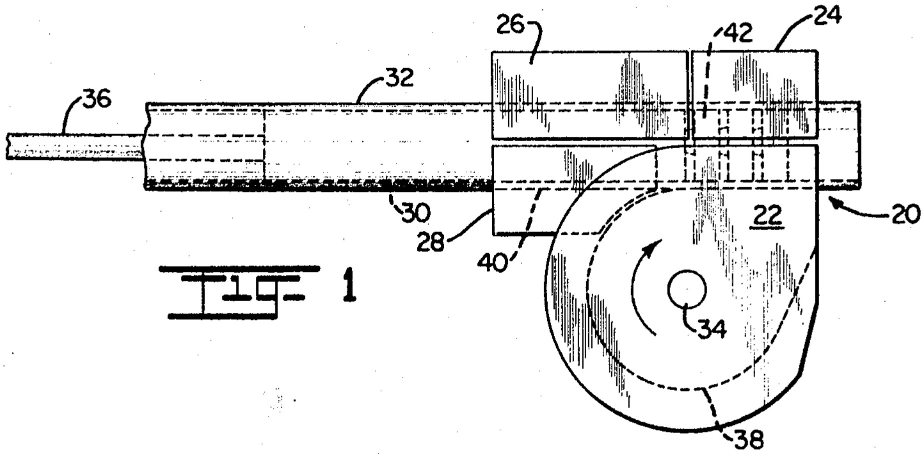

Fig. 1

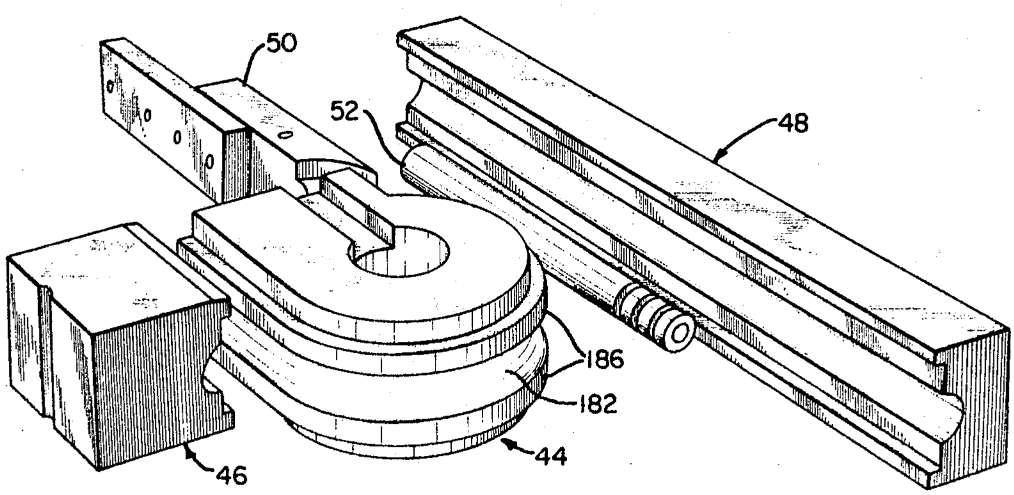

Fig. 2

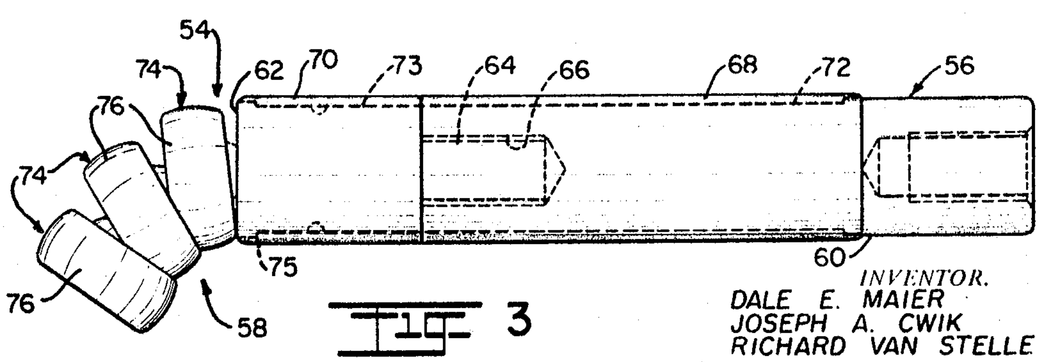

Fig. 3

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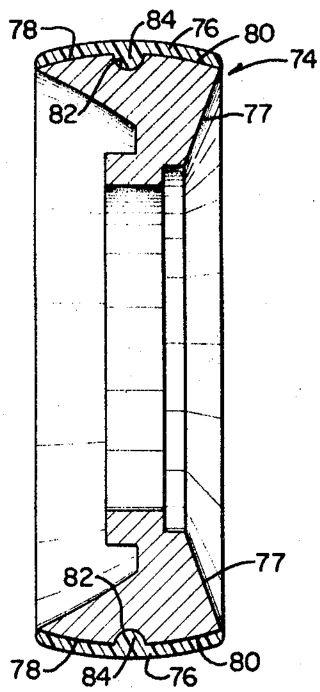

Fig. 4

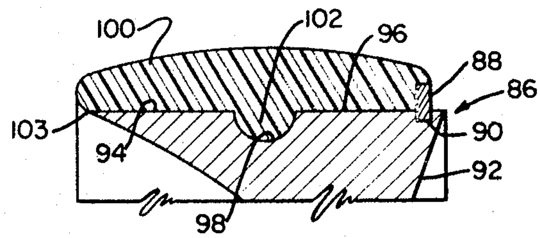

Fig. 5

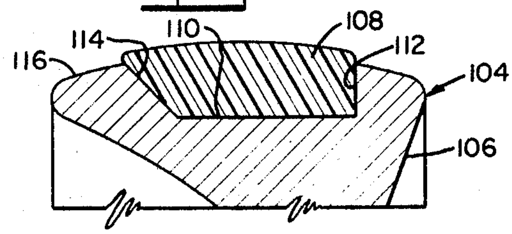

Fig. 6

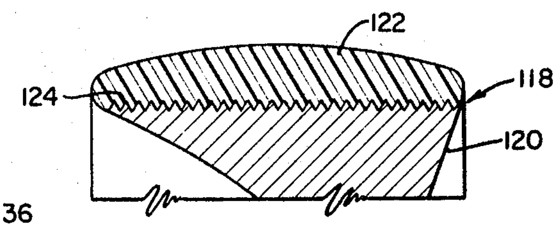

Fig. 7

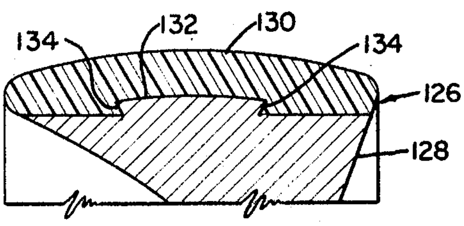

Fig. 8

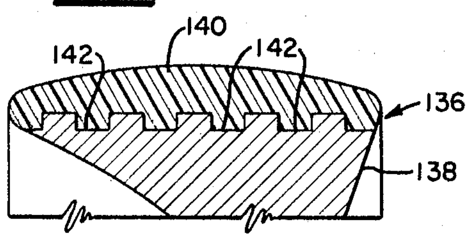

Fig. 9

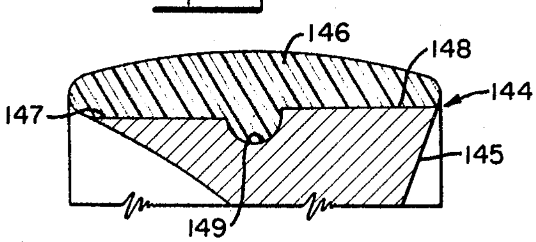

Fig. 10

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METHOD AND APPARATUS FOR DRAW FORMING TUBES AND THE LIKE INCLUDING MANDRELS THEREFOR

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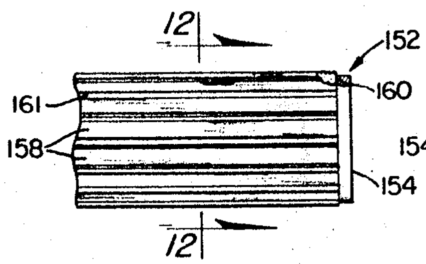

FIG. 11

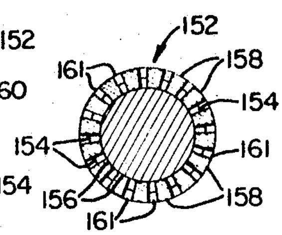

FIG. 12

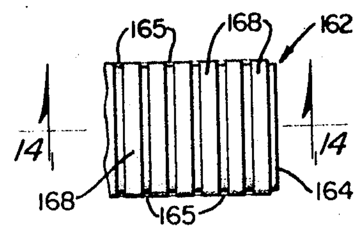

FIG. 13

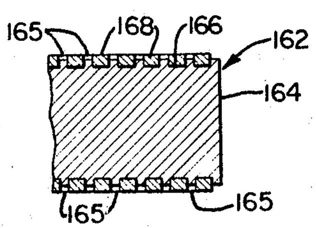

FIG. 14

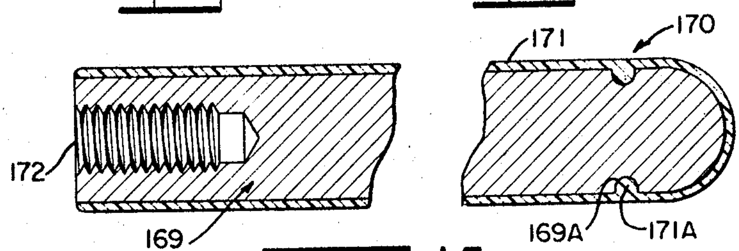

FIG. 15

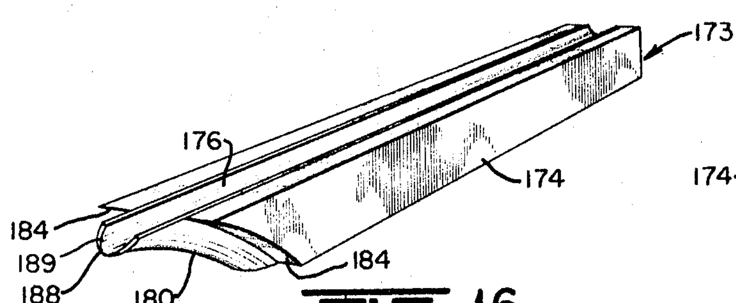

FIG. 16

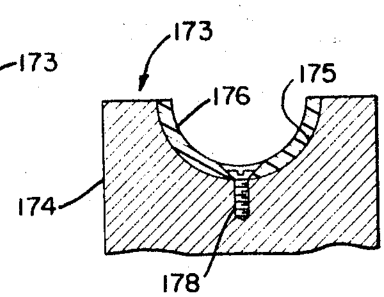

FIG. 18

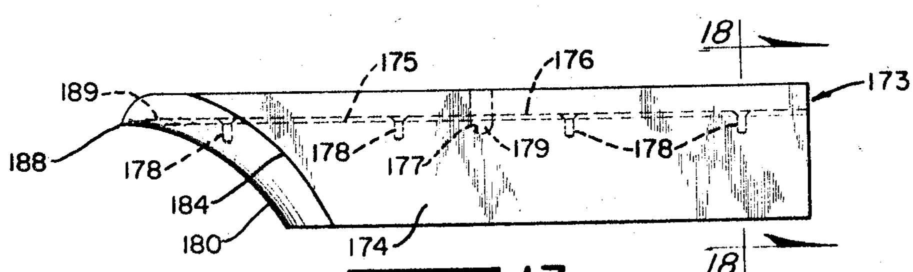

FIG. 17

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METHOD AND APPARATUS FOR DRAW FORMING TUBES AND THE LIKE INCLUDING MANDRELS THEREFOR

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Int. Cl. B21b *25/00;* B21d *9/05, 7/04*
U.S. Cl. 72—465 27 Claims

ABSTRACT OF THE DISCLOSURE

A tube bending mandrel having surface portions coated with a material having a relatively low coefficient of friction. This invention also relates to a tube bending mandrel comprising a relatively rigid support member and a wear resistant member, said wear resistant member being disposed to encompass at least a portion of said support member and being mechanically bonded thereto, said wear resistant member being formed from a material of different composition of the material used to form said support member.

This invention relates generally to a method and apparatus for draw forming tubes, pipes and the like and more particularly to an improved method and apparatus for draw forming tubes to a radial arc with a minimum of wall distortion, thickening, and marring of the tube surface, involving reducing the interface friction during the draw forming operation thereby greatly reducing tool wear, reducing power or torque requirements, and achieving greatly improved results. More specifically, the method of the herein invention involves the maintaining during the draw forming operation of a relatively low coefficient of friction between the surfaces of the tube to be draw formed and a preselected surface or surfaces of the bending apparatus to prevent galling and/or spalling. The apparatus of the herein invention, including a mandrel for use therewith, involves coating some or all of the surfaces thereof which move relative to the surface of the tube during the draw forming operation with a material having a relatively low coefficient of friction. The bending apparatus of the herein invention also comprises a relatively rigid support member and a wear resistant member disposed in encompassing engagement about at least a portion of said support member and being mechanically bonded thereto wherein said wear resistant member is formed from a material of different composition than the material used to form said support member.

Many methods and apparatuses have been heretofore utilized in draw forming tubes, pipes and the like to change the configuration thereof. However, critical problems have been associated with all such methods and apparatuses which problems stem principally from the fact that such methods and apparatuses caused marring of the inner tube surface, produced excessive thinning out of the tube or pipe wall as a result of galling or spalling in a manner as to substantially reduce the overall strength characteristics of the draw formed tube or pipe, and/or caused excessive wear of the tooling thereby greatly decreasing the life thereof. Moreover, such methods and apparatuses produced tube wall sections the thickness of which were substantially less than adjacent sections or areas. Additionally, the existence of wrinkles or merely uneven surfaces were serious defects where the finished tube or pipe was to be used to convey fluids at relatively high velocities since such defects produced undesirable turbulence within the tube or pipe. In an attempt to minimize the foregoing problems heretofore, the tube or

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pipe as well as the various contacting surfaces of the bending apparatus were simply coated with a lubricant. However, this has not proven satisfactory for a number of reasons. For example, it has not been possible to maintain constantly a layer of lubricant between the surfaces of the tube or pipe and the contacting surfaces of the bending apparatus. Thus, any metal to metal contact occurring between such surfaces produced poor draw forming results as a result of galling or fretting and/or spalling. With respect to the use of a lubricant as aforementioned, for many applications a lubricant could not be used at all since same would adversely contaminate the surfaces of the tube or pipe being draw formed or present difficult and expensive problems of applying and removing same. Further, heretofore no attempt has been made to solve the high wear rate experienced by certain portions of tube bending apparatuses used in tube draw forming operations.

It has been found, however, that the foregoing disadvantages may be eliminated or overcome by providing and maintaining during the draw forming operation a low coefficient of friction between the surfaces of the tube or pipe and the surfaces of the tube bending apparatus which move relative to each other during the draw forming operaion, particularly the surfaces of the tube bending mandrel. For example, good results are obtained merely by maintaining a predetermined coefficient of friction between the surfaces of the tube and a portion of the surface of the tube bending mandrel. Although the theory involved is not clearly understood, it is believed that a substantially three dimensional increase in metal flow occurs within the wall of the tube due to the elimination of the high frictional interface between the surfaces of the tube and the surfaces of the tube bending apparatus. By selecting a sufficiently low coefficient of friction to prevent galling and/or spalling, it has been found that there is no substantial increase in thickness of the tube wall at the inner radial plane and only a minimal decrease in the thickness of the tube wall at the outer radial plane. Further, by reducing friction at the sliding interfaces, it has also been found that there is a reduction in the amount of dislocation of the neutral axis of the tube. Thus, the thickening and thinning factors are more nearly equalized by virtue of a reduction in stresses within the tube wall and consequent work-hardening of the material from which the tube is formed.

With the elimination of conditions producing galling or fretting and/or spalling, it has been found that the wall of a draw formed tube is greatly improved from a uniform thickness viewpoint, and the inner surface of the tube, particularly for small radiuses of curvature, is formed substantially free from surface defects which would produce high turbulence when fluids are passed therethrough at relatively high velocities. From the foregoing, it is to be understood that although the tube wall forming the inner radius of the bend is normally thicker than the tube wall forming the outer radius of the bend, it has been found that the thickness of the wall, as compared to adjacent portions within the respective areas, is much more uniform than has heretofore been possible and this is so even for small radius of curvature bends.

In some draw forming operations, such as the forming of tubular parts for furniture and the like, it is desirable to merely reduce the wear rate of the tooling used. Heretofore, when the surfaces of the tooling had worn a predetermined amount the entire part was discarded. However, it has been found that this wasteful and expensive practice can be eliminated by manufacturing various parts for a tube bending apparatus comprising a relatively rigid support member and a replaceable wear resistant member which is mechanically bonded to said rigid support member. The wear resistant member is disposed to encompass at least a portion of said rigid support member and is formed from a material of different composition than the material used to form the support member. For example, the wear resistant member may be formed from a number of materials such as plastics, ceramics and carbides. When the wear resistant member has experienced a predetermined amount of wear, said member is removed from the rigid support member and a new wear resistant member is mounted thereon.

It is to be understood that draw form bending differs from form bending in that draw form bending involves a simultaneous drawing and deformation of the tube or pipe whereas form bending simply involves a deformation of a tube or pipe. Although draw form bending is normally more difficult to perform than form bending, draw form bending is used to a much larger extent than form bending since a better control is obtained in the setting of the metal where same is drawn in a sharp radial bend configuration, and a certain degree of work-hardening may also be realized. Further, in form bending it is customary to use a tube bending mandrel having a longer flexible body portion, and thus more exposure, than is required in connection with draw form bending.

One of the principal objects of this invention is to provide a unique method and apparatus for draw forming tubes and the like.

Another object of this invention is to provide a method for draw forming tubes and the like while effecting a reduction of incidence in wrinkles developing on the surface of the tube during the draw forming operation.

Another object of this invention is to provide a method of tube draw forming which involves maintaining during the draw forming operation a predetermined coefficient of friction between the surfaces of the tube and a preselected surface or surfaces of the tube bending apparatus.

Another object of this invention is to provide a method of tube draw forming which comprises the step of drawing a tube through a tube bending apparatus while maintaining during the tube bending operation a predetermined coefficient of friction between the surfaces of the tube and the tube bending apparatus which move relative to each other during the draw forming operation to prevent galling and/or spalling.

Another object of this invention is to provide a method of tube draw forming which involves the step of maintaining during the draw forming operation a relatively low coefficient of friction between the surfaces of the tube and the surfaces of the flexible body portion of the tube bending mandrel which slidably engage the surfaces of the tube during the draw forming operation.

Another object of this inveniton is to provide a method of effecting a substantially three dimensional increase in metal flow within the tube walls during the bending operation comprising the step of drawing a tube through a tube bending apparatus while maintaining a layer of material intermediate the surfaces of the tube and the surfaces of the tube bending apparatus which move relative to each other during the tube bending operation, the coefficient of friction of said layer of material, relative to the material of said tube, being approximately 0.10 or less.

Another object of this invention is to provide an improved method of tube draw forming involving the use of a layer of resilient material having a low coefficient of friction intermediate the surfaces of the tube and the tube bending apparatus which move relative to each other wherein said surfaces of said tube bending apparatus provide a substantially non-yieldable support for said resilient material.

Another object of this invention is to provide a method of tube draw forming involving the steps of drawing a tube through a tube bending apparatus while maintaining a layer of material intermediate the surfaces of the tube and the surfaces of the tube bending apparatus which move relative to each other during the tube draw forming operation, the coefficient of friction of said layer of material relative to the material of said tube being approximately 0.10 or less and, during the draw forming operation, applying a coating of lubricant to either of the surfaces of the tube or the surface of the layer of material.

Another object of this invention is to provide a method of bonding a molybdenum disulfide impregnated nylon material to a metallic surface.

Another object of this invention is to provide a method of bonding a molybdenum disulfide impregnated nylon material to a metallic surface comprising the steps of preparing the metallic surface by roughening the surfaces, such as by grit blasting, and degreasing same; preparing the nylon material surface by applying an acid solution thereto, removing the excess acid solution from said surface, exposing said surface to an acid neutralizing solution, rinsing said surface with water, and drying said surface; applying epoxy to at least one of the prepared surfaces; bringing the prepared surfaces into contact with each other; and allowing said epoxy to cure.

Another object of this invention is to provide a method of bonding a molybdenum disulfide impregnated nylon material to a metallic surface comprising the steps of preparing the metallic surface by grit blasting and degreasing same; preparing the nylon material surface by subjecting same to a temperature of approximately 600° F. or more until the molybdenum disulfide has been converted into an abrasive; applying an epoxy to at least one of said prepared surfaces; bringing the prepared surfaces into contact with each other; and allowing said epoxy to cure.

Another object of this invention is to provide a secure bond between a molybdenum disulfide impregnated nylon material and a metallic surface.

Another object of this invention is to provide a tube bending apparatus in which the surfaces thereof which move relative to a tube to be bent therein are coated with a layer of material having a low coefficient of friction.

Another object of this invention is to provide a tube bending mandrel in which the surfaces of the flexible body portion which engage the surfaces of the tube during the tube bending operation are coated with a layer of material having a relatively low coefficient of friction.

Another object of this invention is to provide a tube bending mandrel comprising a rigid stem portion interconnected to a flexible body portion wherein the surface portions of said flexible body portion and at least a part of the surface portion of said rigid stem portion have a layer of material disposed thereon, said layer of material having a coefficient of friction of 0.10 or less, and means to resist longitudinal movement of the layer of material in a direction toward said flexible body portion and away from said rigid stem portion.

Another object of this invention is to provide a tube bending mandrel comprising a rigid stem portion and a flexible body portion in which said rigid stem portion comprises at least two separate portions, the surfaces of said rigid stem and said flexible body portion which move relative to a tube during the tube draw forming operation having a layer of material disposed therein, said layer of material having a low coefficient of friction.

Another object of this invention is to provide a tube bending mandrel having a greatly extended operating life.

Another object of this invention is to provide a wiper die and/or a pressure die in which a surface portion thereof is coated with a material having a low coefficient of friction.

Another object of this invention is to provide a tube bending apparatus having replaceable wear resistant wear surfaces which are mechanically bonded to a relatively rigid support member and which are formed from a material of different composition than the material used to form the support member.

Another object of this invention is to provide a tube bending mandrel having a flexible body portion comprising a plurality of members, each of said members having a layer of material disposed on the surfaces thereof, said layer of material preventing galling and/or spalling when disposed in slidable contact with the surfaces of a tube during the tube draw forming operation.

Another object of this invention is to provide a tube bending mandrel having a rigid stem portion, said rigid stem portion having a surface portion upon which is mounted a plurality of material portions, the coefficient of friction of said material being approximately 0.10 or less.

Another object of this invention is to provide a tube bending mandrel having a rigid stem portion upon which is disposed a plurality of spaced apart material portions, said material having a low coefficient of friction, and a lubricant material disposed intermediate said spaced apart material portions.

Another object of this invention is to provide a tube bending mandrel having a rigid stem portion upon which is disposed a plurality of material portions, said material having a relatively low coefficient of friction, the distance separating adjacent material portions being approximately equal to the thickness of the wall of the tube to be bent or less.

Various other advantages and features of novelty will become apparent as the description proceeds in conjunction with the accompanying drawings, in which:

FIGURE 1 is a plan view of a tube bending apparatus with a tube mounted therein;

FIGURE 2 is a perspective, exploded view of various parts of a tube bending apparatus;

FIGURE 3 is an elevational view of a tube bending mandrel constructed in accordance with the subject invention;

FIGURE 4 is a cross-sectional view, in elevation, showing one member suitable for use in the flexible body portion of a tube bending mandrel constructed in accordance with the subject invention;

FIGURES 5–10 are partial, cross-sectional views in elevation showing various embodiments of other members of a flexible body portion suitable for use in a tube bending mandrel constructed in accordance with the invention;

FIGURE 11 is an elevational view of a part of another embodiment of a rigid stem portion of a tube bending mandrel constructed in accordance with the subject invention;

FIGURE 12 is a cross-sectional view taken along line **12—12** of FIGURE 11;

FIGURE 13 is an elevational view of a part of another embodiment of a rigid stem portion of a tube bending mandrel constructed in accordance with the subject invention;

FIGURE 14 is a cross-sectional view taken along line **14—14** of FIGURE 13;

FIGURE 15 is a cross-sectional view, in elevation, of a solid or plug type tube bending mandrel constructed in accordance with this invention;

FIGURE 16 is a perspective view of a wiper die;

FIGURE 17 is a plan view of a wiper die constructed in accordance with the subject invention; and

FIGURE 18 is a cross-sectional view taken along line **18—18** of FIGURE 17.

Referring now to the drawings and particularly to FIGURE 1, a tube bending apparatus **20** is shown in FIGURE 1 comprising a rotating form die or bend die **22**, a clamping die **24**, a pressure die **26**, a wiper die **28**, and a tube bending mandrel **30**. The tube bending apparatus **20** is shown with a tube or pipe **32** mounted therein and ready for draw forming. It will be noted that one end of the tube or pipe **32** is secured between the clamping die **24** and a portion of the bend die **22**. Another portion of the tube or pipe **32** is shown disposed between the wiper die **28** and the pressure die **26**. In practice, the bend die pivots about a shaft **34** and since the clamping die **24** is secured relative to the bend die **22**, the clamping die **24** and the bend die **22** move as an integral unit.

Upon rotation of the bend die **22** and the clamping die **24**, the tube **32** is drawn to the right, as viewed in FIGURE 1, through the opening formed between the wiper die **28** and the pressure die **26**. However, the tube bending mandrel **30** remains unchanged in position due to the rod **36** which is secured to a support (not shown). As a result of the rotation of the bend die **22** and the clamping die **24**, the tube **32** undergoes deformation at the arcuate surface **38** which extends about at least a portion of periphery of the bend die **22**. It will be understood that during rotation of the bend die **22** and the clamping die **24**, the tube **32** undergoes deformation at the point of tangency between the inner surface **40** of the wiper die with the inner surface **38** of the bend die. It will be noted that the tube bending mandrel **30** includes a flexible body portion **42** which is disposed in the vicinity of this point of tangency.

In FIGURE 2 is shown, in perspective, an exploded view of the various parts of a tube bending apparatus. These parts comprise a bend die **44**, a clamping die **46**, a traveling pressure die **48**, a wiper die **50** and a tube bending mandrel **52**. It will be noted that the bend die **44** and the clamping die **46** are not shown disposed in the starting position as the bend die **22** and the clampin die **24** are shown in FIGURE 1 but are shown in a subsequent position. The pressure die **48** moves with the tube during deformation thereof rather than remain in place as is the case with pressure die **26** shown in FIGURE 1.

The tube bending apparatus shown in FIGURE 2 is for use with a cylindrically shaped tube rather than a square or rectangular shaped tube. This is indicated by the groove portions formed in the various parts thereof which are, in cross-section, semi-circular in shape. Likewise, the tube bending mandrel **52** is cylindrically shaped. However, it will be appreciated that if the grooves and the tube bending mandrel were rectangular in shape that the tube bending apparatus as shown in FIGURE 2 could be used for tubes or pipes which have a rectangular or square cross-sectional configuration.

In FIGURE 3 is shown a tube bending mandrel **54** constructed in accordance with the subject invention. Tube bending mandrel **54** comprises a rigid stem portion **56** and a flexible body portion **58**. The rigid stem portion **56** preferably includes a pair of members **60** and **62** which are secured together in a suitable manner such as through the use of an externally threaded stud portion **64**, shown as an integral part of member **62**, which is mounted within an internally threaded recess **66** formed in the end of member **60**. The rigid stem portion **56** has an outer surface at least a part of which is coated with a layer **68** and **70** of low coefficient of frictional material such as a nylon impregnated with molybdenum disulfide, sold under the designation "Nylatron GS" by Polymer Corporation of Pennsylvania, Reading, Pa. It will be noted that members **60** and **62** of the rigid stem portion have, respectively, a peripherally extending surface **72** and **73** each of which has a reduced diameter as compared to the remaining outer surface portions of said members. The remaining outer surface portion **75** of member **62** provides a stop means to resist longitudinal movement of the layer of material **70** in a direction toward the flexible body portion **58**. It will be readily appreciated that the layers of material **68** and **70** may be mounted upon the respective surface portions **72** and **73** when member **60** is disconnected from member **62**. Although the combined axial length of the layers of material **68** and **70** is shown in FIGURE 3 to be somewhat of a considerable length, it will be understood that a much shorter axial length may suffice. As a matter of fact, in some applications, depending upon the material from which the tube is formed and the positioning of the flexible body portion relative to the point of tangency of the inner surface of the wiper die with the inner surface of the bend die, a tube bending mandrel may be constructed without coating any part of the outer surface of the rigid stem portion with a layer of material as described. However, as previously indicated, it is preferred that at least a part of the outer surface of the rigid stem portion have a layer of material disposed thereon as described herein. Although the rigid stem portion **56** is described as being formed from a pair of members **60** and **62**, it will be understood that same may comprise a single member.

The flexible body portion **58** preferably comprises a plurality of members **74** each of which is flexibly mounted relative to an adjacent member **74** for the purpose of permitting said members to conform to the general contour of the inner surface of the bend die during the tube bending operation. The members **74** may be interconnected to each other and to the adjacent end of the rigid stem portion in a number of ways such as that shown in U.S. Patent No. 3,190,106 and U.S. patent application No. 535,504 filed on Mar. 18, 1966. The peripheral surfaces of each of the members **74** is likewise coated with a layer of material **76** similar to the layers of material **68** and **70**. It is to be understood that said peripheral surfaces may be coated with a material highly resistant to wear such as a ceramic or a carbide as well as a plastic.

In FIGURE 4 is shown a cross-sectional elevational view of one of the members **74** coated with the layer of material **76**. The member **74** includes an inner portion **77** which has a pair of peripherally extending surface portions **78** and **80**. Surface portions **78** and **80** are interconnected by a radially inwardly extending recess means which is depicated by groove **82**. The layer of material **76** has a radially inwardly extending integrally formed boss means **84** which seats within the groove **82**. Groove **82** and portion **84** cooperate to provide a means to resist longitudinal movement of the layer of material **76** in either direction but particularly a direction towards the right as viewed in FIGURE 4. The outer surface of the layer of material **76** is in cross-section, preferably convex in configuration.

In FIGURE 5 is shown another embodiment of a member **86** similar to member **74** shown in FIGURE 4. Member **86** includes a snap ring **88** which is mounted in peripherally extending groove **90** formed about one end of an inner member **92**. Inner member **92** has a pair of peripherally extending surfaces **94** and **96** interconnected by a radially inwardy extending groove **98**. Although the peripherally extendig surfaces **94** and **96** as being disposed substantially the same distance from the longitudinal axis of member **86**, it will be understood that surface **94** may be disposed closer to such longitudinal axis than surface **96**. Inner member **92** has a layer of material **100** coated about the outer surface thereof. The layer of material **100** has an inwardly extending portion **102**, and the outer surface thereof is, in cross-section, convex in configuration. In view of the foregoing, it will be readily apparent that the snap ring **88** resists longitudinal movement of the layer of material **100** toward the right, as viewed in FIGURE 5, relative to the inner member **92**. In addition, the inwardly extending portion **102** of the layer of material **100** cooperates with the peripherally extending groove **98** to resist longitudinal movement of the layer of material **100**, to the right as viewed in FIGURE 5, relative to the inner member **92**. From a structural viewpoint, it is perferred that the peripherally extending surfaces of the inner members be, in cross-section, convexly formed like surfaces **78** and **80** in FIGURE 4 rather than as shown in FIGURE 5 since the peripheral edge of the inner member, such as edge **103** in FIGURE 5, will resist better deformation.

In FIGURE 6 is shown another embodiment of a member **104** somewhat similar to members **74** and **86** shown, respectively in FIGURES 4 and 5. Member **104** includes an inner member **106** and an annular layer of material **108**. Inner member **106** is like the other inner members in that it is formed from a relatively rigid, non-yieldable material as compared to the composition of layer of material **108**. Inner member **106** has a peripherally extending recess means **110** formed in the outer surface thereof and intermediate the ends thereof. As viewed in FIGURE 6, one side **112** of the recess **110** is formed substantially perpendicular to the bottom surface of the recess **110** while the other side **114** is formed at an angle of inclination to the bottom of the recess **110**. The surfaces of the recess **110** have been roughened by grit or sand blasting. The purpose of finishing this surface in this manner will be later described. The surfaces of the layer of material **108** which contact the surface s of the recess **110** have complemental shapes to insure that the layer of material **108** seats snugly within the recess **110**. It will be noted that the layer of material **108** extends above the outer surface **116** of inner member **106** by a predetermined amount, the exact amount depending upon a number of factors such as the resiliency, compressibility, durometer characteristic, amount of deforming pressure to be encountered and the memory characteristics of the layer of material **108**. In view of the foregoing, it will now be readily apparent that the inclined surface **114** of recess **110** assists in the installation of the layer of material **108** within the recess **110** while the perpendicularly disposed surface **112** assists in resisting the longitudinal movement of the layer of material **108**, relative to inner member **106**, toward the right as viewed in FIGURE 6.

In FIGURE 7 is shown another embodiment of a member **118** somewhat similar to members **74**, **86**, **104** show, respectively, in FIGURES 4, 5 and 6. Member **118** comprises an inner member **120** and a layer of material **122**. The outer surface **124** of inner member **120** and the inner surface of the layer of material **122** are complementally threaded as shown. The outer surface of the layer of material **122** has, when viewed in cross-section, a convex configuration.

In FIGURE 8 is shown another embodiment of a member **126** somewhat similar to members **74**, **86**, **104** and **118**. Member **126** comprises an inner member **128** and an encompassing layer of material **130**. Inner member **128** has a peripherally extending boss means **132** formed intermediate the ends thereof. The sides **134** of the boss means **132** are divergently formed in a direction proceeding radially outwardly from the longitudinal axis of the member **126**. The inner surface of the layer of material **130** complementally conforms to the outer surface of the inner member **128**. It will be understood that an inner member could be formed with a peripherally extending recess means rather than the boss portion **132** of member **128**.

In FIGURE 9 is shown another embodiment of a member **136** somewhat similar to members **74**, **86**, **104**, **118** and **126**. Member **136** comprises an inner member **138** and an encompassing layer of material **140**. The outer surface of the inner member **138** has a plurality of peripherally extending grooves or recesses **142** formed therein. The inner surface of the layer of material **140** complementally conforms to the outer surface of member **138**.

In FIGURE 10 is shown yet another embodiment of a member **144** which is somewhat similar to the other members described above. Member **144** comprises an inner member **145** and an encompassing layer of material **146**. The outer surface of inner member **145** has a pair of peripherally extending surfaces **147** and **148** interconnected by a radially inwardly extending recess portion **149**. The inner surface of the encompassing layer of material **146** complementally conforms to the outer surface of the inner member **145**. Peripherally extending surface

147 is disposed closer to the longitudinal axis of inner member 145 than peripherally extending surface 148. This arrangement is beneficial since it provides a larger area to resist any imposed shear loading.

In FIGURES 11 and 12 is shown another embodiment of a rigid stem portion of a tube bending mandrel constructed in accordance with the subject invention. The rigid stem portion 152 comprises a generally cylindrically shaped member 154 having a plurality of longitudinally extending recesses or grooves 156 formed in the outer surface thereof. A strip 158 of material having a low coefficient of friction is disposed in each recess or groove 156. Each strip of material 168 extends radially outwardly from the outer surface of member 154 by a predetermined amount, the exact amount depending upon the same factors as specified above in connection with the description given for the member shown in FIG. 6.

The distance separating each longitudinally extending strip 158 from an adjacent strip is kept quite small, preferably equal to about the thickness of the wall of the tube with which the tube bending mandrel is to be used. More specifically, the overall guiding criteria is to insure that the metal surface of the member 154 does not come in contact with the wall of the tube to be bent while at the same time providing adequate support for the tube wall during the deformation thereof. It will be noted that each recess or groove 156 terminates against an end wall 160 formed adjacent the right end of the rigid stem portion as viewed in FIGURE 11. The purpose of the end wall 160 is to resist longitudinal movement of the strips 158, relative to the member 154, in a direction to the right as viewed in FIGURE 11. If desired or required, a lubricant 161 may be disposed intermediate adjacent strips 158.

In FIGURES 13 and 14 is shown another embodiment of a rigid stem portion suitable for use in a tube bending mandrel constructed in accordance with the subject invention. The rigid stem portion 162 includes a generally cylindrically shaped member 164 which has a plurality of peripherally extending recesses or grooves 166 formed in the outer surface thereof. An annular piece of material 168 is mounted within each groove 166. The same criteria as outlined above with respect to the distance separating each strip 168 from an adjacent strip 168 and the amount that each strip extends radially outwardly from the outer surface of member 164 applies here as well. If desired or required, a lubricant 165 may be disposed between adjacent strips 168.

In FIGURE 15 is shown a cross-sectional view in elevation, of a solid or plug type tube bending mandrel 170. The plug type tube bending mandrel 170 has a substantial portion of the external surface thereof coated with a layer of material 171. Said mandrel 170 has formed on the outer surface of member 169 a recess portion 169A which cooperates with a boss portion 171A integrally formed about the inner surface of said layer of material 171 to resist longitudinal movement of said layer of material 171 relative to said member 169. The plug type tube bending mandrel 170 has an internally threaded recess 172 as shown. The plug type tube bending mandrel 170 may be used in those applications in which a plug type tube bending mandrel is normally used. Since such use is well understood in the art, further explanation thereof is not deemed necessary. Further, although the layer of material 171 is shown as extending along the entire longitudinal length of the tube bending mandrel 170, it will be understood that a much shorter longitudinal length will suffice in many applications.

In FIGURES 16–18 is shown a wiper die 173 constructed in accordance wih the subject invention. The wiper die 173 includes a base member 174 having a semi-cylindrically shaped recess 175 formed in one surface thereof. A layer of material 176 is mounted within said recess 175 and secured thereto by a plurality of screws

178, the heads of which are suitably recessed as is more clearly shown in FIGURE 18, as well as being bonded thereto in a manner to be later described. The boss member 174 may also be formed with a recess or groove 177 which intercepts said recess 175. Said recess 177 cooperates with a boss portion 179 integrally formed on said layer of material 176 to provide additional resistance to longitudinal movement of said layer of material 176 relative to said base member 174. As is customary with wiper dies, one end thereof has a male portion 180 which complementally conforms with the inner surface formed in the bend die such as the inner surface 182 of bend die 44 shown in FIGURE 2. The male portion 180 also includes a pair of shoulders 184 which are disposed to seat against boss portions which are formed on the bend die such as boss portions 186 shown on the bend die 44 in FIGURE 2.

During the draw forming operation, the tube or pipe moves relatively with respect to the wiper die. As a consequence, it is preferred that the surface of the wiper die which is disposed in slidable engagement with the tube or pipe during the draw forming operation be coated with a layer of material having a low coefficient of friction. It is to be understood, however, that since the tube or pipe does not undergo any deformation except only at the trailing edge 188 of the wiper die, see FIGURE 16, that a tube bending apparatus constructed in accordance with the subject invention may include a wiper die which does not have a layer of material 176 disposed as shown without adversely affecting the beneficial results obtained herein. In FIGURE 17 it will be observed that the upper surface of said layer of material 176 tapers from a predetermined point such as at point 189 downward to the trailing edge 188.

Where the pressure die remains stationary during the draw forming operation, it is likewise preferable that the inner surface thereof be coated with a layer of material somewhat in the same manner as described with respect to the wiper die 173 shown in FIGURES 16–18. However, as in the case with the wiper die 173, it will be understood that the method and apparatus described herein may be performed with a pressure die which does not have a layer of material mounted on the inner surface thereof without adversely affecting the beneficial results obtained herein.

Heretofore, it has been impossible to bond securely a molybdenum disulfide impregnated nylon material to a metallic surface. However, it has been discovered that such a material may be securely bonded to a metallic surface if the following steps are observed. First of all, the metallic surface is roughened by grit or said blasting same followed by a degreasing thereof. The metallic surface may be degreased through the use of any one of several oil removing solvents such as ketone and trichlorethylene. Following the degreasing operation, steps must be taken to insure that the surface does not become contaminated. Thereafter or concurrently, the surface of the nylon material is prepared by applying for approximately one minute an acid solution such as a hydrochloric acid solution having approximately 20 to 28 percent acid concentration. The excess acid is suitably removed such as by wiping or blotting same. If the excess acid solution is removed by wiping with a clean paper tissue, it will be noted that the surface exhibits some tackiness. Next the surface is exposed to an acid neutralizing solution such as by being immersed in a soda solution. The surface should be exposed to the acid neutralizing solution for approximately two minutes or more. Next, the surface is rinsed in clear water and then allowed to dry Following this, an epoxy is applied to either of the prepared surfaces and preferably to both of said surfaces. Any excess epoxy is removed, care being taken to see that no solvent is used near the bond line. The two surfaces are then brought into and held in contact with each other and the epoxy is cured by exposing same to a temperature of approximately 200 to 250° F. for approximately one to one and one-fourth hours. The bonded materials are then allowed to cool to room temperature.

It has also been found that the nylon surface may be prepared by subjecting same to a temperature of approximately 600° F. or more until the molybdenum disulfide has been converted into an abrasive. It has been found that molybdenum disulfide changes from a lubricant to an abrasive when exposed to temperatures of approximately 600° F. or more for a short interval of time. Such conversion may be effected without adversely affecting the nylon material underlying the surface area. Thereafter, the epoxy is applied to the prepared surface and the remaining steps outlined above are followed to effect a good bond between the nylon material and a metallic surface.

It is to be understood that certain plastic materials, including a molybdenum disulfide impregnated nylon material, which can be applied to the surfaces of the various parts of the tube bending apparatus can be deposited thereon by extruding and/or injection molding. For example, referring to members **126**, **136** and **144** shown, respectively, in FIGURES 8–10, it is to be understood that the respective layers of material may be extruded onto the outer surfaces of the inner members shown therein.

In view of the foregoing, it will be understood that certain conditions must be maintained during the draw forming operation if the advantages and benefits of the subject invention are to be realized. More specifically, one metallic surface should not be disposed in slidable engagement with another metallic surface under conditions where galling occurs, i.e., a fretting or wearing away of one metallic surface by friction whereby a metal flake from one metallic surface transfers to the other metallic surface and becomes securely attached thereto by the action of cold welding. Where this condition occurs, the coefficient of friction between the two metallic surfaces greatly increases and the transferred metallic flake acts as a cutting edge thereby marring or scarring the metallic surface from which same originally came. By maintaining a predetermined coefficient of friction, the condition as just described can be prevented thereby greatly improving the quality of a draw formed tube while at the same time reducing the amount of power or energy required to accomplish same.

By further controlling the coefficient of friction existing between the metallic surfaces, spalling, i.e., the scaling or flaking off of metal particles as a result of friction, may also be prevented. Conditions causing spalling are to be avoided since spalling causes the surfaces to be marred, scarred or pitted and also increases the coefficient of friction between two metallic surfaces which are disposed in slidable engagement and, upon an increase in the applied load, spalling increases and ultimately changes to detrimental galling.

It is to be understood that the coefficient of friction, particularly in a draw forming operation, depends upon a number of factors. Some of the factors affecting the coefficient of friction are surface finish (degree of roughness or smoothness), surface conditions (annealed ior hardened and oxide coating), composition of material used, temperature, rate of movement of one of the surfaces relative to the other surface, and the amount of applied load. It has been found that where preselected surface portions of a tube bending apparatus, particularly certain surface portions of a tube bending mandrel, have been coated with a layer of material having a coefficient of friction of approximately 0.10 or less and said layer of material is mounted upon a rigid support member, the coefficient of friction at the interfacial work area is reduced to such a substantial degree that no seizure occurs between the two surfaces, even for large pressure gradients. Although good results have been obtained where a coefficient of friction of approximately 0.10 has been used, it is actually preferred to use a lower coefficient of friction of approximately 0.08 or less. Further, it has been discovered that excellent results are obtained where a coefficient of friction of approximately 0.06 or less is used especially from the view point of reduced power requirements and increased longevity of the tooling.

In view of the foregoing, it is to be understood that the conditions to be maintained between the surfaces of the tube to be draw formed and the surfaces of the tooling which are disposed in slideable engagement with the surfaces of said tube are such that no metal flakes will be transferred from the surfaces of the tube to the metallic surfaces of any of the tooling, or vice versa, and preferably such that little, if any, flaking of metal particles from any metallic surface will occur. It will also be understood that under some circumstances flaking from the surface of the material disposed intermediate the metallic surfaces of the tubing and the metallic surfaces of the tooling may occur and that same generally does not adversely affect the draw forming operation or the quality of the draw formed tube since such flakes or particles do not materially change the coefficient of friction and since same do not provide a cutting edge, as is the case with a metallic flake or particle. However, as used throughout this case, the prevention of spalling means the prevention of metal flakes or particles scaling or flaking off from a metal surface, while the prevention of galling means the prevention of flakes or particles of a material, including metal flakes or particles, scaling or flaking off from a surface of a material and becoming attached to any surface whereby same presents a "cutting" edge to any other surface disposed in slidable engagement therewith. Thus, it will now be appreciated that by maintaining a predetermined coefficient of friction between the surfaces of the tube and preselected surface portions of the tube bending apparatus, such as the flexible portion of the tube bending mandrel, during the draw forming operation to prevent galling and/or spalling, unusual and unexpected benefits are realized.

Although a nylon material impregnated with molybdenum disulfide has been described as a preferred type of plastic material to be used for coating the various surfaces, it is to be understood that a number of plastic materials may be used such as a glass filled nylon with or without molybdenum disulfide impregnation, for example, the products sold by Fiberfill Corporation of Warsaw, Ind. under the designation "Nylatron-G" and "Nylatron-G-MF," respectively. Still another example of a satisfactory material is a glass-reinforced nylon molding compound sold by Belding Corticelli Industries under the designation "BC I Nylon Resin LX–1115 F." Another example of a material which could be used is "Kel-F" which is a polymer of trifluorochlorethylene sold by M. W. Kellogg Company. Still another product which may be used is tetrafluorethylene and polytetrafluoroethylene.

It will be appreciated that some of the preferred plastics, ceramics and carbides might be applied by a spraying process as well as by those methods already outlined.

From the foregoing, it will be readily apparent that a greatly improved method and apparatus for draw forming tubes, pipes and the like have been described. Such draw forming may be done at greatly increased speeds thereby improving the efficiency of the entire operation. Further, the quality of the bend is likewise improved as a result of the elimination of spalling and galling and the production of tube walls which have a greatly improved thickness and uniformity and the inner surface of the tube itself being much smoother than has heretofore been possible under identical forming conditions. Further, since the life of the tube bending parts has been greatly increased, particularly the life of a tube bending mandrel constructed in accordance with the subject invention, the overall cost of tube bending has been decreased. Additionally, the unique bonding of a molybdenum disulfide impregnated nylon material to a metallic surface has greatly facilitated the manufacturing of various portions of a tube bending apparatus constructed in accordance with the subject invention including a tube bending mandrel.

It has also been found that galling and/or spalling may be prevented by subjecting either the surfaces of the tube or a portion of the surfaces of the tube bending apparatus, such as the tube bending mandrel, to a vibratory force during the draw forming operation. The draw forming of a tube in this manner has greatly reduced the amount of power heretofore required for draw forming tubes of a predetermined size while at the same time has increased the rate at which same can be draw formed. Although the exact phenomena involved is not fully understood, it is believed that the improvements obtained by draw forming in this manner are attributable to a reduction in friction between the respective surfaces and that as a result of such reduction in friction, galling and/or spalling is prevented.

It is to be understood that this invention is not limited to the exact embodiments of the methods and apparatuses shown and described, which are merely by way of illustration and not limitation, as various other forms and modifications will be apparent to those skilled in the art, and it is therefore intended that the appended claims cover all such changes and modifications.

We claim:

1. In a tube bending mandrel for draw forming of a tube, a relatively rigid support member and a wear resistant member, said wear resistant member being disposed to encompass at least a portion of said support member and being mechanically bonded thereto, said wear resistant member being formed from a material of different composition than the material used to form said support member.

2. In a tube bending mandrel as described in claim **1**, said wear resistant member being formed from a material selected from the class consisting of plastics, ceramics and carbides.

3. In a tube bending mandrel as described in claim **2** in which said wear resistant member has an external surface coated with a lubricant.

4. In a tube bending mandrel for draw-forming of a tube, a relatively rigid support means having external surface portions which are coated with a material having a coefficient of friction, relative to the material of the tube to be draw formed, of approximately 0.10 or less.

5. A tube bending mandrel comprising a rigid stem portion, a flexible body portion, means for connecting said flexible body portion to said rigid stem portion, said flexible body portion having external surface portions disposed to engage slidably a tube to be draw formed during the draw forming of a tube, at least a part of said external surface portions being coated with a material having a coefficient of friction, relative to the material of the tube to be draw formed, of approximately 0.10 or less.

6. A tube bending mandrel as described in claim **5** in which said rigid stem portion has an external surface portion at least a part of which is coated with a material having a coefficient of friction, realtive to the material of the tube to be draw formed, of approximately 0.10 or less.

7. A tube bending mandrel as described in claim **6** in which said rigid stem portion has means mounted about the end thereof and disposed adjacent said flexible body portion, said means resisting longitudinal movement, in a direction proceeding toward said flexible body portion, of said material coating said rigid stem portion.

8. A tube bending mandrel as described in claim **6** in which said rigid stem portion comprises a pair of members securely connected to each other.

9. A tube bending mandrel as described in claim **8** in which said material coating said rigid stem portion comprises at least two separate portions.

10. A tube bending mandrel as described in claim **5** in which said flexible body portion comprises a plurality of members, each of said members having means mounted on the periphery thereof for resisting longitudinal movement, proceeding in a direction from said rigid stem portion toward said flexible body portion, of the material coating the external surface portion thereof.

11. A tube bending mandrel as described in claim **10** in which said resisting means includes a snap ring mounted about a periphery of one end of said member wherein a portion of said material coating said member is disposed intermediate said snap ring and said rigid stem and at least a portion of said snap ring is disposed in an abutting engagement with a portion of said material.

12. A tube bending mandrel as described in claim **10** in which said resisting means includes a pair of peripherally extending surface portions, said surface portions being interconnected by a radially inwardly extending recess means.

13. A tube bending mandrel as described in claim **12** in which said radially inwardly extending recess means is, in cross section, generally semi-circular in shape.

14. A tube bending mandrel as described in claim **12** in which said radially inwardly extending recess means has a pair of generally opposed walls, said walls being convergently formed in a direction proceeding radially outward from said member.

15. A tube bending mandrel as described in claim **12** in which said radially inwardly extending recess means has a pair of walls, said walls being divergently formed in a direction proceeding radially outwardly from said member, one of said walls being disposed intermediate one end of said member and said rigid stem portion and being generally radially disposed with respect to said member.

16. A tube bending mandrel as described in claim **10** in which said resisting means includes a plurality of peripherally extending surface portions and a plurality of radially, inwardly extending recess portions, adjacent peripherally extending surface portions being interconnected by a corresponding one of said radially inwardly extending recess portions.

17. A tube bending mandrel as described in claim **10** in which said resisting means includes a pair of peripherally extending surface portions, said surface portions being interconnected by a radially outwardly extending boss means.

18. A tube bending mandrel as described in claim **12** in which a first one of said pair of peripherally extending surface portions is disposed closer to the longitudinal axis of said member than the other said peripherally extending surface portion, said first one of said pair of peripherally extending surface portions being disposed intermediate said rigid stem and the other said peripherally extending surface portion.

19. A tube bending mandrel as described in claim **6** in which said material coated upon said rigid stem portion comprises a plurality of peripherally disposed portions axially spaced along said rigid stem.

20. A tube bending mandrel as described in claim **19** in which the distance separating adjacent peripherally extending portions is equal to approximately the thickness of the wall of a tube to be draw formed.

21. A tube bending mandrel as described in claim **19** in which a lubricant is disposed intermediate adjacent peripherally extending portions.

22. A tube bending mandrel as described in claim **6** in which said material coated upon said rigid stem portion comprises a plurality of axially extending portions circumferentially disposed about the outer surface of said rigid stem portion.

23. A tube bending mandrel as described in claim **22** in which the distance separating adjacent axially extending portions is equal to approximately the thickness of the wall of a tube to be draw formed.

24. A tube bending mandrel as described in claim 23 in which a lubricant is disposed intermediate adjacent axially extending portions.

25. A tube bending mandrel as described in claim 10 in which said resisting means comprises a pair of peripherally extending boss portions, one of each of which is disposed adjacent a corresponding end of each of said member.

26. A tube bending mandrel as described in claim 5 in which said external surface portions are coated with a material having a coefficient of friction, relative to the material of the tube to be draw formed, of approximately 0.08 or less.

27. A tube bending mandrel described in claim 5 in which said external surface portions are coated with a material having a coefficient of friction, relative to the material of the tube to be draw formed, of approximately 0.06 or less.

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