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METHOD OF PRODUCING A FERROUS METAL ARTICLE INFILTRATED WITH A CUPROUS INFILTRANT

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Fig. 1.

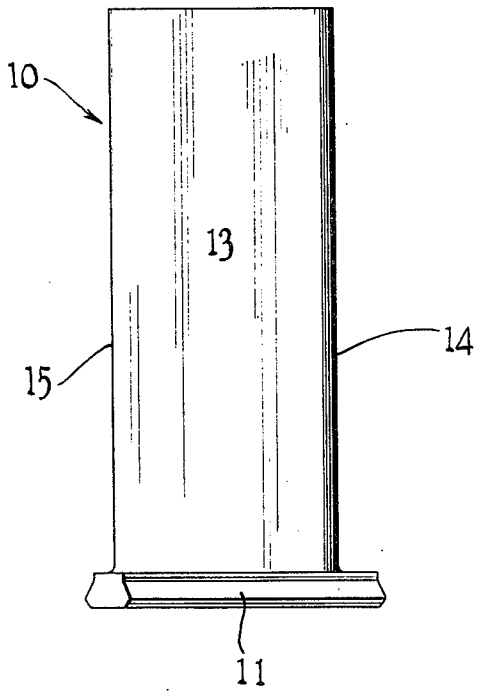
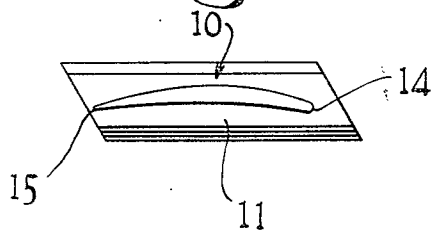


Fig. 2.



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METHOD OF PRODUCING A FERROUS METAL ARTICLE INFILTRATED WITH A CUPROUS INFILTRANT

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5 Claims. (Cl. 148—12.3)

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This invention relates to the manufacture of shaped bodies, mainly of ferrous material infiltrated with a cuprous infiltrant. More specifically the invention refers to the production of parts having sufficient strength and high damping capacity for jet propulsion engines and equipment, such as compressor bladings and like parts.

This application is a continuation-in-part of my co-pending application Ser. No. 22,649, filed April 22, 1948.

Shaped bodies and parts of the above type have been prepared heretofore in a combined powder metallurgical and infiltration process by molding ferrous powder, preferably of an average particle size of minus 80 to minus 325 mesh, under pressure of about 15 to 30 tons per square inch whereby a shape having a density of about 65% to 75% is obtained. The porous shape was sintered thereafter, preferably at about 900° C. to 1150° C. for about one-half to one hour in a protective or reducing atmosphere, subsequently reshaped or sized under pressure (coined) to a density of about 75% to 85% and exact dimensions, and then infiltrated with copper or copper alloy. The infiltrated body may be further sized or shaped by coining if warpage or other deformation occurred during infiltration.

When bodies, and particularly parts of the type herein concerned, were required to exhibit a minimum yield strength of about 75,000 to 80,000 pounds per square inch ("p. s. i."), appreciable amounts of carbon were added to or contained in the initial ferrous powder, so that the completed shape contained between about 0.01% and 0.8% carbon. The ferrous powder was also admixed with proper and known amounts of powdery alloying constituents of alloy steel, such as, for instance, chromium, manganese, tungsten, tantalum, vanadium, titanium, which are known as carbide-formers, silicon, aluminum, copper, nickel, cobalt, which are known to have less tendency than iron to combine as carbide in steel. Any number of these elements can be added to obtain from the ferrous powder, upon shaping and sintering, a skeleton or porous matrix exhibiting the potentialities of alloy steel. In such cases carbon, if added or present in the initial ferrous powder, should not exceed about 0.8% and preferably should be from 0.01% to 0.25% by weight of the powder. Instead of adding the alloying elements to the ferrous powder or in addition thereto, such alloying element or elements can also be associated with the copper infiltrant, particularly for the purpose of being carried by the molten infiltrant into the pores of the ferrous

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matrix and partially incorporated thereafter in the ferrous matrix by diffusion. Alloying elements of the kind hereinbefore stated for use with the ferrous powder can be added to the cuprous infiltrant, provided that the admixture of such alloying element or elements with the copper do not increase the melting point of the infiltrant above about 1250° C.; the proportions of the additions are accordingly limited as may be established from the phase diagrams of the respective systems.

After infiltration of the molten cuprous infiltrant into the porous ferrous matrix, the infiltrated shape has been usually coined again and subjected to a heat treatment including solution or diffusion heat treatment followed by quenching or otherwise cooling at controlled rate and advantageously backdrawing or reheating.

It has been found that the physical properties of the infiltrated shape and particularly blading can be enhanced and the subsequent heat treatment, if applied, rendered more effective if subsequent to infiltration the solid ferrous particles of the matrix are soaked in the substantially liquid infiltrant. This is accomplished by maintaining the ferrous skeleton and infiltrant therein at a temperature above the melting point of the infiltrant and considerably below that of the matrix-skeleton for from about one to about six hours, and more. Heretofore, the ferrous matrix having intercommunicating pores was contacted with the infiltrant and the contacted matrix and infiltrant held at infiltration temperature for a time period which secured complete infiltration and therefore did not substantially exceed 15 to 20 minutes. The infiltrated body or shape was cooled thereafter to freeze the infiltrant, and various heat treatments were applied to the infiltrated body in its solid state. By soaking the ferrous matrix particles in the liquid infiltrant according to the invention, diffusion between the copper (and other alloying elements if carried by the infiltrant into the matrix) and the ferrous material of which the matrix consists as well as penetration of constituents of the liquid cuprous infiltrant substantially throughout the matrix particles is secured. By heating the matrix and infiltrant at or above the melting point of the latter for a time period sufficient to secure complete filling of the pores of the matrix, at best some diffusion between the infiltrant and surface layers of the solid matrix particles can be accomplished. By the soaking treatment according to the invention such diffusion is promoted under optimum conditions to desirable and new

effects. Since the matrix comprises small and larger particles, not only diffusion of components of the cuprous infiltrant throughout the small particles is obtained, but also the larger particles are permeated substantially throughout as a result of the high temperature and liquidity of the infiltrant phase in which the ferrous particles are soaked and the inherent greater rate of diffusion at such temperature, and because the ferrous and infiltrant phases may be given time to approach or even reach equilibrium. Considering particularly the iron and copper phases concerned, the iron phase in its solid gamma state can dissolve a larger amount of copper than in its alpha state. Equally, the copper phase can dissolve in its liquid state a larger amount of iron than in its solid state. While the dissolved iron is distributed quite rapidly throughout the liquid and rather thin copper network, the penetration of copper substantially throughout the solid particles of the matrix-skeleton is accomplished effectively and economically by the soaking treatment according to the invention. Thereby potentialities are created not present upon mere infiltration or diffusion heat treatments in the solid state below the transformation temperature of the iron. Diffusion treatments in the solid state are always far more sluggish than the soaking treatment according to the invention.

It is therefore an object of the invention to produce in a combined powder metallurgical and infiltration process shaped bodies and particularly compressor bladings of ferrous material infiltrated with a cuprous infiltrant some of which is diffused into the ferrous material while some ferrous material is diffused into the infiltrant within the austenitic range of the ferrous material and the liquid state of the infiltrant.

It is a further object of the invention to produce in a combined powder metallurgical and infiltration process shaped bodies and particularly compressor bladings consisting of a ferrous and a cuprous phase, in which the ferrous phase predominates and the materials of the two phases are diffused in an economical manner.

It is a further object of the invention to produce in a combined powder metallurgical and infiltration process shaped bodies and particularly compressor bladings and like parts for jet propulsion engines and equipment which consist of a predominant ferrous phase and minor infiltrated cuprous phase and exhibit enhanced physical properties compared with bodies of similar composition after mere infiltration of the cuprous infiltrant into and throughout the intercommunicating pores of the ferrous skeleton or matrix followed by furnace cooling.

It is another object of the invention to secure penetration of constituents of the cuprous infiltrant substantially throughout the ferrous skeleton particles.

These and other objects of the invention will be more clearly understood when the description proceeds with reference to the drawings in which Fig. 1 shows by way of exemplification a compressor blading for jet propulsion equipment in elevation and Fig. 2 in plan view.

Referring to the drawing, the blade **13** comprises an air foil **10** and a root **11** by which it is assembled. The blade **13** consists of a ferrous matrix permeated throughout by an infiltrated cuprous network alloyed with the matrix.

The blade **13** is preferably produced by compacting ferrous powder of the particle size and under a pressure previously stated. Its porosity

depends on the compacting pressure and amounts to about 35% to 25%. The ferrous powder may contain powdery alloying constituents of the kind previously stated, and carbon in the form of lamp black or graphite may be added thereto within the limits previously stated. A lubricant, such as camphor or a stearic acid compound, may be added to facilitate compacting particularly if no graphite has been added which may act as a lubricant. The compacted ferrous shape of sufficient coherence to be handled is preferably sintered at about 1100° to 1150° C. for about one half to one hour in a protective atmosphere, such as dry cracked ammonia, whereby its coherence is increased and its porosity may be reduced to about 25 to 20%. The sintered porous body is then sized under a pressure of about 30 to 35 tons per square inch in one or more steps to the close tolerances of the dimensions of the blading. The sizing or coining can also effect a lateral spreading of the air foil **10**, the rounding of the leading edge **14** and the forming of the thin and rather sharp trailing edge **15**. Upon such sizing or coining the shape or blading has a porosity of about 20 to 15% and is ready for infiltration. It is preferred to use a cuprous infiltrant consisting of about 90% copper, 2% iron and 8% manganese. The manganese forms an alloying constituent and also renders fluffy and readily removable any excess infiltrant which remains outside the infiltrated body after its pores are filled. Other alloying elements exemplified hereinbefore can be added in proper proportions to the copper in order to carry them into and distribute them throughout the porous ferrous skeleton or matrix. The above addition of iron to the copper can be omitted.

Infiltration is performed by contacting the ferrous porous matrix or skeleton with the cuprous infiltrant which may be copper or a preformed copper alloy, or a pressed to shape powdery mixture of copper and desired additional constituents, or a sintered or presintered shape of desired configuration of the powdery constituents of the infiltrant. The contacted ferrous mass and infiltrant thereon are heated to a temperature of about 1100° to 1250° C. and in any event above the melting temperature of the copper or copper alloy or mixture of copper with the other constituents. Depending on the liquidity of the molten infiltrant and therefore the temperature to which it has been heated above its melting point, and further on the dimensions of the skeleton or porous matrix, infiltration is completed within a few seconds or minutes. The infiltrated body is maintained thereafter, according to the invention, at infiltration temperature and in any event at a temperature above the melting temperature of the cuprous infiltrant and below that of the skeleton for about one or more hours, preferably 75 to 150 minutes, up to about six hours. Thereby the ferrous particles of the matrix or skeleton are soaked in the substantially liquid infiltrant and diffusion is secured of a portion of the infiltrant into the ferrous skeleton within the limits of the solubilities of the constituents of the infiltrant in the ferrous matrix material. Owing to the high temperature and time period of this soaking treatment, these constituents penetrate substantially throughout the skeleton (matrix) particles. Simultaneously, diffusion into the substantially liquid infiltrant of constituents of the ferrous matrix, i. e. of iron if the matrix consists of iron, or of iron and other alloying components which can diffuse into liquid

copper, is also secured toward the limit of the solubility of iron and such other components, as the case may be, in the cuprous infiltrant. Thus, without melting or destroying the shape, the system comprising the ferrous and infiltrant phases can approach an equilibrium within the limits of the respective solubilities and depending upon the amounts of iron, copper and other components present in the system.

More specifically, with a porous matrix of compacted (and sintered) commercial iron powder of particle sizes stated hereinbefore and a cuprous infiltrant of about 90% copper, 2% iron and 8% manganese, up to 8% and even 13% copper by weight of the matrix (in the gamma state) and up to almost half of the manganese contained in the cuprous infiltrant can diffuse from the latter into the ferrous matrix particles and penetrate substantially throughout the latter, upon heating above the melting temperature of the infiltrant for the time period according to the invention. Constituents of the matrix also diffuse into and are dissolved in and distributed throughout the molten infiltrant. In the example stated, the liquid cuprous infiltrant contains far less iron than is soluble therein at the infiltration temperature and therefore additional matrix iron can diffuse into it, up to a total of about 3.5% iron (by weight of the infiltrant phase) at 1100° C. and about 7% iron at about 1250° C. The amount of other alloying constituents carried by the copper into and distributed throughout the pores of the matrix which diffuse into the latter in such a soaking treatment can be ascertained from the respective phase diagrams the same way as the amount of alloying constituents which can be associated with the copper and carried by it in the liquid state into the pores of the matrix.

The infiltrated body is cooled thereafter to solidify the cuprous infiltrant and below the transformation point of gamma iron to alpha iron. Upon such transformation the amount of copper and other metal constituents which can be held by the alpha iron in solid solution is considerably decreased, and this solubility further decreases at lower temperatures. For instance, alpha iron can retain in solid solution about 1.5% to 3.4% copper at 810° C. and less than 1% (about 0.4%) copper at room temperature. The rejection of the copper by the alpha iron upon cooling is, however, rather sluggish. Upon cooling through the transformation temperature, the amount of copper dissolved in the gamma iron in excess of that soluble in alpha iron is substantially rejected as a finely dispersed precipitate. This effect cannot be obtained after mere infiltration without subsequent soaking according to the invention, nor upon diffusion heat treatment in the solid state below the transformation temperature. Moreover, upon passing the transformation temperature on cooling, the alpha iron is highly saturated with copper which can be substantially retained therein in metastable condition upon rapid cooling at a rate between quenching rate (such as quenching in oil or water) and about 25° C. per minute; a minimum rate of 40° C. is preferred. Upon cooling at slower rate, down to about 5° C. and sometimes even 1½° C. per minute, only part of the excess copper contained in the alpha iron is rejected and a larger or smaller portion thereof retained in metastable condition. Similar conditions may prevail for other alloying metal constituents diffused into the ferrous phase from the infiltrant, and whether such alloying metals are retained in stable or metastable solution can be ascertained in first approximation from the respective phase diagrams.

On quenching or controlled cooling to the effects stated the ferrous skeleton remains supersaturated with copper dissolved therein which tends to prevent the skeleton from hardening.

If appreciable amounts of carbon are present in the ferrous matrix, quenching tends to impart to the iron-carbon system of the matrix a structure of martensite, and if a controlled slower cooling rate as exemplified hereinbefore is applied, some or even all of the carbon may form bainite or pearlite. In all these cases, the carbon content tends to harden the ferrous matrix and thereby to counteract the effect of the excess copper dissolved in the matrix: If manganese is present in the ferrous matrix (skeleton) and in particular has diffused into the matrix from the infiltrant, a portion of the manganese is apt to form ternary solid solutions with the copper and iron, while another portion is apt to form complex carbide with the carbon and iron.

The cuprous infiltrant in which matrix-iron has been dissolved up to the limits previously stated and in which also manganese and other alloying constituents, if present, may have been dissolved, retains the iron in metastable solution upon quenching or precipitates a portion thereof upon cooling at a controlled slower rate; similar conditions apply to other alloying metal constituents dissolved in the liquid infiltrated copper if the solubility of these constituents in copper decreases with decreasing temperature. Iron dissolved in liquid copper to the limit of solubility will therefore be substantially retained in metastable condition upon quenching, or at least a far larger portion of such iron will so be retained upon cooling at a controlled slower rate as exemplified hereinbefore than would be retained upon ordinary furnace cooling.

In any event, upon quenching or cooling at a controlled rate the resulting body, due to copper in metastable condition in the iron phase and similarly iron in the cuprous phase, will be soft enough for subsequent final shaping or sizing (coining).

The shape or blading thus infiltrated and soaked at a temperature within the austenitic range of the ferrous phase and at the liquid state of the cuprous phase, and quenched or cooled at the controlled rate previously stated, already exhibits outstanding physical properties. For instance, a specimen consisting of an electrolytic iron powder matrix having about 15% porosity, infiltrated with copper and soaked thereafter at the infiltration temperature for 120 minutes, exhibited upon rapid cooling a yield strength of about 71,200 p. s. i. and an ultimate tensile strength of 75,900 p. s. i., whereas the same iron matrix infiltrated with copper within 15 to 20 minutes exhibited upon furnace cooling a yield strength of only 51,200 p. s. i. and an ultimate tensile strength of 60,400 p. s. i.

The infiltrated and soaked shape or blading is readily susceptible to precipitation treatments the effect of which is the greater the smaller the amount of copper, if any, is which was rejected upon cooling from above the transformation temperature. For instance, if an electrolytic iron matrix of 15% porosity was infiltrated with the cuprous alloy previously stated (2% iron, 8% manganese), soaked at infiltration temperature (about 1150° C.) for 120 minutes, thereafter solution heat treated at about 870° C. for one half

hour and oil quenched, and then precipitation treated at about 500° C. for one hour, a yield strength of 86,500 p. s. i. and a tensile strength of 90,500 p. s. i. were observed; whereas upon normal infiltration for 15 to 20 minutes and subsequent heat treatments the same as just described, a yield strength of only 78,300 and a tensile strength of 83,500 p. s. i. resulted. When the iron matrix contained appreciable amounts of carbon, e. g. 0.01% to 0.25% carbon after infiltration and heat treatment, and the cuprous infiltrant contained 2% iron and 8% manganese, upon infiltration and subsequent soaking at about 1150° C. for 150 minutes followed by solution treatment at about 870° C., oil quench and precipitation treatment at 500° C. for one hour, a yield strength of 90,500 p. s. i. and a tensile strength of 101,000 p. s. i. were observed.

In general, a soaking treatment within infiltration temperature range for about one to six hours, and more, followed by quenching or cooling at controlled rate, solution heat treating at about 760° to 870° C. for one half to three hours, quenching or controlled cooling either to room temperature or the desired temperature for the subsequent precipitation treatment, and precipitation treating for one to three hours at a temperature between 300° and 600° C. and preferably about 500° C., results in a shape or blading in which there is a finely dispersed cuprous precipitate in the ferrous phase and a finely dispersed ferrous precipitate in the cuprous phase which greatly enhance the physical properties of the blading. In particular, minimum yields of about 75,000 to 80,000 p. s. i. can be obtained in an invariably reproduceable manner, while the ductility represented by an elongation of at least about 3 to 5% is satisfactory. In addition, the entire process as described permits the production of bladings within closest tolerances in reliable and economical mass production.

The porous skeleton of compacted and, if desired, sintered ferrous particles infiltrated with a cuprous infiltrant and soaked thereafter for from about one to about six hours, and more, above the melting point of the infiltrant and below that of the skeleton contains ferrous particles permeated substantially throughout by constituents of the cuprous infiltrant. Photomicrographs taken from the infiltrated skeleton quenched to reveal the situation at infiltration temperature show that after a soaking treatment for one hour at about 1100° C. all the small ferrous particles are completely saturated with constituents of the infiltrant, particularly copper, and the large particles comprise a deep shell saturated with the infiltrant and a core penetrated by it throughout although not completely saturated. Upon a soaking treatment for four hours, all except the very largest particles of the skeleton appear saturated throughout. The ferrous particles are markedly rounded in all these cases, indicating the dissolution by the cuprous infiltrant of ferrous material from their surfaces. A marked increase of the hardness of the infiltrant phase indicates the solution therein of ferrous material from the skeleton. This hardness is considerably increased upon precipitation treatments as described. The cuprous phase is distributed as a fine network between the ferrous grains and its shape approaches the typical triangular form.

It should be understood that the invention is not limited to any of the exemplifications herein-before described but to be derived in its broadest aspects from the appended claims.

What I claim is:

1. The method of producing a composite ferrous metal article of high strength which comprises compacting and forming ferrous particles containing less than about .25% carbon into a shaped sintered porous skeleton having a sufficiently low carbon content so that when said skeleton is quenched from a raised temperature it exhibits a relatively high degree of softness and is readily given the desired shape, infiltrating said skeleton with a cuprous infiltrant containing at least 90% copper and having a melting temperature lower than 1250° C., maintaining the skeleton and infiltrant at a temperature in the range from about 1100° C. to about 1250° C. and above the melting temperature of the infiltrant for a period from about one to six hours to cause diffusion between the infiltrant and the skeleton and penetration of a substantial amount of constituents of the infiltrant substantially throughout the skeleton particles, thereafter cooling the infiltrated body at a quenching rate to give said body a relatively high degree of softness, and thereafter heating the quenched body at a temperature between about 300° and 600° C. for a period from about one hour to three hours for causing infiltrant constituents diffused into the skeleton to precipitate and thereby materially increase the strength of said body.

2. The method of producing a composite ferrous metal article of high strength which comprises compacting and forming ferrous particles containing less than about .25% carbon into a shaped sintered porous skeleton having a sufficiently low carbon content so that when said skeleton is quenched from a raised temperature it exhibits a relatively high degree of softness and is readily given the desired shape, infiltrating said skeleton with a cuprous infiltrant containing at least about 90% copper and having a melting temperature lower than about 1250° C., maintaining the skeleton and infiltrant at a temperature in the range from about 1100° C. to about 1250° C. and above the melting temperature of the infiltrant for a period from one to six hours to cause diffusion between the infiltrant and the skeleton and penetration of a substantial amount of constituents of the infiltrant substantially throughout the skeleton particles, thereafter heating said infiltrated body to an elevated temperature in the range from about 760° C. to about 870° C. for a period from about one-half to about three hours and thereafter cooling the heated body at a quenching rate to give said body a relatively high degree of softness, and thereafter heating the quenched body at a temperature between about 300° and 600° C. for a period between about one hour to about three hours for causing infiltrant constituents diffused into the skeleton to precipitate and thereby materially increase the strength of said body.

3. The method of producing a composite ferrous metal article of high strength which comprises compacting and forming ferrous particles containing less than about .25% carbon into a shaped sintered porous skeleton having a sufficiently low carbon content so that when said skeleton is quenched from a raised temperature it exhibits a relatively high degree of softness and is readily given the desired shape, infiltrating said skeleton with a cuprous infiltrant containing at least 90% copper and having a melting temperature lower than 1250° C., maintaining the

skeleton and infiltrant at a temperature in the range from about 1100° C. to about 1250° C. and above the melting temperature of the infiltrant for a period from about one to six hours to cause diffusion between the infiltrant and the skeleton and penetration of a substantial amount of constituents of the infiltrant substantially throughout the skeleton particles, thereafter cooling the infiltrated body at a quenching rate from an elevated temperature lower than the melting temperature of the infiltrant for giving said body relatively softness so that it may be further formed into the desired shape, thereafter further shaping the so-softened body, and thereafter heating the further shaped body at an elevated temperature lower than said last mentioned temperature for causing the infiltrant constituents diffused into the skeleton to precipitate and thereby materially increase the strength of said body.

4. The method of producing a composite ferrous metal article of high strength which comprises compacting and forming ferrous particles containing less than about .25% carbon into a shaped sintered porous skeleton having a sufficiently low carbon content so that when said skeleton is quenched from a raised temperature it exhibits a relatively high degree of softness and is readily given the desired shape, infiltrating said skeleton with a cuprous infiltrant containing at least about 90% copper and having a melting temperature lower than about 1250° C., maintaining the skeleton and infiltrant at a temperature in the range from about 1100° C. to about 1250° C. and above the melting temperature of the infiltrant for a period from one to six hours to cause diffusion between the infiltrant and the skeleton and penetration of a substantial amount of constituents of the infiltrant substantially throughout the skeleton particles, thereafter heating said infiltrated body at an elevated temperature in the range from about 760° C. to about 870° C. for a period from about one-half to about three hours and thereafter cooling the heated body at a quenching rate to give said body a relatively high degree of softness, thereafter further shaping the so-softened body, and thereafter heating the quenched body at a temperature between about 300° C. and 600° C. for a period between about one hour to about three hours for causing infiltrant constituents diffused into the skeleton to precipitate and thereby materially increase the strength of said body.

5. The method of producing a composite ferrous metal article of high strength which comprises compacting and forming ferrous particles containing less than about .25% carbon into a shaped sintered porous skeleton having a sufficiently low carbon content so that when said skeleton is quenched from a raised temperature it exhibits a relatively high degree of softness and is readily given the desired shape, infiltrating said skeleton with a cuprous infiltrant containing predominantly copper and having a melting temperature lower than the melting temperature of the skeleton, maintaining the skeleton and infiltrant at a temperature below the melting temperature of the skeleton and above the melting temperature of the infiltrant for a period from about one to six hours to cause diffusion between the infiltrant and the skeleton and penetration of a substantial amount of constituents of the infiltrant substantially throughout the skeleton particles, thereafter cooling the infiltrated body at a quenching rate from an elevated temperature lower than the melting temperature of the infiltrant for giving said body relatively softness so that it may be further formed into the desired shape, thereafter further forming the so-softened body into the desired shape, and thereafter heating the quenched body at an elevated temperature lower than the last mentioned temperature for causing infiltrant constituents diffused into the skeleton to precipitate and thereby materially increase the strength of said body.

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