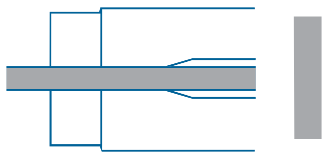
COLD FORMING BASICS FOR INDUSTRIAL FASTENERS

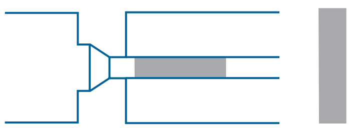
PIVOTPOINT INC.

PINS > CABLES > **SOLUTIONS**

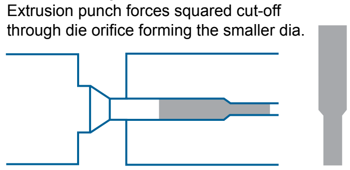
Station 1—Cut-off
Coiled wire is fed into cold-former.
Slug is cut off to specified length.



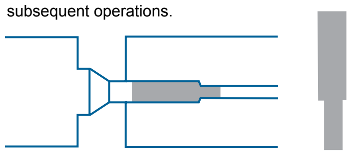
Station 2—Squaring
Ends of cut-off are squared.



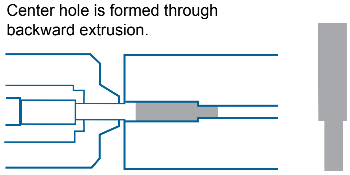
Station 3—Impact Extrusion
Extrusion punch forces squared cut-off through die orifice forming the smaller dia.



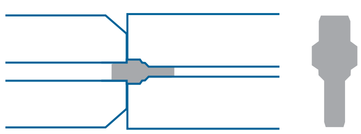
Station 4—2nd Blow Extrusion
Shoulder is squared, and centering marks formed in ends to assist in subsequent operations.



Station 5—Backward Extrusion
Center hole is formed through backward extrusion.



Station 6—Forward Extrusion
Taper is formed above large shoulder. Two smaller shoulders are formed and stem is forward extruded.



Station 7—Finishing Blow
Large shoulder is trimmed forming sharp-cornered hexagon for wrenching.

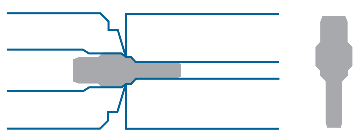


Fig. 1 Today's sophisticated cold forming machines include as many as seven die stations. Here is one possible sequence for producing a part on a seven-die header.

Introduction to Cold Heading

Cold heading is a cold forming process that essentially involves applying force with a punch to the end of a metal blank contained in a die. The force must exceed the metal's elastic limit (yield strength) to cause plastic flow. It may be considered a forging operation without heat. Heading includes upsetting and extruding, and is often performed in conjunction with other cold forming operations such as sizing, piercing, trimming, thread rolling, blank rolling and pointing.

Upsetting, a term used synonymously with heading, means to form a head on a fastener, or a bulge in a cylindrical part being headed. Extruding means either decreasing the diameter of the blank by pushing it through a hole, or punching a hole in the center of the blank and allowing the metal to flow backward over the punch. In both cases the volume of the metal blank remains constant; it is merely reshaped by upsetting or extruding.

Heading is a metalworking process that goes back before the turn of the century and for many years was used only to produce simple fasteners. Today heading is a high-speed, automated and multi-station operation that is capable of producing not only increasingly complex metal fasteners economically, but a growing variety of other components, including some that are asymmetrical. Combined with this dramatic improvement in heading equipment is the ability to successfully cold form parts from tougher metals, including stainless steels and high temperature alloys.

Advantages of Cold Heading

Heading differs considerably from machining where material is actually cut away to form a finished part. In heading there is no scrap except for a minimal amount which may occur during secondary operations, such as trimming. Heading, however, is not intended to replace machining. There are many cases—very complex parts, larger parts or low production requirements—where machining is more economical. In fact, there are some materials that cannot be headed. Heading and cold forming now, however, enable more economical and faster production of many fasteners and other parts that previously could only be made with machining.

Why Cold Heading Is On the Increase

Fasteners represent the single largest category of headed parts produced. Today, the multi-billion-dollar domestic fastener industry manufactures some 260 billion fasteners from a variety of materials. Many people are not aware that heading and cold forming are used to make a wide range of components—from spark plugs to axles. Cold heading and forming technologies continue to expand and improve.

How the Heading Process Works

Heading equipment primarily takes round wire in a coil form and converts the wire into desired parts at a high rate of speed.

Four basic steps comprise the heading process:
1. A length or blank of wire is cut from the wire coil.
2. The blank is placed in line with a cavity or die.
3. The blank is forced into a desired shape with one or more upsetting and/ or extruding operations called blows.
4. The part is ejected.

This heading process may be part of a sophisticated cold forming machine that has additional points or stations where further operations—trimming, piercing or pointing—are carried out following upsetting and extruding. Most headers, however, are of the single or double blow variety. Multi-station part formers can include up to seven die stations. The part being formed is transferred from one die to another until a completed part is produced. The typical arrangement is horizontal, though some multi-station formers are arranged vertically; the part progresses from the first die station at the top to the last die station at the bottom in this case.

Forming parts on a heading machine using upsetting or extruding is not merely a matter of hammering the metal blank until the desired shape is reached.

The punch and die work together. The punch is a simply shaped hammer that strikes the blank on its end. This forces the other end into the die which produces, for example, a headed bolt. In a typical heading machine the punch, carried on the gate or ram, moves toward the blank with a great deal of force, striking it with an impact of many tons per square inch.

Perhaps no operation in the cold heading sequence is more important than the wire cut-off to form the blanks. This is because the volume of the finished part essentially equals the volume of the blank from which it was made. Since part dimensions and part volume are interdependent, blanks must be cut to consistent volume.

In many instances the upsetting of the blank is controlled by the punch and takes place outside the die. However, the head can also be formed in the die, in both the punch and die, or between the punch and die, a technique called free upsetting.

Commonly, each die station in the heading machine has two punches that oscillate to form the fastener head. The first punch action partially shapes the head and is called coning, while the second punch finishes the head.

A heading machine includes either solid dies or open dies. Solid dies are more common; open dies are used when a fastener requires a very long shank that cannot be fabricated with a solid die. In solid die headers, the knockout (or kickout) pin is equally important to the interaction of the punch and die. The knockout pin serves as a support at the back end of the blank as the punch strikes the front end, and the knockout pin then ejects the finished part.

Different combinations of upsetting and extrusion blows are possible, but upsetting is generally the first blow, with an extrusion blow following. Upsetting and extrusion can take place in the same blow.

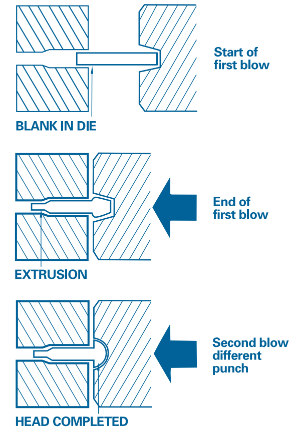


Fig. 2 The typical one-die, two-punch method is common in producing headed parts, especially fasteners. The first blow combines partial head upset (coning) with shank extrusion, while the second blow finishes head shape.

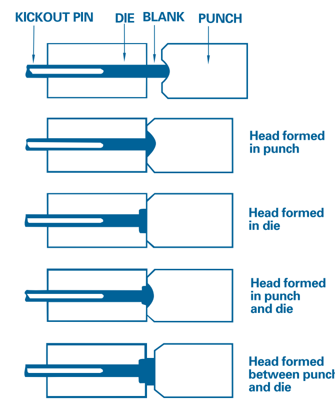


Fig. 3 The upset of fastener heads is accomplished using one of these four methods:
1. Head formed in punch.
2. Head formed in die.
3. Head formed in punch and die.
4. Head formed between punch and die (free upset).

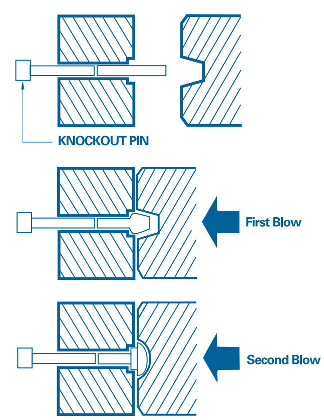


Fig. 4 The knockout (or kickout) pin plays an important role in solid die heading. The pin acts as a blank support and also ejects finished parts.

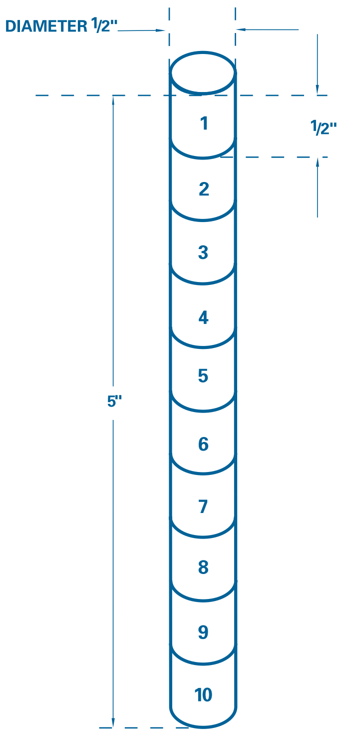


Fig. 5 This simplified diagram shows how diameters of wire are calculated to determine upsetting limits.

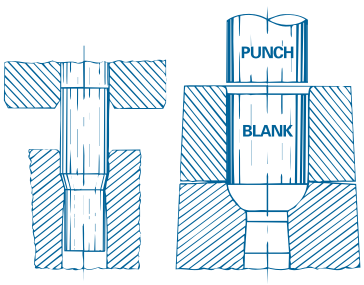
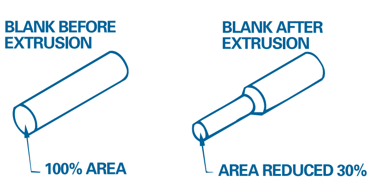


Fig. 6 Extrusion is either open (left) in which the blank is forced under pressure into a smaller diameter die hole, or it is trapped where the blank is totally confined within the die prior to extrusion (right). Trapped extrusion permits reductions in area of up to 75 percent, while open extrusion allows only 30 percent area reduction in one blow.



Controlled Upsetting

There is a limit to the amount of material that can be upset in one blow under controlled conditions. Forming a more complex part in which more metal is moved farther is better accomplished in two stages, or blows, which is why single-die, double-stroke (two punches) headers are more widely used.

Upsets are calculated on the basis of wire "diameters". The length of the blank is divided by the wire's diameter. Thus, a 5" blank of 1/2" wire is 10 diameters long; a 10" blank of 1" wire is also 10 diameters long. A rule of thumb is that in a single blow on a solid die header, the maximum amount of wire that can be upset under control is 2-1/4 diameters. Theoretically we could use approximately 1" of the 5" blank to upset into a fastener head. Most single blow heading, however, is within the 1 to 1-1/4 diameter range. With a two-blow heading sequence, up to 4-1/2 diameters can be upset.

At the moment of contact between the punch and blank, the part of the blank to be upset extends out of the die unsupported. If this unsupported length is too long, or greater than 2-1/4 diameters, the blank will simply bend over on itself when struck, which produces what is known as a cold shut defect. With our 5" blank, 1" unsupported can be upset in one blow; 2" unsupported can be upset in two blows. If an attempt was made to upset 3", it could not be controlled since this equals 6 diameters.

There are, of course, exceptions to the rule. A sophisticated header with a sliding punch that supports more of the blank allows two-blow upsets of 6-1/2 diameters. Also, in multi-station headers the number of diameters that can be upset is limited only by the available dies.

This relationship between diameters of wire and upsetting is critical. Improper calculation can mean mismatching the diameter of the feed wire with the machine's capabilities.

Extruding

Many cold headed parts are also extruded. Forward extrusion occurs when the metal blank is forced to enter a die diameter smaller than itself. Length is increased, while diameter is decreased. Backward extrusion involves subjecting the blank to pressure from an angular punch. Because it has no place to go, the metal literally squirts along the outer perimeter of the punch, flowing backward. Forward extrusion is used to produce bolts, screws or stepped shafts; backward extrusion is useful in forming a variety of cylindrical shapes such as nuts, sleeves and tubular rivets. Like upsetting, extrusion simply rearranges the shape of the blank and there is no loss of material.

Extrusion can be in an open or trapped (contained) manner. Open extrusion means the blank is forced into a die; trapped extrusion means the blank is totally contained within a die prior to extrusion.

While controlled upsetting is based on diameters of wire, extrusions are governed by the area reduction of the blank (calculated as a percentage) and the angle of extrusion. The basic ground rules for open extrusion, which is more widely used than trapped extrusion, is that the percentage of area reduction in one blow cannot exceed 30 percent. The extrusion angle (the angle the shoulder of the extrusion makes with the original blank) cannot exceed 30 degrees.

Contained (Trapped) Extrusion

This practice is responsible for allowing headers to produce more complicated and multi-shaped parts formerly made on automatic screw machines. It's especially applicable for extruding larger diameter wire to the required shank, a method that makes it possible to increase the ratio of the head diameter to the shank diameter.

Types of Heading Machines

Many types of heading machines are available and they combine standard and special tooling to carry out a variety of heading and cold forming operations and sequences. Some weigh as much as 500,000 pounds and have seven die stations. Since only so much metal can be formed in one blow, the number of dies and wire diameter acceptance range are usually used to describe machine types. Typical measurements cover wire diameter, blank length and heading force.

Heading machines are divided into two basic types, crank and toggle headers. The toggle type, the older version, provides a mechanical advantage and gives two forward strokes per machine revolution. The crank machine is capable of one blow per revolution. Neither is considered to be more advantageous. The toggle type is used to produce simpler parts, while the crank version, which is more prevalent today, is used for more complex forming.

These are the common machines available:

Single-Stroke: Has one die, one punch.These are used to make simple parts that can be formed in one blow. Ball headers are a variation of this type. Production rates up to 600 parts per minute are possible.

Single-Die, Double-Stroke: Considered the most versatile and widely used machine. It includes one die, two punches, and produces most screw blanks and other fasteners. Wire capacity ranges up to 3/4" diameter. Production up to 450 parts per minute. Some double-stroke headers are custom designed for tubular rivet production.

Three Blow, Two Die: Includes two dies and three punches,and has the same basic design as the double-stroke header. It offers an added advantage of extruding or upsetting in the first die, with double-blow heading, or heading and trimming in the second die. It's used to produce large-head small-shank fasteners, or parts requiring trapped extrusion and upsetting. It's also excellent for making stepped-diameter parts where transfer between dies would be difficult.

Progressive or Multi-Station: These are equipped with as many as seven die stations; most are two-to-five-die machines with an identical number of punches. A simple transfer mechanism moves workpieces from the cutter through successive dies. Multiple upsetting blows, combined with extruding, piercing and trimming, make these machines ideal for long shank parts production. They can accommodate materials up to an inch in diameter with under-the-head parts lengths of up to nine inches.

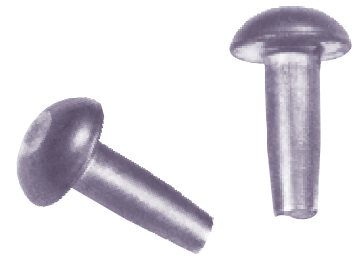


Fig. 7 Simple upsetting was used for the screw blank on the left, while contained extrusion was used to form the part on the right.

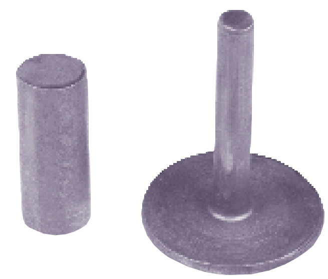


Fig. 8 The shank of this part was trap extruded, and the head trapped and upset to produce the exaggerated head to shank ratio.

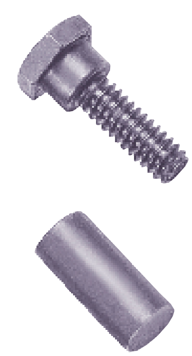


Fig. 9 The shoulder on this part is the same size as the wire diameter, while the shank was extruded and the head upset and trimmed.

Boltmakers: These are three- and four-die headers that combine heading, trimming, pointing and threading in the same machine. Materials up to 1-1/2” in diameter are used, and production rates vary up to 300 pieces per minute. Boltmakers produce completely finished hexagonal and socket capscrews, as well as a number of other special threaded parts.

Cold Nut Formers: Standard or special nuts are run on this machine with five die stations. A simple transfer mechanism rotates the blanks end-for-end between successive dies, which allows for working of the metal on both sides to produce high quality nut blanks. Center plugs are easily reclaimable, so there is very little material waste. Nuts an inch or larger are run on this machine.

Cold Formers: Four, five or six die stations and a variety of transfer mechanisms make these the most versatile heading machines. Forming operations for making odd-shaped parts can be combined on this one machine. They are set up to feed wire, bar or blanks, and can form metal cold or warm. Materials in the 2” diameter and larger range can be run. Multiple upsetting blows combined with extruding, piercing and trimming operations make cold formers ideal for producing long shank or specially designed components.

All the above machines have five basic operations—upsetting, extruding (forward and backward), trimming and piercing. Other related operations like swaging, coining or embossing can also be performed. Since all heading machines include a predetermined number of die stations or operations, the design of parts must match equipment capabilities.

Materials That Can Be Headed

Although at one time it was felt cold heading techniques were somewhat limited to ductile materials with low work hardening rates, that is no longer the case. With today’s more advanced equipment, techniques and tooling, higher strength materials like the stainless steels and high temperature alloys are routinely being cold headed. A number of stainless steels are produced with modified compositions to provide lower work hardening rates.

Formability Considerations

Strength of materials is the determining factor in the ease of cold forming. The yield and tensile strength of an alloy governs formability. Yield strength is the point at which the metal begins to deform permanently; tensile strength is the point at which the metal begins to tear apart. Plastic flow occurs when the force applied exceeds the material’s yield strength. If the metal is stressed beyond its tensile strength during forming, the blank splits, cracks or breaks. The range in which a metal can be cold worked lies between its yield and tensile strength values.

Tensile strengths (ultimate strengths) found in most technical literature differ from the actual strengths of the materials being formed in the header. These strengths, therefore, must be considered in cold forming. The strength of a material is affected by both the temperature at which it is being formed and by the speed with which it is being formed. It is also affected by the geometry of the part being made.

What occurs physically with materials during the heading process is very complex. While it can be frustrating, for example, when trying to determine exactly why certain materials may crack, it is comforting to know that modern technology is addressing this problem. CAD/CAM techniques are being employed to more accurately predict and control what happens to materials in the headers. Software packages are available that can allow design engineers or operators to precisely determine if slowing the part production rate per minute would eliminate cracking problems.

Cold worked metal work (or strain) hardens due to a reorganization of its microstructure. A series of cold forming operations means both the yield strength and tensile strength increase. However, the yield strength increases faster than the tensile strength, which narrows the metal's formability range mentioned above. Depending on the type of metal, this range can become so narrow that further attempts to cold work the metal result in fracture.

Work hardening accounts for the increased strength of formed parts, and there is an associated increase in tooling pressure required to deform them. The standard grades designed for cold heading take into account the desirability of low cold working rates.

Design Versatility: Cold heading or forming opens unlimited possibilities to the part designer:

1. Cold forming allows use of high strength parts to be produced from non-heat-treatable alloys.
2. Cold forming is often the most cost effective way to produce complicated configurations compared with profile milling, electric discharge machining, hobbing or chemical etching.
3. Cold forming has inherent capabilities for greater strength and high production rates.

Designers can, and should, rely on the expertise of cold forming production people who are most familiar with machining capabilities. Extruding, for example, is an efficient and highly economical method for creating two or more different diameters on a part. With backward extrusion, the designer has an excellent way to form tubular shapes, including those produced with double reverse extrusions. Multi-station headers also contribute to the designer's ability to produce a component that requires closely allied cold forming operations.

Variety of Sizes, Shapes, Part Complexity: Economically produced, cold formed parts today include bolts, studs, screws, rivets, special fasteners, cams, valves and many other components requiring the diameter of the head to be substantially larger than the shank. Total upsetting of the blank also is performed on cold headers to mass produce nuts and balls for ball bearings. Symmetrical parts are the easiest to cold form and cylindrical parts require only that a transfer mechanism move them from one die to another. Asymmetrical parts require positioning at each station, which calls for close cooperation between the product designer and tool engineer.

Tolerances: Tolerances vary with the style of the upset and, as with any other manufacturing process, closer tolerances require greater cost and precision. Diameter tolerances in cold forming operations are easily held within acceptable limits for standard fasteners. Tolerances are naturally affected by tool wear, so a check on die wear is mandatory when running parts with tighter tolerances.

Advantages of Heading

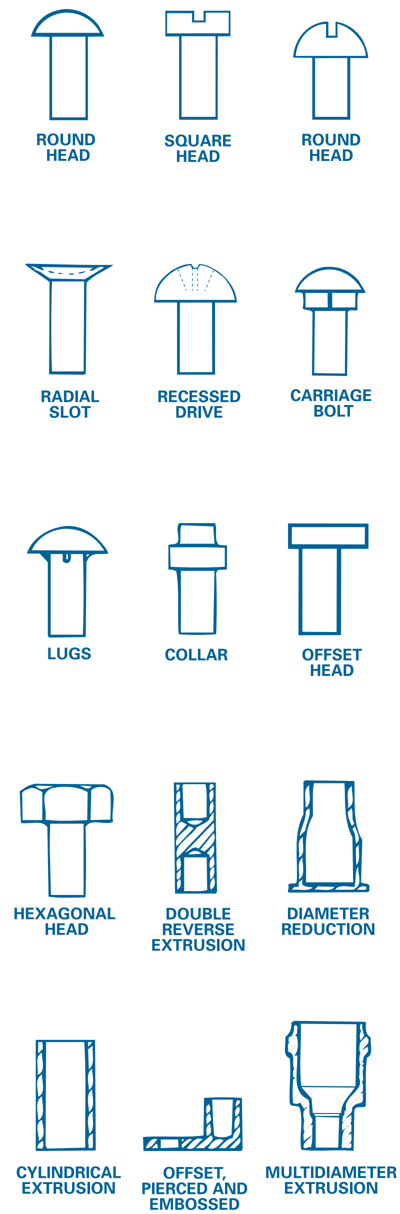


Fig. 10 A wide range of designs are possible for cold headed parts.

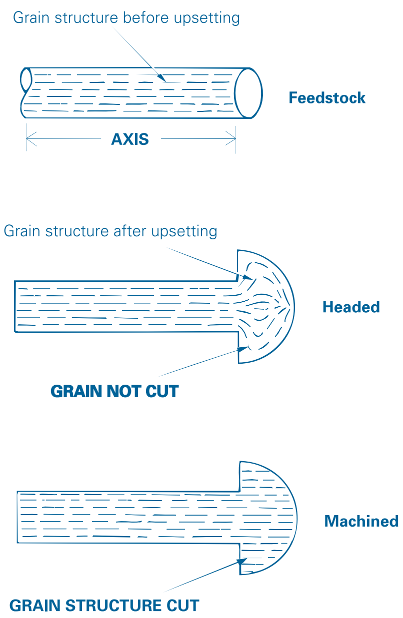


Fig. 11 Heading improves the finished part's grain structure by making it conform to the flow of the design. The machined fastener on the bottom indicates how metallurgical structure is weakened by operations that cut across flow lines.

Positive Metallurgical Effects: A primary advantage of cold forming is maximization of metallurgical properties in the finished part. The upset process actually causes the metal to flow along the axis of the blank; the grain structure is rearranged in the process to follow the contour of the part. This new grain structure supports the part and adds strength to it. Cutting, on the other hand, weakens grain structure. Metal cut away from underneath a bolt head means cutting the grain structure at the same time, so the bolt head is now weaker than the stock from which it was cut.

Cold heading involves working of the metal far below its recrystallization temperature. Existing grains are worked and no new grains are formed. This improves strength, hardness, toughness and fatigue resistance. Cold worked grains are usually finer than in hot-forged parts and the grain flow lines established by the various cold forming operations remain uninterrupted in the finished part. The result is enhanced strength at critically stressed corners. This metallurgical advantage often allows headed parts to be smaller without sacrificing properties.

High Production Rates, Repeatability: Today's headers can turn out parts at a rate as high as 100 times greater than that achievable with machining. While production rates are controlled by part size and complexity, heading and cold forming machines are automated production lines that take raw material and convert it to finished parts, ready for use. In a multi-station header where all the die units are working in unison, a finished part is ejected with every stroke. With good die design, low temperature and good lubrication, repeatability is excellent.

Material Savings: Cold forming is a type of "chipless machining." Parts are produced to net or near net shapes. The only waste comes from piercing and trimming. Heading scrap losses average from one to three percent, while turning or forging can produce scrap losses as high as 75 percent. An excellent example of material savings occurs in the cold forming of spark plug bodies. Prior to using cold forming, the pieces were cut with scrap losses averaging 74 percent. Now, the bodies can be cold formed 10 times faster and with scrap losses of only six percent.

The weight of a finished part that is headed can generally be held within ±1 percent when required, or to even ±0.2 percent when more precise cut-off is used to produce blanks. Oftentimes further machining is not required, and on many jobs cold forming eliminates secondary grinding.

Finished Quality: Longer part life is a benefit of cold formed parts since the controlled flow lines offer added resistance to impact, fatigue and shear failure. Cold forming means improved surface finishes. Extruding may improve surface finish from 10 to 100 micro inches and upsetting results in high quality finishes when the part is confined in the tooling or comes in contact with tooling surfaces. High quality finishes result when a high quality wire feed stock is used.

Disadvantages of Heading

Heading, like any other metalworking process, has its limitations. Relatively simple designs that can be produced on standard one- or two- blow headers usually require a minimum quantity of about 5,000 parts to cover tooling costs and set up. Complex parts that call for multiple dies, development work and other procedures usually require a quantity of at least 25,000 to 30,000 pieces. Larger or more complicated designs may not lend themselves to cold forming, but require machining instead. Some materials, because of their exceptionally high strength levels, may exceed the formability range limits for cold forming.

Examples of cold formed parts available from Pivot Point Inc.

The information and data presented in this publication are typical or average values and are not a guarantee of maximum or minimum values. Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make his or her own evaluation and are not intended as warranties, either express or implied, of fitness for these or other purposes. There is no representation that the recipient of this literature will receive updated editions as they become available. Information provided courtesy of Carpenter Technology.

PIVOTPOINT INC.

*PINS > CABLES > **SOLUTIONS***

pivotpins.com

PRECISION MADE
in the
U.S.A.

Pivot Point is proud to manufacture the majority of our fasteners in the U.S.A.

761 Industrial Lane
P.O. Box 488
Hustisford, WI 53034

(800) 222-2231
(920) 349-3251 Int.
(920) 349-3253 Fax
mail@pivotpins.com