Aug. 28, 1962 P. F. ZIEGLER 3,051,567

METHOD AND APPARATUS FOR MAKING POWDERED METAL ARTICLES

Filed July 28, 1958 2 Sheets-Sheet 1

Fig. 1

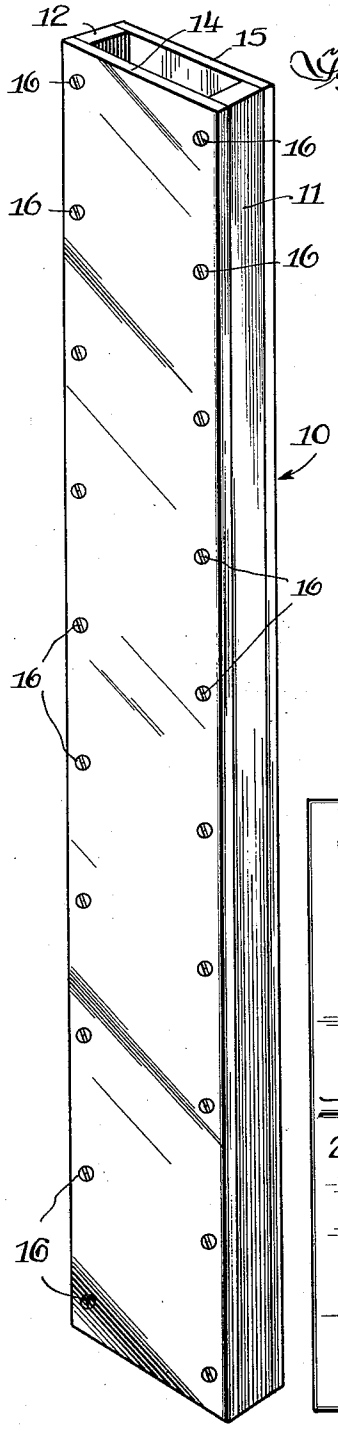


Fig. 2

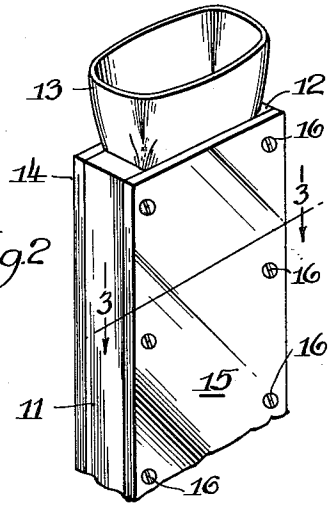


Fig. 9

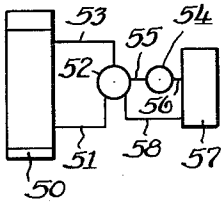


Fig. 3

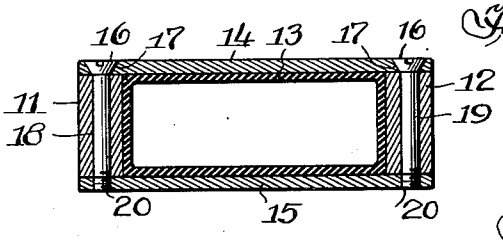
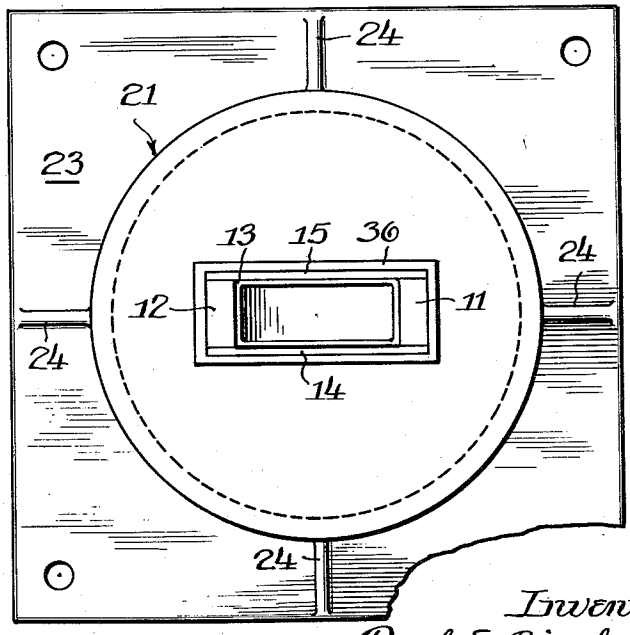


Fig. 4



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METHOD AND APPARATUS FOR MAKING POWDERED METAL ARTICLES

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Fig. 5

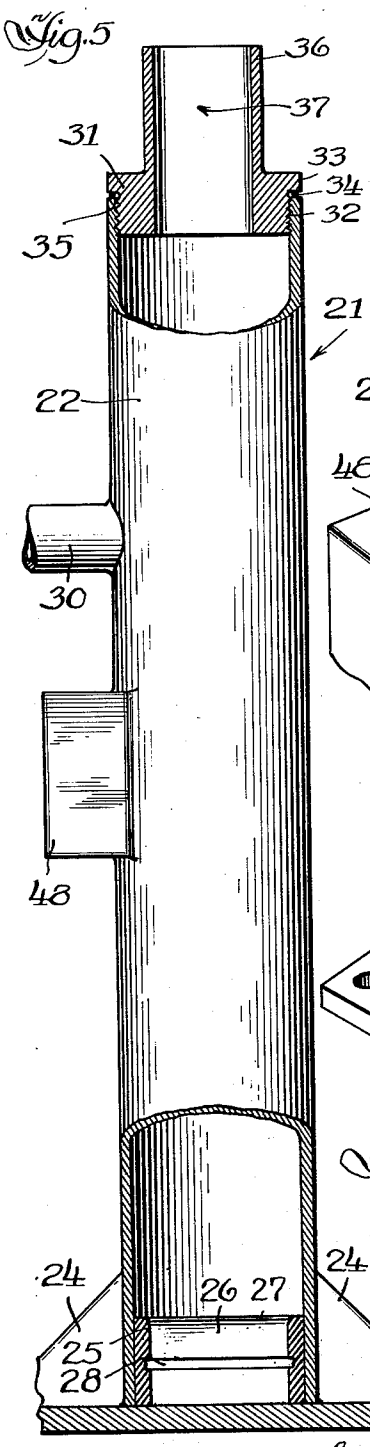


Fig. 6

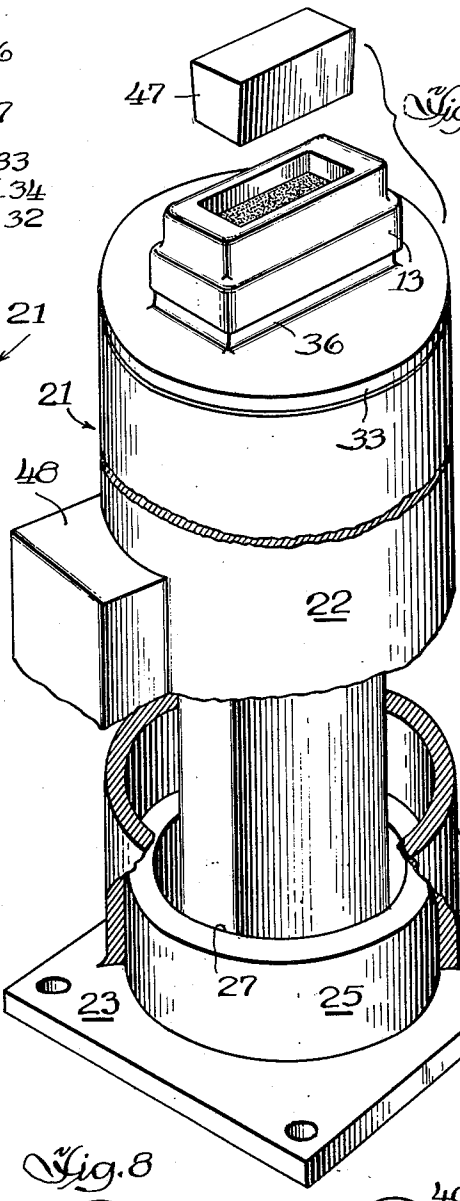


Fig. 7

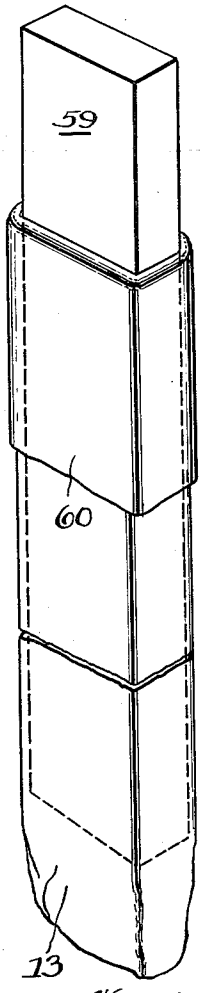
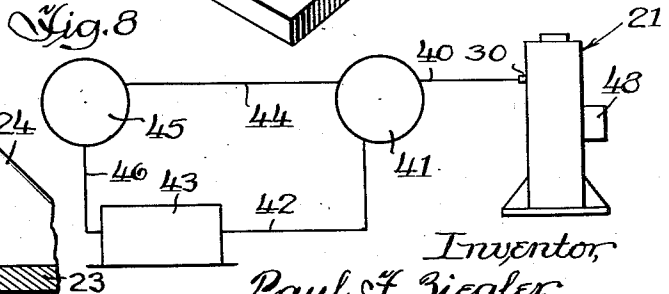


Fig. 8



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METHOD AND APPARATUS FOR MAKING POWDERED METAL ARTICLES

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Filed July 28, 1958, Ser. No. 751,416
13 Claims. (Cl. 75—214)

The present invention relates to method and apparatus for making powdered metal articles, and particularly to method and apparatus for pressing powdered metal into shaped articles.

Refractory metals such as tungsten, tantalum, columbium and molybdenum, ordinarily are extracted from their ores by chemical and electrochemical processes which leave the metal in discrete particulate form. These metals may be formed into articles either by arc melting or by powder metallurgy processes. Because arc melting leaves the metal too brittle for most purposes powder metallurgy is usually employed to make bars which are subsequently worked as by rolling or machining.

To make the bars the powdered metal was heretofore weighed and poured into molds for mechanical pressing the same into green compacts having substantially the same size and shape as the die cavity. Mechanical pressing was ordinarily effected at pressures in the range of from about 5 to about 50 tons per square inch. After pressing, the bars were sintered to permanently join the metal particles.

Mechanically pressed bars, however, had several disadvantages which resulted in difficulties when efforts were made to sinter the bars. Since the mechanical pressure was applied unidirectionally, the bars were not uniformly pressed. That is, the pressure gradient pattern across the bars differed depending upon the direction in which the gradient was measured. For example, the pressure patterns taken cross-sectionally of a rectangular bar, were elliptically shaped. This was a direct result of unidirectional pressure applied to the bar during the pressing operation. The pressures within the bar were greater in the direction in which the pressure was applied than they were transversely of the direction in which the pressure was applied.

The irregular or elliptical pressure gradient patterns resulted in irregular or nonuniform sintering and warpage of the bar during sintering.

When mechanically pressing, care must be taken to fill the die cavity as uniformly as possible since the metal powder does not distribute itself within the die cavity during pressing. If the die cavity is not properly filled with metal powder and there is more powder at one point in the die cavity than at another point in the die cavity, when the die parts mate the high point will be pressed much more than the low point with the result that the compact will be very weak at the low point and the bar will be nonuniform in strength. Such a bar will ordinarily tend to break during the sintering operation. Additionally, if the bar does not fail during the sintering operation, any sheet or foil formed from the bar will be nonuniform in density and will have varying properties, which results are undesirable.

Mechanical pressing also introduced other difficulties to sintering due to the surface smearing which occurred while the powder was being pressed into the green compact bar form. As the die and die cavity were mated, and the powder was pressed, the relative movement of the die parts and the powder caused the powder which engaged the surfaces of the die parts to be mechanically worked to an extent such that there was formed a skin-like surface on the green compact. This was known as "smearing."

Smearing of the surface particles of a green compact created difficulties in sintering since it obstructed the free flow of gases which formed with the bar due to volatilization of the impurities while the bar was being sintered. In many instances the impurities did not escape and in other instances the bars were ruined due to the collection of gases at weak points in the compact and a resultant "bellying" of the bar.

In addition to the foregoing, mechanical pressing of powdered metal to form bars is expensive in several respects. First, the equipment necessary to press powder into bar form is extremely expensive; a large press may cost more than one quarter of a million dollars. Second, when it is desired to change a bar size and shape, conversion of the mechanical press by removal of dies and replacement with dies of other size and shape, requires several hours of work. Third, the process of filling a die cavity, pressing by operation of a mechanical press and removing the pressed compact from the die cavity is time consuming. Fourth, there are strict limitations on the size and shape of the bars which can be pressed in any given mechanical pressing device.

By the present invention, all of the foregoing difficulties created by pressing the metal powder in a mechanical press have been obviated and there are provided new and improved method and apparatus for pressing metal powder into green compact form for sintering and rolling into bars, sheet and foil form as well as for fabricating in other forms. Also, by the present invention there are provided method and apparatus for pressing metal powder into shaped forms without mechanically engaging the powder by any means which would smear the surface of the powder.

In accordance with the present invention metal powders may be pressed in any desired form such as round rods or square or rectangular bars, etc. Hereinbelow, all such forms, unless specifically otherwise referred to, are intended to be included in the term "bars" for convenience of reference and expression.

Bars formed in accordance with the principles of this invention are pressed by means of hydrostatic pressure applied directly against a sealed flexible covering which protects the powdered metal from being directly engaged or permeated by the water or oil or other fluid pressure medium, and which will transmit the pressure of the fluid to the powder, uniformly in all directions. When the powder is pressed in this manner, the pressure gradient patterns in the green compact form are uniform cross-sectional of the bar and in a symmetrical bar assume pattern shapes which are each substantially equidistant at all points thereon from the outer surface of the bar. That is, if a square bar is pressed in accordance with this invention, the pressure gradient patterns will be substantially square, ranging to circular at the center of the bar.

After the bar is pressed, the covering material may be removed and the bar may be sintered more easily and efficiently than a mechanically pressed bar. The sintered bar pressed in accordance with this invention will have less tendency to "belly" than a mechanically pressed bar and will have a higher purity than a mechanically pressed bar starting with metal of the same composition and having the same impurities therein. This is so because of the porous character of the surface of the bar and the complete elimination of "smearing" when the bar is being pressed. Since the bar has a porous surface, volatilized impurities will easily escape through the porous surface and will not tend to collect at any point in the bar. Further, since the cross-sectional pattern of the pressure gradient is uniform within the bar, there is less distortion of the bar during sintering due to weak points in the bar.

In accordance with the present invention, the "bars" of metal powder may be hydrostatically pressed in any desired shape and configuration. To form the bars, a mold having fluid leakage paths therein is lined with a fluid impervious, flexible liner. The mold has an inner surface which is shaped to the desired configuration and which is dimensioned slightly larger than the desired dimensions for the article by an amount to compensate for the thickness of the liner and the amount by which the powdered material is compacted.

By the method and apparatus of this invention it is possible to form "bars" of irregular as well as regular configurations, as desired. Heretofore it was considered that the shape of hydrostatically pressed powdered materials could not be controlled due to the spherical pressure pattern in the pressure applying medium.

In addition to the versatility of the present invention for making shaped articles, it has also been found that the quality, i.e. purity, of the articles is increased when they are made by the principles of this invention. For example, foil rolled from bars made in accordance with this invention has been found to have substantially higher purity than foil rolled from bars which were mechanically pressed. The purity is, as in the case of tantalum, measured in terms of capacitor characteristics such as capacitance and microamps per square inch leakage in electrolytic capacitor testing conditions. In terms of percentage of bars tested, it was found that the D.C. leakage characteristic in microamps per square inch area of tantalum foil having a thickness of 0.0005 inch, was as follows: only 46.1 percent of mechanically pressed bars having a weight of 4700 grams as pressed, had a D.C. leakage of 2.0 or less microamps per square inch area of foil, whereas 85 percent of hydrostatically pressed bars in accordance with this invention, having a pressed weight of about 7000 grams, had a D.C. leakage of 2.0 or less microamps per square inch area of foil D.C. leakage.

It also has been found that rolling bars which have been hydrostatically pressed in accordance with this invention is more easily effected than rolling bars which have been mechanically pressed. For example, when rolling mechanically pressed bars of 4700 grams to a thickness of 0.005 inch from a starting thickness of ½ inch, it was necessary to anneal the bar twice. Each 4700 gram mechanically pressed bar had to be annealed for twenty minutes at 1450° C. when 0.115 inch thickness was reached, and for twenty minutes at 1150° C. when a thickness of 0.050 inch was reached.

A 7000 gram hydrostatically pressed bar, when rolled from a thickness of 0.610 inch to a thickness of 0.005 inch required annealing for twenty minutes at 1150° C. only at a thickness of 0.050 inch.

It has also been found that a hydrostatically pressed bar in accordance with this invention has improved mechanical characteristics such as ductility. For example, the percentage elongation, after rolling, of a 7000 gram hydrostatically pressed bar was 42.9 percent in the direction of rolling, 38.3 percent in a direction perpendicular to the direction of rolling and 48.3 percent in a direction at 45° to the direction of rolling. The tensile strength, after rolling, of the hydrostatically pressed 7000 gram bar is about 43,200 pounds per square inch in the direction of rolling, about 43,600 pounds per square inch in a direction perpendicular to the direction of rolling and about 41,800 pounds per square inch in a direction of 45° with respect to the direction of rolling.

These figures compare very favorably with corresponding figures for a 4700 gram bar which was mechanically pressed prior to sintering and rolling. In the tests of the 4700 gram bar, it was found that the percentage of elongation was 37.6 percent in the direction of rolling, about 34.9 percent in a direction perpendicular to the direction of rolling and about 40.6 percent in a direction at 45° to the direction of rolling. The tensile strength of the 4700 gram bar, after rolling, was 49,500 pounds per square inch in the direction of rolling, 52,000 pounds per square inch in a direction perpendicular to the direction of rolling, and 46,800 pounds per square inch in a direction at 45° from the direction of rolling.

Thus, the hydrostatically pressed bar rolled with greater percentages of elongation than the mechanically pressed bar and had a greater ductility than the mechanically pressed bar.

In addition to the foregoing, it was found that there was 6 percent less loss of material due to all other possible loss factors when rolling hydrostatically pressed and sintered bars to foil dimensions than when rolling mechanically pressed and sintered bars to foil dimensions.

Metal powder, according to this invention, is poured into a flexible liner which is disposed within a shaped form and drawn tightly against the interior surface of the form while it is being filled. By filling in this manner, the powdered metal will have a shape which matches the shape of the interior surface of the form. The form, the liner and the powdered metal are then maintained as a single assembly while hydrostatic pressure is applied thereto. The form has fluid leakage paths therein which permit access of the fluid pressure to the liner to compact the metal powder disposed within the liner without substantially changing the shape to which the powder is compacted from the shape of the interior surface of the form.

In accordance with this invention the mold form is first provided with a flexible, fluid impervious, preferably resilient liner. If the mold form is such as one for use in forming a rectangularly shaped elongated bar, the mold form is open at both ends and is lined with a liner such as tubular rubber band stock or plastic or other similar material.

One end of the liner is then plugged and sealed as by driving an oversize rubber block into the liner and into the form. The form with the liner having one end plugged and sealed is then disposed in an evacuation chamber with the open end of the liner and form extending out of the open end of the evacuation chamber. The open end of the liner is then rolled back over the edge of the tube and over the mouth of the evacuation chamber to provide a seal. At this time the evacuating mechanism for the evacuation chamber is energized and a vacuum is drawn within the chamber.

The form is preferably formed of machined and finished parts with fluid leakage paths that extend therethrough so that when a vacuum is drawn in the chamber, the liner will be drawn tightly against the interior surface of the form. With the evacuation mechanism operating to draw a vacuum preferably down to a few millimeters of mercury, powdered metal is poured into the open end of the liner and mold form. While the tube and mold form are being filled with powder, they are also vibrated so as to insure complete filling of the tube and the mold form. When they are properly filled, a sizing plug is inserted into the open mouth of the liner and the mold form. The evacuation mechanism is then turned off and the tube end is removed from the mouth of the evacuation chamber and sealed by means of tying.

After the mold form with the filled and sealed liner is removed as a whole assembly from the evacuation mechanism, it is deposited in a pressure vessel such as a removably capped cylinder which is connected to a hydraulic pump system. When the metal powder to be pressed is tantalum or other refractory metal, it is preferred that the hydraulic pump system be operative to supply the cylinder with fluid at any pressure up to about 100,000 pounds per square inch and preferably in the range of from about 10,000 pounds per square inch to about 100,000 pounds per square inch. With tantalum, it is preferred to press at a pressure in the range of from about 55,000 pounds per square inch to about 85,000 pounds per square inch. At higher pressures the density

of the bar approaches the theoretical maximum density of the metal asymptotically.

As soon as the desired pressure is reached, the pressure of the pressure applying medium may be relieved and the form, liner and metal powder, which is now a compact having a configuration substantially the same as the interior of the form, may be removed from the pressure vessel. The compact with the liner thereon is then removed from the form and the liner is stripped from the compact.

The compact is properly shaped and uniformly pressed since uniform pressure has been applied thereto over the entire surface thereof regardless of any variations in the contour and configuration of the bar.

In the drawings there are shown: a preferred form of mold for production of rectangularly shaped, elongated bars, a liner for the mold, and an evacuation chamber used in connection with the mold for filling the mold. It should be understood, of course, that numerous modifications and variations may be effected in this apparatus without departing from the present invention. The accompanying drawings show preferred illustrative embodiments of the present invention. In the figures of the drawings, like reference numerals refer to like parts, and

FIGURE 1 is a perspective view of a mold form embodying this invention;

FIGURE 2 is a fragmental perspective view of a mold form with a liner therein;

FIGURE 3 is a sectional view of the mold form and liner of FIGURE 2 taken substantially along the line 3—3 of FIGURE 2;

FIGURE 4 is a plan view of the evacuation chamber with a mold form therein;

FIGURE 5 is an elevational, partly sectional, view of an evacuation chamber embodying the present invention;

FIGURE 6 is a fragmental perspective view of an evacuation chamber with a filled mold form therein and of a plug for sealing the mouth of the mold form and liner;

FIGURE 7 is a perspective view of a pressed bar embodying this invention with a mold liner partially removed therefrom;

FIGURE 8 is a schematic illustration of the evacuation system and the evacuation chamber; and

FIGURE 9 is a schematic illustration of a fluid pressure system for applying hydrostatic pressure to the mold form with the liner and powdered metal therein.

In FIGURES 1, 2 and 3 there is illustrated a mold form for use in accordance with this invention for forming hydrostatically pressed powdered metal bars having rectangular cross section. The mold **10** is shown in FIGURE 2 with a liner **13** therein and is preferably formed of a pair of side or edge mold bars **11** and **12** which are machined to precise dimensions and shape. The bars **11** and **12** are rigid bars which form a support structure for the mold. These bars **11** and **12** are secured to a pair of spaced side plates **14** and **15**, respectively, which are dimensioned to overlie the edges of the bars **11** and **12** and to space the bars **11** and **12** by a distance corresponding to the transverse dimension of the bar. The side plates **14** and **15** are secured to the edge bars **11** and **12** by spaced screws **16—16**. These screws preferably extend through apertures **17—17** in the side plate **14**, and through apertures **18** and **19** in the edge bars **11** and **12** and cooperatively engage threaded apertures **20—20** in the side plate **15**.

Even though the side plates and the edge bars are machined, accurately interfitting parts and even though they are secured together by means of the screws **16**, there remain fluid leakage paths between the adjacent faces of the side plates and of the edge bars, and between the screws **16** securing the plates to the bars. Thus, when the mold form is inserted in either the evacuation chamber **21** in FIGURES 4, 5 and 6, or the fluid pressure vessel shown in FIGURE 9, fluid pressure can leak between the plates and the bars and between the screws which hold the plates to the bars for drawing the liner **13** tightly against the inner surface of the mold and for applying fluid pressure to the outer surface of the liner to compress the metal powder.

While the mold **10**, in this embodiment of the invention, is uniform in its dimensions and shape throughout the entire length thereof, it should be understood that it may have a varying cross sectional configuration and the sides thereof may be variously shaped and need not be planar.

At the beginning of the operation for making bars, an elongated tubular liner **13** is disposed within the mold **10**. The liner is preferably formed of sheet material and is a fluid impervious flexible material. The liner is preferably made of such a material as rubber band stock which is either natural or synthetic, or may be made of any desired other natural or synthetic material such as other forms of rubber, and flexible copolymers. It is preferred that the liner be flexible, resilient and elastic for several purposes. A resilient and flexible material has been found to be the most efficient type of material in that it is more easily removed from the pressed bar by rolling it back on itself and stripping it from the bar in the manner shown in FIGURE 7. A resilient flexible material does not stick to the powdered material of the bar as do other materials which may be flexible but which are not resilient. Sticking of the material of the liner to the bar could create serious difficulties in removal of the liner from the bar after the liner and bar have been subjected to pressures which may range up to as high as about 50 tons per square inch.

After the liner is inserted into the mold form, one end thereof is sealed as by driving an oversize rubber plug therein which will seal one end of the interior of the liner against fluid passage between the plug and the liner.

The mold with the liner therein having one end thereof sealed is then inserted into an evacuation chamber **21** best seen in FIGURES 4, 5 and 6. In this embodiment of the invention, the evacuation chamber is formed of an elongated, rigid tubular element such as a length of pipe **22** of sufficient thickness to withstand mechanical shock and vibration with a pressure differential thereacross ranging up to atmospheric pressure. One end of the evacuation chamber wall **22** is sealed as by welding the same to a base plate **23** having support fillets or fins **24** thereon secured to both the base plate and the chamber wall or pipe **22**. At the end of the pipe **22** adjacent to the base plate **23**, a loose fitting plug **25** is inserted therein. The fittitng plug has an annular recess or an aperture **26** therein which has a diameter substantially the same as the diagonal dimension of the mold **10** and which has a rounded mouth **27** which forms an ingress and egress guide for the mold **10** when the mold is being inserted in and removed from the evacuation chamber **21**.

The fitting plug **25** is also provided with an inner peripheral recess **28** to facilitate placing the plug in the pipe and removing the plug from the pipe. A pair of tongs having projecting fingers thereon may be used to catch in the recess **28** to hold the plug when inserting the same or removing it from the pipe.

It is desirable to change the plug **25** to another internal diameter when a change is made in the size and dimensions of the mold **10**. The plug preferably has contacting engagement with the corner edges of the mold **10** so as transmit vibrations thereto and thereby improve settling of the metal powder in the mold when filling the mold.

At an intermediate point between the ends of the evacuation chamber wall or pipe **22**, it is provided with a vacuum and air connecting tube **30** for connection with the evacuation system shown in FIGURE 8.

At its upper end, the evacuation chamber is provided with an open cap or plug **31** which threadably engages the interior of the pipe **22** at the upper end thereof as by cooperative threads **32** on the interior of the upper

end of the pipe and on the exterior of the inner end of the plug 31. The plug 31 is provided with a sealing flange 33 for compression of a seal ring 34 between the flange and the upper edge 35 of the pipe 22.

The plug 31 is also provided with an upstanding mouth piece 36 which is longitudinally channeled to provide a rectangular opening 37 which is slightly larger than the outside of the mold 10 to provide a sliding fit with respect thereto when the mold 10 is inserted therethrough into the evacuation chamber 21.

In FIGURE 8 there is schematically shown an evacuation chamber for use in conjunction with the evacuation chamber 21. The connection element 30 at the side of the evacuation chamber 21 is connected through a hose or vacuum line 40 to a two-way valve 41. The other connections of the valve extend through a hose or vacuum line 42 to a tank 43, and through a hose or vacuum line 44 to a vacuum pump 45 which is also connected to the tank 43 as by a vacuum line or hose 46. This arrangement is so connected that when the pump 45 is operating as by being driven from a motor or other prime mover, it will reduce the pressure in the evacuation chamber substantially below atmospheric pressure and preferably to a pressure measured as low as 1 or 2 millimeters of mercury.

In accordance with the method of the present invention, the liner 13 is inserted into the mold form 10 to extend smoothly throughout the length of the mold form. Thereafter, one end of the liner 13 is sealed as by the insertion thereinto of a plug such as a relatively hard rubber plug or other form of plug which will form a substantially airtight seal with the liner 13. One form of plug is shown in FIGURE 6. The plug 47 in FIGURE 6 is the top plug and is slightly smaller than the bottom plug. The top plug 47 is a loose fitting plug which gives shape to the metal powder in the mold prior to pressing.

After the lower end of the liner 13 is sealed, the form and liner together are inserted into the evacuation chamber through the mouth 37 and into the recess 26 in the fitting 25. The mold form 10 is slightly longer than the evacuation chamber so that its upper end projects slightly above the upper end of the mouth piece 36. The liner is then stretched over the upper ends of both the mold form 10 and the mouthpiece 36 of the evacuation chamber to form a vacuum seal therebetween.

The evacuation system shown in FIGURE 8 is then energized to draw a vacuum in the evacuation chamber. The vacuum in the evacuation chamber extends through the mold form to the liner 13 by exhausting the air between the liner and the mold form through the leakage gaps between the side plates 14 and 15 and the end bars 11 and 12, to draw the liner tightly against the inside surface of the mold form. With the evacuation system operating, pre-weighed quantities of metal powder are poured into the liner from the top. To insure proper and complete filling of the liner in the mold form, a small vibrator 48 is connected to the side wall or pipe 22 of the evacuation chamber to vibrate the mold form 10, and shake the powder compactly into the mold form. The vibrator 48 may be of any desired type so long as it will impart sufficient vibration through the evacuation chamber to the mold form to shake the powder for proper filling of the mold form.

After the mold is filled, the top plug 47 is inserted into the mold. Then the evacuation system is de-energized and the upper end of the liner 13 is released from the top of the mouthpiece 13 on the evacuation chamber and the top of the mold form 10. A fluid-tight seal is made by tying the liner tightly over the top of the plug 47.

With the mold form properly filled, the mold form, the liner and the powder therein are transported as a unit to a compression system shown diagrammatically in FIGURE 9. This system is a hydrostatic pressing system preferably capable of applying high fluid pressures in the range of for example from about 35,000 pounds per square inch to about 100,000 pounds per square inch for tantalum and from about 10,000 pounds per square inch to about 50,000 pounds per square inch for molybdenum and tungsten. The system includes a pressure vessel 50 supplied with fluid through a high pressure fluid feed line 51 connected to a two-way valve 52, and a fluid pressure release line 53 which is also connected to the valve 52. The valve, in turn, is connected to a multiple stage high pressure pump 54 through a feed line 55. The other side of the pump 54 is connected through a line 56 to a fluid reservoir 57. The valve 52 also has an exhaust line 58 which is connected to the reservoir 57.

In accordance with the method of this invention, the mold form 10 with the liner 13 and the powder therein is inserted as a unit into the pressure vessel 50 which is then sealed. After the pressure vessel 50 is sealed, the pump 54 is driven by any power source such as a motor or other prime mover to supply a high pressure fluid through the valve 52 to the pressure vessel. The pressure is brought up to the desired level as quickly as possible and then, as soon as the desired pressure is attained, the pump system is de-energized to relieve the pressure by appropriate operation of the valve 52.

In accordance with the present invention, it is not necessary to hold the vessel at the desired pressure for any particular length of time. It is only necessary to bring the pressure in the vessel up to the desired level in order to press the powder within the liner of the mold form.

Fluid pressure in the vessel is applied to the powder by fluid movement through the leakage gaps between the side plates 14 and 15 and the edge bars 11 and 12 of the mold form and between the screws 16 which hold the side plates onto the edge bars of the mold form. This fluid pressure, which is then present within the mold form, is applied against the liner uniformly thereabout to apply uniform pressure circumferentially about the entire surface of the liner and the powder therein. In addition, the fluid pressure acts against the loose top plug to apply end pressure to the powder in the mold form.

The application of pressure in this manner uniformly presses the powder in the liner at all points on the surface of the liner and does not leave any weak spots in the compact thus pressed.

After the pressure in the pressure vessel 50 has been relieved, the mold form and its contents are removed as a unit from the pressure vessel. The plug at the lower end of the mold form and liner is then removed so that the liner and powder compact may be removed from the mold form easily by sliding movement. The pressure applied to the liner and the powder was sufficiently great to press the powder to an extent sufficient to decrease the size of the compact and liner to dimensions slightly less than the inside dimensions of the mold form so the liner and compact may be easily removed from the mold form.

When the liner and compact are removed from the mold form, they adhere together due to surface adhesion resulting from the high pressure applied thereagainst. The green compact and liner are shown in that state in FIGURE 7 wherein the liner is shown partly removed from the compact. The compact 59 in FIGURE 7 is firm and rigid and has sufficient strength to be handled. The liner 13 is removed from the compact 59 by stripping one end 60 thereof back along the length of the liner until the entire liner is removed from the compact 59.

After the liner 13 is removed from the compact, the compact is ready for sintering and other operations.

In the event that the compact should break through handling, it is easily and conveniently reprocessed by light pulverizing of the powder. Losses due to breakage of the compact, however, have been found to be substantially less than losses due to breakage of compacts formed by mechanical pressing, since the pressure applied to form the compact is uniform over the entire outer sur-

face thereof with resulting increase in the strength of the compact.

It will be observed that numerous modifications and variations may be effected in the method and the apparatus of the present invention without departing from the true spirit and scope of the novel concepts and principles of this invention. It should be understood that the examples, the method and the apparatus described hereinabove, are illustrative embodiments of the invention and should not be construed to form any limitation upon the scope of the invention.

I claim:

1. A method of forming shaped articles of powdered metal, comprising disposing a flexible fluid impervious liner of sheet material in a hollow substantially rigid form of the desired shape and size for the article to be formed and having fluid leakage paths therein, filling said liner with powdered metal and sealing the ends thereof, applying fluid pressure to said form and said liner to press said powder into a green compact of substantially the same size and shape as the interior of the hollow form.

2. A method of forming shaped articles of powdered metal, comprising disposing a flexible fluid impervious liner of sheet material in a hollow substantially rigid form of the desired shape and size for the article to be formed and having fluid leakage paths therein, filling said liner with powdered metal and sealing the ends thereof, applying fluid pressure to said form and said liner at a pressure in the range of from about 10,000 pounds per square inch to about 100,000 pounds per square inch to press said powder into a green compact of substantially the same size and shape as the interior of the hollow form.

3. A method of forming shaped articles of powdered metal, comprising disposing a flexible fluid impervious liner of sheet material in a hollow substantially rigid form of the desired shape and size for the article to be formed and having fluid leakage paths therein, filling said liner with powdered metal and sealing the ends thereof, applying fluid pressure to said form and said liner to press said powder into a green compact of substantially the same size and shape as the interior of the hollow form and sintering said compact to permanently join the particles of said metal powder.

4. A method of forming shaped articles of powdered metal, comprising disposing a flexible member of fluid impervious sheet material in a hollow substantially rigid form of the desired shape for the article to be formed, filling said member with powdered metal, sealing said member, disposing said form with the filled and sealed member therein in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said member and the contents thereof substantially uniformly thereabout, relieving said fluid pressure, removing said form and said member from said vessel, and stripping said member from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of the hollow form.

5. A method of forming shaped articles of powdered metal, comprising disposing a flexible member of fluid impervious sheet material in a hollow substantially rigid form of the desired shape for the article to be formed, filling said member with powdered metal, sealing said member, disposing said form with the filled and sealed member therein in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said member and the contents thereof substantially uniformly thereabout, relieving said fluid pressure, removing said form and said member from said vessel, and stripping said member from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of the hollow form and sintering said compact to permanently unite the powdered metal particles in the compact.

6. A method of forming shaped articles of powdered metal, comprising disposing a flexible member of fluid impervious sheet material in a hollow substantially rigid form of the desired shape for the article to be formed, filling said member with powdered metal, sealing said member, disposing said form with the filled and sealed member therein in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said member and the contents thereof at a pressure in the range of from about 10,000 pounds per square inch to about 100,000 pounds per square inch, relieving said fluid pressure, removing said form and said member from said vessel, and stripping said member from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of the hollow form.

7. A method of forming shaped articles of powdered metal, comprising disposing a flexible member of fluid impervious sheet material in a hollow substantially rigid form of the desired shape for the article to be formed, filling said member with powdered metal, sealing said member, disposing said form with the filled and sealed member therein in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said member and the contents thereof substantially uniformly thereabout, relieving said fluid pressure, removing said form and said member from said vessel, and stripping said member from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of the hollow form.

8. A method of forming shaped articles of powdered metal, comprising the following steps: placing a flexible liner of sheet material in a hollow substantially rigid form having the desired shape for the article to be formed, sealing an end of said liner, disposing the hollow form in an evacuation chamber, filling said liner with powdered metal and evacuating said evacuation chamber to draw said flexible liner tightly against the interior of said hollow form while said liner is being filled with powdered metal and while said liner is being sealed, sealing the other end of said liner, removing said form with said sealed liner therein from said evacuation chamber and disposing the same in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said liner and the contents thereof, relieving said fluid pressure, removing said form and said liner from said vessel, and stripping said liner from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of said hollow form.

9. A method of forming shaped articles of powdered metal, comprising the following steps: placing a flexible liner of sheet material in a hollow substantially rigid form having the desired shape for the article to be formed, sealing an end of said liner, disposing the hollow form in an evacuation chamber, filling said liner with powdered metal and evacuating said exacuation chamber to draw said flexible liner tightly against the interior of said hollow form while said liner is being filled with powdered metal, sealing the other end of said liner, removing said form with said sealed liner therein from said evacuation chamber and disposing the same in a fluid pressure vessel, admitting pressurized fluid to said vessel to apply fluid pressure to said liner and the contents thereof, relieving said fluid pressure, removing said form and said liner from said vessel, and stripping said liner from said powdered metal which has been pressed into a green compact of the desired shape substantially the same as the shape of the interior of said hollow form and sintering the compact to permanently join the particles of the metal powder together.

10. In a method of forming shaped articles of pow-

dered metal, comprising disposing a shaped hollow substantially rigid form of a desired shape for the article to be formed in an evacuation chamber having an open end, disposing a flexible tube of fluid impervious sheet material in the hollow form and sealing an end of said tube, sealing the open end of said evacuation chamber but leaving access to said tube, evacuating said chamber to draw said tube against the interior of the hollow form, said hollow form having means therein permitting passage of fluid therethrough from the exterior thereof to the interior thereof, filling said tube with powdered metal, vibrating said form, and sealing the other end of said tube.

11. In a method of forming shaped articles of powdered metal, providing a substantially rigid form having an interior surface of a shape desired for the size and shape of the article to be formed, said form having fluid leakage paths therein for the passage of fluid therethrough from the exterior thereof to the interior thereof, lining said form with a fluid impervious and flexible sheet material, filling said form with powdered metal and sealing said fluid impervious flexible material about said powdered metal.

12. In a method of forming shaped articles of powdered metal, providing a substantially rigid form having an interior surface of a shape desired for the size and shape of the article to be formed, said form having fluid

leakage paths therein for the passage of fluid therethrough from the exterior thereof to the interior thereof, lining said form with a fluid impervious and flexible sheet material, evacuating said evacuation chamber to draw said fluid impervious and flexible material tightly against the interior surface of said form, filling said form with powdered metal and sealing said fluid impervious flexible material about said powdered metal.

13. In apparatus for forming powdered metal into an article having a desired shape and configuration, a hollow substantially rigid mold form, the interior of said form having the desired shape and configuration for the article to be formed, and an evacuation chamber cooperatively arranged with said mold form, said mold form having fluid leakage paths therein for the passage of fluid therethrough whereby when said evacuation chamber is evacuated a flexible liner in said mold form will be drawn tightly against the interior surface of said mold form.

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