Oct. 25, 1960 K. M. BARTLETT 2,957,232

FORGED POWDERED METAL ARTICLES

Filed July 29, 1954 2 Sheets-Sheet 1

Fig-1

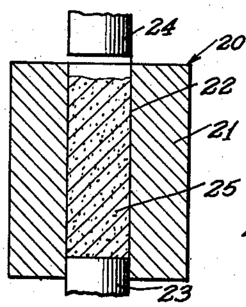


Fig-2

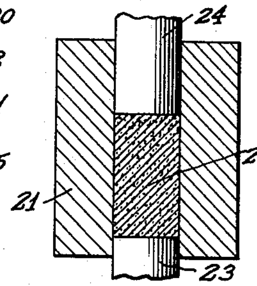


Fig-3

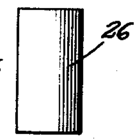


Fig-7

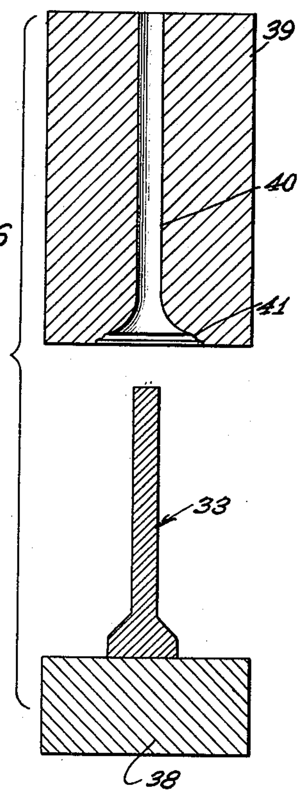


Fig-4

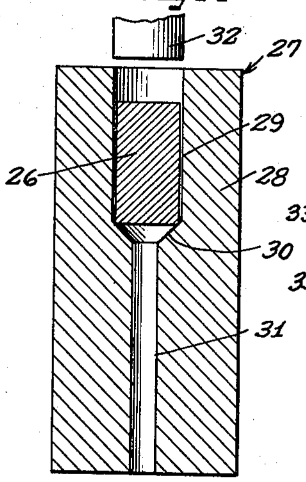


Fig-5

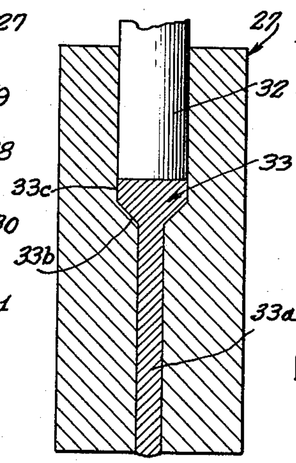


Fig-6

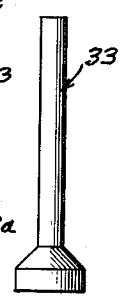
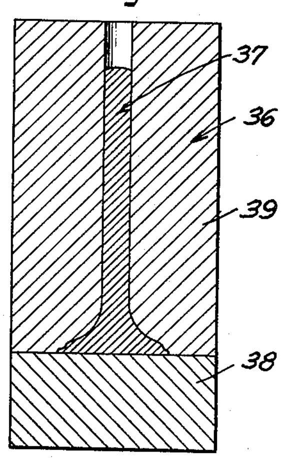


Fig-8



Inventor
KENNETH M. BARTLETT

by Hill, Sherman, Meroni, Gross & Simpson Attys.

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Fig. 9

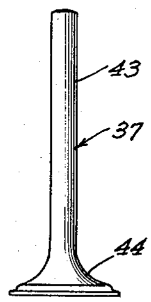


Fig. 10

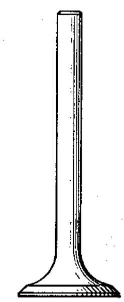


Fig. 11

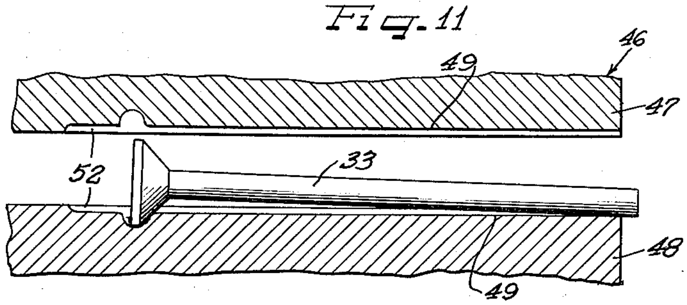


Fig. 12

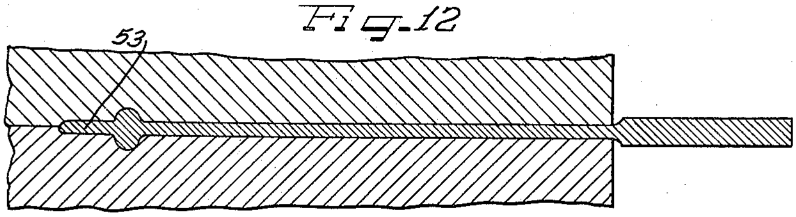


Fig. 13

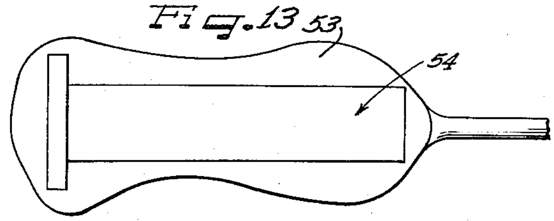
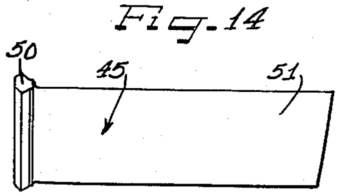


Fig. 14



Inventor
KENNETH M. BARTLETT

by Hill, Sherman, Meroni, Gross + Simpson Attys.

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FORGED POWDERED METAL ARTICLES

Kenneth M. Bartlett, Lyndhurst, Ohio, assignor to Thompson Ramo Wooldridge Inc., Cleveland, Ohio, a corporation of Ohio

Filed July 29, 1954, Ser. No. 446,495

1 Claim. (Cl. 29—192)

This invention relates to a method of producing strong, dense, creep-resisting powdered metal articles.

Specifically this invention deals with the production of powdered metal fluid-directing members, such as poppet valves for internal combustion engines and blades or vanes for turbine engines, by closed die forging of powdered metal compacts containing slip-preventing aggregates.

In accordance with this invention, powdered metals are pressure molded and sintered to form starting slugs or billets. These slugs or billets are then heated and forged in closed type dies to further compact and weld the particles together without melting the particles. The closed die forging is typified by extrusion. The powdered metal mixture preferably contains slip-preventing aggregates such as refractory metal carbides or intermetallic compounds, which are insoluble in the metals forming the main body of the mixture. These aggregates minimize and control slippage of the constituent main body, particles, thereby decreasing creep under stress, both in the finished product and during the die forging formation of the product. In the sintering operation or during the hot die forging treatment, some of the constituents of the powdered metal mixture may be oxidized to provide an enhanced refractory property to the article.

The invention will be hereinafter specifically described as embodied in fluid directing members for high temperature usage, such as poppet valves for internal combustion engines and turbine vanes or buckets for gas turbine engines and the like, but it should be understood that the principles of this invention are generally applicable to the production of strong, dense articles from powdered metals. Therefore, the invention is not intended to be limited to the preferred hereinafter described embodiments.

It is then an object of this invention to provide dense, strong, die-forged powdered metal articles.

A further object of the invention is to provide a method of increasing the strength and stress resistance of powdered metal articles.

A still further object of the invention is to provide a method of making fluid directing members of enhanced density and strength from sintered powdered metal compacts by extruding the compacts at elevated temperatures to weld together and further compact the metal particles and thereafter finish shaping the resulting extruded body into the form of a fluid directing member.

A still further object of the invention is to provide stronger powdered metal articles than have heretofore been produced under known powdered metallurgy techniques.

A specific object of the invention is to provide poppet valves and turbine blades from sintered powdered metal compacts by extrusion and coining operations.

A still further and specific object of this invention is to provide strong powdered metal articles having a density of 95% or more.

Other and further objects of the invention will be apparent to those skilled in the art from the following

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detailed description of the annexed sheets of drawings which, by way of preferred examples only, illustrate several embodiments of the invention.

Figure 1 is a fragmentary elevational view, with parts in vertical cross section, illustrating a pressure molding die and punch assembly for producing a starting slug from powdered metal and illustrating the open position of the assembly;

Figure 2 is a view similar to Figure 1 but illustrating the closed position of the assembly;

Figure 3 is a side elevational view of a sintered powdered metal slug or billet forming a starting blank for the process of this invention;

Figure 4 is a fragmentary side elevational view, with parts in vertical cross section, illustrating an extrusion die assembly for extrusion of the slug of Figure 3 and showing the assembly in open position;

Figure 5 is a view similar to Figure 4 but showing the assembly at the completion of the extrusion operation;

Figure 6 is a side elevational view of an extruded headed rod produced in the dies illustrated in Figures 4 and 5;

Figure 7 is a cross sectional view of a coining die assembly for the extruded headed rod of Figure 6 and illustrating the open position of the assembly;

Figure 8 is a view similar to Figure 7 showing the closed position of the assembly;

Figure 9 is a side elevational view of a coined poppet valve blank produced according to this invention;

Figure 10 is a side elevational view of a finished poppet valve produced from the coined blank of Figure 9;

Figure 11 is a vertical cross sectional view, with parts in elevation, showing a coining die assembly employed in producing a turbine engine blade from an extruded, headed rod similar to the one shown in Figure 6;

Figure 12 is a view similar to Figure 11 illustrating the closed position of the coining die;

Figure 13 is an elevational view of a turbine engine blade blank produced by coining the headed rod in Figure 6 in the manner shown in Figures 11 and 12; and

Figure 14 is an elevational view of a finished turbine bucket produced from the coined blank shown in Figure 13.

As shown on the drawings:

The method of the instant invention is applicable to substantially any metal which is capable of lending itself to working and processing by powdered metallurgical techniques. Since, however, the preferred invention deals with the production of fluid directing members, such as poppet valves, turbine buckets and the like, the present discussion shall be limited to those metals which are particularly suitable for these purposes. Such metals are iron and iron base alloys, nickel base alloys and especially nickel-chromium and nickel-cobalt base alloys. Iron-aluminum alloys containing from about 98% to 85% iron and from about 2% to 15% aluminum are useful since some of the aluminum may be converted to the oxide during sintering and hot forging for increasing the refractory properties of the product.

Preferred nickel-base chromium alloys are "Inconel" alloys as such are disclosed in the Bieber et al. Patent 2,664,354 and T.P.A. alloys containing:

	Percent
Cr	13–15
Ni	13–15
W	1.75–3.0
Mo	.20–.50
Si	.30–80
C	.40–.50
Fe	Bal.

Preferred nickel-cobalt base alloys include alloys containing 35–70% Ni; up to 20% Co, up to 10% W, .05–1.0% C; bal. Fe with small amounts of Mo; Si; Cr, etc.

In order to decrease and control slippage resulting in tensile strains and creep both during extrusion and in the use of the finished product non-slip aggregates are incorporated into the powdered metal mix. The preferred materials for such use as aggregates comprise the so-called hard metals and intermetallic compounds of aluminum.

The hard metals comprise carbides of metals of the 4th, 5th and/or 6th group of the periodic system, particularly titanium carbide and tungsten carbide. In addition to the hard metals, such aggregates also include chromium carbide, and mixtures of chromium carbide with titanium carbide and tungsten carbide; intermetallic compounds of nickel and aluminum and of nickel and boron; and the borides and nitrides of zirconium and titanium.

These insoluble aggregates will decrease slippage of the crystal planes so that molecular continuity will be maintained and rupture or slip cracks or pressing cracks will not develop when the compact is extruded. When extruding nickel-base alloys, mass slippage of a part of the compact may sometimes occur during extrusion resulting in cracking or rupturing of the extruded piece. Mass slippage usually results in a complete loss of the article produced. If, however, a hard phase aggregate material, such as for example an insoluble powdered hard metal, is dispersed throughout the matrix of a nickel-base alloy compact, a definite resistance is offered to deformation of the compact during the extrusion step. The resistance to deformation has been found to be proportional to the logarithm of the average length of a straight path through the continuous (nickel alloy) phase. Therefore, by dispersing an insoluble aggregate material throughout the matrix of the alloy it is possible to interrupt or eliminate straight paths through the continuous phase which otherwise would afford a nucleus for the creation of slippage or cleavage planes. The amount of aggregate admixed with the powdered nickel-base alloy prior to compacting the same varies to some extent depending upon the continuous or alloy phase employed. In general, however, a ratio of from about 0.5% to 25% by volume of aggregate to from about 99.5% to 75% of the alloy gives operable and advantageous results.

The particle size of the powdered metal from which the compact is produced is not critical and can vary within limits. If iron or a ferrous alloy are employed without the use of an aggregate, metal powders finer than about 100 mesh are operable; with particle sizes of from 100 mesh to 325 mesh being preferred.

Where nickel-base alloys are admixed with aggregates prior to compacting the same, the alloy phase of the mixture should have particle sizes about the same as indicated above; and the aggregate preferably has a particle size in the low micron range, for example, from ½ to 20 microns and preferably from 1 to 5 microns.

In accordance with the instant invention the powdered metals are pressure molded into a suitable slug or billet by means of a suitable compacting die assembly **20**. The compacting die assembly **20** includes a die body member **21**, having a suitable cylindrical bore or die cavity **22** formed therein, a lower punch member **23** slidably receivable in the bottom portion of the die cavity **22**, and an upper punch member **24** slidably receivable in the top portion of the die cavity **22**. The die assembly **20** is preferably of the double action type; that is, both the upper punch member **24** and the lower punch member **23** are capable of exerting pressures upon a powdered metal **25** contained in the die cavity **22**. In this fashion the molding pressure is maintained at a uniform rate on both sides of the powder thereby producing a slug or billet displaying substantially uniform density throughout. In a single action press, such as where only the upper punch member **24** is activated to deliver compacting pressures, uniform densities do not always result, and the resulting slug or billet displays inferior extruding properties.

As seen in Figures 1 and 2 the die cavity **22** is filled flush with the top of the die body member **21** with a suitable powdered metal mixture **25** which, as noted previously, may comprise iron; iron-aluminum alloys; nickel base alloys; etc., and 0.5–25% by volume of a suitable insoluble, slip-preventing aggregate. The powdered metal or mixture **25** is then compressed between the upper punch member **24** actuated downwardly and the lower punch member **23** actuated upwardly in the die cavity **22**.

In general, the compacting pressures employed will vary to some extent with the metal being pressure molded. In general, however, compacting pressures of from about 20 tons per square inch to about 60 tons per square inch are operative and produce slugs or billets which, after being sintered, may be extruded satisfactorily to produce a suitable fluid directing member blank.

After the powdered metal **25** has been pressure molded to form a suitable slug or billet **26** as shown in Fig. 2, the billet or slug **26** is expelled from the die cavity **22** by withdrawing the upper punch member **24** and raising the lower punch member **23**. Thereafter the slug **26** is sintered to produce a self-sustaining extrusion slug. The temperature employed in sintering will vary depending upon the metal employed; the length of the heating time; and the size of the slug **26** produced. In general, however, sintering at a range of from about 1400° F. to about 2400° F. for from about 1 to 20 hours produces a slug or billet **26** having suitable self-sustaining properties, and which is capable of being extruded. The longer heating times, of course, are employed with the lower sintering temperatures, while the shorter periods are associated with the higher temperatures.

The compact or slug **26** should preferably be sintered in a non-oxidising atmosphere. An atmosphere of this type may be provided by employing cracked or dissassociated ammonia; partially combusted hydrocarbon gases; inert gases such as argon or the like; hydrogen; or under vacuum conditions. If the powdered metal employed comprises a high carbon steel, it is important that the sintering atmosphere be non-decarburizing. Likewise, when a nickel-base alloy is employed it is important that a sulphur-free atmosphere be employed, for nickel and sulfur at elevated temperatures are extremely reactive.

The sintered compact slug or billet **26** may be cooled and stored for extrusion at a later time or may be taken directly in its heated condition from the sintering furnace and extruded. The extruding step is carried out in closed extrusion dies to keep the material in a state of complete compression during extrusion to prevent the formation of excessive tensile forces and stresses. This is best effected by means of the extruding die assembly **27** shown in Figures 4 and 5. As seen therein the slug or billet **26** is placed in an extruding die member **28** having a cylindrical die hole **29** of a larger diameter than the slug **26**. The die hole **29** extends to a conical throat **30** which converges to a small diameter cylindrical outlet passage **31**. An extrusion plunger **32** snugly fitting the hole **29** is pressed on top of the slug **26** to force the slug partially through the extrusion throat **30** to form a headed rod or blank **33** (Fig. 5). The blank or rod **33** has a solid cylindrical elongated rod portion **33*a*** of the same diameter as the outlet passage **31** and a conical head portion **33*b*** conforming with the tapered throat **30**. The head **34** has a cylindrical top rim portion **33*c*** of the same diameter as the hole **29**. The divergent end of the head is therefore of larger diameter than the original slug **26**.

The temperature to which the slug **26** is heated prior to the extrusion step, in general, will vary depending upon the metal employed. Generally, speaking, however, a range of from about 1600° F. to about 2400°

F. gives operable results, with a temperature range of from about 1800° to about 2200° F. being preferred. Temperatures of from about 1600° F. to 2000° F. are preferred for iron and ferrous alloys, while temperatures generally in excess of 2000° give the best results with nickel-base alloys.

Preferably the extrusion die **27** should be lubricated prior to the extrusion step. This may be best effected by means of a mixture of a sulphur-free grease and graphite, such as tallow and bone black.

The pressures employed during the extrusion operation, again will vary depending upon the metal employed; the size of the slug **26**; the temperature to which the slug or billet **26** was heated prior to the extrusion; and the rate at which the pressure is applied by the extrusion plunger **32**. In general, however, pressures of from about 100 tons per square inch to about 300 tons per square inch denote an operable range, with pressures of from about 150 tons per square inch to about 200 tons per square inch being preferred.

The pressures and heat created during the extrusion process causes the discrete particles of the powdered metal or powdered metals and aggregate to become more completely welded together in the sintered compact. This further welding together of the individual particles creates what appears to be, in reality, a solid stage diffusion of the constituents in a non-fluid condition. This welding together of the particles produces a headed rod or fluid directing member blank **33** having a density of from about 95 to 100% of the theoretical density. The density and other physical properties of the extruded blank **33** are substantially equal to the properties which might be expected in a blank produced from a cast ingot. However, the headed rod or blank **33** has, in addition to densities approaching those of cast rods, the distinct advantages which can be achieved only in articles produced by powdered metallurgical techniques, for example, the controlled proportioning of the constituents in the blank; the working of alloys and metals which are not amenable to conventional casting techniques, to name only a few.

The extruded headed rod or blank **33** may then be formed into various shaped articles. For example, as seen in Figures 7–10, the blank **33** may be coined by means of a suitable coining die **36** to produce a poppet valve blank **37**. As seen therein the blank or headed rod **33** is positioned on a lower die member **38** of a coining die assembly **36** beneath an upper die member or punch **39**. The upper die member **39** has a cylindrical bore **40** formed therein which terminates downwardly in a flared-out circular recessed portion **41** having the general shape of the valve head to be produced. This is preferably a hot coining operation; the blank **33** being heated to from about 1800° to about 2000° F. prior to the coining operation. The blank **33** is heated and centered on the lower die member **38** directly below the upper die member **39**, so that the elongated rod portion of the headed rod **33** is in direct alignment with the cylindrical bore **40**. The upper die member **39** is actuated downwardly over the blank **33** and the blank **33** is blocked down or coined to form a poppet valve blank **37**. The valve blank **37** has an elongated stem portion **43** conforming to the diameter and length of the cylindrical bore **40** and has a flared-out circular head portion **44** conforming to the flared circular recess **41** on the die **39**. The poppet valve blank **37** is thereafter suitably machined and finished to produce the finished poppet valve V (Fig. 10).

As best seen in Figures 11–14, the headed rod or blank **33** may also be employed advantageously in producing a turbine bucket **45**. As seen in Figures 11 and 12 the headed rod or blank **33** is coined or blocked down in a suitable coining die assembly **46**. The die assembly **46** comprises an upper die member **47** and a lower die member **48**. The upper and lower die members **47** and **48** have diametrically opposed aligned die faces **49**, **49** shaped for forming the root portion **50** and the vane or air foil portion **51** of the turbine bucket **45**. A flash gutter portion **52** is provided to receive flash metal **53**. The headed rod or blank **32** is heated to from about 1800° to about 2000° F. prior to the coining operation. The turbine bucket blank **54** (Fig. 13) resulting from the coining operation is freed of the flash metal **53** and suitably finished and machined into a turbine bucket having a transverse root section **50** and an upstanding integral vane portion **51**.

By means of the instant invention it is now possible to produce articles of intricate shapes from metals which are extremely difficult to handle by conventional techniques. Certain metals or mixtures of metals or alloys cannot be cast adequately due to the extreme activity of such metals at elevated temperatures. Therefore such metals must be worked, if at all, strictly by powder metallurgical techniques. The flexibility of the type of article which can be produced by powder metallurgical methods, however, is limited. This is due to the inherent difficulty of producing proper dies of intricate or nonsymmetrical shapes. In addition, the compacting of powdered metals in odd shaped or intricate dies is far from satisfactory, for uneven molding pressures are created often resulting in defective products. By the instant invention, however, this limitation in producing intricate objects from non-castable metals has been eliminated.

By the instant method it is now possible to produce articles from powdered metal having a density substantially equal to 100% of theoretical. Heretofore, powdered metal compacts having a density equal substantially to 100% of theoretical could only be achieved by infiltrating the compact with a low melting metal, or cold pressing the compact at extreme pressures often in excess of 160 tons per square inch and/or sintering the compact at extreme temperatures often in excess of 2600° F.

Previous attempts at producing compacts of 100% theoretical density by drop hammer forging sintered compacts in open dies has been generally unsatisfactory. Such methods have inevitably resulted in articles having extreme strains and defects and considerable tensile forces and slippage. In the instant invention, however, none of these defects or limitations are present, due to the fact that the extruding step is carried out entirely under extruding compression in closed dies.

In addition to the above features and advantages another distinct feature of the instant invention lies in the production of an article wherein certain materials and properties can be localized and controlled in specific portions of the article. For example, by employing the present invention it is possible to produce a billet or extrusion slug such as **26** wherein a certain portion, such as the top, consists primarily of highly refractory metal particles, while the remainder of the slug may consist of a non-refractory metal. A headed rod or blank **32** produced therefrom would, then, have refractory metal particles concentrated primarily in the head portion thereof. A poppet valve produced from such a blank or headed rod would have a stem formed of a standard ferrous alloy while the integral head portion would consist of a highly refractory metal. This structure is advantageous, for the head portion of a poppet valve is the part which is subject to the most extreme temperatures of the exhaust gases. In a similar manner it would be possible to produce turbine buckets or other fluid directing members having specific portions or parts thereof produced from a particular material while the remainder or other portions could be produced from other desirable components.

It will be apparent to those skilled in the art that I have now provided a new and improved method for producing fluid directing members from powdered metals. It will also be apparent that the method of the instant invention is applicable to substantially any metal which is amenable to working by powdered metallurgical techniques.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

A fluid directing member comprising, a shaped body having a matrix formed from 99.5 to 75.0% by volume of a metal selected from the group consisting essentially of iron-aluminum, nickel-chromium and nickel-cobalt base alloys, the iron-aluminum alloy containing from about 98 to 85% iron and from about 2 to 15% aluminum, said matrix having uniformly dispersed therethrough 0.5 to 25.0% by volume of an insoluble powdered slip-preventing metal aggregate selected from the group consisting essentially of the carbides of titanium, tungsten and chromium and mixtures thereof, borides and nitrides of zirconium and titanium, and intermetallic compounds of nickel and aluminum and of nickel and boron, the shaped body having a density substantially 100% of theoretical.

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