

UNITED STATES PATENT OFFICE

2,301,805

HIGH-CARBON FERROUS-BASE COMPOSITION FOR PRODUCING ARTICLES BY POWDER METALLURGY

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No Drawing. Application August 7, 1939,
Serial No. 288,833

12 Claims. (Cl. 75-22)

This invention relates to high-carbon ferrous-base composition for producing articles by powder metallurgy. It is particularly directed to the use of powdered iron in the manufacture of ferrous-base metallic articles by powder metallurgy methods.

In the prior art in powder metallurgy, such ferrous base components as powdered sponge iron, powdered electrolytic iron and powdered cast iron have been employed. Powdered sponge iron, electrolytic iron or gray cast iron possess certain undesirable features which will be apparent from the following description in which both sponge iron and electrolytic iron will be referred to as "sponge iron."

Iron in a finely comminuted high purity form is usually produced by direct gas reduction of powdered oxides of iron, or by the electrolytic deposition of iron, and hence is relatively expensive. Electrolytic iron usually requires annealing for softening. Due to its softness pure iron can be readily cold compacted. For many applications this soft iron is lacking in desired strength and hardness properties. Hence at times the finished products are subjected to carburization treatments and subsequent heat treatment operations to obtain the desired properties. Also at times it is desirable to have free graphite intermixed with iron to obtain the lubricating effect of the contained graphite, in such articles as bearings and the like. This is facilitated by mechanically mixing powdered graphite with the sponge iron prior to briquetting.

One of the drawbacks of the use of sponge iron in powder metallurgy is the necessity of carburization and subsequent heat treatment of the sintered articles. Cast gray iron of the prior art is essentially an alloy of iron, carbon and silicon, its major structural constituents being graphite in flake form and the various products of the austenite-pearlite transformation. Cast iron powders are generally obtained by pulverizing gray iron borings and chippings by means of various impact and grinding methods and is thus likely to be contaminated with dirt, grease and other objectionable impurities. Though gray cast iron is extensively used for bearings and the like by virtue of its wearing qualities and the lubricating effect of its free graphite, cast iron powder does not lend itself to cold-compacting or bonding during the sintering operation and such methods must be resorted to as zinc coating of the iron particles or the addition of a substantial amount of other constituents to facilitate bonding of the particles.

One object of this invention is to provide a relative inexpensive ferrous base metal which can be readily comminuted to powder form and which, by a subsequent heat treatment, can be softened so as to allow compacting into desired shapes by the application of pressure.

Another object of this invention is to provide a finely comminuted ferrous-base component which has graphite or free carbon uniformly and highly dispersed within the individual iron particles, making it desirable for use as a bearing material and the like.

A further object of this invention is to provide a ferrous-base component which, by virtue of the composition, is susceptible to hardening and strengthening through the application of suitable heat-treating methods.

Other objects and advantages will appear as this description progresses.

My invention involves the use of powdered white or chilled iron in the manufacture of ferrous-base metallic articles by powder metallurgy methods. The ferrous-base composition of my invention has most of the desirable features of all of the above-mentioned prior art materials and also has certain desirable features not possessed by either sponge iron, electrolytic iron, or gray cast iron. Generally speaking my invention provides a powdered ferrous base composition which has certain desirable characteristics akin to those of sponge iron, other desirable characteristics not attainable with sponge iron, and other characteristics akin but more desirable than can be obtained with sponge iron, certain of which are briefly stated in the following.

In general, my invention provides a powdered ferrous-base composition which is less expensive than sponge iron by virtue of its method of manufacture; it also provides a powdered composition suitable for the manufacture of articles of commerce, the hardness and strength of which can be varied at will from those akin to malleable iron to those of hardened steel, by employing appropriate cooling methods from the sintering temperature; it eliminates the necessity of carburization and subsequent heat treatment of the sintered article as is at times necessary when sponge iron is employed; it provides a component which under most conditions of sintering and subsequent cooling will contain free graphite in nodular form, highly dispersed and intimately embedded in the iron grains, hence affording a desirable lubricating effect; it thus provides a more uniform distribution of graphite than is

possible by mixing powdered graphite with powdered sponge iron.

Whereas cast gray iron powder does not readily bond, the ferrous-base composition of my invention bonds readily after a suitable heat-treatment and can be sintered at temperatures lower than those usable with pure iron. I therefore do not need to coat the powdered metal with zinc or employ any other constituent to effect bonding, the advantages of which are self-evident.

The white or chilled iron composition of my invention is essentially an alloy of iron, carbon and silicon, quite similar to that of cast gray iron; however, it differs structurally from cast gray iron. It is known that alloys consisting of essentially iron, carbon and silicon may have either a gray or white structure, depending on the adjustment of composition and/or the rate of solidification and cooling to a low temperature. The structural constituents of white or chilled iron are largely cementite (Fe_3C) and the various transformation products of austenite. Generally, the major portion of the contained carbon is present in the combined form as cementite, which makes the material quite hard and brittle; hence, it can be readily pulverized by various impact or crushing methods. "Free" or "massive" cementite is not generally found in cast gray iron, rather the contained carbon is largely present as free graphite in plate-like form, the remainder being in the form of pearlite.

Briefly, the preferred method which I use in obtaining my product consists of granulating the molten metal by any suitable process which will induce rapid enough cooling to produce the white or chilled iron structure and form pellets of a size which can be readily comminuted to powder by various impact and grinding methods. Good results have been obtained by directing a stream of water against a stream of the molten iron as it flows from a container or from a cupola. I, however, do not wish to be limited to the above preferred method which I have mentioned largely due to its economic feasibility and other advantages developed later in the specification.

The permissible range of composition of the white or chilled iron of my invention would in general embrace all the cast iron materials, and would in general contain the common chemical elements of such materials in amounts within the limits given below:

	Per cent
Carbon.....	2.00-3.80
Silicon.....	.50-2.60
Manganese.....	0.2-1.0
Phosphorus.....	0.1-1.0
Sulfur.....	.05-.3

The generally preferred limits of the commonly present elements are somewhat narrower than the above-mentioned amounts. They are the following:

	Per cent
Carbon.....	3.00-3.55
Silicon.....	1.20-2.0
Manganese.....	Less than 0.50
Phosphorus.....	Less than 0.3
Sulfur.....	Less than .15

Additional elements may be added such as copper, nickel, chromium, molybdenum, et cetera, to modify and enhance certain properties or to either modify or enhance such properties. I consider that this is within the scope of my invention.

The selection of the specific composition of the white or chilled iron is to some extent based on

the influence of the component chemical elements on the ease of subsequent malleabilization of the white iron powder and their effect on desired physical or mechanical properties.

By employing powdered white or chilled iron of composition within the stated preferred range of carbon, silicon, manganese, phosphorus and sulfur contents, and produced by the stated preferred method, I have been able to effect practically complete malleabilization, or in other words practically complete decomposition of cementite (Fe_3C) in a shorter period of time than I am aware has heretofore been reported. As an example of the simplicity of processes by which it is possible to malleabilize the white or chilled iron of composition within the preferred limits of my invention, the following experiments are cited.

A powdered white iron containing 3.42% carbon, in the combined form as cementite, was packed in a sealed container, inserted into an electrically heated muffle furnace and heated to a temperature of 1700° F. A period of three-quarters of an hour was required for the powder to reach this temperature at which time the current to the furnace was shut off and the powder and furnace cooled to 1390° F. in about one hour. The temperature of 1390° F. was maintained for one-half hour, then the powder was cooled with the furnace to room temperature. Only .05% carbon was found remaining as cementite after this treatment, the remainder having been changed to temper carbon, a form of graphite. Another similar treatment with the exception of the maximum temperature being but 1650° F. resulted in malleabilized product containing but .08% combined carbon. The material resulting from these heat treatments was quite soft and readily compacted.

Other cycles of heat treatment for malleabilization may be employed and be within the scope of my invention, and it is realized that with adjustments in composition to enhance certain desirable properties of the product other cycles of heat treatment may necessarily have to be employed to effect decomposition of the carbide and softening of the powder. The simplicity of the malleabilization cycle cited is thought to be largely due to the fine structural nature of the white irons produced by my preferred method and to the balance or adjustment of composition of white iron material of my preferred composition limits.

The malleabilized white iron powder of my invention is structurally distinctly different from cast gray iron in that the former contains small nodules of graphite well dispersed in a ferritic matrix, while cast gray iron generally contains relatively coarse plate or stringer-like areas of graphite in a pearlitic matrix. The malleabilized white iron powder is softer than cast gray iron and hence can effectively be compacted while the latter cannot; this difference in compacting properties is probably also due in part to the difference in the form and distribution of the free graphite in the two materials.

After the malleabilization treatment of the white iron powder of my invention the steps necessary for the formation of metallic articles, such as briquetting and sintering, are substantially the same as employed in the art of powder metallurgy; the exact procedure will be dependent on the porosity, hardness and strength or other properties desired in the finished article. The heating for sintering will effect the reabsorption of some carbon to form austenite at temperatures

above the critical temperature (A_1), hence the cooling procedure through the austenite-pearlite transformation will determine the matrix structure and affect the hardness and strength of the sintered product.

If the cooling rate from the sintering temperature is extremely slow, the result of the austenite transformation on cooling will be a structure consisting largely of ferrite and temper carbon. When the cooling rate is rapid as by quenching from the sintering temperature, the transformation product from austenite will be martensite. Intermediate cooling will produce such structures as a mixture of ferrite and pearlite and the resulting products will have the hardness and other properties usually associated with these different microstructures. The composition of my invention is thus capable of producing powder metallurgy articles of a wide variety of properties.

Certain test results which give an indication of the order and range of properties that can be obtained with the malleablized white iron powder of my invention are presented in Table I.

Table II gives the screen analysis of the malleablized white iron powder employed in making the test specimens. The screen analysis given in Table II is by no means limiting because it is desirable to vary the screen analysis to modify compacting, sintering and the resulting properties.

TABLE I.—Properties of pressed and sintered specimens of malleablized white iron powders—#226¹

Sintering temperature ²	Compressive strength	Density ³	Relative porosity ⁴
	P. s. i.	Gms./cc.	
1815° F	28,100	5.16	28.3
1855° F	42,600	5.25	27.1
1890° F	54,500	5.38	25.3
1900° F	80,100	5.54	23.0
1930° F	98,200	5.88	18.3
1950° F	110,600	5.99	16.8
1975° F	116,100	6.14	14.7

¹ The specimens were hollow cylinders or bushings .7" O. D. x 1" long, with a 0.1" wall. A briquetting pressure of 69,000 p. s. i., was employed.

² Sintering conducted in hydrogen atmosphere at temperature one hour. Furnace cooled.

³ Density of material as compacted 5.31—porosity 26.4%.

⁴ Relative porosity was obtained by comparing the density of sintered material with that of malleable iron (7.2).

TABLE II.—Particle size distribution of malleablized white iron powders—#226

U. S. S. screen size	Cumulative percent by weight on sieve
50	0.2
100	1.3
200	20.1
270	28.6
325	56.8
Pan (-325)	100.0

The data in Table I are cited to give a brief indication of the range of properties available as a function of sintering temperature.

Variations in the cooling process from the sintering temperatures are capable of producing a wide range in strength, hardness, ductility and wear resistance.

The porosity of the powdered metal articles is mainly a function of the particle size of the powders, the compacting pressure, and the sintering temperature. Whereas the porosity de-

termines to a large extent the capacity of the material to absorb a lubricant in such applications as bearings, the material of my invention will contain, under most conditions of sintering and subsequent cooling, free graphite in nodular form highly dispersed within the matrix, thereby enhancing the lubricating qualities of the material. As previously pointed out, the matrix may vary over a wide range of microstructures depending upon the rate of cooling. It is within the scope of this invention, when special properties are desired, to add some graphite to my preferred powder before compacting.

Comparative wear tests, both oilless and lubricated, have indicated that the materials made from the malleablized white iron powders of my invention compare favorably with bearing materials made from Swedish sponge iron and graphite and the commercial porous bronze bearings.

Whereas the material of my invention when used alone compacts and bonds readily and has chemical and structural characteristics which make it desirable and adaptable for innumerable applications, it may also be used as a component in more complex materials for special purposes. For example, it is within the scope of this invention to add other powdered metals and alloys to my preferred composition of a malleablized white iron powder and good results have been obtained when the mixture contained approximately 10% powdered copper and 1½% powdered graphite. The special additions would be made when it is desirable to develop in the finished product special properties or to modify the sintering temperature, especially to lower the sintering temperature.

Some of the important features of my invention are that: It provides a material which is relatively inexpensive and which can be readily comminuted to powdered form; it provides a material, the chemical composition of which may be selected to facilitate ease of malleabilization and/or to develop or enhance certain desirable mechanical or physical characteristics in the final product; it provides a material which after a suitable malleabilization heat treatment can be compacted into most any desirable shape; it provides a material which by adjustment of the process of cooling from the sintering temperature can produce a wide range of mechanical and physical properties; it provides a material which under most conditions of sintering and subsequent cooling will contain free graphite uniformly and highly dispersed.

For the purpose of the claims in this application, the term "matrix" will be used to mean the principal structure obtained on cooling from the sintering temperature. As previously pointed out, the structure or matrix will vary depending upon the sintering temperature and time and particularly upon the rate of cooling from the sintering temperature. Likewise, in the appended claims the term "austenite transformation" is always used in connection with cooling from the sintering temperature and is used to include the resulting products whether they be martensite, pearlite or ferrite, or a combination of two or more of these.

Having thus described my invention, what I claim is:

1. As a new article of manufacture, a metallic article such as bearings, small machine parts, hardware, etc., originally formed from finely

comminuted high carbon chilled white iron which has been malleableized by a heat treatment that converts a major portion of the combined carbon into temper carbon which is highly dispersed in small nodules intimately embedded in the matrix, and which has been compacted and sintered by powder metallurgy methods and cooled from a temperature above that of the austenite transformation at such a rate as to effect the desired microstructure and mechanical properties.

2. A metal powder designed for compacting and sintering to form shaped articles, said powder comprising malleableized powder-like particles, with substantially all of said powder-like particles embodying an iron matrix and carbon with said carbon mainly composed of temper carbon highly dispersed in small nodules intimately embedded in the matrix.

3. A metal powder designed for compacting and sintering to form shaped articles, said powder comprising malleableized powder-like particles, with substantially all of said powder-like particles consisting of from 2.0 to 3.8 per cent carbon, from 0.50 to 2.60 per cent silicon, from 0.2 to 1.0 per cent manganese, with the usual impurities such as up to 1.0 per cent phosphorus and up to 0.3 per cent sulfur and the balance substantially all iron, and embodying an iron matrix and carbon with the carbon mainly composed of temper carbon highly dispersed in small nodules embedded in the matrix.

4. A metal powder designed for compacting and sintering to form shaped articles, said powder comprising malleableized powder-like particles, with substantially all of said powder-like particles consisting of 3.00 to 3.55 per cent carbon, from 1.20 to 2.00 per cent silicon, from 0.2 to 0.5 per cent manganese, from 0.1 to 0.6 per cent phosphorus, from 0.05 to 0.15 per cent sulfur and the balance being substantially all iron and embodying an iron matrix with the carbon mainly composed of temper carbon highly dispersed in small nodules intimately embedded in the matrix.

5. An article of manufacture comprising malleableized powder-like particles with substantially all of said powder-like particles embodying a ferrous metal matrix and carbon with said carbon mainly composed of temper carbon highly dispersed in small nodules intimately embedded in the matrix, said article having been shaped by compacting and sintering the said particles of powder together.

6. An article of manufacture comprising malleableized powder-like particles with substantially all of said powder-like particles each embodying a ferrous metal matrix and carbon with said carbon mainly composed of temper carbon highly dispersed in small nodules intimately embedded in the matrix, said article having been shaped by compacting and sintering the said particles of powder together, and cooling from the sintering temperature at such a rate as to produce desirable microstructures and mechanical properties.

7. An article of manufacture comprising malleableized powder-like particles each consisting of from 2.0 to 3.8 per cent carbon, from 0.50 to 2.60 per cent silicon, from 0.2 to 1.0 per cent manganese, with the usual impurities such as up to 1.0 per cent phosphorus and up to 0.3 per cent sulfur and the balance being substantially all iron, and embodying an iron matrix and carbon with the carbon mainly composed of temper carbon highly dispersed in small nodules embedded in the matrix, said article having been shaped by compacting and sintering the particles of powder together.

8. The method of producing a powder for use in the formation of articles by compressing and sintering which consists in subjecting a powder of chilled, white iron to a malleableizing heat treatment which converts a major portion of the combined carbon therein into temper carbon which is highly dispersed in small nodules intimately embedded in the matrix.

9. The method of producing a powder for use in the formation of articles by compressing and sintering which consists in subjecting a powder of chilled, white iron consisting of from 2.00 to 3.80 per cent carbon, from 0.50 to 2.60 per cent silicon, from 0.2 to 1.0 per cent manganese, from 0.1 to 1.0 per cent phosphorus, from 0.05 to 0.3 per cent sulfur and the balance substantially all iron to a malleableizing heat treatment which converts a major portion of the combined carbon into temper carbon which is highly dispersed in small nodules intimately embedded in the matrix.

10. The method of producing a new article of manufacture which consists in subjecting a powder of chilled, white iron to malleableization by a heat treatment that converts a major portion of the combined carbon into temper carbon which is highly dispersed in small nodules intimately embedded in the matrix, compacting and sintering by powder metallurgy methods and cooling from a temperature above that of the austenite transformation at such a rate as to produce desirable microstructures and mechanical properties.

11. The process of producing articles of powdered iron which comprises forming white cast iron powder particles, annealing said powder particles to convert the combined carbon therein to temper carbon, and thereafter forming and sintering said annealed powder particles to form a coherent mass.

12. The process of producing powdered iron which comprises granulating molten iron to produce pellets with a white iron structure, comminuting said pellets to a powder, and malleableizing said powder to convert a major portion of the combined carbon therein into temper carbon which is highly dispersed in small nodules intimately embedded in the matrix.

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