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COMPOSITE MATERIAL AND SHAPED BODIES THEREFROM

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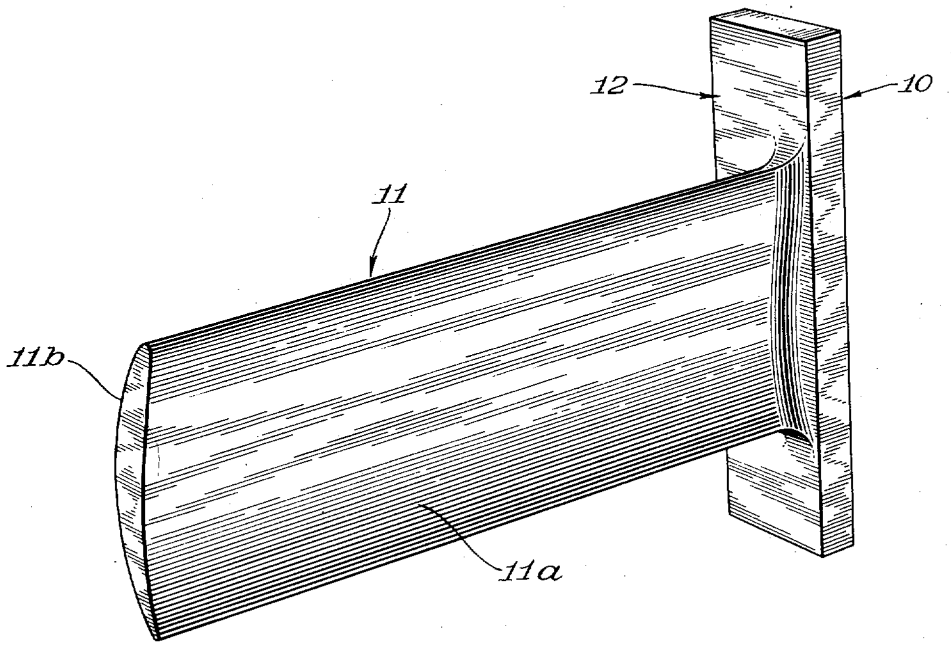

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COMPOSITE MATERIAL AND SHAPED BODIES THEREFROM

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13 Claims. (Cl. 75—22)

This invention relates to the manufacture of infiltrated composite material and shaped bodies thereof which essentially consists of iron or iron alloy, and copper or copper alloy.

Specifically, the invention deals with composite metal articles, such as blades or the like parts for turbo-jet engines, having a porous ferrous matrix or skeleton with the pores thereof filled with cuprous infiltrant metal and having been diffusion heat-treated and precipitation-treated to develop physical properties not heretofore obtained in copper-infiltrated ferrous metal parts.

This application is a continuation-in-part of my prior applications Serial Nos. 645,134 and 645,135, filed February 2, 1946, both now abandoned.

Heretofore known copper-infiltrated compacted powdered iron or steel articles do not possess sufficiently high strength and other physical properties to render them suitable for many industrial uses such as blades and other parts for turbo-jet engines.

The present invention now provides an article composed of a powdered ferrous metal matrix or skeleton having the pores thereof filled with a cuprous infiltrant and having been heat treated to develop ample strength and other physical properties capable of withstanding conditions such as exist in a turbo-jet engine and which would soon impair the heretofore known articles.

According to this invention powdered iron, of an average particle size of from about minus 80 to minus 325 mesh, is pressed to a porous compact under pressures ranging from about 6 to 50 tons per square inch (t. s. i.), so that the compact exhibits a porosity of about 30% to 10%, and advantageously about 25% to 15%. The powdered iron can, if it is desired to form a steel, contain carbon up to about 1.7% by weight of the iron powder and preferably between about 0.01% and 0.7% carbon. Alternatively, the iron powder can contain combined carbon and thus be in the nature of a steel powder, although the use of steel powders is somewhat objectionable because of their hardness, which causes excessive wear of the compacting dies.

The porous ferrous compact is infiltrated with copper to fill the intercommunicating pores throughout the compact. This infiltration is preferably effected by contacting the compact with copper and by heating the assembly in a clean and dry protective atmosphere to a temperature above the melting temperature of copper and preferably between about 1125° and about 1250° C. until infiltration is completed.

The infiltrated article is then diffusion heat treated at or above about 500° C. to alloy the cuprous and ferrous phases and precipitation heat treated at lower temperature than used in the preceding diffusion treatment to develop the desired physical properties.

The copper infiltrant metal is preferably admixed with or pre-alloyed with manganese and/or other metals such as nickel, chromium, silicon, and titanium which are capable of alloying with the infiltrated article. This forms a convenient method of introducing alloying ingredients into the porous ferrous compact. The manganese, besides serving as an alloying metal, will form a fluffy or spongy residue on the surface area through which the cuprous metal was infiltrated. This residue can be easily removed.

A suitable iron powder for forming the porous compact is electrolytic iron or powdered reduced iron. Solid carbon, if added, can be in the form of graphite or lamp black. The graphite will also serve as a lubricant during pressing but other volatile lubricants, such as sodium stearate and the like, can be used without adding carbon to the product. The copper infiltrant material can be electrolytic or reduced copper powder, granules, shot, cuttings, machinings, trimmings from copper wires, sheets or bar stock which, if desired, can be fragmentated or powdered. Commercial copper, if used, should be purified or remelted in order to prevent evolution of gases upon heating to infiltration temperature.

If desired, the porous ferrous compact can be presintered, prior to infiltration, at temperatures between about 900° and 1100° C. for a short period of time in a clean and dry protective atmosphere to increase the coherence and density of the compact. This presintering can be included in the heat treatment for infiltrating the copper, for instance, by extending the period during which the porous compact is heated in the furnace to the melting temperature of the copper.

It is, then, an object of this invention to produce by infiltration of copper and, if desired, minor amounts of other metal, into a porous matrix obtained by pressing to shape and, if desired, sintering minute iron particles to which other alloying metal and carbon may be added, and by subsequent heat treatment, a shaped composite body which exhibits superior qualities.

It is another object of the invention to produce a shaped composite body of enhanced strength by infiltrating cuprous metal into a powdered ferrous metal compact and by so heat treating the infiltrated body as to alloy the cuprous and ferrous phases thereof and to precipitate iron from the copper phase and copper from the iron phase.

Another object of this invention is to provide blades and the like parts for turbo-jet engines by combined powdered metallurgy and infiltration technique including the infiltration of a porous ferrous metal compact with molten cuprous metal and the heat treatment of the resulting infiltrated compact to develop physical strengths sufficient to withstand operating conditions in a jet engine.

Another object of the invention is to enhance the strength of copper-infiltrated ferrous metal articles by diffusion heat treatment at and above about 500° C. and by precipitation heat treatment at lower temperatures than used in the preceding diffusion heat treatment.

Another object of the invention is to utilize the cuprous infiltrant to carry alloying metal into a porous ferrous metal compact during infiltration.

Another object of the invention is to prepare an alloy by combined powder metallurgy and infiltration technique wherein alloying ingredients are introduced into a porous ferrous compact by infiltration and to diffuse them into the compact material so that subsequent heat treatment will produce the desired alloy structure.

A further object is to incorporate manganese into a cuprous infiltrant to form an easily removable residue of excess infiltrant on the infiltrated article.

Other and further objects of the invention will be more clearly understood from the following description taken in connection with the accompanying drawing which shows a perspective view of a compressor blade for a turbo-jet engine composed of a heat treated copper infiltrated ferrous metal compact in accordance with the invention.

The blade **10** has an air foil vane section **11** and a root **12** for anchoring in a turbo-jet engine compressor rotor or stator. The air foil portion **11** has a concave face **11***a* and a convex face **11***b* designed to effectively pack air into the engine. In addition, the section is twisted along its length. Heretofore, these complicated blade shapes could only be made by expensive forging and machining operations. Since a turbo-jet compressor requires hundreds of the blades, their cost has been a considerable item in jet engine production. In accordance with this invention, however, blades **10** and other complicated shapes are easily and inexpensively produced in mass quantities.

Various procedures to produce the articles of this invention will now be explained, as applied to test bars of about 3″ long and 0.3″ square and therefore of a size comparable to that of a blade insofar as the results obtained are concerned.

A compact of the dimensions of the test bars stated was prepared by pressing at about 15 t. s. i. an electrolytic iron powder of a particle size corresponding to minus 100 mesh with one-fourth of the powder having a size of minus 325 mesh. This soft iron powder permits the use of relatively low compaction pressures and results in practically no wear of the dies; it also exhibits desirable flow characteristics. The compact or matrix thus produced had intercommunicating pores and as a result of the applied pressure stated a porosity of about 25%. It was then heated in contact with pure copper in an infiltration furnace having a clean and dry protective atmosphere of purified cracked ammonia dried to a dew point below minus 30° C. The temperature of the compact and copper in contact therewith was raised to about 1200° C. whereby the copper was melted and quickly infiltrated throughout the porous compact. The infiltration temperature was held for between ten and fifteen minutes. Thereafter, the compact with the infiltrant therein was cooled in the furnace to form a composite body consisting of approximately 75% by weight iron and 25% by weight copper. Another test bar specimen was produced from the same materials under equal conditions except that the compacting pressure was increased to 30 t. s. i. resulting in a porous compact or matrix of 15% porosity. Upon infiltration with copper a composite body resulted consisting of approximately 85% by weight iron and 15% by weight copper.

A series of other test bars was produced from reduced iron powder commonly available on the market and again compacts of the size stated made therefrom under pressures of 15 and 30 t. s. i. resulting in compacts of about 25% and 15% porosity, respectively; the compacts were infiltrated with copper in the manner previously described and composite bodies consisting of approximately 75% and 85% iron and 25% and 15% copper, respectively, resulted.

Other test bars were prepared by infiltrating the compacts with copper to which alloying constituents were added, mainly in order to increase the strength of the cuprous infiltrant and of the composite body. Alloying metals including manganese, nickel, chromium, silicon and titanium were added to or prealloyed with the copper preferably in amounts of a fraction of 1% up to about 2% by weight of the completed infiltrated body. These additions to the copper infiltrant are carried by the latter during infiltration into the ferrous porous matrix and can alloy with both the copper infiltrant and the matrix material in the completed body whereby the physical properties and densities of the bodies are improved.

It is sometimes found desirable to add small amounts of iron to the cuprous infiltrant; up to about 5% iron by weight of the infiltrant can be readily dissolved therein at the infiltration temperature stated but it is preferable to use only up to about 2% iron which is far below the limit of solubility of iron in copper at the infiltration temperature.

The infiltrated composite bodies obtained in any manner hereinbefore described, are susceptible to heat treatments which greatly enhance their desired physical properties.

Upon heat treating the ferrous compact infiltrated with copper and any of the additions previously stated and carried by the copper into the ferrous matrix, alloying by diffusion can be obtained, as evidenced, e. g., by a marked decrease of the electric conductivity of the body. Such alloying heat treatment can be effected at and above about 500° C., for instance, by heating for four hours. If additional metal is carried by the cuprous infiltrant into and distributed throughout the ferrous matrix, upon heating the infiltrated body to a temperature of and above about 500° C. also some of the additional metal, and of course copper, is alloyed by diffusion with the matrix metal whereby the level of the overall physical properties of the infiltrated and heat treated body is raised. Heating the infiltrated body to temperatures between about 500° and 900° C. usually suffices to enhance the overall strength of the heterogeneous composite body.

In particular, if manganese is added to the cuprous infiltrant and the latter is used in an amount exceeding that required to fill the pores of the ferrous matrix, the excess forms a fluffy and spongy residue on the surface of the matrix and can be easily wiped off or otherwise removed.

Iron in its austenitic state (gamma iron) can hold in solid solution about 3.4% copper at 810° C. and up to about 13% copper at 1100° C. The solubility of copper in iron is considerably reduced upon its transformation from the gamma to the alpha state, alpha iron holding in solid solution a maximum of about 2% copper at 810° C. and less than 1% copper at room temperature. Inversely, copper can dissolve about 3.5% iron at 1100° C. and the solubility of iron in copper is reduced to less than 1% by weight of the copper at room temperature. Thus, both the ferrous and cuprous phases of the infiltrated composite body are susceptible to precipitation heat treatments.

By alloying the infiltrated cuprous and ferrous matrix phases in a diffusion heat treatment whereby cuprous metal is diffused into the ferrous matrix in alloyed condition therewith and ferrous matrix metal is diffused into the cuprous infiltrant phase, the conditions are set for a successful precipitation treatment. The precipitation treatment will precipitate cuprous metal in the iron matrix and ferrous metal in the cuprous infiltrant.

Accordingly, upon reheating a matrix infiltrated with copper to about 845° C., quenching in water or otherwise cooling at a controlled rate, and precipitation treating, by reheating to about 500° to about 700° C. and holding this temperature for about two hours, a minimum yield strength of 55,000 pounds per square inch (p. s. i.), a minimum tensile strength of 90,000 p. s. i. and a minimum elongation of about 10% were observed.

If it is desired to incorporate additional or free carbon in the ferrous matrix so that its overall carbon content is up to 1.7%, the following procedure may be followed.

Electrolytic or reduced iron power is admixed with solid carbon in desired proportions and also powdery constituents of alloy steel in minor amounts may be added. This initial powder, of a particle size previously stated, is pressed at the aforesaid compacting pressures to a compact of a porosity of preferably 25% to 15%. If alloying constituents are added to the initial powder, or diffused into the ferrous porous matrix from the infiltrant, it is preferred that the overall content of carbon in the ferrous matrix is within the range from 0.01 to 0.7%. The compact may be presintered at a temperature between about 900° and 1100° C., and is thereafter infiltrated with the cuprous infiltrant in a clean and very dry protective atmosphere. If the matrix and infiltrant metal are sufficiently pure or purified, evolution of gases during heating and infiltration can be reduced to a minimum. Upon infiltration of copper into the ferrous matrix followed by a diffusion treatment, again iron from the matrix is dissolved in the copper infiltrant and copper is dissolved in the ferrous matrix; upon subsequent precipitation treatment iron is precipitated from the copper to form a finely dispersed precipitate and thus enhances the strength of the cuprous phase.

The infiltrated and heat treated body requires little or no finishing or machining operations, and the molding of the porous matrix from the aforesaid initial powders can be effected by relatively low pressures and with practically no wear of the dies.

If electrolytic iron powder is admixed with 1% graphite by weight of the powder, so that the overall content of carbon of the final body is about 0.7%, a composite body comprising a 70% to 90% ferrous matrix and a 30% to 10% cuprous infiltrant is obtained which is susceptible to heat treatments just as a composite body of the same composition obtained from reduced iron powder the carbon content of which, due to added carbon, amounts up to about 0.7%.

If alloying constituents such as manganese, chromium, nickel, silicon and titanium are added to or prealloyed with the copper in amounts of a fraction of 1% up to above 2% by weight of the completed composite body, they can be alloyed by diffusion with the carbon containing ferrous matrix of the infiltrated body upon proper heat treatment.

Outstanding results were obtained by the use of a ferrous matrix containing carbon and prepared in a manner described hereinbefore, and infiltrated with copper containing manganese within the limits stated, more specifically 5 to 8% manganese. Iron can also be added to the copper infiltrant in amounts up to about 5% but preferably not exceeding about 2%.

A test bar of the dimensions previously stated and containing 80% to 85% ferrous metal and 20% to 15% cuprous metal was prepared by compacting electrolytic iron powder admixed with about 1% carbon, presintering it and infiltrating it with the aforesaid copper alloy at a temperature between 1125° C. and 1250° C. in a very dry protective atmosphere. The slowly furnace cooled bar was heated thereafter at about 650° C. for about 18 hours and exhibited a minimum yield strength of about 50,000 p. s. i., minimum tensile strength of about 80,000 p. s. i., a minimum elongation of about 8% and a minimum Rockwell B hardness of 85. Upon reheating the infiltrated body to about 845° C. (diffusion treatment), quenching in water and precipitation heat treating (back-drawing) at about 650° C. for one hour, a minimum yield strength of 60,000 p. s. i., a minimum tensile strength of about 90,000 p. s. i., a minimum elongation of about 5% and a minimum Rockwell B hardness of 85 were observed. Upon diffusion heat treatment and quenching the test bar in the same manner but precipitation treating (back-drawing) at 350° C. for one hour, a minimum yield strength of about 80,000 p. s. i., a minimum tensile strength of 110,000 p. s. i., a minimum elongation of about 4% and a minimum Rockwell B hardness of 100 were observed.

If reduced iron powder is used for the matrix instead of electrolytic iron powder, the same treatments resulted in still higher tensile strength, elongation and hardness. Upon heating the slowly furnace cooled bar infiltrated with the aforesaid copper alloy at 650° C. for 18 hours to alloy the cuprous infiltrant and ferrous matrix, the tensile strength was increased to about 85,000 p. s. i., elongation to about 10% and the Rockwell B hardness to 90. Upon diffusion heat treatment, quenching and precipitation treatment (back-drawing) at 650° C. a minimum tensile strength of 110,000 p. s. i. was obtained; upon precipitation treating the same material at 500° C. a minimum tensile strength of 130,000 p. s. i., and upon precipitation treating the same material at 315° C. a minimum tensile strength of about 135,000 p. s. i. were obtained. The minimum elongations in the last mentioned three cases were between 3 and 4%, and the hardnesses were between Rockwell B 95 and Rockwell C 30.

If manganese was added to the cuprous infiltrant any excess of the latter again forms a fluffy or spongy residue which can easily be removed.

If chronium, nickel, titanium and/or silicon were added to the matrix, similar trends and effects were observed upon heat treating the infiltrated composite body. While these alloying constituents may be carried into the ferrous matrix by the cuprous infiltrant and thereafter a portion of them alloyed with the matrix in a subsequent heat treatment, such alloying constituents may also be admixed in powdery state with the iron powder and carbon, and in such cases also molybdenum, vanadium and other alloying constituents which cannot be melted with the cuprous infiltrant, can be incorporated and alloyed with the final body.

The effects of the heat treatments are dependent upon the size of the infiltrated composite body. Sizes of test specimens have been stated before. Satisfactory results have been observed with larger bodies, up to 5" diameter and 2" height, or bars of up to 6" lengths and 1" square.

From the above description it should be understood that the invention provides composite metal material and especially shaped bodies, such as blades for turbo-jet engines composed of a porous skeleton or matrix of ferrous metal particles having the pores filled with a network of cuprous infiltrant material to form a solid dense mass. The material is heat treated to alloy the cuprous and ferrous phases and to precipitate ferrous metal in the cuprous phase and cuprous metal in the ferrous phase. The invention also provides for the introduction of alloying metals into the ferrous phase through the medium of the infiltrant metal during the infiltration process so that these metals and phase can be alloyed to desired extent during the heat treatment. The products of the invention possess physical properties not heretofore obtained in copper infiltrated ferrous metal bodies. If desired, carbon is added to the iron powder used to produce the ferrous matrix or skeleton and is subsequently combined with the iron to form steel.

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

What I claim is:

1. The method of making a composite shaped body, which comprises compacting powdered ferrous metal particles to form a shaped porous mass, contacting the mass with cuprous infiltrant associated with another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium, heating said contacted mass and infiltrant to melt the infiltrant and associated metal and infiltrate them into the mass, and further heating the infiltrated mass to temperatures above about 500° C. to alloy with said ferrous metal of the mass some of said cuprous infiltrant and associated metal thus carried into and distributed throughout said mass.

2. A composite metal article comprising a 70% to 90% sintered powdered ferrous metal matrix having intercommunicating pores, and a 30% to 10% cuprous metal infiltrant containing another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium filling said pores, and said matrix metal and infiltrant therein having been heat treated above about 5000 C. to alloy the said matrix metal with some of the infiltrant metal and other metal contained therewith in said matrix.

3. A composite metal article comprising a 70% to 90% powdered ferrous metal matrix having intercommunicating pores, and a 30% to 10% cuprous infiltrant metal and another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium filling said pores, said matrix, infiltrant and said other metal having been diffusion heat treated to alloy said matrix and infiltrant phases, and having been quenched and precipitation treated to also precipitate iron from the copper phase.

4. The method of making a composite shaped body, which comprises compacting powdered ferrous metal particles to form a shaped porous mass, contacting the mass with an excess amount of a cuprous infiltrant material containing manganese, infiltrating the mass with a portion of said infiltrant to infiltrate the cuprous infiltrant and manganese into the mass and to leave an easily removable excess of infiltrant material in a fluffy and spongy state on the mass, and further heating said infiltrated mass to temperatures above about 500° C. to alloy some of said cuprous infiltrant and manganese thus carried into and distributed throughout said mass with the ferrous metal of said mass.

5. A composite metal article comprising a 70% to 90% powdered ferrous metal matrix having intercommunicating pores, and a 30% to 10% cuprous infiltrant metal filling said pores, said matrix and infiltrant metals having been diffusion heat treated to alloy said matrix and infiltrant phases, and having been cooled at a rate to hold alloyed metals in solution and then precipitation treated to precipitate iron from the copper phase and copper from the iron phase.

6. A composite metal article comprising a 70% to 90% powdered ferrous matrix having intercommunicating pores, and a 30% to 10% cuprous infiltrant metal filling said pores, said ferrous metal and cuprous infiltrant therein having been heat treated above about 500° C. to alloy the infiltrant and matrix phases and having been quenched and precipitation treated to precipitate iron from the copper phase and copper from the iron phase.

7. The method of making a composite metal article of enhanced strength, which comprises compacting iron powder containing free carbon up to about 1.7% by weight to form a matrix having a porosity of about 10% to 30%, contacting the matrix with cuprous infiltrant associated with another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium, heating said contacted mass and infiltrant to melt the infiltrant and associated metal and infiltrate them into the matrix, and further heating the infiltrated matrix to temperatures above about 500° C. to alloy with the matrix metal some of the cuprous infiltrant and associated metal thus carried into and distributed throughout said matrix and to combine carbon with the iron to form a steel.

8. A composite metal article comprising a 70% to 90% powdered ferrous metal matrix containing carbon up to 1.7% by weight and having intercommunicating pores, and a 30% to 10% cuprous metal infiltrant containing another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium filling said pores, and said matrix metal and infiltrant

therein having been heat treated to above about 500° C. to alloy said matrix metal with some of the infiltrant metal and other metal contained therewith in said matrix and to combine carbon with the matrix metal.

9. A composite metal article comprising a 70% to 90% powdered ferrous metal matrix containing carbon up to 1.7% by weight and having intercommunicating pores, and 30% to 10% cuprous metal filling said pores, said ferrous metal matrix and cuprous infiltrant therein having been heat treated above about 500° C. to alloy the infiltrant and matrix phases and to combine carbon with the matrix metal and having been precipitation treated to precipitate iron from the copper phase and copper from the iron phase.

10. A blade adapted for a turbo-jet engine and the like composed of 70% to 90% by weight of a powdered ferrous metal matrix having intercommunicating pores and 30% to 10% by weight of a cuprous infiltrant metal filling said pores, said ferrous metal and cuprous infiltrant therein having been heat treated above about 500° C. to alloy the infiltrant and matrix phases and having been quenched and precipitation treated to precipitate iron from the copper phase and copper from the iron phase.

11. A blade adapted for a turbo-jet engine and the like composed of 70% to 90% by weight of a powdered ferrous metal matrix containing 0.01 to 0.7% combined carbon and having intercommunicating pores and 30% to 10% by weight of a cuprous infiltrant metal filling said pores, said ferrous metal and cuprous infiltrant therein having been heat treated above about 500° C. to alloy the infiltrant and matrix phases and having been quenched and precipitation treated to precipitate iron from the copper phase and copper from the iron phase.

12. A blade adapted for a turbo-jet engine and the like composed of 70% to 90% by weight of a powdered ferrous metal matrix having intercommunicating pores and 30% to 10% by weight of cuprous infiltrant metal and another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium filling said pores, said matrix, infiltrant and said other metal having been diffusion heat treated to alloy said matrix and infiltrant phases, and having been quenched and precipitation treated to also precipitate iron from the copper phase.

13. A blade adapted for a turbo-jet engine and the like comprising a one-piece member having an air foil vane portion and a root portion composed of 70% to 90% by weight of a powdered ferrous metal matrix having intercommunicating pores and 30% to 10% by weight of a cuprous infiltrant metal containing another metal selected from the group consisting of manganese, nickel, chromium, silicon and titanium filling said pores, and said matrix metal and infiltrant therein having been heat treated above about 500° C. to alloy the said matrix metal with some of the infiltrant metal and said other metal contained therewith in said matrix.

CLAUS G. GOETZEL.

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