Sept. 30, 1952 C. G. GOETZEL ET AL 2,612,443

POWDER METALLURGY

Filed Dec. 26, 1947 2 SHEETS—SHEET 1

Fig. 1.

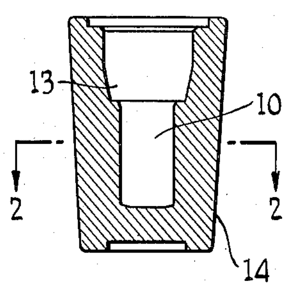

Fig. 2.

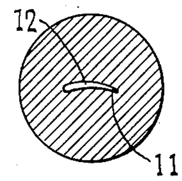

Fig. 3.

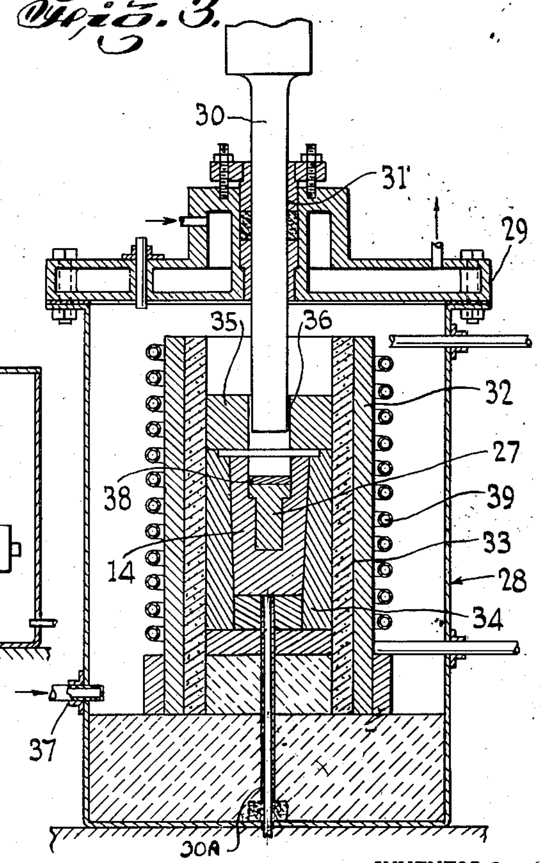

Fig. 4.

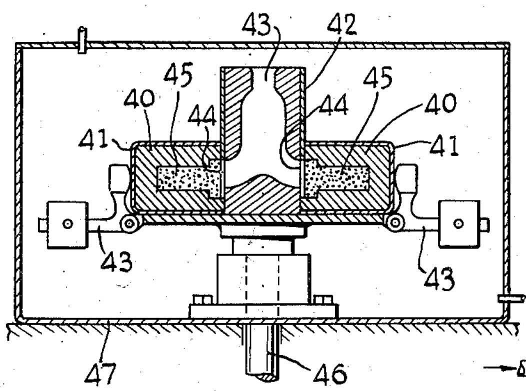

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Fig. 5.

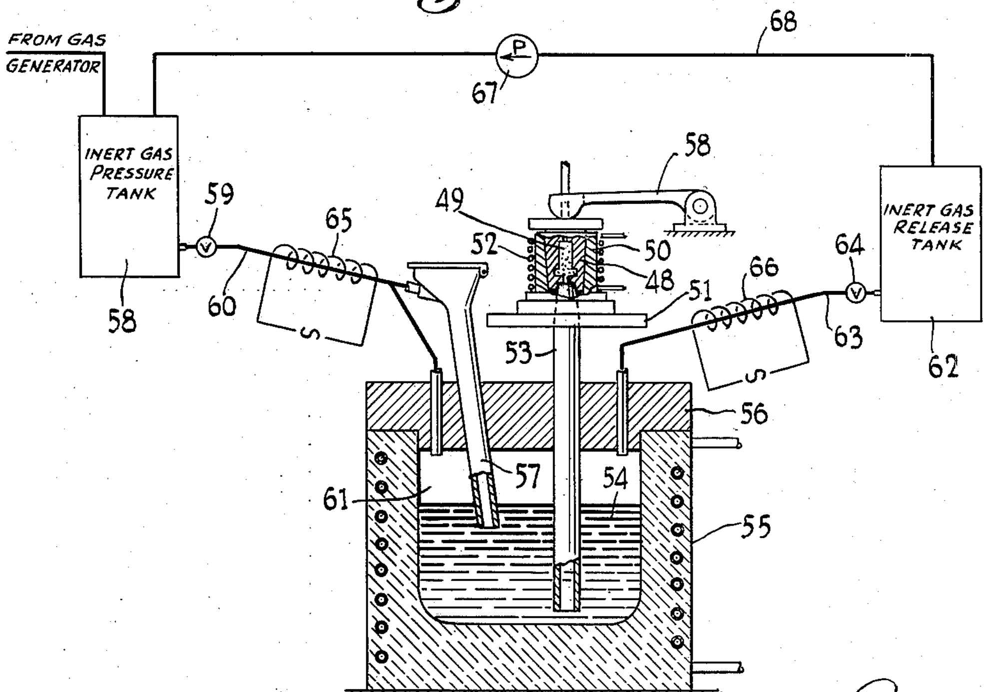


Fig. 6.

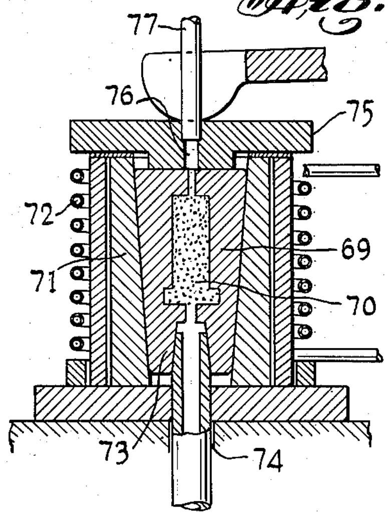
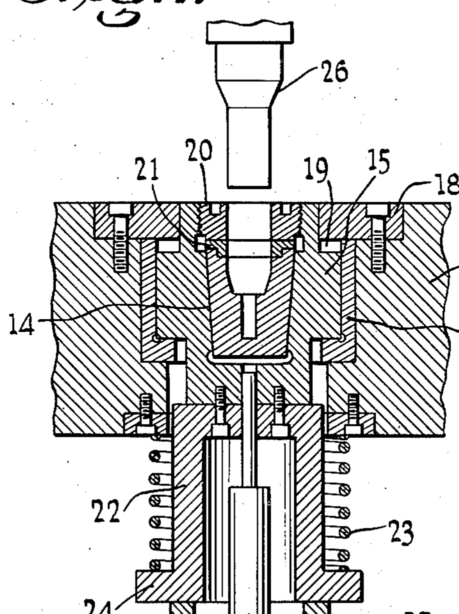


Fig. 7.



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UNITED STATES PATENT OFFICE

2,612,443

POWDER METALLURGY

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Application December 26, 1947, Serial No. 793,990

1 Claim. (Cl. 75—22)

1

This invention relates to a method of forming composite material shaped bodies of metals, alloys, metal compounds, refractories, and the like, and especially to the complete impregnation of a porous skeleton with a second lower melting metal or the like which excels by a high resistance to corrosion and oxidation at elevated temperatures.

In the manufacture of heat resistant metallic components for articles such as blades, buckets, valves and the like for jet engines, rockets, or gas turbines and the like, conventional casting or forging methods are not satisfactory. One of the reasons for this is that the temperature at which the casting or forging operation is carried out is near that of the operating temperature of the element in service. It thus is apparent that the element would not be stable in its dimensions under operating conditions.

Powder metallurgy methods must be used in order to meet the high temperature requirements in the fields mentioned as well as in many other places. The previously used powder metallurgy processes employing simple pressing and sintering operations have limitations due to inherent porosity of the article, fine grain size and weak grain boundaries, all of which contribute to unfavorable hot tensile strength, hot fatigue strength, and resistance to creep at elevated temperatures.

Previously, composite material shaped bodies in the field of powder metallurgy have been made by mixing the powders comprising the same and then shaping by pressing in a suitable die, following which the shaped body has been removed from die and the body heated or sintered until one of the constituents is melted so that the liquid metal fills the pores of the mixture. Also in prior practice, the first or higher melting constituent has been placed into a mold and a porous skeleton formed therein, following which the skeleton has been removed from the mold, sintered, and then placed in contact with or immersed in the second or auxiliary lower melting metal depending only upon capillary action to fill the pores of the skeleton. In this latter case, the second metal has been brought into contact with the skeleton in a suitable ceramic or metallic boat, and heat applied so as to liquefy the second metal and cause the same to be drawn into the skeleton by capillary action. Also the second metal has been placed in contact with the skeleton and melted, the impregnation taking place by capillary action.

In relying upon capillary action to fully im-

2

pregnate a skeleton, it is sometimes impossible to produce a large quantity of formed bodies having exactly the same uniformity, because of the irregularities in the size and form of granulation of particles of the skeleton. When capillary action is depended upon, forces affecting the penetration of the infiltrant into the pores of the skeleton may vary from article to article. Physical examination has shown that the condition of the contact faces between powder and liquid is very important for capillary action, as is also the cross-section of the capillaries. E. R. Parker and R. Smoluchowski in "Capillarity of Metallic Surfaces" (American Society for Metals, 13 Preprints, 1944) show that the rise of liquid in grooves depends upon the angles of the grooves. In a sintered metal body, it is obviously impossible to determine the exact form of the capillaries, or variation thereof, in each body without sectioning the same which would obviously destroy the usefulness thereof. It is apparent therefor that there may be a lack of homogeneity and uniformity in many instances in parts made where impregnation depends upon capillary action by itself.

Other difficulties inherent in the process of infiltration by capillary action have been found to consist of poor penetration, or no penetration at all of the infiltrant metal through the pore system owing to lack of wetting or surface affinity with the skeleton material. In other instances, there have been found difficulties arising from an opposite trend, with a pronounced solubility between skeleton and infiltrant material, resulting in skeleton erosion effects at the surface as well as drastic changes and variations in size and/or shape. Also, it often may be considered of a disadvantage that a coverage of the surface of the body with the infiltrant metal may remain incomplete and discontinuous, as well as uncontrollable, as to thickness and location of the surface casing.

Another difficulty with the use of the aforementioned contact method or of an immersion method of infiltrating the skeleton is that there may be an adherence of the molten metal on the surface of the skeleton and the possibility of dissolution of protusions of the skeleton.

One of the principal objects of the present invention is the production of uniform, dense, composite bodies from powdered materials and particularly bodies having intricate shapes whereby improved physical characteristics of the finished product can be obtained, in particular at elevated temperatures.

In one aspect of the invention, a skeleton is formed in a mold, or die having a cavity corresponding to the exact shape of the finished product, and then the skeleton is sintered, or heat treated, in the same mold. In the compacting of the powdered material in the mold, preferably it is pressed under a pressure in combination with a pulsating, dynamic loading, or vibratory action superimposed thereon. After the skeleton has been sintered, it then can be transferred to the point of impregnation of the skeleton with the second metal.

Under certain conditions the porous skeleton may be hot pressed in the mold to substantially the desired shape before it is impregnated with the infiltering metal, by heating the material forming the porous skeleton and pressing to the desired density either in or outside of the infiltration mold. The density to which the skeleton is hot pressed is less than the theoretical density attainable by such a hot pressing.

The skeleton also can be formed from powdered materials in other manners and removed from the mold or formed without a mold as conditions permit. The desired attribute of the skeleton is that it have pores intercommunicating with each other substantially throughout the entire skeleton.

The impregnation of the skeleton with a lower melting metallic material is performed in a mold in the present invention by means of a pressure differential, in the pore system of the skeleton in the mold, instead of depending upon capillary action which as explained above may have distinct disadvantages and limitations in the attainment of uniformity and other properties. The infiltrant or auxiliary second metal can be heated and melted in a receptacle separated from the mold and skeleton, and brought into contact with the skeleton in a liquid or semi-liquid form and forced into all of the pores under a pressure differential so as to completely and uniformly fill the same, a pressure being exerted on the infiltrant relative to the skeleton. The pressure differential exerted is in the same direction as the capillary force, and can be made high enough to overcome all types of mechanical, metallurgical, or chemical barriers, and thus insure complete impregnation of all of the pores of the skeleton by driving the infiltrant metal in the pore system thereof, which is necessary for uniformity, surface and size control, as well as to obtain the optimum physical characteristics at ordinary and elevated temperatures, and other effects which will be explained at a later point.

In particular, when impregnation is carried out by a pressure differential, the time can be made so short as to inhibit solubilities of the components in each other. The higher the differential, the shorter will be the time.

In a preferred aspect of this invention, the impregnation is carried out while the skeleton is in a mold or die which may be the one from which it has not been removed since forming, but also may be one in which it has been placed after prior treatment. When the skeleton is impregnated in a mold or die, the exact form of the finished product can be attained without further machining because the pores of the skeleton may just be filled under the pressure differential to the surfaces of the body where these surfaces are in contact with the mold. There will then be no excess metal on the surface of the article where in contact with the mold. The shape of the body will be maintained with better accuracy if the skeleton is not removed from the mold after it is formed until following the impregnation and other steps or treatments thereafter. Another advantage of using the same mold is that loose powder packs can be used for producing the skeleton. The skeleton thus can be of low concentration so that they could not form a stable body in themselves that could be transferred outside of the mold. If desired, a sizing operation can be performed on the skeleton before impregnation.

The size of the skeleton relative to the mold also can be chosen so as to obtain a casing of infiltrant metal around the article to provide the desired casing thickness of the infiltrant metal.

As is well known, considerable size variations are encountered both in direction of growth and shrinkage depending on the reaction between the infiltrant and the skeleton material and also in the skeleton itself upon sintering. Refractory metals such as tungsten, molybdenum, and cobalt-cemented tungsten carbide, for example, shrink up to 15% as is well known in the art. The exact size control requires careful calculation. It is commonly experienced that the greater the shrinkage, the more will be the size variation of the finished product. In the process of the present invention performed in a mold of the exact shape of the finished article, the mold will be completely filled and the side of the article thus will depend on the mold and will be comparable to precision casting processes.

In the aspect of the invention, where the impregnation takes place in a second mold, said second mold is of the exact size of the finished product and related to the first mold in such a way that there will be a small space between the skeleton faces and the mold walls as desired. When impregnation is made under a pressure differential so as to fill all of the pores of the skeleton and also the entire mold exactly, the skeleton will thus have a surface of the infiltrant metal entirely surrounding the same. The infiltrant can be chosen to be corrosion resistant to the operating conditions under which the article is to be used.

The mold also can be arranged such that a space can be left for infiltrant metal to fill for machining purposes which may be called "under-casting."

The invention can be carried out advantageously when the skeleton is formed from powdered material of such a particle size and distribution so as to produce the desirable porous structure. As an example, the density of the skeleton should not be more than about 85% to 90% because if the pore volume is less than about 10%, the pores may lose their intercommunicating characteristics. For a uniform body, the porosity should be uniformly distributed throughout the skeleton. When such a body is placed in contact with the infiltrant metal so that it is possible for the infiltrant to flow into the pores, a pressure differential created in the pores of the skeleton, there being a pressure on the infiltrant relative to the skeleton, a complete and uniform impregnation of the skeleton will result.

There are various methods and devices by which the pressure differential in the pore system of the skeleton in the mold can be created in carrying out the invention. In one form of the invention, a piston can be employed to exert the necessary pressure on the molten metal as it is forced into the skeleton located in the mold or otherwise. In another form, the pressure on the molten metal may be exerted by centrifugal force by suitable apparatus.

In still another form of the invention, one portion of the skeleton remote from the point of application of the molten infiltrant may have a vacuum applied thereto. In such an instance, the infiltrant will be drawn into the skeleton so as to completely impregnate the skeleton. Also a combination of vacuum applied to the skeleton and superatmospheric pressure applied to the infiltering metal may be used.

In still another aspect of the invention, inert gas or fluid pressure may be applied to the surface of a body of molten metal in contact with the skeleton to force the same into the pores and thus completely impregnate the skeleton in the mold.

Merely by way of example, the skeleton body may be made of tungsten, molybdenum, titanium, tantalum, columbium, chromium, zirconium, or their alloys with each other, or with iron, nickel, cobalt, or their compounds of metalloidal character with carbon, boron, silicon, nitrogen, etc. Some examples of the aforementioned compounds of metalloidal character are tungsten carbide (WC), titanium carbide (TiC), molybdenum carbide (Mo_2C), tantalum carbide (TaC), columbium carbide (CbC), chromium carbide (Cr_3C_2), zirconium carbide (ZrC), vanadium carbide (VC), tungsten boride (WB_2), titanium boride (TiB_2), molybdenum boride (MoB), tantalum boride (TaB), columbium boride (CbB), chromium boride (CrB), zirconium boride (Zr_3B_4), vanadium boride (VB_2), thorium boride (ThB_6); also stable refractory materials or compounds such as beryllium oxide, magnesium oxide, aluminium oxide, zirconium oxide, silicon carbide, and boron carbide can be used, these being stable at elevated temperatures.

A typical composition of a homogeneous skeleton material as employed by this invention consists of 70% by weight of tungsten carbide (WC), 25% titanium carbide (TiC), and 5% cobalt (Co), the tungsten carbide (WC) and titanium carbide (TiC) components being combined as a solid solution. Another typical composition of a homogeneous skeleton material as employed by this invention consists of 45% by weight of tungsten carbide (WC), 25% titanium carbide (TiC), 25% chromium carbide (Cr_3C_2) and 5% cobalt (Co), the tungsten carbide (WC) and titanium carbide (TiC), and chromium carbide (Cr_3C_2) components again being combined as a solid solution.

Again merely by way of example, the impregnating material may be iron, nickel, cobalt, chromium and their alloys with each other, or their alloys with the previously mentioned refractory metals, or mteal compounds as minor constituents. It is to be understood that the appropriate infiltrant having a dissimilar lower melting point relative to the skeleton can be used. A typical composition of impregnating material employed successfully by this invention comprises an alloy containing 69% by weight of cobalt, 25% chromium and 6% molybdenum. Another example is a material containing 50% by weight of cobalt, 29% chromium, 15% nickel and 6% molybdenum. Still another example is one containing 52% by weight of cobalt, 28% chromium, 11% nickel, and 9% tungsten. Another example contains 60% by weight of nickel, 16% molybdenum, 14% chromium, 5% tungsten and 5% iron, while still another contains 60% by weight of chromium, 25% molybdenum and 15% iron.

Certain combinations of skeleton and infiltrant are particularly difficult to impregnate completely by depending upon capillary action alone such as for example impregnation of an iron, nickel, or cobalt skeleton by aluminum.

The intermetallic compound AlNi of aluminum and nickel which melts at 1640° C. contains 68.5% by weight of nickel. The intermetallic compound AlCo of aluminum and cobalt which melts at 1628° C. contains 68.5% by weight of cobalt. A skeleton of pure nickel melts at 1452° C. and a skeleton of pure cobalt melts at 1490° C. After infiltration of either of the aforementioned skeletons with liquid aluminum having a melting point of 660° C. there results a composite structure which after a subsequent diffusion heat treatment is converted to the above mentioned intermetallic compounds AlNi and AlCo respectively. These cases illustrate two examples of the diffusion heat treatment of infiltrated skeletons wherein an intermetallic compound is formed having a higher melting point than the original skeleton or infiltrant metal.

As mentioned, an efficacious method of introducing the low melting aluminum phase into the skeleton is to utilize a pressure differential in the interconnected pore system such as can be done, for example, in a die casting machine.

Various presintering heat treatments, diffusion alloying heat treatments after impregnation, or precipitation hardening heat treatments can be performed in the carrying out of the invention.

These and other objects, advantages and features of the invention will become apparent in the following description and drawings which are merely exemplary.

In the drawings:

Figure 1 is a schematic sectional view of a mold for an article such as a turbine blade which can be made advantageously by the present invention.

Figure 2 is a sectional view taken along the line 2—2 of Figure 1.

Figure 3 is a sectional view wherein mechanically applied pressure is used to create a pressure differential during impregnation of the skeleton.

Figure 4 is a schematic sectional view of one manner in which the impregnation may be effected by a pressure differential created centrifugally.

Figure 5 is a schematic view of one form of apparatus wherein gas pressure can be applied intermittently to impregnate the skeleton.

Figure 6 is a schematic sectional view of one form of apparatus for applying a vacuum to the skeleton for creating the pressure differential in impregnation of the skeleton.

Figure 7 is a diagrammatic view of one form of apparatus which may be used for applying pressure and dynamic loading to the mold in formation of the skeleton therein.

The invention is especially adapted for use in producing objects having intricate or complex shapes wherein the cavity of the mold is so shaped that it is difficult to obtain uniform densities by prior methods. As previously mentioned, the invention is illustrated in conjunction with the manufacture of a turbine blade but it is to be understood that many types of articles such as turbine blades, nozzles, vanes, valves, etc., may be produced in accordance with the invention.

The mold schematically illustrated in the drawings may be of a ceramic, graphite, heat resistant alloy steel, or any other suitable material or combination of materials. The mold may be formed, for example, by investment mold techniques conventionally used in precision casting or may be made or constructed in any suitable manner.

In the complex shaped mold shown in Figures 1 and 2, the cavity 10 for the turbine blade can have a feather edge 11, a curved portion 12, and base 13 of the desired fom. Sidewall 14 of the mold can have a suitable taper therein so that the mold will be receivable in a suitable mold holder. The particular shape of the mold and entrance aperture will vary with the article to be formed and with the particular manner in which the pressure differential is to be exerted thereon as will be explained hereafter.

In the forming of the skeleton, the mold can have a suitable powdered material with the desired particle size distribution fed therein, it being preferable to so select the particle size distribution of the material so as to obtain the desired density and desired pore size distribution. One example of a suitable particle size analysis would be 50% of the particles ranging between 30 and 40 microns, average particle diameter; 30% between 20 and 30 microns; and 20% between 10 and 20 microns. Still another example would be one wherein 50% of the particles are 5 to 10 microns; 30% are between 2 to 5 microns; and 20% are between ½ to 2 microns. The particle size distribution of course depends upon the material, mold shape and pressure used. Preferably, the density attainable in compacting should not be more than about 85% to 90% because a pore volume of less than 10% will cause the skeleton to lose its intercommunicating character of its pores.

One manner of compacting the skeleton is to place mold 14 with powder therein in a mold holder 15 (Fig. 7), said mold holder being slidably carried in a mold holder support 16 which in turn is mounted in a press bed 17 of any suitable construction. The clamping ring 18 can hold the mold holder support in a predetermined position and be arranged so that space 19 between the top of the mold holder 15 and the bottom of clamping ring 18 will permit a vertical reciprocating motion of mold holder 15 with mold 14 therein.

A mold holder cap ring 20 can be screw-threadedly engaged in the mold holder 15 with a spacer ring 21 of any suitable material there between, said spacer ring serving to evenly apply the pressure exerted by cap 20 to the fragile and irregular mold 15.

Spring guide 22 is fastened to the mold holder 15 and holds spring 23 in place between the press bed 17 and flange 24 of the spring guide. A jolting ram 25 is engageable with flange 24, spring 23 normally holding the mold holder and mold in their lowermost position relative to the press bed 17. The jolting ram can be operated in a reciprocating fashion so as to cause a reciprocation of the mold holder and mold therein.

The main ram 26 is enterable through cap 20 into the mold cavity. The rams may be furnished with pressure in any desired and conventional manner so that as the main pressure is applied to ram 26, a dynamic loading can be applied by the jolting ram 25, for example, by applying a pulsating hydraulic pressure thereto. In this manner a constant pressure force on the powder in the mold can be exerted in conjunction with a vibratory or dynamic loading, and this will serve to properly and uniformly compact the powdered material therein. Other types and manners of producing pulsating or dynamic action in this manner of compacting the skeleton may be used, such as for example, a vibrating table or platen (not shown) operating with varying amplitude and frequency. The dynamic force in some instances should be of a sudden or impact type of load superimposed on the main pressing action so as to produce the desired high and uniform density in the skeleton in the mold.

If desired the material forming the skeleton may be heated to a high temperature before or after it is placed in the mold and hot pressed in the mold merely by the use of a ram 26 operated under suitable pressure, or as a reciprocating hammer. In this event the mold must be constructed of metal or other material suitable to withstand the pressures applied. As mentioned previously, the hot pressing of the skeleton is arranged so that it is stopped before the highest theoretical density is attained. This could be accomplished, for example, by a stop arranged in a predetermined position in relation to the size of the skeleton so as to attain the desired density therein.

Following compacting or forming of the skeleton in the mold, which as previously mentioned can be accomplished in various manners, including hot pressing, the mold with the skeleton therein can be moved to a sintering point, zone, or furnace where the sintering operation can be carried out. By keeping the skeleton in the mold, the size thereof will be controlled to better advantage.

Before the sintering operation, in some instances, the mold with the skeleton therein can be subjected to a presintering treatment in a protective atmosphere for the purpose of diffusion alloying, temperatures in the range of 1500° C. to 2000° C. being employed. Such presintering and sintering treatments will depend upon the particular object being made and materials employed.

Upon completion of the sintering operation, the compacted and sintered skeleton in the mold is ready for impregnation. If the sintering operation has been carried out when the skeleton is not in a mold, the skeleton is placed in a mold before impregnation. It is possible, if desired, at this point to subject the skeleton to sizing or mild coining operation, either while the skeleton is in the mold or otherwise.

The pressure differential desirable to insure a complete impregnation of the skeleton may be applied in different manners as previously mentioned. One way in which the pressure differential can be applied by mechanical pressure is seen in Figure 3 wherein mold 14 with sintered skeleton 27 therein is placed in a receptacle 28. The receptacle 28 may have a water cooled cover 29 through which pressure plunger 30 can reciprocate and the cover 29 can have a suitable packing gland 31 therein. Tube 32 can be made of some suitable material such as quartz, and the space between tube 32 and outside walls of receptacle 28 filled with a suitable insulating powder. A graphite retainer tube 33 can be employed to hold the mold holder 34 in its desired position within receptacle 28. A graphite cover 35 having an aperture 36 can be placed on top of the mold holder 34 after the mold 14 is in place and a protective gas inlet 37 can be used for furnishing a protective gas to the housing.

A knockout pin 30A can be provided to assist in loosening and removing the mold when cover 29 is removed.

The infiltrant or auxiliary metal 38 is located on top of the skeleton and the auxiliary metal can be brought to a liquefying temperature by the heating coil. The graphite mold holder 34 is heated by high frequency coil 39 and the heat from holder 34 is transmitted to the skeleton 27 through mold 14, the skeleton thus being brought to a temperature at least that of the infiltrant metal.

Upon application of pressure to plunger 30 an impregnation of the skeleton will be caused by means of the pressure differential created in the pores of the skeleton. It thus is seen that a mechanical pressure in this instance creates the pressure differential assisting the capillary action so as to insure complete impregnation of the skeleton by the auxiliary metal.

The pressure differential also may be effectuated by centrifugal force in an apparatus such as shown diagrammatically in Figure 4 wherein molds 40, similar to mold 14 of Figure 1, are held in place by mold positioners 41, mold positioners 41 in turn being held firmly against the central feeding member 42 by weights 43 when the centrifugal device is rapidly rotating. A cover may be provided and a protective gas atmosphere maintained in the casing. The centrifugal feeding chamber 42 has an inlet aperture 43 an doutlet apertures 44 for conducting the infiltrant metal to the skeletons 45 in molds 40. Heating apparatus as desired can be employed in conjunction with the centrifugal apparatus just described which apparatus is mounted on shaft 46, there being a suitable protecting cover 47 for the device. It is obvious that any number of molds may be employed in accordance with the particular arrangement of the apparatus.

With the molds in place and when the device is rotating at a high rate of speed, the centrifugal force exerted on the molten impregnating metal will cause the metal to flow into the pores of the skeleton due to the pressure differential created. It is apparent that various types of centrifugal arrangements can be used.

In another form of the invention, the molten metal can be forced into the compacted skeleton in a mold under a pressure differential created by means of intermittently applied gas pressure. Mold 48 (Fig. 5) has a compacted skeleton 49 therein, said mold being in a mold holder 50 carried on mold table 51. A high frequency heating coil 52 may be employed for heating the metals as necessary in the mold. An electrically resistance heated casting tube 53 extends from the mold table downwardly into a molten bath 54 of metal in the metal holding furnace 55, said furnace being heated by a suitable heating apparatus. A refractory cover 56 may be located on said holding furnace 55. Casting tube 53 extends below the surface of the molten metal 54 as does also the filling spout 57. The cover for the spout and cover 56 are arranged so that they will remain closed when gas pressure is present inside of the holder furnace 55 and a clamp arrangement 58 may be employed to hold the mold 48 on mold table 51 and in contact with the casting pipe.

The intermittent gas pressure system has an inert gas pressure tank 58 which may have an inert gas generator connected thereto as conventionally used in continuous casting machines. The generator through a suitable system of valves and controls may be arranged to hold the inert gas pressure tank at a constant pressure regardless of loss and leakages in the system. Control valve 59 controls the flow of inert gas through the supply gas line 60 into the gas space 61 of the metal holding furnace 55. An inert gas release tank 62 is connected to the gas space 61 of the furnace 55 through pipe 63, control valve 64 being interposed therein. A heating coil 65 may be connected with the gas supply pipe 60 and a cooling coil 66 associated with the outlet 63. A gas pump 67 is connected in the return line 68 from the inert gas release tank 62 to the inert gas pressure tank.

In operation, after a mold 48 with a compacted skeleton therein has been placed on the table 51 and clamped thereon, the heating coils 52 can be energized as needed to bring the skeleton to the required temperature. Valve 59 then is opened to subject holding furnace space 61 to the gas pressure of inert gas pressure tank 58. Upon completion of the penetration of the pores of skeleton 49 in mold 48 with the infiltrant metal, the high frequency power on coil 52 can be interrupted so as to rapidly cool the mold assembly with the exception of the electrically heated casting tube 53. Immediately after the molten metal has somewhat solidified in the skeleton, valve 64 is opened so as to allow the accumulated gas pressure in space 61 to escape into the release gas tank 62 thereby dropping the level of the metal inside of the casting tube to the level of the metal in the holding furnace 55. Thereafter the mold and impregnated skeleton can be removed from the table and the article removed from the mold or a further heating treatment given to the impregnated skeleton as desired.

An automatic timer arrangement (not shown) can be connected to valve 59 so as to cause operation of valve 59 at a predetermined time after current is supplied to coil 52 and thus insure proper heating of the skeleton before impregnation takes place. The particular time delay can be determined by experiment after several casting operations of a given combination. It also is possible to have control means in the holding tank so as to de-energize the control system when the level of metal 54 in the holding furnace 55 drops below a predetermined point and thus prevent gas being forced upwardly into the casting tube.

Still another manner of applying a pressure differential for impregnation is the application of a vacuum to the skeleton while in a mold. This can be accomplished by placing the mold 69 (Fig. 6), with a compacted skeleton 70 therein into a mold holder 71, said mold holder having a high frequency heating coil 72 associated therewith. The mold 69, similar to that shown in Figure 5, can have an aperture 73 therein to fit on to the casting pipe 74. Cover 75 has an aperture 76 therein having a vacuum pipe 77 connected thereto. When a vacuum is applied to pipe 77, atmospheric pressure can be employed to cause molten metal in the casting tube 74 to flow into the skeleton 69 and impregnate the same.

As previously mentioned, various heat treatments can be employed if desired. A high temperature heat treating technique could be used for the purpose of producing a solid stable structure of optimum strength, toughness and resistance to deformation at high temperatures. It may be desirable to eliminate the liquid phase at infiltration temperature after a complete penetration of the pores of the skeleton has been attained. This can be accomplished only by a diffusion causing the formation of a new alloy or metallic compound between the skeleton and infiltrant of a higher melting point than the liquid phase temperature used for impregnation of the skeleton.

In the practice of the present invention, the skeleton to be impregnated can be formed in various manners. Preferably the skeleton is formed, at ordinary or at elevated temperatures, by pressure and dynamic loading and transferred in the same mold to the impregnation point. If the skeleton is not in a mold, it is placed in a mold prior to impregnation. As described herein the impregnation is carried out under a pressure differential while the skeleton is in a mold whereby the skeleton pores are completely impregnated and the size and shape of the object maintained. The pressure differential can be applied or created by mechanical means, centrifugally, by a vacuum, and by similar mechanisms and processes.

It should be apparent that variations may be made in the described process and apparatus involved without departing from the spirit of the invention except as defined in the appended claim.

We claim:

A method of producing uniform dense composite material shaped blades, buckets, valves for jet engines, rockets, gas turbines comprising, compacting a refractory metal carbide in a mold, controlling the compacting work to establish in the compacted body an intercommunicating system of pores, of which the pore volume amounts to at least 10 per cent of the total volume, sintering said compacted body in said mold into a skeleton body while maintaining the said porosity, heating said mold-contained skeleton body and a molten metal infiltrant selected from the group consisting of nickel, cobalt, iron and alloys thereof with chromium, molybdenum and tungsten during the infiltration while forcing by fluid pressure said molten metal infiltrant into the pores of said skeleton body.

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