Sept. 19, 1967 D. ZUCKER ET AL 3,342,648

PRODUCTION OF TUBING

Filed April 22, 1963 3 Sheets-Sheet 1

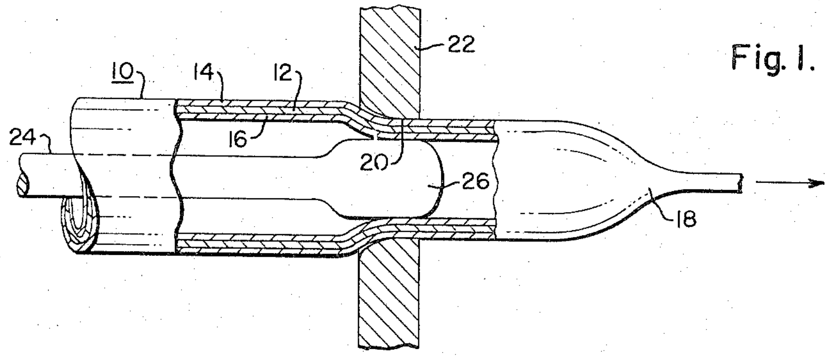

Fig. 1.

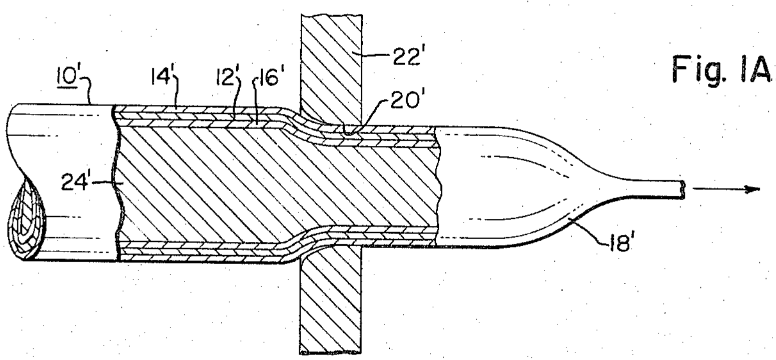

Fig. 1A.

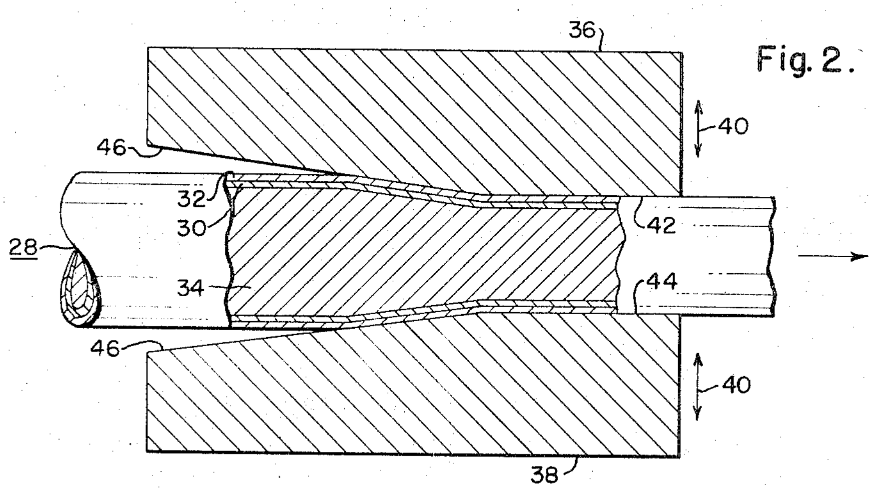

Fig. 2.

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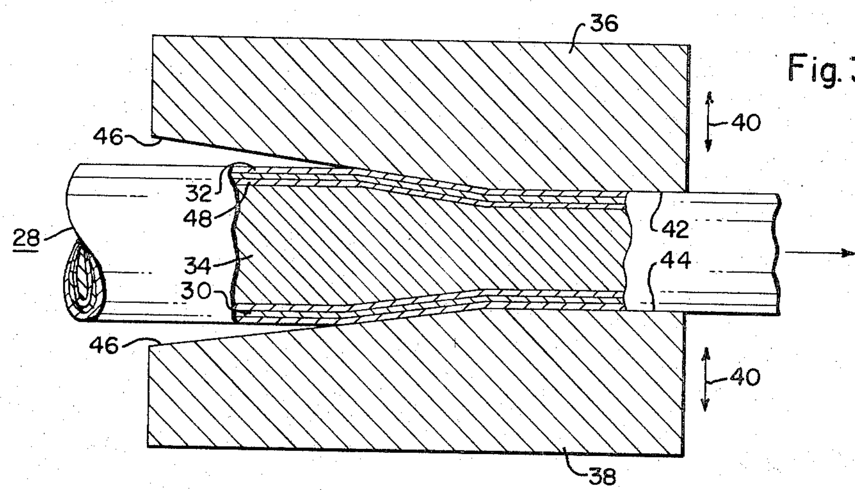
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Fig. 3.

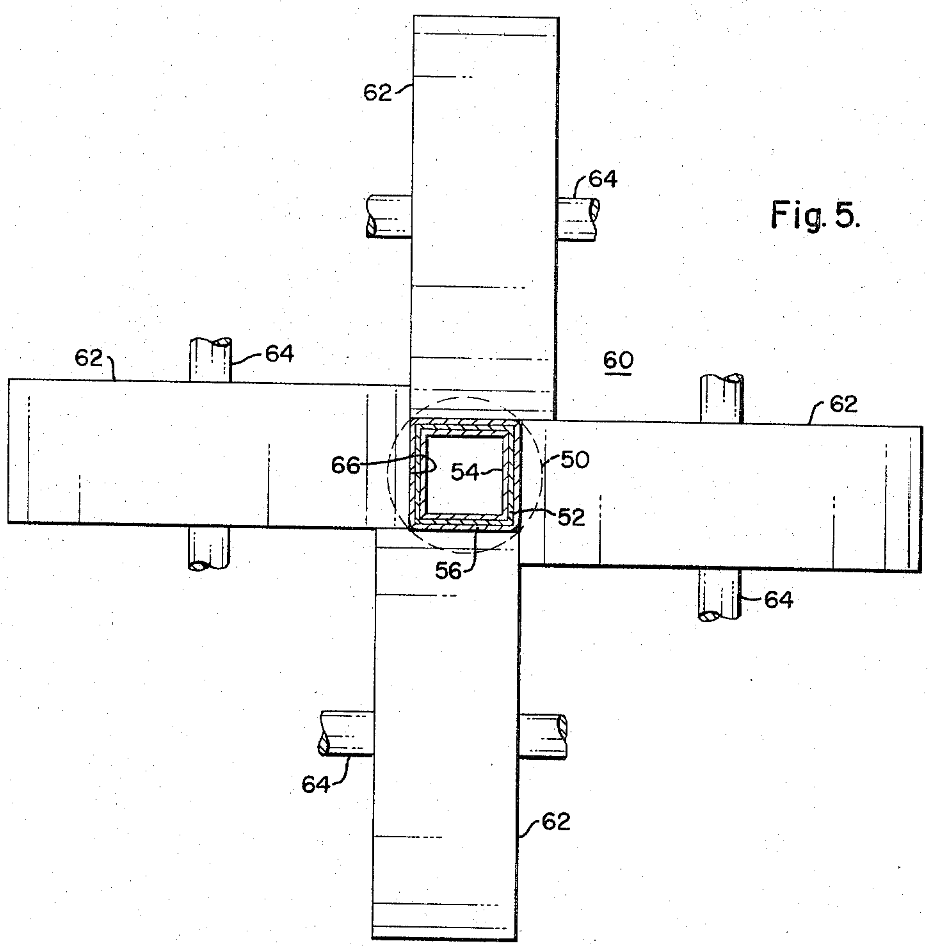
62
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Fig. 5.

PRODUCTION OF TUBING

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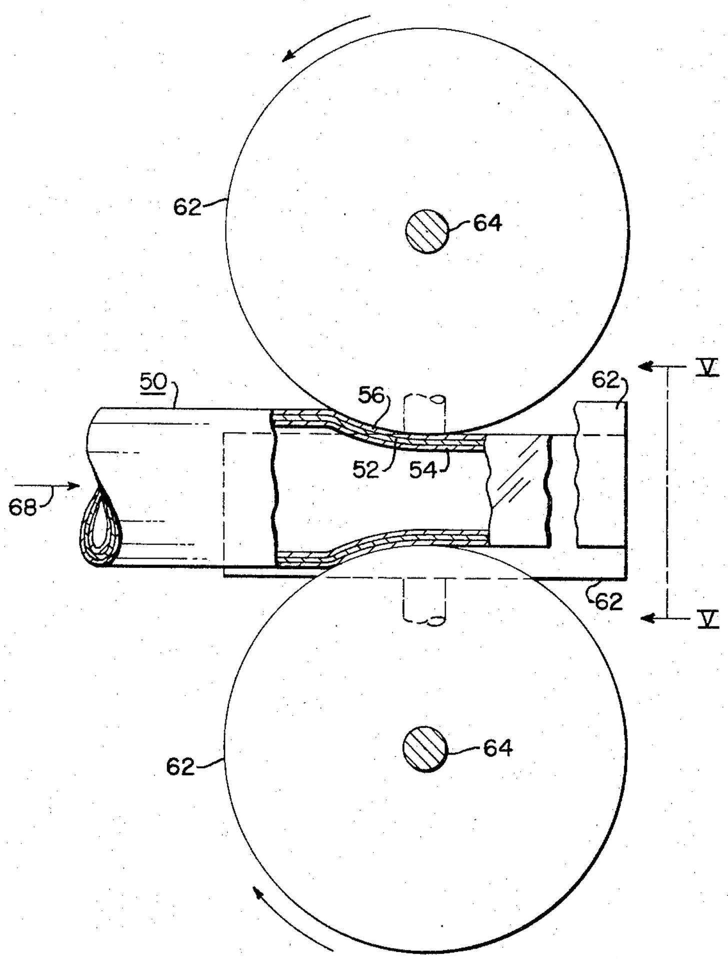
Fig. 4.



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PRODUCTION OF TUBING

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10 Claims. (Cl. 148—11.5)

This invention relates to the production of tubing from metals which cannot be readily swaged or drawn or which are subject to excessive oxidation upon annealing.

As is known, metal tubing is usually produced by initially extruding or otherwise producing a relatively thick tubular blank which is subsequently either drawn through a die or swaged a number of times. In this process, the diameter and thickness of the blank is reduced and its length increased, the repeated draws or swaging operations producing a cold-working effect which improves the physical properties of the final product. In some case, the cold-working necessitates annealing of the blank between sucessive draws or swaging operations to remove excessive brittleness produced during plastic deformation.

Commercial production of tubing in this manner from certain metals and their alloys is exceedingly costly and difficult either because the metals are highly reactive and oxidize excessively during annealing or because of seizing or galling of the workpiece in being swaged or drawn through a die. That is, the workpiece, in contrast to metals such as copper and aluminum, tends to stick to the die during the drawing or swaging operation with the result that drawing is extremely difficult and the resulting surface of the workpiece is rough and/or scaled. The production of tubing from ziroconium and its alloys, for example, is extremely difficult due to the tendency of the material to seize and the necessity for numerous protective anneals in a vacuum or inert atmosphere. The same is true of titanium and its alloys.

As one object, the present invention seeks to provide a method whereby tubing formed from metals subject to galling or seizing can be readily produced in large quantities.

Another object of the invention is to provide a method whereby highly reactive and oxidizable metals can be formed into tubing by drawing or swaging techniques without the necessity for costly protective anneals under vacuum or inert atmosphere conditions.

Still another object of the invention is to provide, as an article of manufacture, a workpiece from which tubing may be drawn comprising a tubular core of a highly reactive metal or a metal subject to seizing clad with a metal protective jacket which prevents seizing and at the same time prevents oxidation or other contamination of the workpiece during annealing.

In accordance with the invention, we produce tubing from metals which cannot be readily drawn because of seizing or which are highly reactive by the steps of initially cladding the tubular stock to be drawn with a metal which draws readily and which is not subject to excessive oxidation, thereafter drawing or otherwise plastically deforming the tubular stock with the cladding thereon to reduce the diameter of the stock while increasing its length, performing any necessary annealing in air while the cladding is in place, and finally removing the cladding. In the case where the tubing is formed in a drawing operation with the workpiece being drawn through a die and over a mandrel, both the inside and outside diameters of the highly reactive tubing or tubing subject to seizing must be clad. In the case where the tubing is formed in a swaging operation requiring a copper or the like core, the inside diameter of the tube which is highly reactive or subject to seizing need not necessarily be clad since

the copper core itself serves to protect the inner surface. However, in certain applications cladding of the inside diameter may also be necessary or desirable even in this latter case, depending upon requirements.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIGURE 1 is an illustration of one embodiment of the invention wherein the tubing is formed by a drawing process;

FIG. 1A is an illustration of a modified drawing process of this invention;

FIG. 2 is an illustration of another embodiment of the invention wherein the tubing is formed in a swaging process, and the internal diameter of the tube is not separately clad, but is prevented from exposure to air by a central core;

FIG. 3 is an illustration of an embodiment of the invention employing swaging which is similar to that of FIG. 2 except that both the internal and external diameters of the tubing are clad;

FIG. 4 is an illustration of a further embodiment of this invention for producing tubing of non-circular cross section; and

FIG. 5 is a sectional view of the apparatus illustrated in FIG. 4 and taken along the lines V—V thereof.

Referring now to the drawings, and particularly to FIG. 1, there is shown a tubular workpiece **10** comprising an inner core **12** of a metal such as an alloy of zirconium or an alloy of titanium which is either highly reactive so as to readily oxidize under annealing conditions or is subject to seizing or galling. The outside diameter of the core **12** is clad with a metal jacket **14**; and, likewise, its inner diameter is clad with a similar protective jacket **16**. In the drawing process, a reduced diameter end **18** of the workpiece is pointed to be passed through a drawing die opening to begin the drawing process. More specifically, the pointed end **18** is initially passed through an opening **20** in a die **22**, and a mandrel **24** having an enlarged head **26**, formed from a hardened material, such as steel, is inserted into the tube such that the enlarged head **26** will become lodged in the workpiece **10** in the area of opening **20**. The trailing end of the mandrel **24** (i.e., the left end as viewed in FIG. 1) is securely fixed such that the enlarged head **26** cannot move further to the right from its position shown in the drawing.

At the beginning of the drawing operation, the workpiece **10** is initially loaded onto the mandrel **24**, and its swaged or reduced diameter end **18** is inserted through the die opening **20**. Thereafter, the reduced diameter end **18** is securely gripped by jaws on a drawbench draw carriage, not shown, which moves to the right away from the die **22**, thereby pulling the workpiece **10** through the die opening **20**. In this manner, the diameter of the workpiece is reduced and its length increased.

As will be understood, pulling of the workpiece **10** through the die opening **20** produces a cold-working effect. As was explained above, it was more or less common practice previous to the present invention to attempt to draw metals such as zirconium and titanium and their alloys without a protective cladding. Such metals, however, are extremely difficult to draw because of seizing or galling and require that the workpiece **10** be annealed in a non-oxidizing atmosphere or under vacuum conditions in order to prevent excessive oxidation and/or contamination during the annealing process. Since the workpiece may have to be drawn through the die a large number of times before it is reduced to its final size, and since an anneal is required between successive drawing operations, it can be readily appreciated that the production of tubing from metals such as zirconium and titanium with prior art procedures is a very costly and difficult process.

In accordance with the present invention as shown in FIGURE 1, however, the tubing **12** formed from metals such as zirconium, titanium or their alloys is clad with the protective jackets **14** and **16** before the initial drawing operation is performed. Preferably, the jackets **14** and **16** are formed from a low carbon steel; however, any metal may be used which does not seize and which will protect the inner core **12** during an annealing process, such as copper. It has been determined, however, that a low carbon steel clad performs more satisfactorily than copper, although the latter metal has been successfully used. The steel jacketing however, produces a satisfactory surface finish on all the contacting surfaces of a zirconium or zirconium alloy workpiece. Furthermore, higher annealing temperatures can be used with a steel jacket in view of the relatively high temperatures at which zirconium-iron intermetallic compounds are formed. With the procedure shown in FIG. 1, the jackets **14** and **16** act, in effect, as a lubricant for the inner core **12** during a drawing operation. After the workpiece **10** including the inner core **12** is reduced to the desired diameter, the metal cladding (i.e., jackets **14** and **16**) can be readily removed by dipping the tube assembly or workpiece **10** in an acid bath, such as a 50% HNO_3 solution. If desired, the internal jacket **16** may be removed by either pumping the acid solution through the tube or into the tube as the situation permits. For improved surface finish, it is desirable that the workpiece **10** be sandblasted or rubbed with emery cloth after each anneal to remove scale, although this is not absolutely necessary since the scale formed during the anneal is usually very loose and flakey. It has been determined that annealing is required after each 30% of reduction of the workpiece. The annealing temperature may vary from 1300 to 1550° in air. It has also been determined that the annealing time at temperature may vary from as short as 5 minutes at the higher portion of the temperature range to 30 to 60 minutes at the lower end of the temperature range. However, it is to be realized that at the higher annealing times and temperatures, flaking and scaling of the jacket **14** increases in severity. Sandblasting has satisfactorily removed such scaling. It is to be realized that when an exposed inner jacket **16** is utilized, sandblasting of the interior of the workpiece **10** is difficult and lower annealing temperatures desirably are utilized to prevent excessive scaling of the interior clad **16**.

Other methods of annealing may be employed. However, a bare or unclad core **12** must be annealed in an argon atmosphere requiring that the bare reactive metal core **12** be also cooled in an argon atmosphere. In accordance with the prior art, a forty-five minute cooling of the workpiece **10** in argon after each anneal has been found to be necessary. It is to realized that the instant invention contemplates an anneal of the workpiece **10** in air, at a substantial time saving rather than in an inert atmosphere such as argon. If a bare or unclad core **12** were to be vacuum annealed, the cycle would be at least four hours per anneal.

The embodiment of this invention illustrated in FIGURE 1 desirably is utilized only for larger diameter tubing lengths. It will be appreciated that for smaller diameter tubing, it is extremely difficult to utilize a stationary mandrel **24** in view of the very small internal diameter of the workpiece.

For such small diameter tubing it has been found desirable to utilize a fixed internal mandrel such as a plug or core which is encapsulated in and extends substantially the entire length of the workpiece. An example of this arrangement is illustrated in FIG. 1A. This figure is similar to FIGURE 1 and like parts are designated by the same reference characters primed.

In this embodiment of the invention the relatively hard, stationary mandrel **24**, of FIGURE 1 is replaced by a relatively softer deformable plug or mandrel **24′**, preferably formed from copper. The mandrel **24′** is drawn through the opening **20′** as a part of the workpiece **10′** and as such is concurrently reduced in diameter and elongated by the drawing process. If desired, the workpiece **10′** can be initially compacted in a swage to provide intimate contact between the adjacent surfaces of the portions **12′**, **14′**, **16′** and **24′** of the workpiece **10′**. With the above exceptions the process of FIG. 1A is the same as that described in conjunction with FIGURE 1.

Referring now to FIG. 2, there is shown a method for producing tubing of a highly reactive metal or a metal subject to seizing by the use of a swaging process. In this case, the workpiece **28** again includes a core **30** formed from a highly reactive metal or a metal subject to seizing. The outside diameter of the core **30** is, as in the embodiment of FIGURE 1, clad with a metal protective jacket **32**, desirably formed from a low carbon steel or any suitable material capable of providing a relatively smooth surface on the contacting surfaces of the core **30**. The swaging process requires an internal core, and this core is provided by means of a copper plug **34**, the plug **34** also acting to protect the internal diameter of the core **30** during anneals.

The swaging machine (not shown) includes two dies **36** and **38** each of which is adapted to reciprocate in the direction of arrows **40**. The dies **36** and **38** are incorporated into a machine comprising a mechanical means for rapidly opening and closing the dies by reciprocating them along the path of arrows **40**. The dies are carried in a slot in the face of a revolving spindle and are held between a pair of steel blocks usually called "backers." Around the spindle is a circular roll cage containing a number of hardened steel rolls. Revolution of the spindle causes the backers and the dies **36** and **38** to pass between successive pairs of opposing rolls, thereby forcing the dies together along the path of arrows **40**. In this manner, it can be seen that the dies **36** and **38** rotate around the workpiece **28** and are at the same time reciprocated toward and away from each other while the workpiece **28** is moved from left to right as viewed in FIG. 2.

The dies **36** and **38** are blocks of hardened steel or the like having upon their inner faces **42** and **44** the impression of the shape of the work to be produced. The left end of the die groove is flared outwardly as at **46** to allow the unreduced stock to enter.

In the swaging process, the workpiece **28** is moved from left to right as mentioned above while the dies **36** and **38** reciprocate inwardly and outwardly along the direction of arrows **40** while being rotated around the workpiece **28**. In this process, the workpiece **28** is effectively "hammered" into a reduced cross-sectional area while its length is increased, the internal copper core **34** serving to prevent collapse of the tubing during the swaging process. Between successive swages, the workpiece **28** desirably is annealed in the same manner described in conjunction with FIGURE 1 and the resulting scale on the outer jacket **32** is preferably removed by sandblasting in the manner described above. Aftter the workpiece **28** is reduced to its final or desired diameter, both the copper core **34** and the outer jacket **32** may be removed by suitable means, such as nitric acid.

With reference now to FIG. 3, the embodiment of the invention shown is similar to that of FIG. 2; and, accordingly, elements in FIG. 3 which correspond to those shown in FIG. 2 are identified by like reference numerals. In this case, however, the internal diameter of the core **30** is clad with a protective jacket **48** as well as the outside diameter. Positioned within the inner protective jacket **48** is the copper core **34**.

Considering now the embodiment of this invention illustrated in FIGS. 4 and 5, there is shown therein an apparatus for obtaining tubing of non-circular cross section with the tubing material being formed from a reactive material which readily oxidizes in air under annealing conditions or is subject to seizing or galling during the formation process. More specifically, there is illustrated in FIGS. 4 and 5 an apparatus for forming from a circular core 52, a final product comprising tubing having a generally rectangular cross section.

In accordance with the invention, a generally circular workpiece **50** includes a core **52** formed from one of the aforementioned reactive materials, such as zirconium and its alloys and titanium and its alloys. The core **52** receives therein a generally annular inner cladding member **54** desirably formed to be closely received within the core **52** and formed from a suitable material such as copper or a low carbon steel. A tubular outer clad **56** receives therein the assembly of the core **52** and inner clad **54**. The outer clad **56** desirably also is of annular configuration and is formed from a suitable material such as a low carbon steel or copper. In accordance with the invention, one of the ends of the workpiece **50** desirably is pointed to begin the drawing process for the workpiece **50**. Normally, prior to drawing the tubing to its desired shape and size, the workpiece **50** is compacted in a suitable manner such as by swaging to provide intimate contact between adjacent surfaces of the core **52** and inner and outer cladding pieces **54** and **56**. The workpiece **50** is then drawn through a series of rollers, assembled to provide an outer cross-sectional area of the shape desired. In this example a Turk's-head roller assembly **60** is provided and includes four rollers **62** formed from a relatively hard material such as steel and fixedly positioned to provide an opening therein of the desired cross-sectional shape. Each of the rollers **62** desirably is rotatable about rigidly mounted axes **64**. As is illustrated in FIG. 5, the opening **66** formed by the rollers **62** is of rectangular cross section so that when the workpiece **50** is drawn therethrough, the rollers act to collapse the protruding sides of the workpiece **50** to form a final member of rectangular cross section. Each of the rollers **62** desirably is adjustably mounted on a suitable frame (not shown) to permit variations of the size of the opening **66** during the drawing procedure. The workpiece **50** desirably is drawn to the rollers in the direction indicated by the arrows **68**.

It will be appreciated that for the formation of tubing wherein large reductions in size are not necessary, an annular inner clad or core **54** is substituted for the solid cores **34** illustrated in FIGS. 2 and 3. After each pass of the workpiece through the opening **66**, the rollers **62** are adjusted to decrease the size of the opening **66** for subsequent passes in order to form the workpiece **50** to its desired final size.

As described in conjunction with other embodiments of this invention, the workpiece **50** desirably is annealed in the same manner heretofore described, i.e., at least after each 30% of reduction of the sides thereof.

There now follows specific examples of the formation of tubing employing certain of the processes heretofore described and combinations thereof:

EXAMPLE I

In this example of the invention a workpiece was formed pursuant to the embodiment of this invention illustrated in FIGS. 1A and 3 so that the workpiece was drawn to a relatively small size.

In accordance with this invention, a workpiece **10′** was assembled and included an outer clad **14′** comprising a low carbon steel tube having an outer diameter of 0.502 inch. A core member **12′** was formed from an alloy of zirconium and initially comprised a length of tubing having an outer diameter of 0.420 inch. The inner cladding member **16′** initially comprised a low carbon steel tube having an outer diameter of 0.318 inch. The mandrel or plug **24′** comprised a copper rod having a diameter of 0.215 inch. The workpiece **10′** was initially swaged in suitable apparatus such as the dies **36** and **38** illustrated in FIGS. 2 and 3 for the purpose of compacting the entire assembly to provide initimate contact between adjacent surfaces of the core **12′** and inner and outer clads **14′** and **16′** and mandrel **24′**, respectively. In addition, a swage step was utilized for the purpose of pointing the right-hand end **18′** of the assembly **10′**. The pass schedule for the swaging operation is described in the following Table I.

TABLE I.—SWAGING FOR COMPACTION OF ASSEMBLY

Swage Die Opening, Inches	Workpiece Outer Diameter, Inches	Anneal
.440	.465	(*)
.408	.409	(*)

*Indicates annealing —10 min. in air at 1,450° F.

After the assembly was compacted, the workpiece **10′** was passed through a suitable drawing die such as the **22′** of FIG. 1A having an opening **20′** therein. After each pass, the size of the die opening **20′** was varied and the workpiece **10′** was repointed at **18′** pursuant to the following Table II. An annealing step was utilized after each approximately 30% reduction with the annealing taking place in air at 1450° F. for 10 minutes. The annealed assembly was sandblasted prior to the next drawing pass. The final size of the core **12′**, after the inner and outer cladding had ben removed by a 50% solution of nitric acid, was 0.094 inch outer diameter.

TABLE II.—DRAWING PASS SCHEDULE

Die Opening, Inches	Outer Diameter of Workpiece, Inches	Outer Diameter of Pointed End, Inches	Anneal
.391	.391	.350	----------
.375	.375	.350	----------
.359	.358	.350	----------
.325	.328	.308	(*)
.312	.312	.308	----------
.300	.300	.261	----------
.283	.283	.261	(*)
.269	.269	.218	----------
.242	.241	.218	(*)
.230	.230	.218	----------
.214	.213	.183	(*)
.204	.204	.183	----------
.196	.195	.183	----------
.186	.185	.155	(*)
.1705	.170	.155	----------
.161	.160	.155	----------
.152	.152	.125	(*)
.143	.143	.125	----------
.129	.129	.115	----------
.122	.122	.115	(*)
.115	.118	.105	----------
.110	.110	.105	----------

*Indicates annealing step at pass completion.

EXAMPLE II

The following example employs a process of FIG. 3 wherein a 0.420 inch outer diameter zirconium alloy tubing length was swaged. More specifically, the outer cladding piece **32** comprised a low carbon steel tube having a 0.502 inch outer diameter and the inner core **48** comprised a low carbon steel tube having an outer diameter of 0.318 inch. The core **34** comprised a copper rod having an outer diameter of 0.215 inch. The workpiece **28**, as described above, was reduced in a swage with approximately 30% reductions per pass and with an air anneal at 1450° F. for 15 minutes after each pass. After each anneal, the assembly was sandblasted. The sandblasting operation took 10 minutes for the workpiece.

The swaging pass schedule for Example II is described in Table III.

TABLE III.—PASS SCHEDULE FOR SWAGING OF EXAMPLE II

Swaged die opening, inches:	Outer diameter of workpiece, inches
.440	.465
.408	.409
.340	.350
.304	.307
.256	.261
.215	.218
.180	.183
.152	.155
.125	.129
.115	.115

EXAMPLE III

The following example is similar to Example II and illustrates the swaging process of FIG. 3. In this example a workpiece of the same dimensions as utilized in Example II was constructed. The workpiece was reduced in swage with approximately 30% reductions per pass and with an air anneal at 1400° F. for 10 minutes after each 30% reduction. The annealed assembly was sandblasted prior to further reductions with the sandblasting operation taking approximately 10 minutes. At certain stages of the swaging operation, a portion of the outer cladding was removed and the outer diameter of the zirconium alloy tube was measured. The annealing schedule is indicated by an asterisk in the appropriate column in the following Table IV which shows the pass schedule for Example III.

TABLE IV.—SWAGING OPERATION PASS SCHEDULE

Swage Die Opening Inches	Workpiece Outer Diameter, Inches	Reduction (Percentage)	Anneals*	Outer Diameter of Zirconium Alloy Tube, Inches
.456	.462	15	--------	-----------
.420	.428	14	*	-----------
.360	.363	28	*	-----------
.340	.309	28	*	-----------
.270	.285	15	--------	-----------
.252	.250	16	(*)	0.245 OD-.190 ID
.215	.218	30	(*)	-----------
.180	.185	28	(*)	-----------
.150	.160	25	(*)	-----------
.130	.134	30	(*)	0.107
.110	.115	26	(*)	-----------
.092	.095	31	(*)	0.077
.080	.080	29	(*)	0.066

EXAMPLE IV

This example is illustrative of the process for forming a zirconium alloy tubing member of generally rectangular cross section pursuant to the embodiment of this invention illustrated in FIGS. 4 and 5. The starting materials comprise an outer cladding member **56** formed from a low carbon steel tube having a 0.410 inch outer diameter, a length of zirconium alloy tubing **52** having a 0.320 inch outer diameter and an inner cladding tube **54** of copper having a 1/32 inch wall and having a 0.250 inch outer diameter. The above-described assembly was reduced in a swage having a die opening of 0.375 inch for the purpose of compacting the assembly. The outer diameter of the workpiece after the swaging pass was measured to be 0.387 inch. A Turk's-head roller assembly having a final overall opening of rectangular cross section with the size thereof being 0.370 inch and 0.148 inch, respectively, was utilized in the drawing operation prior to removing the outer clad member. After the eighth pass through the Turk's-head rollers, the outer cladding was removed by a 50% nitric acid solution and the cross section of the exposed assembly was reduced to its final desired size of 0.305 inch by 0.080 inch. After

each of the first seven passes through the Turk's-head assembly, an air anneal of the workpiece was performed at 1450° F. for 10 minutes. The inner copper core was removed after the final sizing. The following Table V is illustrative of the pass schedule for the Turk's-head drawing operation. The Turk's-head roller assembly comprised two rollers disposed vertically and two rollers disposed horizontally. In considering Table V, the roller setting for the vertical rollers and for the horizontal rollers will be depicted separately. One of the ends of the workpiece was pointed by a suitable swaging operation prior to each of the jacketed passes.

TABLE V

Pointed End Outer Diameter, Inches	Vertical Rollers, Setting, Inches	Workpiece Vertical Dimension, Inches	Horizontal Rollers Setting, Inches	Horizontal Dimension, Inches
.335	.385	.387	.335	.337
.281	.384	.388	.284	.288
.241	.382	.386	.241	.250
.206	.380	.385	.206	.213
.188	.378	.383	.188	.197
.168	.374	.381	.168	.177
.152	.372	.378	.158	.167
.142	.370	.375	.148	.155
-------	(1)	.310	(1)	.105
-------	---------	.307	---------	.103
-------	---------	.308	---------	.098
-------	---------	.308	---------	.095
-------	---------	.307	---------	.092
-------	---------	.306	---------	.089
-------	---------	.306	---------	.086
-------	---------	.307	---------	.083
-------	---------	.305	---------	.080

[1] Measurements discontinued.

EXAMPLE V

This example is illustrative of the process for forming small diameter tubing from reactive tubular stock pursuant to the embodiment of this invention described in conjunction with FIG. 2.

The starting materials for forming the workpiece **28** of FIG. 2 comprised a copper core **34** made from a 0.320 inch outer diameter copper rod, a core **30** of zirconium alloy tubing having an initial outer diameter of 0.420 inch which received the copper rod **34** therein, and an outer tubular clad member **32** which receives the assembled core **30** and rod **34** therein. The outer clad member **32** comprised a 0.500 inch outer diameter low carbon steel tube.

The workpiece **28** was reduced in swage dies **38** and **36** with approximately 30% reductions per pass. An air anneal to the workpiece **28** was performed for 15 minutes at 1550° F. following each pass. Following each anneal, the workpice was sandblasted for 10 minutes to remove scale from the outer clad **32.** The outer cladding was removed prior to the last pass. A zirconium alloy tube was produced pursuant to this example having a final outer diameter of 0.119 inch. The pass schedule for this example is shown in Table VI.

TABLE VI.—PASS SCHEDULE FOR OUTER CLAD SWAGED TUBING

Die Opening, Inches	Workpiece Outer Diameter, Inches	Reduction (Percent)	Anneal*
.370	.387	20	(*)
.335	.342	24	(*)
.285	.295	28	(*)
.245	.248	28	(*)
.210	.215	22	(*)
.180	.183	30	(*)
.150	.155	29	(*)
.130	.133	28	(*)
.120	.119	------------	----------

Referring to Table VI, at the end of the eighth pass, the exterior steel tube was removed from the workpiece. Measurements subsequent to the eighth pass were made on the exposed zirconium alloy tubing. No annealing took place subsequent to the eighth pass.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention. For example, the removal of the inner cladding 16′ of FIG. 1A so that the outer surface of the mandrel 24′ serves also as an inner cladding is within the contemplation of this invention. Accordingly, it is specifically intended that the afore-described specific embodiments and examples be interpreted as illustrative, rather than in a limiting sense.

We claim as our invention:

1. A method for producing relatively smaller tubing from reactive metals which cannot be readily plastically deformed selected from the group consisting of zirconium and titanium and alloys thereof, respectively, comprising the steps of cladding both the inside and outside surfaces of relatively larger tubular stock of said reactive metal with members formed from a metal which can be readily plastically deformed, cold working the clad assembly to produce intimate contact between said tubular stock and said members, reducing the diameter of the clad assembly while increasing its length, and thereafter removing said claddings.

2. The method of claim **1** including the step of annealing the clad assembly in air after a predetermined reduction of the diameter thereof.

3. The method of claim **2** wherein the predetermined reduction of the diameter is approximately a 30% reduction.

4. The method of claim **1** wherein the clad assembly is swaged to provide the intimate contact between the tubular stock and said members.

5. The method of claim **2** wherein the clad assembly is annealed in air at a temperature of from 1300 to 1550° F. for from 5 to 60 minutes.

6. The method of claim **2** wherein the exterior of clad assembly is cleaned after annealing to remove scale therefrom and wherein the steps of reducing the diameter of the clad assembly and annealing are repeated after cleaning until a predetermined final diameter thereof is obtained.

7. In a method of producing relatively smaller diameter tubing from relatively larger diameter tubular stock selected from the group consisting of zirconium and its alloys and titanium and its alloys, the steps comprising cladding the interior and exterior of said stock with a clad material selected from the group consisting of iron and its alloys and copper to form a workpiece, elongating said workpiece thereby reducing the outer diameter thereof, annealing said workpiece in air after at least each 30% of reduction in the outer diameter thereof, and removing said clad material after said tubular stock has been sized to said relatively smaller diameter.

8. In a method of producing relatively smaller diameter tubing from relatively larger diameter tubular stock selected from the group consisting of zirconium and its alloys and titanium and its alloys, the steps comprising cladding the interior and exterior of said stock with a clad material selected from the group consisting of iron and its alloys and copper to form a workpiece, elongating said workpiece thereby reducing the outer diameter thereof, annealing said workpiece in air after at least each 30% of reduction in the outer diameter thereof, said annealing step being performed at a temperature between 1300 and 1550° F. for a time of from 5 to 60 minutes, said annealing time being dependent upon the annealing temperature, and removing said clad material after said tubular stock has been sized to said relatively smaller diameter.

9. In a method of producing relatively smaller sized tubing of a predetermined cross-sectional configuration from a relatively larger sized tubular stock selected from the group consisting of zirconium and its alloys and titanium and its alloys, the steps comprising cladding the interior and exterior surfaces of said tubular stock with tubular clad members selected from the group consisting of iron and its alloys and copper to form a workpiece, passing said workpiece through an opening of the desired cross-sectional configuration, annealing said workpiece in air after passing said workpiece through said opening at least once, said annealing step being performed at a temperature between 1300 and 1550° F. for a time of from 5 to 60 minutes, said annealing time being dependent upon the annealing temperature, and removing said clad material.

10. In a method of producing relatively smaller sized tubing of a predetermined cross-sectional configuration from a relatively larger sized tubular stock selected from the group consisting of zirconium and its alloys and titanium and its alloys, the steps comprising cladding the interior and exterior surfaces of said tubular stock with tubular clad members selected from the group consisting of iron and its alloys and copper to form a workpiece, swaging said workpiece to cause intimate contact of adjacent surfaces of said stock and said tubular clad members, passing said workpiece through an opening of the desired cross-sectional configuration, annealing said workpiece in air after passing said workpiece through said opening at least once, said annealing step being performed at a temperature between 1300 and 1550° F. for a time from 5 to 60 minutes, said annealing time being dependent upon the annealing temperature, and removing said clad material.

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