frac{R_i}{R_f} = 4(\frac{R_i Y}{Et})^3 - 3(\frac{R_i Y}{Et}) + 1$

Springback decreases as the yield strength decreases.

Overbending is one way of compensating for springback. Another way is by subjecting the sheet to compressive stress – coining between die and punch before bending. This is called bottoming. High temperature can also reduce springback, as the yield stress is reduced. Stretch bending, in which the sheet is subjected to tensile stress at the time of bending can also reduce springback. This is because excess tensile stress applied during stretching reduces the bending moment for bending.

1.4 Bend force:

The force required for bending a sheet of thickness t, length L, to a radius R is given by:

$F = \frac{YLt^2}{2\left(R+\frac{t}{2}\right)}\tan(\alpha/2)$

The maximum bend force is given by:

$F_{max} = kUTSLt^2 / W$

Where UTS is ultimate tensile strength of the material, W is die opening width

k→ takes values between 1.2 to 1.33 for v-die bending and 0.3 to 0.4 for wiping.

1.5 Other bending processes:

Long and narrow sheet metals are usually formed or bent to required shapes, using a hydraulic or mechanical press. Simple long die and tool and cast iron or carbon steel die materials make this press brake forming process a very widely used process.

Air bending is the bending of sheets freely between an upper roll or punch and a lower die freely. In **roll bending**, a pair of rolls support the plate to be bent and the upper roll applies the bend force. In continuous roll bending, called roll forming, a series of rolls are used. The strip or sheet is passed through the rolls, making the bending in stages. Panels, frames, channels etc can be formed by this process. Rolls are made of gray cast iron and chrome plated. Basic force involved in roll forming is bending, not compression as in rolling.

Beading or curling: In this process, the edge of the sheet is bent into a circular or other contour shape of the die itself, or formed into a curl, using one die or a pair of dies. Beading of ends of a sheet improves its stiffness by enhancing its moment of inertia at the edges. Hinges are examples for beading.
Hemming refers to a bending process in which the end of a sheet is bent into itself, to increase stiffness or protect the edge of the sheet, or to avoid sharp edge.

Seaming is assembling of two hemmed sheet ends in order to form a joint of the sheets. Double seams are used for water tight or air tight joints, such as that used in food beverage containers.

U shapes, corrugations, channels, tubes can be formed by bending sheet metals to specific shapes using a pair of shaped dies.

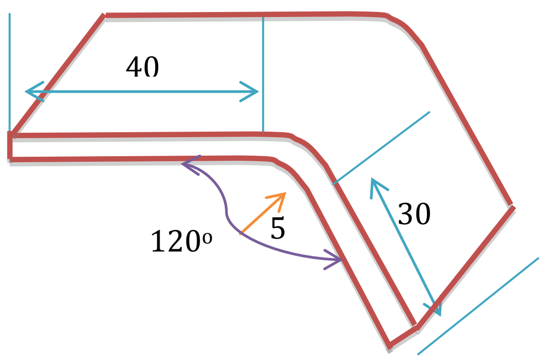
Flanging: Bending the edge of sheets to 90 degrees for improving their stiffness or for assembly is called flanging. If the angle of bend is less than 90 degrees, it is called flaring. Either compressive or tensile hoop stress is involved in flanging process.

Flanges can also be made by combining piercing the sheet with a punch and followed by expansion of the pierced edge using an expander punch. This process is called dimpling. A bullet shaped piercing punch is also sometimes used.

1.6 Tube bending:

Bending of tubes is more difficult than sheets because tubes tend to undergo folding or they may collapse if subjected to bending stress. When a tube is subjected to bending, the tube wall on the outer side of the bend is subjected to tensile stress, while that inside the bend is subjected to compression. As a result the tube wall thins out on the outer and thickens on inside of bend. Excessive compressive stress inside the bend results in wrinkles or folds. Usually, tubes are bent after filling the inside with sand. Sand fill prevents the tube from buckling during bending. Internal flexible mandrels or plugs are usually used during tube bending. Thick tubes may not require internal fills or plugs. Various methods of tube bending such as draw bending, stretch bending and compression bending are shown in figure below:
The minimum radius of bending is generally 1.5 times the tube diameter for thin walled tubes with internal mandrels used. Minimum bend radius in the case of bending of thick walled tubes without mandrels is 3 times the tube diameter.

Example:
A certain sheet metal(tensile strength = 500 MPa, E = 200 GPa), having a thickness of 3 mm and width 40 mm is subjected to bending in a v-die with opening of 22 mm. The other dimensions are as shown in figure. What are the blank size and bending force required? Ignore springback.



From the figure we see the bend angle = 60°

The length of the blank can be determined as:

L = 40+30+Bend allowance

Bend allowance is given by:

$L_b = \alpha i(Ri+t/2) = \alpha f(Rf+t/2) = 6.8$ mm

L = 76.8 mm

Now, the bend force can be determined from the expression:

$Fmax = kUTSLt^2 / W$
k = 1.33

F = 1.33X300X76.8X9 / 22 = 12535.85 N