Feb. 14, 1961  D. E. ARMSTRONG ET AL  2,971,556  COLD TUBE BENDING AND SIZING  

Filed Nov. 12, 1959

FIG. 7.  

FIG. 8.  

FIG. 9.  

FIG. 10a.  WRINKLES.  

FIG. 10b.  

FIG. 11a.  

FIG. 11b.  COMPRESSION DIRECTION  

TENSION DIRECTION  

FIG. 12.  GAP OR UNSUPPORTED AREA  

FIG. 13.  

FIG. 14.  

FIG. 15.  INVENTORS  

David E. Armstrong  
Thomas J. J. Dunn  
Walter H. Stidum  
Gerald P. Roesser  

BY  

Abraham A. Trafton  
ATTORNEY
COLD TUBE BENDING AND SIZING


Filed Nov. 12, 1959, Ser. No. 852,462

20 Claims. (Cl. 153—32)

The present invention relates generally to a method and apparatus for simultaneously cold-forming and cold-sizing of open-ended metal tubular material to its final shape in a shaping die under opposing forces within the leading edge and against the trailing edge of the tubular workpiece and is specifically adapted for the manufacture of open-ended tubular fittings of metals from open-ended metal blanks which are difficult to cold-form and cold-size in the shaping die by reason of the hardness of the metal or by reason of the seizing and galling characteristics of the metal against the die under cold-forming conditions.

The present invention is an improvement over the method disclosed in Patent No. 2,907,102 to two of the inventors herein.

The apparatus of the present invention differs mainly from that in Patent No. 2,907,102 in respect to the utilization of a multiple part mandrel formed of elastomeric material, said multiple part mandrel having end-retaining sections formed of homogeneous hard elastomer and a middle section of soft homogeneous elastomer. The hard elastomer end sections of the multiple part mandrel have a critical modulus of elasticity within a relatively narrow range, and further have a limited range of hardness to provide a brake-shoe type of frictional engagement of the retaining end sections in direct contact with the inner walls of the open-ended tubular stock whereby extrusion of the soft middle section is prevented under the extremely high pressures which are developed within the tube during forming and sizing. These end sections are further characterized by a good elastic memory to permit these frictional engaging end sections to quickly recover and return to their original shape for easy removal from the finished tubular product and be reused in the multiple mandrel assembly for mass production.

The method and apparatus of the present invention enable the rapid production of uniformly formed and sized product from tubular stock of hard metals and metals which are subjected to seizing and galling as illustratively shown in Tables A and B below, with practically no waste of the metal.

The art has long recognized the distinction between the cold-forming of hard metals of the type as shown in Tables A and B below and the relative ease of cold-forming of metals which are soft and have good lubricity, such as, for example, copper, copper base alloys, zinc and zinc base alloys. In the case of the soft metals or metals of good lubricity, cold-forming operations are carried out prior to a separate sizing.

Wrinkling and buckling occur with the hard or seizing metals in the region of the smallest radius during forming to a 45°, 90° or 180° L which is readily ironed out during the sizing operation for soft metals but which cannot be carried out for hard metals.

It is a necessary requirement of the present invention that the leading edge of the hard tubular blank metal which is beveled at the start of cold-forming dare not be restrained by shouldering or spherical capping where-

by the flow of metal in the tube blank during cold-forming causes upsetting of the hard metal. By use of a freely floating leading guiding member within the workpiece the flow of metal is such that upon completion of the formed 90° L the opposite side of the blank has been flowed forwardly to be square with the leading bevel of the tubular blank. If the metal flow is restricted by shouldering at the leading edge the upsetting of the hard metal which occurs results in the production of wrinkles, thickened areas and unduly thinned areas in the finished fitting which cannot be removed while maintaining the desired dimensional tolerances of the formed product.

The prior art recognizes that wrinkling readily occurs during cold-forming of hard metals having relatively high tensile strength in the order of about 70,000 p.s.i. It is not practical to try to iron out in hard metals, such as stainless steel, wrinkles which are caused by upsetting of the metal. Once the hard metal has been upset and wrinkled, the metal cannot readily be thereafter mechanically smoothed to size in the cold and cannot be smoothed in heated condition without completely altering the structure of the metal. It is the microstructure of the metal which affects the metallurgical characteristics and the physical properties of the metal and heating alters this structure.

Thus, a cold-forming operation carried out for hard metals readily wrinkles the hard metal and it is necessary thereafter to iron out the wrinkles by processes involving heating. The ironing process suggested in the prior art requires a series of heating and mechanical working steps to make the metal malleable and ductile. Ironing which must therefore be carried out at high temperatures defeats the entire purpose of the present invention which is expressly designed to carry out a forming and sizing operation in the cold.

The present invention provides a freely floating leading element which acts entirely within the tubular blank and which first transmits counter-thrust locking pressure to the multiple part mandrel to cause the self-locking multiple part mandrel to come into brake-shoe locking engagement under the counter-thrust pressurizing action of a restraining ram. The leading element is thereafter fulcrumed about a central pivotal linkage and a spherical lever surface thereof at the edge contacting the maximum radius of bend of the blank to guide the leading element which acts as a control by directing the metal flow during cold-forming.

Examples of seizing metals and of hard metals are listed in Tables A and B below.

**TABLE A**

<table>
<thead>
<tr>
<th>Metals exhibiting high seizing and galling characteristics against hardened steel die surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconium and zirconium alloys</td>
</tr>
<tr>
<td>Titanium and titanium alloys</td>
</tr>
<tr>
<td>Stainless steel</td>
</tr>
<tr>
<td>Carbon steel</td>
</tr>
<tr>
<td>Cobalt and cobalt alloys</td>
</tr>
<tr>
<td>Aluminum and aluminum base alloys</td>
</tr>
</tbody>
</table>

**TABLE B**

<table>
<thead>
<tr>
<th>Metals, alloys and related metallic mixtures of high hardness hitherto not capable of being cold-formed into standard fixtures without wrinkling, upsetting and fracturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalum and tantalum alloys</td>
</tr>
<tr>
<td>Titanium and titanium alloys</td>
</tr>
<tr>
<td>Tungsten and hard tungsten alloys</td>
</tr>
<tr>
<td>Molybdenum and hard molybdenum alloys</td>
</tr>
<tr>
<td>Cobalt and cobalt alloys—Hastelloy B, Hastelloy C</td>
</tr>
</tbody>
</table>
Molybdenum steel
Manganese steel
Chromium and chromium alloys
Stainless steel
Cobalt-alumina Cermets containing up to 40% of cobalt or cobalt alloy and 60% Al₂O₃
Cermets

Harder metals listed under Table A above, when cold-formed in accordance with the invention require the application of pushing force for cold-forming, this pushing force bearing against the trailing edge of the workpiece and the trailing hard end of the multiple part mandrel of about 1000-1500 pounds. Softer metals such as listed under Table B above require lower pushing forces for cold-forming. For example, with an aluminum workpiece, the push force may be as low as about 500-600 pounds for ½-⅞ inch diameter tubular stock.

The manufacturing methods of the invention accomplishes simultaneous cold-forming and sizing of fittings which meets standard specifications of the type used for stainless steel fittings. These standard specifications widely used at the present time for hard metals include:


(b) AS A No. B3619 Specification for Austenitic Stainless Steel Pipe, American Society of Mechanical Engineers, 29 West 35th Street, New York city.

Rapid forming operations can be carried out by copper tube bending apparatus as taught in United States patent to Arboget, No. 2,701,002 granted February 1, 1955. Arboget's push ram element for forcing the tubular blank through the die, supports the trailing edge of the blank while the supporting headpiece engaging the leading edge, results in the upsetting and wrinkling of the metal during the bending operation. A unitary rubber mandrel is employed which is fastened to the push element. Any wrinkling is corrected during the sizing operation which is a necessary subsequent operation for making these fittings.

In contrast to the suitability of the apparatus of Arboget for making copper fittings by employing a unitary rubber mandrel element within the tubular copper stock under opposing hydraulic forces for cold-forming in the die, this Arboget apparatus is unable to cold-form seizing metals of the type which are listed in Table A above or to cold-form hard metals of the type which are listed in Table B without wrinkles.

Cold-forming and sizing of the hard metals and seizing metals are carried out in accordance with the invention by employing a multiple part mandrel of elastomeric material which is constructed as a self-contained unit to come into frictional engagement at its ends, wholly within the interior of the tube blank, to maintain the mandrel in fixed frictional or brake-shoe type of engagement wholly within the tubular blank throughout the entire cold-forming and cold-sizing operation.

Thus it is a feature of the invention to eliminate entirely the supporting engagement of the metal lead piece of Arboget with the leading edge of the tubular workpiece, and to rely upon the multiple part elastomer mandrel under pressure from the flexible force transmitting linkage delivering hydraulic counter thrust for sealing the mandrel during the cold-forming and cold-sizing operation.

The invention includes an improved flexible force-transmitting linkage for transmitting the opposing hydraulic force to the multiple part elastomer mandrel while the tubular workpiece with the mandrel inserted therein is being formed in the die by the forward thrust of the hydraulic ram.

This new linkage comprises an assembly of uncon-
while exerting uniform pressure on the inner walls of the tubular stocks, controls the flow of the metal, preventing upsetting of the metal and prevents wrinkling during the bending and sizing operation. A further object of the invention is to provide a new multiple part elastomer mandrel formed of materials having superior physical properties of resistance to abrasion, elastic memory, toughness, compressibility, and frictional engagement for the interior wall of the tubular workplace to thereby provide a long lasting mandrel capable of long repeated use in production. A further object of the invention is to provide a new contact friction forming operation of the invention in combination with the new flexible force transmitting linkage for rapid production of cold-formed and cold-sized metal bands. A further object of the invention is to provide a new mechanical coaction for tube-forming in the combination of the new guiding member and the flexible force transmitting linkage comprising an assembly of unconnected separate interfitting ball and hat shaped members slidably movable within the die. This combination is adapted to pressurize and lock the multiple part elastomer mandrel solely by counter thrust pressure. It is a characteristic of the multiple part elastomer mandrel of the invention that the form of the mandrel need not be tapered at its leading edge. It is preferred that the ends of the mandrel be squared off for alignment with the force transmitting members at the forward and rearward positions of the oppositely directed hydraulic thrust members. It is surprising that the hard end sections containing the soft middle unit are able to completely withstand the tearing and abrasive forces due to the interior irregularities of the workpiece which cause destruction of the unitary rubber mandrel of the type as used in the Arboagit Patent No. 2,701,002, very rapid forming operations under high pressure.

The non-tapered multiple part mandrel is assembled in accordance with the invention from separate mating sections of hard elastomeric end pressure sealing members and a soft elastomeric middle section. These sections are merely dropped into the workpiece. The forming operation can be carried out in an ordinary hardenable steel die. The thinning which ordinarily occurs at the larger radius of the bend is substantially obviated with the mandrel of the invention and the thinning which ordinarily occurs in the region of smaller radius is confined to a very small segment of the arc.

For example, using the multiple part self-contained pressure sealing mandrel in the apparatus of the invention for the shaping of 2'' tube blanks of stainless steel into full 90° L's, with a wall thickness for the tube blank of 0.109 inch, it has been found that an increase in wall thickness of 37% that is based on the initial thickness occurs in the region of smallest radius. At the same time the thinning in the corresponding region of greatest radius which is due to tensile forces is at most about 5-10% of the original thickness of the tubular blank. Thus, the flow of metal is adequate to prevent thinning of the portion of the bend by maintaining the permissible wall gauge requirement of the accepted industry standard referred to above.

It is an important characteristic of the multiple part mandrel of the present invention in comparison with the mandrel of the patent to two of the present inventors, Patent No. 2907,102, that the mandrel may be used again and again without being mangled, cut, and eroded by surface irregularities and without cracking due to repeated compression and elastic recovery in continuous production.

For example, the service life of the hard end sections of the multiple part mandrel which are preferably formed of a vinyl chloride resin plastisol baked at elevated temperatures to a Durometer Shore Hardness Rating on the D scale preferably of about 55-75 and baked to a modulus of elasticity of preferably 15,000 to 25,000 p.s.i. may be expressed in terms of the number of "perfect" 90° bends made with hard metal, such as Stainless Steel Series 300, this value varying from about 200-400 bends in pipe sizes of ½ inch to 4 inches diameter.

The softer, readily compressible middle section of the multiple part mandrel is formed preferably of soft natural rubber, synthetic compounded rubber, or polysulphide rubber which is adjusted in known manner by formulation to a hardness value varying from about a Shore Hardness Rating of about 5 to 60 on the Shore A scale and which has a modulus of elasticity which is less that ¼ the value of the hard end section part mandrel.

The service life of the soft middle section when made of natural rubber in terms of number of stainless steel fittings made is from about 2000-4000 pieces depending upon the skill of the operator. The service life of polysulphide rubber is about 1000 to 2000 pieces.

In contrast, the use of a single or unitary mandrel, whether made of natural rubber, synthetic rubber such as neoprene, butadiene-styrene polymer, etc., or vinyl resin plastisol, etc., as disclosed by the prior Patent No. 2907,102, there is achieved a service life of only about 3 fits in the hands of an unskilled operator. This can be improved to 10 fits in the hands of a skilled operator after which the mandrel has completely deteriorated.

It has been found that the modulus of elasticity of the hard mandrel end members of elastomer material must decrease in proportion to the ratio of cross sectional area taken at the external diameter of the tube to the wall thickness. Thus, with a small ratio of cross sectional area to wall thickness a higher modulus of elasticity of elastomer end pieces is required. For example, with ¼" to 4" pipe a suitable range of E will lie between 10,000 to about 20,000 p.s.i.

Limits for the modulus of elasticity of the mandrel end pieces in relation to tube cross-sectional area (O.D.) are listed in Table C below, the data given for stainless steel pipe.

<table>
<thead>
<tr>
<th>Pipe size:</th>
<th>E (p.s.i.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼&quot; to 1&quot; inclusive</td>
<td>15,000-25,000</td>
</tr>
<tr>
<td>Above 1&quot; to 2&quot; inclusive</td>
<td>10,000-20,000</td>
</tr>
<tr>
<td>Above 2&quot; to 3&quot; inclusive</td>
<td>5,000-10,000</td>
</tr>
<tr>
<td>Above 3&quot;</td>
<td>300-5,000</td>
</tr>
</tbody>
</table>

In smaller sizes of standard tubing, wall thickness in proportion to cross-sectional area increases and the tendency for the soft middle section to extrude also increases. For this reason the preferred E values for thicker tubes of smaller diameter is close to 20,000 p.s.i.

Corresponding Shore Durometer D values for these pipe sizes are shown in Table D.

<table>
<thead>
<tr>
<th>Pipe size:</th>
<th>Shore D</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼&quot; to 1&quot; inclusive</td>
<td>65-75</td>
</tr>
<tr>
<td>Above 1&quot; to 2&quot; inclusive</td>
<td>55-65</td>
</tr>
<tr>
<td>Above 2&quot; to 3&quot; inclusive</td>
<td>25-55</td>
</tr>
<tr>
<td>Above 3&quot;</td>
<td>12-25</td>
</tr>
</tbody>
</table>

At Durometer D hardness above 80 the end piece tends to fracture.

Preferred materials for the mandrel end pieces include vinyl resin plastisol which is best due to its excellent elastic memory, urethane rubber, cast epoxy resin, and other elastomer materials such as hard rubber either natural or synthetic. These other elastomer rubbers may be formulated to provide the necessary properties within the specified limits for hardness and modulus of elasticity.

The other and further objects of the present invention will appear from the more detailed description set forth below, it being understood that such more detailed description is given by way of illustration and explanation.
only and not by way of limitation, since various changes
therein may be made by those skilled in the art without
departing from the scope and spirit of the present inven-
tion.

In connection with the more detailed description, there
is shown in the drawings, in

Fig. 1 is a fragmentary elevational view of an appara-
tus embodying our invention and adapted for use in prac-
ticing our method with parts being broken away and in
section to illustrate structural details.

Fig. 2 is a fragmentary view of one of the die mem-
bers with a work blank and the forming mechanism in
an initial position with parts sectioned and broken away.

For reasons of space in illustration.

Fig. 3 is a fragmentary view with one of the die mem-
bers removed, illustrating the apparatus in fully actua-
ated position in which position the tubular blank has
been formed to angled shape.

Fig. 4 is a fragmentary view partly in section along
line 4—4 of Fig. 2 showing one type of link which may
be used for connecting the inner metal guiding member
to the hat-shaped leading element-engageable with the flex-
ible hat-shaped elements in the force transmitting as-
sembly.

Fig. 5 is a side elevational view partly in section il-
lustrating a modified form of ball and socket joint.

Fig. 6 is a vertical sectional view on line 6—6 of Fig. 5.

Fig. 7 is a diagram for purposes of mathematical analy-
sis, illustrating the physical forces and factors affecting
the forming of hard metals.

Fig. 8 is a diagram showing, for purposes of mathe-
matical analysis, the elastic and plastic properties of the
tube material.

Fig. 9 is a diagrammatic showing for purposes of
mathematical analysis.

Figs. 10a and 10b are diagrammatic drawings of shear
definitions affecting buckling and wrinkling.

Figs. 11a and 11b are diagrammatic drawings of fac-
tors affecting buckling and wrinkling.

Fig. 12 is a diagrammatic view illustrating the forces
exerted at the leading edge of the work for the purpose
of demonstrating internal brake-shoe frictional forces against
the inner surface of the workpiece and counter thrust
pressurizing forces parallel to the longitudinal surface
of the workpiece.

Figs. 13 and 14 illustrate in diagrammatic fashion by
side view and bottom view, respectively, a special form
of beveled and tapered tubular workpiece which allows a
distribution of forces within the die with no waste of
workpiece material.

Fig. 15 is a side elevation view partly in section il-
lustrating a modified form of ball and socket joint.

Fig. 16 is a vertical sectional view on line 16—16 of
Fig. 15.

Referring now to Figs. 1—3, inclusive, a tubular work-
piece 18 is shown inserted within the entrance portion of
a die cavity 15 formed by a pair of hinged dies, lower
die member 13 and upper die member 14, these die mem-
bers being connected by pins 17 and supported by lower
support 11 and upper support 12, which with the hydrau-
lic mechanism are fixed to the main frame of the press
(not shown).

Within the tubular workpiece 18 there is inserted the
multiple part elastomer mandrel of the invention. The
mandrel as shown in Figs. 2 and 3 comprises hard elas-
tomer end sections 22a and 22b, one of which is in force
bearing relation to the forward push ram 19 and the
other 22c in force bearing relation to counter-thrust ram
23. The other hard mandrel end section 22b is brought
into frictionallocking engagement against the interior
wall of the tubular workpiece at the forward or leading
end of the workpiece as a result of the application of a
pressurizing force by the counter-thrust ram 23 acting
through the flexible force transmitting means and the in-
ternal pressurizing, and aligning lead piece.

The middle sections 22" and 22" of the multiple part
elastomer mandrel are each soft in comparison with the
hard end sections 22a and 22b and are distinguished from
these hard end sections by performing the function of a
fluid under pressure when the entire mandrel is confined
within the workpiece and the workpiece and mandrel
are subjected to high pressures.

Each tubular workpiece 18 cold-formed and cold-sized
in accordance with the invention is forced through die
cavity 15 and curved die cavity 16 under the simultaneous
application of pressure by forward push ram 19 and
counter-thrust ram 23 actuated by a hydraulic force from
cylinder 25.

The forward and rearward movement of push ram 19
is controlled by the hydraulic mechanism shown in Fig. 1
of applicants' Patent No. 2,907,102 and this mechanism
forms no part of the present invention.

With the ram 19 fully retracted and the four-way valve
in port closing position rotated about 45° from the posi-
tion shown in Fig. 1 in Patent No. 2,907,102, the pump
unit is energized for flow of hydraulic fluid through a re-
lied valve, a check valve and by the line into the right-
hand end of the cylinder 36 associated with ram 19.
Fluid pressure is developed against the piston which
moves to the left in cylinder to build up pressure on the multi-
ple part mandrel. The pressure build-up on the multiple
mandrel occurs by reason of the movement of aligning
member 27 against the multiple part mandrel 18, and
particularly against the leading hardened end section 22b
of the mandrel.

Thus, with shoulder 20 of the push ram 19 coming
into force bearing relationship at bearing surface 21
against the trailing end face of the hard end section 22a
of the mandrel (see Fig. 2), the multiple part mandrel is
brought to an initial pressurized condition. To initially
pressurize the multiple mandrel the required movement
is small, of the order of 1/8 of an inch (see Fig. 2 for initial
pressurization). When this pressure attains a predeter-
mined value, of the order of 500—600 pounds per square
inch, the four-way valve of Fig. 1, Patent No. 2,907,102,
is moved to a position to admit fluid pressure from pump
by way of associated lines to the upper end of the cylinder
associated with ram 19 to apply against the piston a form-
ing pressure of the order of about 550—1,500 pounds per
square inch. Since the forming pressure of push ram 19
exceeds that of the mandrel pressure of counter-thrust
ram 23, there will be movement of the tube workpiece
18 into the forming position of the die cavity 16 at the
bend.

The pressure applied by the pistons to the push ram 19
and counter-thrust ram 23 may now be simultaneously
increased and equalized in order to raise the pressure on
the multiple part mandrel and upon the formed tubular
workpiece 18. The pressure applied to the piston for the
push ram 19 is increased by raising the setting on the
relief valve from 500—600 pounds per square inch to
about 1,500 pounds per square inch. By suitably ad-
justing the settings of these relief valves any desired dif-
ferential of pressure may be applied to the tube workpiece
depending upon the materials of the workpiece and any
desired final finishing or sizing pressure may likewise be
established (see Fig. 3 for cold-forming). It will be
understood that particular pressures will be selected on
the basis of the hardness and seizing properties of the
metal material and the wall thickness of the tube work-
piece.

Each of the elastomer mandrel sections, the soft cen-
tral section 22", the adjacent middle sections 22' and the
hardened sections have a form approximating the in-
ternal form of the tubular blank to be slidably movable
within the workpiece for easy removal after forming. About 1/8 inch clearance is provided. Each of these
sections is characterized by good elastic recovery to
permit repeated reuse. Each of the sections is tough to
withstand repeated abrasion in cold-forming and cold-sizing. Each of the sections is homogeneous and reinforcing agents may be used to impart toughness. Sponge rubber cannot be used because of its tendency to tear after one cold-forming operation, particularly due to abrasive forces caused by surface irregularities of the interior of the tubular workpiece; hence it is preferred that the mandrel sections be non-porous.

Radial expansion of hardened end sections 22a and 22b locks the entire mandrel within the tubular workpiece by brake-shoe engagement against the internal surface of the workpiece under the opposing pressurizing forces. This radial expansion prevents extrusion of the soft elastomer sections 22 and 22' shown for the five-part mandrel in Fig. 2 and Fig. 3. As pointed out hereinbefore, extremely high internal pressures are developed to cause the softer internal sections to move like a fluid. When sections 22a and 22b have values of modulus of elasticity and hardness as given previously, no extrusion will take place.

It is an essential feature of the invention that none of the sections of the multiple part mandrel be lubricated. The brake-shoe engagement of the end sections 22a and 22b against the internal surface of the tubular workpiece during pressurizing and cold-forming operations is brought about solely using the frictional forces between the radially expanded end sections and the material of the tubular workpiece. The middle sections move relative to the internal surface of the workpiece during pressurizing and forming operations but the end sections are substantially fixed.

The counter-thrust pressure applied against the leading end section 22b of the multiple part mandrel is transmitted through the flexible assembly of unconnected hat-shaped members 31 which are located in the bend channel portion 16 of the shaping die as shown in Figs. 1–3.

A novel lead element is interposed between the flexible assembly of hat-shaped members 31 and the mandrel hard end section 22b, this element comprising a metal flow guiding element 27 which is located wholly within the tubular workpiece 18 as shown in Fig. 2 and adjacent the leading tapered edge thereof, this guiding element 27 being linked to a hat-shaped member 31 by a connecting rod 28. One surface of the guiding element 27 is planar or flat for directing metal flow along the minimum radius of bend in the die. The opposite surface of the guiding element 27 is spherical to contact the tubular workpiece 18 engaged by the pressure member 19. This guiding element 27 being a fulcrum during the cold-forming operation directing the flow of metal at the inner tube wall of the maximum radius and helps to tilt the lead member around the curved portion of the die cavity.

The connecting rod 28 shown in Fig. 4 is one species and has a rectangular cross-section. Rod 28 is inserted into an opening of disc cover 27 and pivotally mounted within the hollowed out portion by cross-pin 24. The cross-pin 24 and the center of connecting rod 28 intersect at the center of die cavity 16, which is a common center with the central axis of the tubular workpiece 18. This common center lies on the straight line connecting the forward beveled edges of the tubular workpiece 18 as shown in Fig. 2 when the mandrel is pressurized and guiding element 27 lies wholly within the workpiece 18.

The length of the connecting rod 28 is equal to the radius of the die cavity 16 at the bend. If this length is substantially less than the radius, the pin would jam and the workpiece would jam at the bend 16 in the die cavity. If the rod lengths were substantially larger than this radius, the rod would snap when the work and mandrel move under cold-working pressure around the bend.

Two types of leading element which are preferred are shown in Figs. 5 and 6 and Figs. 15 and 16. In each of these types the connecting rod 52 is in ball and socket engagement with the guiding element 50 and the hat-shaped member 60. The ball and socket connections 55, 59 and 61, Figs. 5, 6, 15 and 16, are preferred to the cross-link connection 24 of Fig. 4 since these are longer lasting and provide more uniform action in their direct action for metal flow under cold-forming by the free-floating leading member 27. The guiding member 50 in the embodiments shown in each of these Figs. 5, 6, 15 and 16 is fitted with spherical end 54 to ball socket 59 in the leading element. A similar ball and socket close fit is provided by the other end of the rod terminating in spherical ball portion 54 which fits in the spherical counterbore 61 of the hat-shaped member 60. The spherical dome of the hat extends from the annular edge of the hat member 60 to engage the annular socket or counterbore of an adjacent hat-shaped member 31 in the assembly as shown in Figs. 2 and 3. In Figs. 5 and 6 snap rings 62 and split washers 63 lock the ball ends 54 of the connecting rod in place in the socket 59 of the lead guiding element 50 and hat member 60, respectively.

In Figs. 15 and 16 set screws 71, 72, 73 and 74 in bores 75, 76, 77 and 78 perform the function of the snap rings and washers. The embodiment of Figs. 15 and 16 is preferred to that of Figs. 5 and 6, the set screws providing longer service life than the rings.

By lubricating the forming surfaces and using a metal dissimilar from that of the tube workpiece, the friction developed during the forming is decreased. A differential of pressure of the order of 1,000–1,500 p.s.i. is adequate for the bending of tube workpiece formed from the hardest of metals to the desired dimensions of curvature.

The usual lubricating compounds utilized for dies will be found suitable for cold-forming the harder and seizing metals. Preferred lubricants include Houghton Draw Oil No. 3105, chlorinated rubber solid film lubricant (up to 40–50% chlorine) and carnauba wax emulsion lubricant. Such lubricants as molten lead, molten lead sulfide, lindseed oil, white lead, lindseed oil oil-white lead graphite, and lard oil are not satisfactory since they give rise to seizing and galling in the die.

Each tubular workpiece is open-ended and of a beveled length to keep to a minimum the loss of material in the final finishing operation. The end of the tube workpiece 18 engaged by the pressure member 19 does not require any finishing operation since the end surface thereof is maintained essentially flat and square by the engagement thereof with the shoulder 17a. At the leading end of the tube workpiece 18 only a small amount of metal need generally be removed to dimensioning it to its final dimension of a flat and square surface.

Generally, the tubular workpiece is beveled at one end and square at the other end in order to permit cold-forming and cold-sizing without loss of material. The bevel is such that the flow of the material of the workpiece along the shorter dimension brings the metal to a substantially square edge after forming.

In Figs. 13 and 14 there is shown a preferred beveled tubular workpiece in which the shorter length moves forward during the cold-forming operation.

In order to distribute the pressure on the front end of the tubular blank as it passes the die split, a flat spot is ground on the tube as shown in these figures. This flat spot 2 prevents excessive pressure on the front end 4 of the tubular blank of Figs. 13 and 14.

**Example**

The following example illustrates the bending of stainless steel tubing 304 in accordance with the invention and brings out the physical relationship of push force, restraining force, reaction force and friction force for bending of hard metals.

Reference is made to Figs. 7–14 for the diagrammatic representation of the mathematical factors.
Mathematical analysis

(a) PROBLEM

The problem illustrated in this example is to form a straight tube into a 90° bend. The equations developed herein are applicable to any size and the example given below applies to a stainless tube of the following dimensions:

\[ d = 2.375 \text{ in.} \]
\[ t = 0.109 \text{ in.} \]
\[ l = 9 \text{ in.} \approx \text{(approx.)} \]

(b) NOMENCLATURE

\( P_0 \) = push force in pounds
\( F_1 \) = restraining force in pounds
\( F_2 \) = reaction force at outside turn in pounds
\( F_3 \) = friction force caused by reaction force \( F_1 \) in pounds
\( F_4 \) = friction force caused by tube expansion (this is in addition to \( F_3 \))
\( \mu \) = coefficient of friction
\( t \) = initial wall thickness of tube
\( r \) = outside radius of tube in inches
\( \gamma \) = inside radius of bend in inches
\( R_m \) = mean radius of bend in inches
\( R_e \) = outside radius of bend in inches
\( p \) = mandrel pressure in p.s.i.
\( r_1 \) = inside radius of tube
\( \theta \) = angle between \( P_0 \) and \( P_1 \)
\( E \) = modulus of elasticity of tube material in p.s.i.
\( M \) = moment required to bend tube in inch-pounds
\( A_1 \) = inside area of tube in square inches
\( S_1 \) = ultimate tensile strength of material in p.s.i.
\( S_2 \) = ultimate compressive strength of material in p.s.i.
\( S_3 \) = tensile yield strength of material in p.s.i.
\( S_4 \) = compressive yield strength of material in p.s.i.
\( F_e \) = friction caused by internal mandrel pressure
\( F_i \) = friction caused by internal mandrel pressure at an interference of 0.007' on diameter or greater
\( S = \text{inside surface area of tube in square inches} \]
\( \gamma = \text{Poisson's ratio} \]

(c) EFFECT OF INTERNAL AND EXTERNAL PRESSURE

With the tube free in the die, the burst stress and radial expansion may be readily computed by standard formulae from the internal pressure.

\[ S = \frac{P}{E} \]
\[ \Delta r = \frac{S}{E} \cdot r = \frac{P^2}{E} \cdot \frac{r}{E} \]

In this example:

\[ r_1 = 1.08'^{\prime} \]
\[ t = 0.109 \]
\[ E = 30 \times 10^6 \]
\[ p = 3000 \text{ p.s.i.} \]

\[ \Delta r = \frac{3000 \times 1.08}{.109 \times 30 \times 10^6} = 0.0011' \]

This means that the radial expansion from the mandrel pressure is relatively small.

Formula 10 below may also be used to determine the external pressure exerted by the die when the tube diameter is larger than the die cavity. The flow pressure of stainless steel 304 is about equal to the ultimate tensile strength or may be about 20% higher. Thus, the greatest pressure will occur when the flow pressure causes a circumferential compressive yield and flow which occurs when

\[ \Delta r = 90,000 \times 1.134 = 0.0034' \approx \text{(or about } 0.007'' \text{ interference on the diameter)} \]

Accordingly a preferred fit in the die is a clearance of \( \Delta r \approx 0.007'' \).

12

The corresponding pressure is:

\[ p = \frac{90,000 \times 1.134}{1.134} \approx 8640 \text{ p.s.i.} \]

(i) Moment to Bend Tube

Reference is made to Fig. 8.

35

For a first approximation it may be assumed that the tube material is an ideal elastic-plastic material with no work hardening property. Also, it may be assumed that the yield point in tension is the same as that in compression and that all strains are sufficiently large to be in the plastic range. On this basis the moment resisting the bending may be readily computed as follows for a thin-wall tube:

\[ M = 4S_J \int_0^\pi R_e^2 \sin y dy \]

\[ M = 4S_J R_e^2 \]

(f) Exact Force and Moment Equations

Reference is made to Fig. 9.

50

There are two stages in the forming process. The first stage is when the front end is turning through the bend. The last stage is when the front end is forming the straight part after the bend. Here the tube must "unbend."

55

The forces and moments on the bend are as follows:

The moment to bend and unbend are considered equal.

\[ -P_0 + P_2 \sin \theta + F_2 \cos \theta = 0 \]
\[ P_1 - P_0 \cos \theta + F_3 \sin \theta = 0 \]
\[ 2M + P_1 R_m - P_0 R_m + F_2 R_m = 0 \]
\[ F_2 = \mu F_3 \]

Here we can preset \( P_3 \) since it is known. Also, \( R_m \), \( R_m \), and \( M \) are known. \( P_0 \), \( \theta \) and \( P_3 \) are unknowns.

\[ P_0 = P_2 \left( \sin \theta + \mu \cos \theta \right) \]
\[ P_1 = P_2 \left( \cos \theta - \mu \sin \theta \right) \]
\[ P_3 = \frac{2M}{R_m} - \mu F_2 R_m \]

Squaring the first two equations and adding

\[ \frac{P_2^2 + P_3^2}{1 + \mu^2} = P_3^2 \]

Since \( \mu \) is not likely to be greater than 0.15 then

\[ P_3 = \sqrt{P_0^2 + P_3^2} \]
We can get an approximate solution by noting that $P_o$ is 4 to 6 times greater than $P_1$. Thus

$$P_o = 2P_1$$

and

$$P_1 = \frac{2M}{R_o - \mu R_m}$$

For this example

$$R_o = 4.188, R_m = 1.396\times1.4$$

$$\frac{2M}{R_m} = 8\times800,000\times1.134\times1.109 = 30,000 \text{ lbs.}$$

Since $P_1$ ranges from 8,000 to 20,000 pounds the

$$P_1 = \frac{8,000}{20,000} = 0.4 \text{ inch of plate.}$$

The laterally induced moment is $12 - v \cdot 0.4 = 54.5 \text{ p.s.i.}$

A third cause is the circumferential compressive stresses that are introduced from "pinching" the tube in the die from an oversize tube. Furthermore, the main axial compressive stresses are increased from the frictional forces from an oversize tube. There is one method of preventing local buckling and this is by employing sufficient internal pressure. Of course, the condition leading to buckling may be greatly alleviated by maintaining very low frictional forces (by proper lubricant and having smooth surfaces on die and tube).

An estimate of the required internal pressure is made by taking a one inch square surface of the tube and assuming the axial force corresponding to the compressive yield of the material. The compressive force is equal to:

$$\sigma = \frac{t \times r}{2}$$

If there is a local eccentricity or bow of 0.005 inch, the resulting moment is

$$0.005 \times 100,000 \times 0.0109 = 54.5 \text{ in.}$$

In upsetting practice, the free length of a bar should not exceed about 3/4 diameters to prevent buckling. This length is about 0.4 inch of plate. The laterally induced moment is

$$\frac{0.40}{12} = 54.5$$

$$p = 4000 \text{ p.s.i.}$$

The force $P_1$ to give this is

$$P_1 = \pi/4 \times 2.089 = 13,800 \text{ lbs.}$$

Equation 12 gives the friction developed when the interference is greater than about 0.007 inch. Very high push forces are needed to overcome this friction which developed when the leading edge of the tubular workpiece made of hard metal negotiates the curve in the die cavity. Although the push force may be lowered somewhat by suitable lubricants, high values of push force are still needed due to friction, particularly when the lubrication is inadequate. If $P_o'$ is the force on the end of the tube (excluding the rubber pressure) the compressive stress in the metal is

$$\text{stress} = \frac{P_o'}{2\pi r_o t}$$

Under the worst condition at the start of the push (with maximum interference fit)

$$\text{stress} = \frac{2\pi r_o t (8640 + p)}{2\pi r_o t}$$

Since $r_o$ is roughly equal to $r_m$ then

$$\text{stress} = \frac{l}{\mu (8640 + p)}$$

Typical values are

$$\begin{align*}
\tau & = 0.109 \\
\mu & = 0.05 \text{ to } 0.20 \\
p & = 1500
\end{align*}$$

Then

$$\text{stress} = 1,000,000 \mu$$

Then if the coefficient of friction exceeds about 0.09, compressive yield or upset occurs when the force is first applied. From the present example it is seen that an initial interference fit will cause a large increase in the push load. This increase under bad lubrication can easily be as high as 60 tons. However, even when the lubrication is fairly good, a heavy interference will cause buckling of the tube because of upsetting. No frictional forces (other than that at the reaction $P_o$) will exist if the tube is about 0.002 inch to 0.003 inch loose in the die.

Mandrel pressure

If the mandrel pressure is too high, it will exert excessive bursting stresses causing the tube to bear heavily on the die and creating excessive friction. The limiting rubber pressure may be calculated as follows:

$$p = \frac{60,000 \times 1.109}{1.133} = 5,800 \text{ p.s.i.}$$

The corresponding end force is

$$P = pA_t = 5800 \times 3.65 = 21,200 \text{ lbs.}$$

It can therefore be seen that the push force should not bear too heavily on the mandrel or excessive burst will occur on the tube, to cause metal upset.

Loss of rubber pressure

There is a loss of rubber pressure due to friction between the un lubricated rubber and the tube. See Fig. 12. This is calculated as follows:

$$\begin{align*}
Adp &= 2\pi r_o \mu dx \\
\pi r_o^2 dp &= 2\pi r_o \mu dx \\
\int p_o p &= -\int_{r_o}^{r} \frac{2}{r} \mu dx \\
\ln p &= -\frac{2}{r} (x + \epsilon); \quad \epsilon = p_o \pi \frac{2}{r} 
\end{align*}$$

$$p_o$$
Example:

\[ r_p = 1.08 \quad x = 0 \quad 3.56 \quad 7.12 \quad 5.60 \quad 7.12 \quad p = 4000 \quad p_s.i. \quad p = 4000 \quad 1470 \quad 540 \quad \mu = 0.3 \quad p = 400 \times e^{-20x} \]

This shows that the rubber pressure drops rapidly with distance. If there is a poor fit between shoulder 20 and the hard trailing end 22a, soft rubber from 22 may extrude rearwardly into the gap or unsupported area shown in Fig. 12.

The 2 inch tube of this example is pressurized under a force of 500 pounds and cold worked into a 90° L by forward force of 1500 pounds by the push ram 19, the outer part of the tube workpiece being lubricated with chlorinated rubber solid film lubricant. Other chlorinated and neoprene solid film lubricants may be used as chlorinated paraffin containing 40–50% chlorine.

A sized 90° L was produced which after cleaning to remove the lubricant was shiny, free from wrinkles and free of scratches or other imperfections which might be attributed to scoring or seizing. This was deemed a perfect L.

EXAMPLE II

The steps of Example I were carried out with Hastelloy B tubing, 2 inch pipe size, under forming pressure of 1,600 pounds and mandrel locking pressure of 500 pounds.

A perfect 90° L was made.

EXAMPLE III

The steps of Example I were carried out with aluminum tubing, 2 inch pipe size, under forming pressure of 600 pounds and mandrel locking pressure of 500 pounds.

A perfect 90° L was made.

EXAMPLE IV

The steps of Example I were carried out with titanium tubing, 2 inch pipe size, under forming pressure of 1600 pounds and mandrel locking pressure of 500 pounds.

A perfect 90° L was made.

EXAMPLE V

The steps of Example I were carried out with zirconium tubing, 2 inch pipe size, under forming pressure of 1600 pounds and mandrel locking pressure of 500 pounds.

A perfect 90° L was made.

Modifications of this invention not described herein will become apparent to those skilled in the art. Therefore, it is intended that the matter contained in the foregoing description and the accompanying drawings be interpreted as illustrative and not limiting, the scope of the invention being defined in the appended claims.

In each of the foregoing examples a five part mandrel was used as shown in Figs. 2 and 3, the center part 22″ of the multiple part mandrel being Thikol rubber filled with zinc sulfide and being softest, the intermediate adjacent sections 22″ being natural rubber which is harder than the Thikol rubber and the hard end sections being vinyl chloride plastics in a ratio of 68/32 vinyl chloride resin to tricresyl phosphate plasticizer, baked at 400°F, to shore hardness of 65 D. Other plasticizers, for example dibutyl phthalate and dibutyl sebacate may be used to attain preferred short D hardness values of 55–75 and the modulus of elasticity values indicated hereinbefore and the formulation proportions may be adjusted for lower hardness values, e.g. 12–55 with elasticity values from about 300 to 25,000 p.s.i.

We claim:

1. A method of simultaneously cold-forming and cold-sizing open-ended tubular workpiece to its final shape without upsetting the material and workpiece in a shaping die comprising inserting a removable expansible multiple part elastomer mandrel having the same cross-sectional external shape as the internal cross-sectional shape of said workpiece and being easily slidable into and through said workpiece, said multiple part mandrel comprising end sections having a modulus of elasticity lying between about 300 to 25,000 pounds per square inch, a hardness value on the Shore Durometer D scale of between about 12 and 75 and good elastic recovery and a middle section of soft elastomer having good elastic recovery, applying a pressurizing force within said workpiece against the front face of said mandrel while pushing against the other end of the workpiece to thereby expand the end sections at the front face, and locking the mandrel in position for cold-forming, applying a cold-forming force against the trailing edge of said workpiece while maintaining the pressurizing force against the front face of said mandrel to force said workpiece through said die thereby cold-forming and cold-sizing said workpiece.

2. A method as claimed in claim 1 wherein said workpiece is formed of a hard material which is flowed by a guiding member forwardly of the leading edge of said mandrel to thicken said material uniformly at the inner internal radius of the formed final shape.

3. A method as claimed in claim 2 wherein said uniform flow of the thickened material is carried out by application of a flat guiding surface to the inner thickened portion of the formed tube and wherein said flat guiding surface is fulcrumed at the bend from a fulcrum which is opposite to the thickened section, said uniform thickening taking place under the action of the pushing force and the pressurizing force against said mandrel.

4. A method as claimed in claim 2 wherein said tubular workpiece is beveled to provide a shorter workpiece length at the inner radius of forming and a longer workpiece edge at the outer radius of forming, said longer edge becoming shorter under the application of pushing and tensile forces during cold-forming to be square at the leading edge of the workpiece with the shorter edge in the cold-formed workpiece.

5. A method as claimed in claim 4 wherein said mandrel is pressurized by counter-thrust forces within said workpiece acting on the front face of said mandrel by force transmitting and aligning means, the center of said force transmitting and aligning means being on the axis of said workpiece.

6. A method as claimed in claim 5 wherein the center of said force transmitting and aligning means for said counter-thrust pressurizing force for said mandrel is in alignment with both the forward edge of said mandrel beveled length and the forward edge of said longer beveled length of the workpiece before cold-forming.

7. A method as claimed in claim 6 wherein said tubular workpiece is flat at its longest edge to provide a flat tapered spade section at the outer portion of the longest edge to provide more uniform distribution of forces on the workpiece within the die.

8. A method as claimed in claim 6 wherein said counter-thrust pressurizing force is about 500–600 pounds and said pushing force is about 600 to about 1500 pounds.

9. A method as claimed in claim 8 wherein said workpiece is lubricated with a chlorinated hydrocarbon solid film lubricant, said counter-thrust pressurizing force being about 500 pounds and said pushing force which is larger than said counter-thrust force being about 600 pounds to cold-form a workpiece made of aluminum.

10. A method as claimed in claim 8 wherein said workpiece is lubricated with a chlorinated hydrocarbon solid film lubricant, said counter-thrust pressurizing force being about 500 pounds and said pushing force which is larger than said counter-thrust force being at least about 1300 pounds to cold-form a workpiece made of stainless steel.

11. Apparatus for simultaneously cold-forming and cold-sizing an openended tubular workpiece to its final shape without upsetting the material of the workpiece in a shaping die comprising a removably expansible mul-
multiple part elastomer mandrel having the same cross-sectional external shape as the internal cross-sectional shape of said workpiece and being easily slidable into and through said workpiece, said multiple part mandrel comprising end sections having a modulus of elasticity lying between about 300 to 25,000 pounds per square inch, a hardness value on the Shore Durometer D scale of between about 12 and 75 and good elastic recovery and a middle section of soft elastomer having good elastic recovery, said mandrel being locked in frictionally fixed position within the workpiece under the pressurizing action of a force applied within the workpiece against the front face of the mandrel and a greater cold-working force applied against the trailing edge of the workpiece and mandrel.

12. Apparatus as claimed in claim 11 wherein said multiple part mandrel comprises end sections of hard polyvinyl chloride plastisol and a middle section of soft elastic rubber.

13. Apparatus as claimed in claim 11 wherein said multiple part mandrel comprises end sections of hard polyvinyl chloride plastisol and a middle section of soft elastic polysulfide rubber.

14. Apparatus as claimed in claim 11 wherein said multiple part mandrel comprises five parts, there being two end sections of hard polyvinyl chloride plastisol, intermediate sections of soft elastic rubber and a center section of soft elastic polysulfide rubber, said centrally located polysulfide rubber being softer than said intermediate sections of rubber.

15. Apparatus for simultaneously cold-forming and cold-sizing an open ended tubular workpiece to its final shape in a shaping die under opposing forces acting within the leading edge and against the trailing edge of said workpiece comprising a removably expandable multiple part elastomer mandrel having the same cross-sectional external shape as the internal cross-sectional shape of said workpiece and being easily slidable into and through said workpiece said multiple part mandrel comprising end sections having a modulus of elasticity lying between about 300 to 25,000 pounds per square inch, a hardness value on the Shore Durometer D scale of between about 12 and 75 and good elastic recovery and a middle section of soft elastomer having good elastic recovery, in combination with pressurizing and aligning means delivering a counter-thrust force to the front face of said mandrel within said workpiece while pushing said workpiece and mandrel at the trailing edges of both, said mandrel being locked in frictionally fixed position within the workpiece by the brake shoe action of the end sections under the pressurizing section of the force applied through said pressurizing and aligning means within said workpiece against the forward end section of said mandrel.

16. An apparatus for cold-forming and cold-sizing as claimed in claim 15 wherein said pressurizing and aligning means contain flexible force transmitting means adapted to deliver a pressurizing counter-thrust to a flexible mandrel within the tubular workpiece, said force transmitting means comprising an assembly of a plurality of unconnected identical hat-shaped members, each of said hat-shaped members being constructed of an annular base defining a socket in said base, said annular base slidably fitting within the die cavity, and a socket engaging spherical dome portion opposite said base adapted to fit into and bearingly engage the socket of the adjacent member during forced passage of said unconnected assembly through the bend of the die while cold-forming and cold-sizing.

17. Apparatus as claimed in claim 15 wherein a guiding member for metal flow is provided in advance of said mandrel, said member having a first metal flow guiding surface adapted to direct the metal flow during cold-forming against the inner thickened portion of the formed workpiece in advance of said mandrel and wherein said directing surface is fulcrumed at the bend of the die from a fulcrum opposite the thickened portion, said guiding for said thickened portion taking place under the action of the pushing force and the pressurizing force against said mandrel.

18. Apparatus as claimed in claim 17 wherein said fulcrumed opposite portion of said guiding member is spherically shaped and said guiding member is linked to said pressurizing and aligning means by a ball and socket.

19. Apparatus as claimed in claim 18 wherein said ball and socket includes a connecting rod whose length is shorter than the shortest radius of bend of the workpiece.

20. Apparatus as claimed in claim 11 wherein said tubular workpiece is formed of a metal which exhibits seizing and galling characteristics against steel and wherein the internal forming surfaces of said die are made of hardened steel.

References Cited in the file of this patent

UNITED STATES PATENTS

1,978,452 Fladin Oct. 30, 1934
1,993,361 Cornell Mar. 5, 1935
2,701,002 Arbogast Feb. 1, 1955