

BENDING OF METALS INCLUDING "V", WIPE AND ROTARY DIE OPERATIONS

One of the most widely employed pressworking operations is bending. Bends are used to increase rigidity and produce a part of the desired shape. The simplest type of bending is air bending; so called because the die does not contact the outside of the bend radius. The part to be bent is supported on each side of the bend and a force applied to a forming punch in the center to accomplish the work.

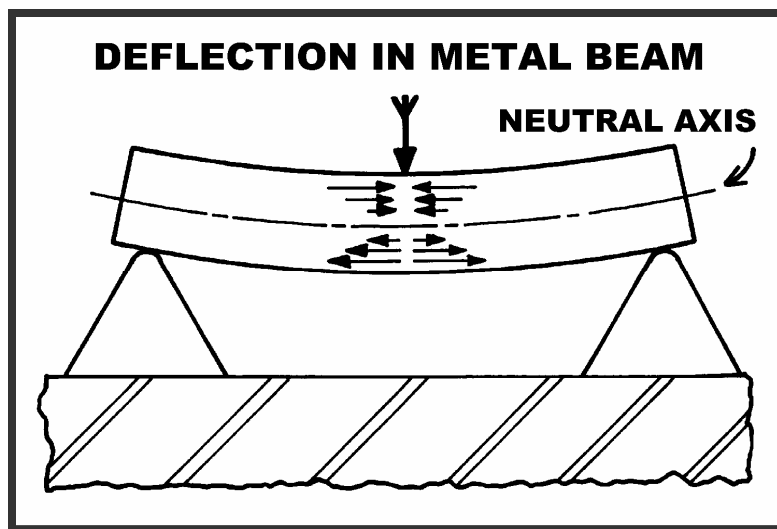


Figure 1. A metal beam supported at two points, with a load applied at the midpoint, resulting in bending or deflection. *Smith & Associates*

Figure 1 illustrates a metal beam supported at two points, with a load applied at the midpoint. The load produces compressive stresses in material on the inside of the bend as it is forced into compression. Tensile stresses or stretching occurs on the outside of the bend. To produce a bend in the finished part, the yield point of the material must be exceeded. If the bending force applied does not exceed the yield strength of the material, the beam returns to its original shape upon removal of the load as shown in Figure 2.

However, if the stress exceeds the material yield strength, the beam retains a permanent set or bend when the load is removed as shown in Figure 3. Bending material the correct amount is the goal of this pressworking process. Springback or elastic recovery will occur. Elastic recovery occurs until the residual stresses in the bend are in equilibrium with the stiffness of the material. This concept is illustrated in Figure 4.

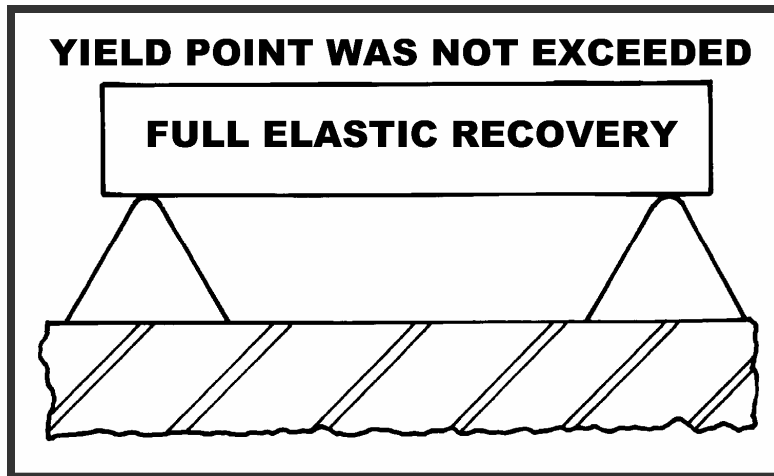


Figure 2. If the applied force does not exceed the material yield strength, the beam returns to its undeflected shape. *Smith & Associates*

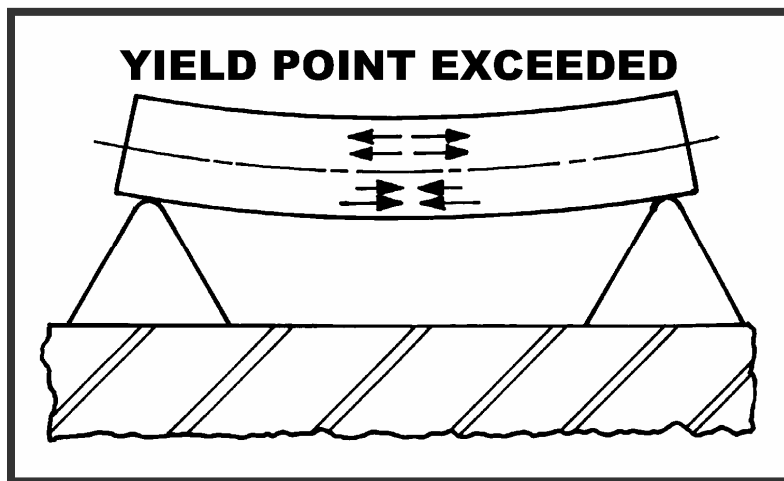


Figure 3. Simple beam deflection occurs in air bending. If the applied force exceeds the material yield strength, the beam retains a permanent set or bend when the load is removed. *Smith & Associates*

Bend Neutral Axis

Not all of the material in the bend zone is stressed equally. The material in the inner and outer surfaces is strained the most, and the stress gradually diminishes toward a neutral axis between the two surfaces. At that point, the strain is zero, and there is no length change.

Bend Allowances

For close work, the exact length of metal required to make a bend is often determined by trial and error. The assumed neutral axis varies depending upon the bending method used, the location in the bend, and the type of stock being bent.

Direction of grain in a steel strip relative to the bend also has a slight effect on the length of metal required to make a bend. Bending across the mill rolling direction of the metal allows the metal to stretch more easily than bending the fibers or grain structure. However, bending at 90 degrees to the rolling direction results in a weaker stamping. Bend allowance depends more upon the physical properties of the material such as tensile strength, yield strength, and ductility than on the metal from which it is made.

Empirical rules

The exact bend allowance is the arc length of the true neutral axis of the bend. Above the neutral axis, metal is stretched; below it, metal is compressed. The problem is that neutral axis can only be approximated. Many manufacturers assume the neutral axis is 1/3 stock thickness from the inside radius of the bend for inside radii of less than twice stock thickness. For inside radii of two times stock thickness or greater, the neutral axis is assumed to lie 1/2 stock thickness from the inside radii. One reason for relatively less metal being required to make a tight bend is the sharp radius tends to be drawn or stretched slightly.

Many experts believe that the location of the true neutral axis from the inside radius varies from 0.2 to 0.5 times stock thickness. An important factor that determines the neutral axis is how the bend is accomplished. Less metal is required for a bend made by a tightly wiped flange than for an air bend on a press brake. Again, wiping the flange tends to stretch the metal.

Formulas and Data

Tables of data for inside of bend radii from 0.015- to 1.250-inch (0.38- to 31.75-mm), including metric equivalents for various materials and types of bends, have been developed and were once widely used. The formulas used to develop these tables are based on extensive experimental data. Such tables were very useful before the availability of the electronic calculator. The late Manufacturing Engineering Magazine Editor, Daniel Dallas who advised the writer during the editing of the Die Design Handbook third edition, pointed this out to the writer.

For 90 degree bends multiply the radius times 1.57 which is the number of radians in 90 degrees to determine the assumed amount of metal required to make the bend at the assumed neutral axis. For bends other than 90 degrees, multiply the number of degrees in the bend by 0.0175 which is the number of radians in a degree.

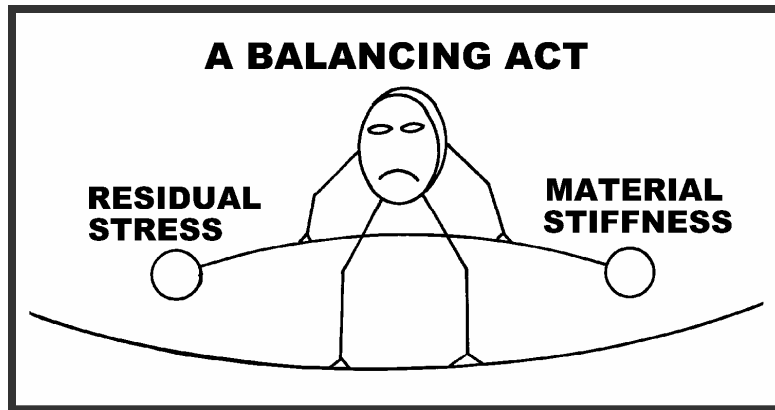


Figure 4. Springback occurs until the residual stress forces are balanced by the material's stiffness. *Smith & Associates*

Springback or Elastic Recovery

Whenever forming metals, some springback occurs. The cause of this springback is the residual stress that is an inevitable result of cold working metals. For example, in a simple bend, residual compressive stress remains on the inside of the bend, while residual tensile stress is present on the outside radius of the bend. The most common method of correcting for springback is to overbend the material to obtain the desired shape after forming. Simply stated, in a bend, residual compressive stress remains on the inside of the bend, while residual tensile stress is present on the outside radius of the bend.

When the bending force releases, the metal *springs back*. When the bending pressure is released, the metal springs back until the residual stress forces are balanced by the material's ability to resist further strain. Stiffness is a function of the material's modulus of elasticity. This explains why materials such as mild steel with a high modulus of elasticity (as compared to tensile strength) spring back less than materials with a lower modulus. An example of this is hard aluminum alloys having comparable tensile strength, to mild steel. The aluminum spring back is much more than mild steel.

Springback Compensation

The most common method to compensate for springback is to bend the material beyond the desired angle a sufficient amount and allow it to *spring back* to the desired angle after elastic recovery occurs. This method of springback compensation is termed overbending. Because of the uncertainty of the exact location of the neutral axis, initially employ trial-and-error methods when developing close tolerance stampings.

Many complex factors determine the amount of springback that will occur in a given operation. Because the exact amount of springback is difficult to predict, data for a specific material and forming method is often developed under actual production conditions to aid process control and future product development. If the die designer and builder fail to include correct spring back compensation into the die, the task of effecting the correction will need to be done by the repair facility of the press shop that uses the tool.

Factors That Affect Springback

Some factors that increase springback are:

1. Higher material strength
2. Thinner material
3. Lower Young's modulus
4. Larger die radius
5. Greater wipe steel clearance
6. Less irregularity in part outline
7. Flatter part surface contour

If a flanged part has a lot of irregularity in the flanged area and the part surface contour contributes to stiffness, the springback will be less. Large wiping-steel clearances can result in springback of several degrees or more.

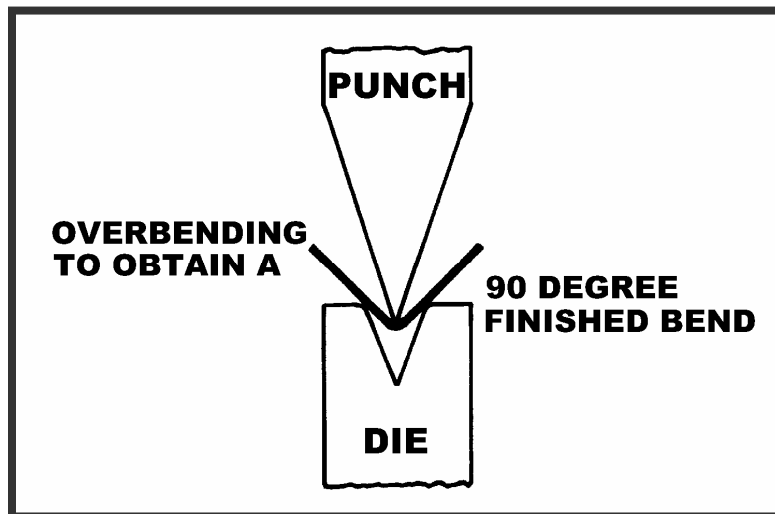


Figure 5. Simple tooling of the type used to air-bend sheet-metal parts in press brakes. Spring is compensated for experimentally by making test bends. The upper die is lowered a little and a hit made until the desired bend angle is obtained.

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Examples of Die Bending Operations

Example of Air-Bending Tooling

Press-brake tooling for air bending such as that illustrated in Figure 5 is quite simple. Air bending is one of the most common press-brake operations. This method of bending also requires minimum tonnages for the work performed. Exact repeatability of ram travel is required to maintain close repeatability of the bend-angle. The amount of overtravel is determined experimentally to compensate for springback.

Causes of Bend-Angle Variation

There are several causes of bend-angle variation, which occur during pressworking operations when bending materials. These include:

1. Changes in stock yield strength.
2. Variation in stock thickness.
3. Machine variations due to temperate changes.
4. Machine deflection, especially in long press-brake bending operations.

Compensation for any change of the conditions that affect the bend angle may require adjustment of the ram travel. Press brake bed deflection may require shimming of the tooling to produce uniform bend angles along the length of long bends. Some press-brake designs have automatic-deflection, compensating devices such as hydraulic cylinders built into the bed. Even with automatic compensation, adding shims may be required to correct for exact machine deflection.

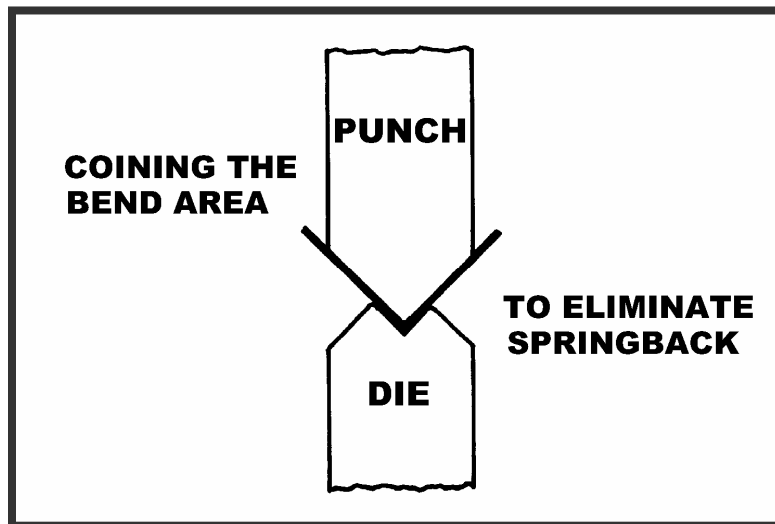


Figure 6. Coining the bend to obtain sharp accurate bend is a method that requires high tonnages, but produces sharp accurate bends. *Smith & Associates*

Coining the Bend to Control Springback

Coining has the advantage of producing sharp accurate bends with less sensitivity to material conditions than air bending. The disadvantages include force requirements many times higher than air bending, and accelerated die wear.

Figure 6 illustrates a press-brake die designed to *coin* the bend in order to obtain a precise angle-of-bend. This coining-action eliminates the root causes of springback, which are the tensile and compressive residual stresses on opposite sides of the bend. This is accomplished by pressure sufficient to subject thickness of the metal in the bend-area up to the yield point.

The tonnage required might be five to ten time that required for simple air bending. In addition, the higher forces will increase machine deflection. Air bending jobs that may produce acceptable bend angles throughout the entire length of the bend may require shimming if coining is required. The amount of machine deflection increases approximately in proportion to the developed tonnage.

Wipe Bending Operations

It is often not feasible to use V-bending tooling for bending. V bending is popular for press brake work. The tooling is simple and a variety of work can be accomplished. Usually only a single bend can be accomplished per stroke. This limits throughput. Accurate finished work requires that each previous step be accomplished accurately. Skilled experienced operators are required. A limiting factor is the cost of press brake work because of low throughput and the skill required to produce accurate work.

Wipe Flanging and Springback Control

Figure 7 illustrates a sectional view through a wipe flanging die. In this design, the flange steel attached to the upper die *wipes* the metal around the lower die. A popular method to control springback is to coin the top of the bend with the flange steel to control springback. A disadvantage is that this method provides very limited springback compensation and can result in a distorted bend angle condition. The top thickness of the bend can be squeezed beyond the material yield point by careful adjustment of the die shut height. Only the top portion of the bend is coined which can result in a score mark that might weaken the stamping and extrusion of the metal being coined.

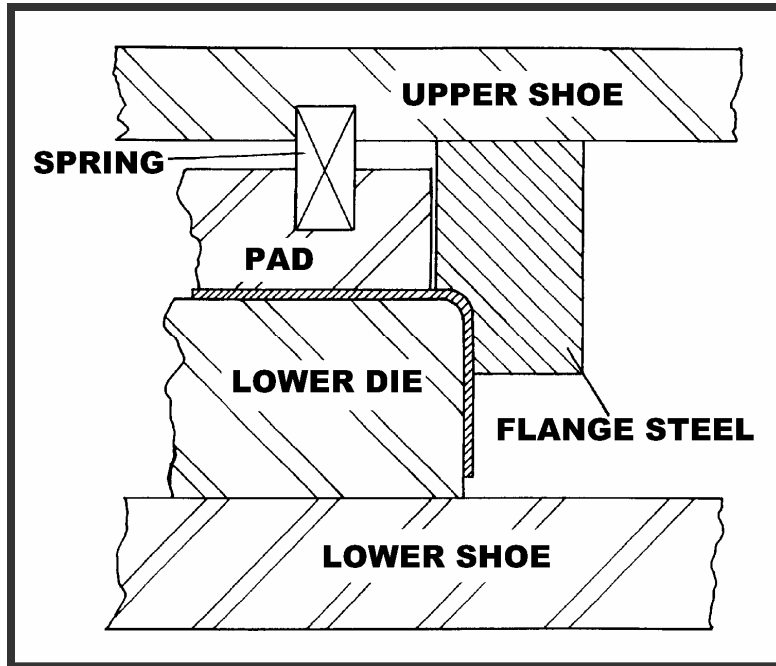


Figure 7. A sectional view of a wipe flanging die. *Smith & Associates*

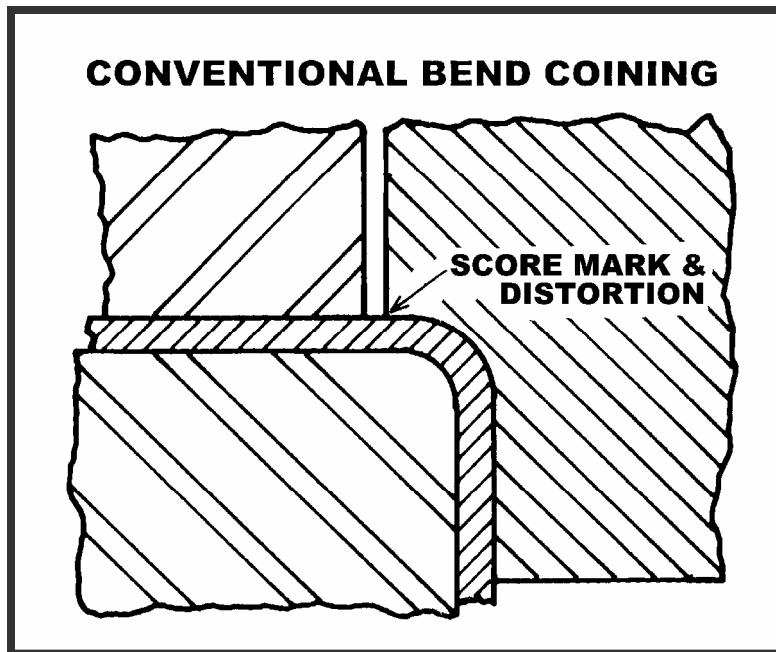


Figure 8. Close up view of the point of flange steel contact on the bend radius in a wipe flanging die. Coining the top of the bend provides limited control of springback and can weaken and distort the stamping. *Smith & Associates*

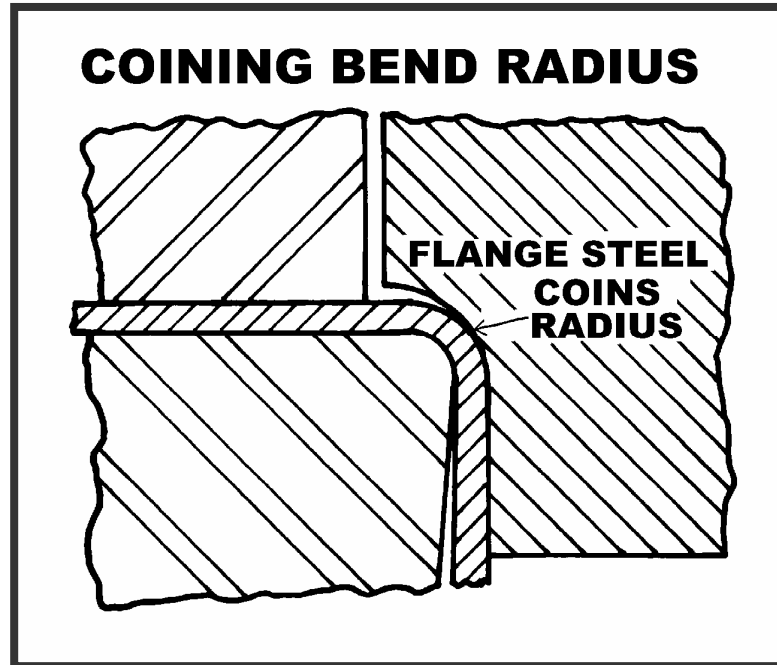


Figure 9. Sectional view of an improved springback control method. The side of the radius is coined. A relief angle is provided in the lower die steel. *Smith & Associates*

Improved Wipe Flanging Springback Control Method

If excessive coining pressures are applied, the metal at the top of the bend will be extruded, resulting in a weak and distorted bend condition. An improved flanging method is to relieve the radius in the flange-steel so it does not contact the top of the bend radius. One way is to relieve the flange-steel at approximately a 20-degree angle tangent to the radius. Another method is to machine the flange-steel to a radius somewhat larger than that of the outside of the bend. The flange-steel is positioned so that the tightest point is 45 to 60 degrees beyond the top of the radius.

The side of the form-steel is relieved five or more degrees to permit the material to be over-bent. This method is several times more effective than coining the top of the bend. Another advantage is that the improved bending process is not as sensitive to variation due to press adjustments and material conditions.

In developing the exact tooling geometry, remember that the metal in the radius will be stretched and thinned. This thinning is normal and usually is greatest in the middle of the bend. A good way to create the needed coining condition is to grind the inside part print radius on the punch and the outside part print radius into the form steel.

The die closure or bottoming condition is then adjusted so the central part of the radius is coined sufficiently to provide the correct bend angle—usually 90 degrees. This method normally is a superior method of forming bends in metal using wipe flange tooling as well as other bends where a correct bend angle is required.

Rotary-Action Bending

A patented rotary-action bender known as the Ready™ bender combines the low tonnage requirements of air bending with the accuracy and multiple bend capability of wipe-flange tooling.

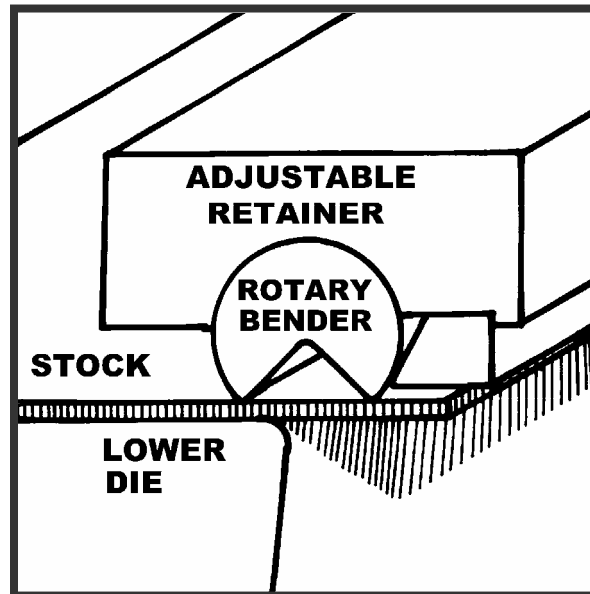


Figure 10. A Ready™ bender making initial contact with the stock. As the die closes, the bender both clamps and bends the stock. *Ready Tools, Inc.*

Figure 10 illustrates a ready bender making initial contact with the stock. As the upper die travels downward, the stock is clamped and bent by the rotating bender. Upon die closure, the rotary bending action progresses until the bend is completed. An optional relief angle in the lower die permits the rotary member to overbend the stock at bottom of stroke to compensate for springback control.

Rotary-action benders can bend angles up to 120 degrees. The rotary member is usually made of tool-steel heat-treated for long wear. The bending pressure is typically 50 to 80 percent less than that required for conventional wipe bending. The lower pressure permits many types of pre-painted materials to be fabricated without damaging the finish. Rotary benders can also be constructed of non-metallic materials such as hard thermoplastics for work with pre-finished materials.

Fine Adjustment of Bend Angle with Ready™ Benders

The bend angle adjustment with conventional wipe-flange tooling is usually made by adjusting the flange-steel up or down by shimming. In the case of rotary-action benders, the bend angle is adjusted by moving the assembly containing the bender in the horizontal plane relative to the lower die member or anvil. Attempts to obtain a tighter bend by excessive lowering of the press shut height can result in tooling damage.

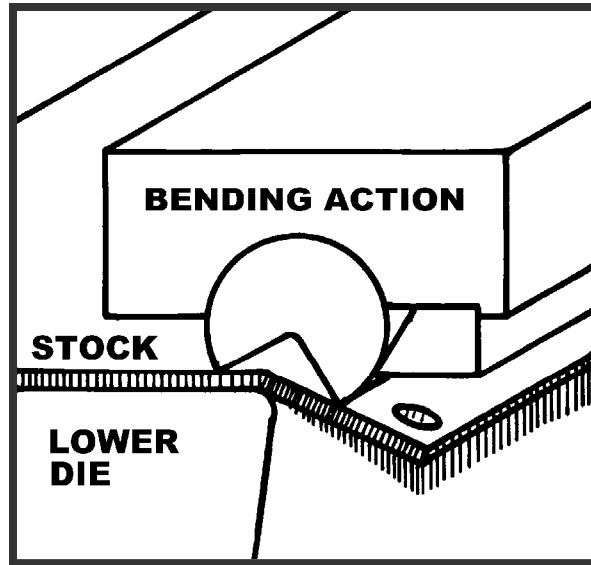


Figure 11. A Ready™ bender bending the stock through rotary action of the circular member which both clamps and bends the stock, Ready Tools, Inc.

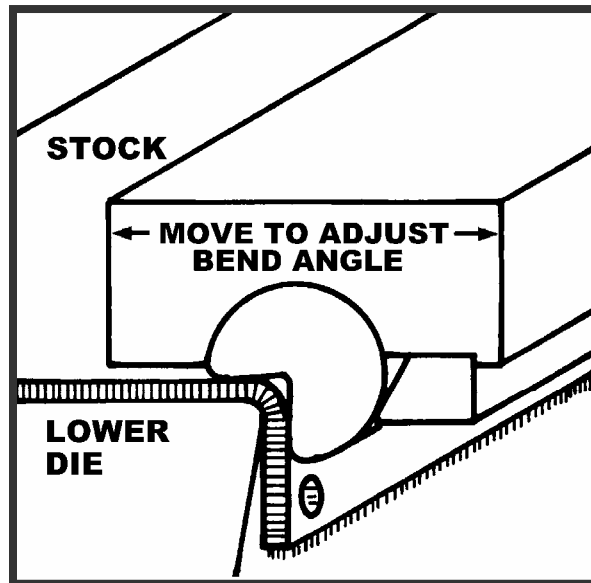


Figure 12. A Ready™ bender overbending the stock is over-bent at bottom of stroke to compensate for springback. Ready Tools, Inc.

Control of Bend Angle by Adjusting Pad Pressure

One of the most frequent stamping variables affecting quality is that of incorrect bend angles. Press brake tooling performing air bending can easily be compensated for bend angle variation by making a shut height adjustment. Many wipe flange dies have a provision to coin the bend radius slightly to control springback. Often pressroom technicians try adjusting shut height immediately to attempt to correct any part dimensional problem. Shut height changes can affect other part features that are sensitive to shut height such as embossments and identification stamps. Any shut height adjustment should be thought out carefully before a change is made to avoid undesired results.

The wipe bending sequence shown in Figures 13 through 16 shows how adjusting pad pressure can occasionally control the bend angles of a wipe flanging operation. The technicians in a pressroom where this procedure is used found that very low pad pressures would result in substantial overbend in a 90° wipe flanging operation. The job operates in a 60-ton (712 kN) OBI press. Why this overbending condition occurred was unclear until studied and documented.

Normal Pad Pressures

Normal pad pressures typically are in the range of 5% to 20 % of the forming force. However, in our case study, pad pressures this high always resulted in varying bend angles less than the specified 90°. It is to be noted that no means to coin or restrike the bend to control springback is provided for in the wipe flanging detail design. However, carefully controlling pad pressure at low values was found a workable method to obtain 90° bends on this job. In fact, several degrees of overbend can be obtained if desired.

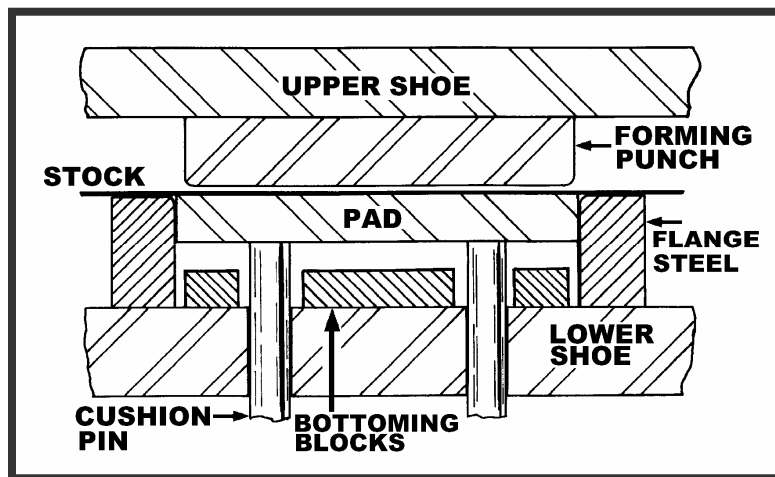


Figure 13. A wipe flanging die closing with a blank to be formed in place. Note the die cushion pressure pins and pad bottoming blocks. *Smith & Associates*

The Effect of Low Pad Pressure on Overbending

In this study, the pad pressure adjustment is critical. Why this method works in this case can be explained. While conventional overbending, bend coining, or Ready Bender™ rotary bending methods may be preferred, this method is understood and may be useful.

The operation involves wipe bending a 0.050-inch (1.37 mm) 6-inch by 9 inch (152.4 by 228.5 mm) rectangular steel blank on two sides. The cold rolled steel material was checked and had a minimum yield strength ranging from 45 to 50 ksi (310 to 345 kPa). Pressroom troubleshooters expect normal variations in material thickness and hardness to cause product variation. The finished part is a symmetrical "U" shaped formed stamping with two straight flanges of equal length. A sectional view of the die with the blank in place is shown in Figure 13.

The die cushion is operated in the 5 to 7 psi (36 to 48 kPa) range. The available cushion force at 80-psi (550 kPa) is 5 tons. This provides a pad force of only 625 pounds (2.8 kN) over a 6-inch (152.4-mm) square pad—low for accurate stock control. However, the symmetry of the part avoided part slippage and product variation.

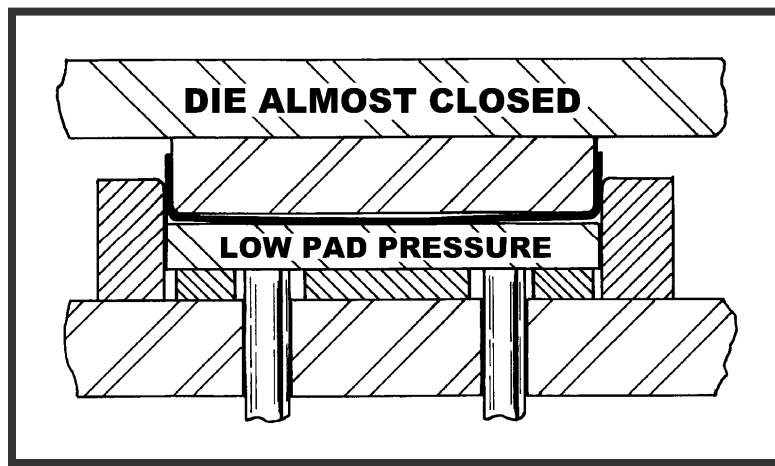


Figure 14. A wipe flanging die having low cushion pressure as it nears the bottom of stroke. Note that the blank has a crown or bow. *Smith & Associates*

Figure 14 illustrates the flange die near bottom of stroke. The excess metal in the crown or bow is deformed but the yield point of the material is not exceeded. As the die bottoms out on the pad bottoming blocks, the excess metal is forced into the bend radii in the corner of each flange. Having excess metal in the crowned or bowed blank, as the die closes is a result of using low pad pressure. This loose or excess metal is also the key to achieving controlled overbending.

Using Pad Pressure to Control Overbend ¹

This is an observed factor in bending and recommended for understanding why it happens for those who may encounter this condition. It is not recommended as a design practice since better means of controlling bend angles are available to the designer.

As the pad pressure is increased, the amount of bowed or loose metal is between the forming punch and pressure pad reduced. This factor in turn decreases the amount of overbend because there is less metal to force into the bend radius as the pad bottoms out. If the pad pressure is high enough to hold the blank firmly against the forming punch throughout the press stroke, the part flanges will be formed less than a 90° angle. The action of the metal being forced into the bend radii at bottom of stroke is shown in Figure 15 and product variation as a function of slight pressure variations is shown in figure 16.

Practical Applications and Process Limitations

Using this method of springback control is not recommended for a forming application of this type for reasons, which include the following:

1. Die cushions operated at very low pressures are apt to provide force variation due to a stick-slip packing adhesion phenomenon known as *stiction*.
2. Slight changes in stock thickness or temper will result in flange angle variation.
3. Low pad pressures are apt to result in blank slippage and product variation. This is especially likely in the case of non-symmetrical parts.

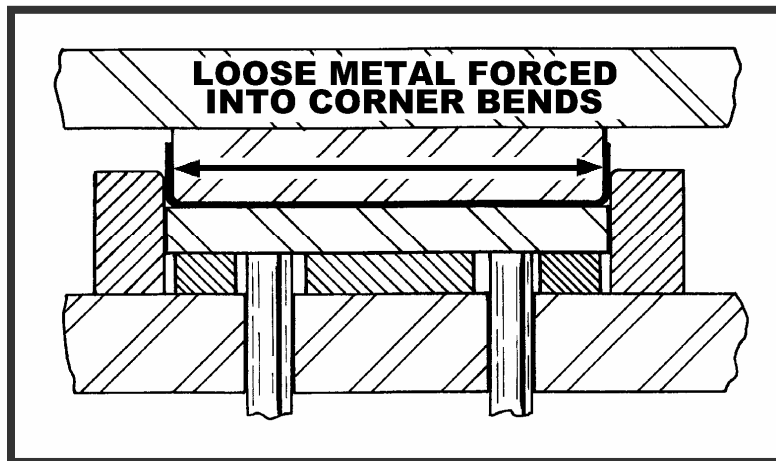


Figure 15. A wipe flanging die shown at bottom of the stroke. As the pad forcefully contacts the bottoming blocks, the loose metal is forced into the bend radii resulting in a controllable overbending condition. *Smith & Associates*

¹ D. Smith, *Die Design Handbook*, Section 6, Shear Action in Metal Cutting, The Society of Manufacturing Engineers, Dearborn, Michigan, © 1990. Section 6 has data on springback compensation methods, which are discussed in detail.

4. Wipe flange details that provide for bend radii coining and the use of Ready Benders™ illustrated earlier are effective and dependable methods of controlling the bend angle variations caused by springback.

However, this method can be useful under some difficult flange bending conditions when a part that is strong and dimensionally accurate is required. One example of a difficult-to-bend stamping is a commercial truck or trailer spring hanger bracket. Other parts include tilting chair hardware and a variety of appliance stampings.

Case Study Success Factors

The main disadvantage of using this method is the care required dealing with process variables. It is not considered the best springback control for the flanging operation in our case study. The factors that permit part geometry to be held within specifications include:

1. The part is symmetrical which balances the lateral forces result from the wipe flanging operation.
2. The flat blank is nested in accurately doweled gages that help prevent lateral shifting until the bend is correctly started as the forming punch contacts the work.
3. The operator frequently checks the parts to assure conformity to dimensional tolerances. This includes catching the parts in a small plastic bin as they are produced for inspection before putting them in the shipping container.

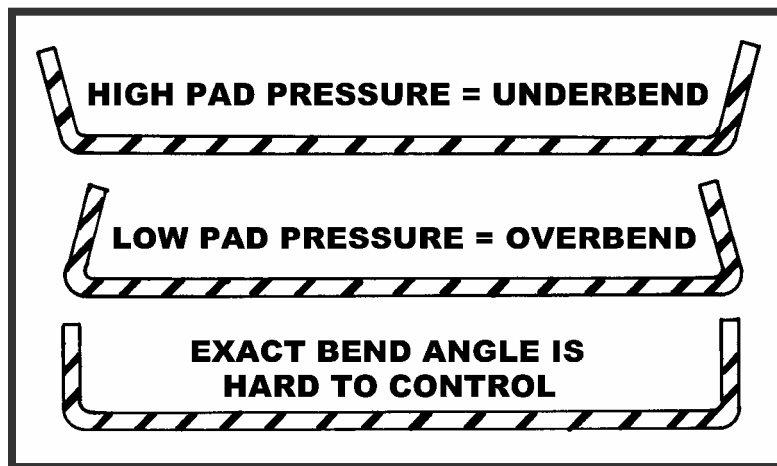


Figure 16. Examples of how bend angles can vary with pad pressure settings.
Smith & Associates

Recommended Practical Applications

Lateral shifting of the blank is the greatest concern when using less pad pressure than that recommended for good design practice. Low pad forces that permit bowing of the stock, which is subsequently forced into the bend radius, can have practical applications in

heavy parts that are difficult to flange. Recommended stock locating and control measures include:

1. The blank should be nested in accurate robust gages to prevent lateral shifting until the bends are correctly started as the forming punch contacts the work.
2. Two or more locating pins projecting from the forming punch should be used to pick up mating holes accurately located in the blank.

The locating pin holes can be non-functional tooling holes if they do not affect the function of the finished part. The use of robust pins in the punch will prevent lateral shifting if the side forces are not great enough to distort the locating pin holes in the blank.

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