

[54] **PREALLOYED STEEL POWDER FOR FORMATION OF STRUCTURAL PARTS BY POWDER FORGING AND POWDER FORGED ARTICLE FOR STRUCTURAL PARTS**

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[57]

ABSTRACT

This invention provides a prealloyed steel powder for formation of structural parts by powder forging, which comprises up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, 0.3 to 1.3% by weight of nickel, and up to 0.6% by weight of manganese. This prealloyed steel powder exhibits a good forgeability and is inexpensive, and it can give a powder forged article which is comparable or superior to structural wrought alloy articles manufactured from conventional wrought alloy steels in respect to heat treatability, carburizing, quench hardening properties and mechanical properties. This invention also includes a prealloyed steel powder which comprises up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process, and which exhibits excellent quench hardenability after powder forging.

7 Claims, 2 Drawing Figures

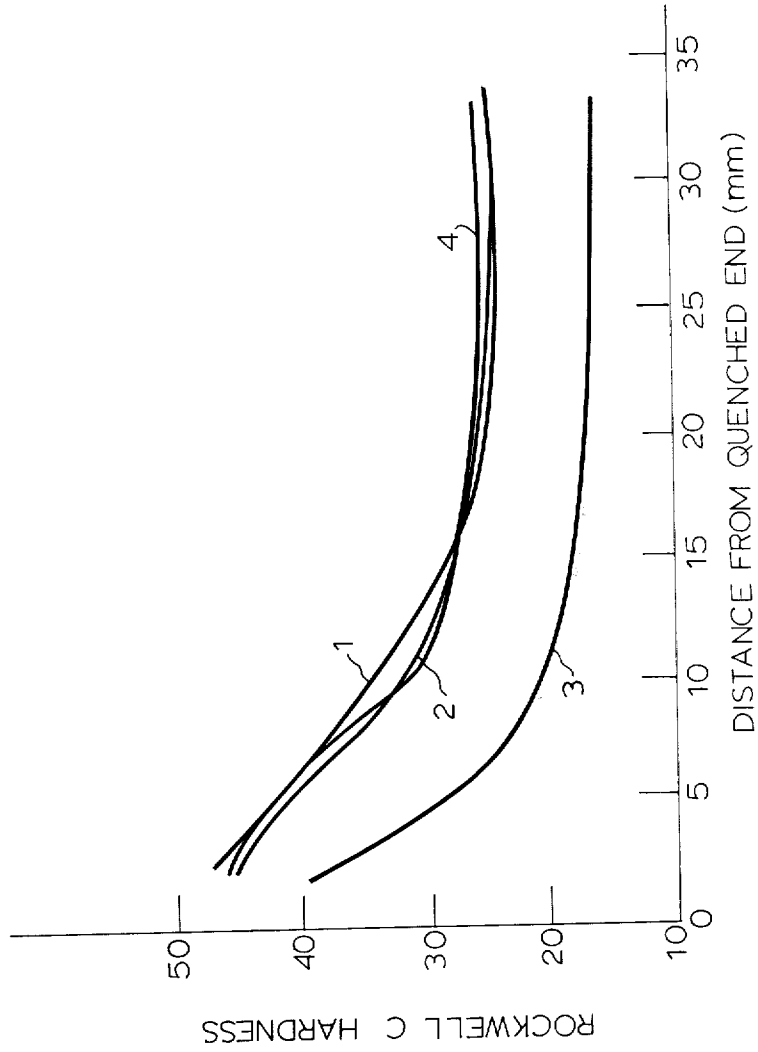
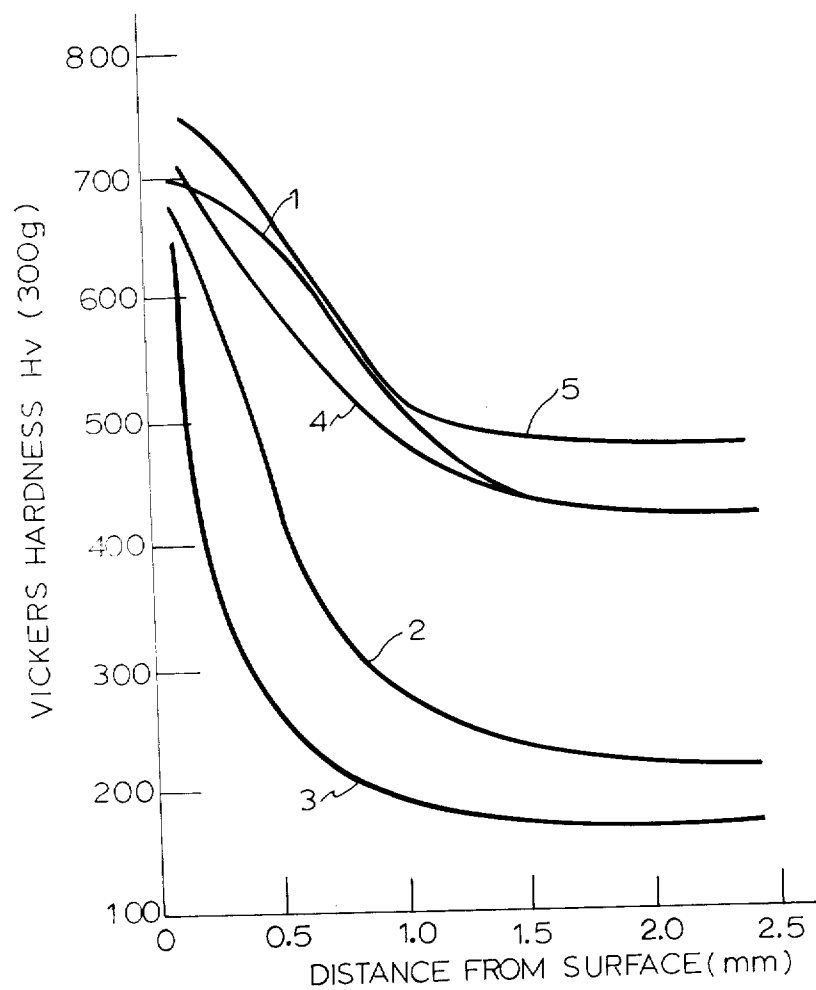


FIG. 1

**FIG. 2**

PREALLOYED STEEL POWDER FOR FORMATION OF STRUCTURAL PARTS BY POWDER FORGING AND POWDER FORGED ARTICLE FOR STRUCTURAL PARTS

This is a continuation-in-part of application Ser. No. 341,944, filed March. 16, 1973, now abandoned.

BACKGROUND OF THE INVENTION

Structural wrought alloy steels are required to have excellent mechanical strength after heat treatment and excellent carburizing and quench hardening abilities.

This invention relates to a prealloyed steel powder for formation of structural parts by powder forging, which has a chemical composition and characteristics suitable for providing steels meeting the above requirements, and the invention also relates to a powder forged steel article prepared from such prealloyed steel powder.

As structural wrought alloy steels cut from conventional wrought alloy steel materials, there may be mentioned wrought nickel-chromium steel, wrought nickel-chromium-molybdenum steel, wrought chromium steel, wrought manganese-chromium steel, wrought aluminum-chromium-molybdenum steel, etc. As regards these wrought alloy steels, the chemical composition, the heat treatment method, the standard values of tensile strength, impact strength, hardness, etc., and the standard value of the Jominy band of the end quench test are specified in Japanese Industrial Standard, G4052, G4102-G4106, and G4202.

The object of this invention is to provide powder forged articles having excellent characteristics by producing a prealloyed steel powder chemical composition for formation of structural parts by forging. This composition exhibits an excellent forgeability, is inexpensive, and gives a structural forged article comparable or superior to structural wrought alloy steel articles cut from conventional wrought alloy steels with respect to heat treatability, carburizing, quench hardening and mechanical properties.

In conventional iron powders for sintering, pure metal powders which will act as alloy elements, such as powders of tin, copper and nickel, are incorporated in an iron powder, a graphite powder is added thereto, and the resulting mixed powder is subjected to compaction forming and sintering. In order to attain a uniform distribution of alloy elements after sintering, it is desired that each of the pure metal powders is a fine powder having a size smaller than 100 mesh (0.149 mm), and the maximum particle size of the powder is maintained at level not exceeding 80 mesh (0.177 mm). Further, in order to improve the mechanical properties of the resulting sintered articles, according to the conventional method the iron powder is made as soft as possible and pure alloy metal powders are added to the so-softened iron powder, whereby the green density of the resulting compact is heightened.

In prealloyed steel powders formed by adding alloying elements to molten steel and atomizing the melt, as the alloying element contents increase, the hardness increases, even after sufficient annealing, and the green density cannot be heightened after compaction forming. Therefore, the resulting sintered articles are poor in mechanical properties, which involves difficulty in the practical use of such articles. Moreover, in conventional structural articles obtained by mixing various

pure metal powders of alloying elements with an iron powder, heightening the green density as much as possible and effecting the alloying at the time of sintering, the density after sintering is as low as 6.6-7.2 g/cm³, the tensile strength after sintering is 30-50 Kg/mm², the elongation is about 1 to about 5%, and the Charpy impact strength is as low as about 0.5 to about 1 Kg.m/cm². Further, after the carburizing, quenching and tempering treatments, the tensile strength is 50-80 Kg/mm², the elongation is about 1% and the Charpy impact strength is drastically low. Thus, the mechanical properties of such conventional structural articles are much lower than those of structural wrought alloy steel articles, for instance, those cut from JIS G4105 SCM21 steel (0.13-0.18% of C, 0.15-0.35% of Si, 0.6-0.85% of Mn, 0.9-1.2% of Cr, and 0.15-0.30% of Mo) having a tensile strength of at least 85 Kg/mm², an elongation of at least 16% and a Charpy impact strength of at least 7 Kg.m/cm². Therefore, these structural articles are hardly used for high strength parts in actual applications.

Recently, an attempt has been made to prepare high strength articles by utilizing the powder forging technique, and the experimental results of the power forging have been reported. Prealloyed steel powders used in these experiments of the powder forging include SAE steels Nos. 1040, 1041, 4140, 4340, 4600, 8600, 9440, etc.

With a view to attaining the foregoing object of this invention, we have continuously experimented with powder forgings by preparing the water atomized prealloyed steel powders having chemical compositions corresponding to conventional structural wrought alloy steels, inclusive of steels corresponding to SAE steels Nos. 1040, 1041, 4140, 4340, 4600, 8600 and 9440, and other prealloyed steel powders containing various alloying elements. From the results of these experiments, it has been found that powder forged articles prepared from prealloyed steel powders rich in chromium or manganese, which have a high affinity with oxygen and are difficult to reduce the oxides thereof, such as those containing chromium in such a high content, as 0.4-1.1% and those containing manganese in such a high content as 0.6-1.7%, as in the case of the above-mentioned SAE steels, and from prealloyed steel powders containing both chromium and manganese, are much inferior in mechanical properties. This is so because at a carbon content of 0.16-0.24%, the elongation is 0 to 9% and the Charpy impact strength with U notch is only 0.2-2 Kg.m/cm², and these powder forged articles can hardly be applied to practical use. These powder forged articles correspond to those prepared from SAE steels Nos. 1040, 1041, 4140, 4340, 8600 and 9440.

Additionally, the results of experiments of powder forgings made on SAE steels of the 4600 series (Ni-Mo-C system) have recently been reported, but, as is apparent from experimental data shown hereinbelow, in the case of these prealloyed steels, the quench hardenability is poor, and after the carburizing and quenching treatments, the depth of hardening is shallow and either the core hardness of the impact strength is low and inferior.

As is seen from the foregoing description, the development of powder forgings have just now begun and no prealloyed steel powders for formation of structural parts by powder forging, which have excellent quench

hardenability and give powder forged articles excellent in mechanical properties such as intended in this invention, have been developed in the art as well.

SUMMARY OF THE INVENTION

As mentioned above, we prepared various prealloyed steel powders containing a variety of alloying elements and made experiments on these prealloyed steel powders. From the results of these experiments it was confirmed that the characteristics of prealloyed steel powders for powder forging, inclusive of those claimed in this invention, are quite different from those of conventional powders for sintering. More specifically, the following matters have been found:

In the case of powder forging, prealloyed steel powders containing coarse particles such as a size of 20 to 80 mesh (0.84-0.18 mm) which cannot be employed for the conventional sintered parts can be used herein. In the case of prealloyed steel powder, it is not necessary to blend the iron powder and the powders of alloying elements with each other. Moreover, the present process involves a shortening of sintering time for the diffusion of the alloying elements, and less segregation of the alloying elements. Therefore, the prealloyed steel powders are much easier to handle and the products obtained have better mechanical properties compared to those produced from conventional mixing powders. At the time of compaction forming, conducted prior to the powder forging, the prealloyed steel powders need not have a high green density, and it is sufficient for them to have a green density of about 6.0 g/cm³ or less, and rather excellent mechanical properties are obtained after the powder forging in the case where the green density is low, as compared with the case where the green density is high. For this reason, even if prealloyed steel powders have a high hardness, they can be used conveniently. Prealloyed steel powders such as claimed in this invention have good reducibility and, therefore, are characterized in that the Vickers hardness just after water atomization is as high as above about 300, and even powders having such a high oxygen content as about 0.7% can be formed into forged materials having excellent mechanical properties by sintering them in a conventionally employed reducing gas at a green density adjusted to about 5.0 g/cm³ and forging the sintered powders. The oxygen content of the compact is easily decreased to less than 0.1% during the sintering treatment. Thus, it was found that prealloyed steel powders for powder forging should possess properties different from those required of powders for sintering.

Based on these experiments, we have now succeeded in determining the chemical composition of a prealloyed steel powder for formation of structural articles by powder forging, which can fully attain the object of this invention, and can give forged structural articles excellent in mechanical properties.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with this invention, there is provided a prealloyed steel powder for structural parts by powder forging, which comprises up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, 0.3 to 1.3% by weight of nickel and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process, and which ex-

hibits excellent quench hardenability and excellent mechanical properties after powder forging.

In accordance with this invention, there is also provided a powder forged article of structural parts, which comprises 0.1 to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, 0.3 to 1.3% by weight of nickel and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process. For use in parts where the required toughness is not so high, it is not necessary to add nickel to the steel.

This invention therefore also includes a prealloyed steel powder which comprises up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process.

This invention will now be described in more detail by reference to accompanying drawings, in which:

FIG. 1 illustrates curves showing the results of the Jominy quench tests made on test pieces cut from various powder forged articles; and

FIG. 2 illustrates curves showing the relation between the distance from the surface and the hardness in test pieces obtained by conducting the carburizing, quenching and tempering treatments after powder forging.

The prealloyed steel powder of this invention is formed by atomizing a molten alloy steel having a particular chemical composition by high pressure water or gas jet, and has a chemical composition comprising up to 0.5% of carbon, 0.8 to 5.0%, preferably 1.0 to 5.0%, of copper, 0.1 to 7.0% of molybdenum, 0.3 to 1.3% of nickel and up to 0.6% of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process. For use in parts where the required toughness is not so high, it is not necessary to add nickel to the steel.

This invention, therefore, also includes a prealloyed steel powder which comprises up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process.

Functions of each of the alloying elements contained in the prealloyed steel powder of this invention will now be illustrated.

Carbon is a fundamental element imparting mechanical strength, and as in conventional structural wrought alloy steels, it is desirable in this invention that the carbon content be adjusted within a range of 0.1 to 5.0%. It is also possible to reduce the carbon content in the prealloyed steel powder below 0.1%, blending in a fine graphite powder before compaction forming so that the total carbon content will be 0.1 to 0.5%. Thus, in the prealloyed steel powder of this invention, it is specified, that the amount of carbon is up to 0.5%. Copper functions to improve the hardness of the powder forged article after quenching, increase quench hardening depth, heighten the core hardness of the quenched article, and impart excellent carburizing and quench hardening properties. At a copper content of 0.8% or more, such effects can be attained, but in order to ensure these effects, it is preferred that the copper content is

at least 1.0%. However, at too high a copper content, the crystal structure necessary to maintain these qualities becomes unstable and degradation is frequently observed in these qualities. Further, at a copper content exceeding 5%, when the powder forging is carried out at a relatively low temperature such as 600° to 700°C, cracks tend to be formed in free projecting surfaces of the forged article. Thus, the upper limit of the copper content is defined in this invention to be 5%. Within the copper content range specified in this invention, no problem of cracking is brought about at the hot forging, and good forgeability can be attained. It is known in the art that the presence of copper in a wrought steel generally causes surface cracking when the steel is subjected to the hot working. However, in the case of the hot forging of prealloyed steel powders, it has been found as a result of our experiments that no problem with surface cracking is encountered. In the hot working of coppercontaining wrought steels, it is considered that when the preheating for hot working is carried out in an oxidative atmosphere, iron is selectively oxidized on the steel surface to form scales and copper beneath the scales tends to concentrate to form a copper-rich layer, and that when the hot working temperature exceeds the melting point of copper (1083°C) in this state, cracks are formed. The reason why cracks are not formed at the hot forging step in powder forging is considered to be that the heating for sintering and the pre-heating for forging are all carried out in a reducing or inert atmosphere, that the hot forging is conducted for a very short time, so that the surface oxidation of the sintered preform does not occur and concentration of copper is thus prevented, and that the hot forging of the powder is carried out at 900° to 1000°C and no higher temperature is required.

Molybdenum is effective for improving the quench hardenability when incorporated in an amount of 0.1 to 0.7%, and is an element necessary for attaining a sufficient depth of quench hardening and a sufficient strength. However, at a molybdenum content below 0.1%, such effects cannot be expected, and the elongation and impact strength are degraded. In contrast thereto, at a molybdenum content exceeding 0.7%, the toughness is damaged.

Nickel is an element effective for improving the toughness and impact strength in the resulting powder forged article. At too low a nickel content, a sufficient toughness cannot be obtained and the lower limit of the nickel content is defined to be 0.3%. When the required toughness is not so high, it is possible to reduce the nickel content below 0.3%. At too great a nickel content, contribution to the quench hardenability is not so great, and the depth of quench hardening or the core hardness of the quenched article is not so increased, but reduction in the impact strength and elongation is brought about. Thus, at a nickel content exceeding 1%, cracks tend to appear at free projecting surfaces at the hot forging step conducted after sintering. Further, in case only nickel is incorporated, even if its content is increased to 3.0% while maintaining the carbon content at 0.17%, the core hardness is not heightened by the oil quenching after forging and carburization, and the quench hardening depth is shallow. Accordingly, it is sufficient to incorporate nickel in an amount enough to impart sufficient elongation and toughness such as impact strength to the forged article. Further, since nickel is expensive and nickel sources are limited and

scanty, a lower nickel content is preferred, and it is recommendable that the nickel content is adjusted within a range of from 0.3 to 1.3%. When the required toughness is not so high, the nickel content can be reduced below 0.3%. In this case, it is not always necessary to add nickel specially.

The required toughness can be achieved by a small amount of nickel incorporated in the steel powder as impurity from the materials during the manufacturing process.

Incorporation of manganese is effective for increasing the depth of quench hardening and the strength in the powder forged article, but with increase of the manganese content, the impact strength tends to lower. Therefore, a lower manganese content is preferred. Namely it is preferred that manganese is incorporated in an amount of up to 0.6%.

The prealloyed steel powder of this invention can be prepared by adding alloying elements into molten steel so that the intended chemical composition is attained, atomizing the resulting molten steel stream by water jet, or jet of such gas as high pressure nitrogen and argon, to pulverize it into particles having a particle size distribution smaller than 20 to 32 mesh (0.84 to 0.5 mm) and powder forging the resulting particles as they are or after subjecting them to the reducing and annealing treatment in an annealing furnace of an inert, non-oxidizing or reducing atmosphere. When the resulting powder is packed in a mold, compacted to have a prescribed shape by means of a press, and sintered at a high temperature in an atmospheric gas and the resulting presintered body is subjected to the hot or cold forging, there is obtained a powder forged article having an aimed shape and a density approximately 100% full density. If desired, such powder forged article is subjected to the surface layer carburizing treatment and quenched in oil or water and tempered. The so-formed powder forged article is put into practical use.

In order for powder forged articles to have excellent mechanical properties such as possessed by the forged article of this invention, it is indispensable that the density of the forged articles is more than 7.6 g/cm³, preferably more than 7.7 g/cm³ and approximating 100% full density as much as possible.

The density of the powder forged article prepared with use of the prealloyed steel powder of this invention is 7.88 to 7.93 g/cm³, which is almost equal to 100% full density, and therefore, the powder forged article of this invention is quite excellent in forging characteristics, heat treatability, carburizing and quench hardening properties. For instance, the powder forged article of this invention which has been heated at 880°C for 30 minutes, quenched in oil and tempered at 450°-600°C has the following mechanical properties:

tensile strength	: 85-130 Kg/mm ²
elongation	: 10-20%
Rockwell C hardness	: 28-35

Charpy impact strength with U notch : 6-12 Kg.m/cm² These mechanical properties are comparable or superior to mechanical properties of structural articles of conventional structural wrought alloy steels.

Further, as is illustrated in FIGS. 1 and 2, the quench hardenability of the powder forged article of this invention after powder forging and oil quenching succeeding carburization is comparable or superior to the quench

hardenability of the structural article prepared from a conventional structural wrought alloy steel. In FIG. 1, the results of the Jominy end quench tests made on test pieces cut from powder forged articles are shown, in which curve 1 is one obtained in Example 1 of this invention, curve 2 illustrates the upper values of the Jominy band of a structural wrought alloy steel, JIS G4052 SCM 21H, curve 3 shows the test results obtained with respect to a comparative powder forged article formed from a prealloyed steel powder comprising 0.19% of carbon, 1.85% of nickel, 0.30% of molybdenum, and 0.6% of manganese, and curve 4 is one obtained with respect to the composition of Example 3 of this invention.

FIG. 2 illustrates the relation between the distance from the surface and the hardness in test pieces of forged articles which have been subjected to the carburizing, quenching and tempering treatments after powder forging, in which curve 1 is one obtained in Example 2 of this invention, curve 2 is one showing the test results made on a comparative powder forged article prepared from a prealloyed steel powder comprising 0.18% of carbon, 1.70% of nickel, and 0.15% of molybdenum, curve 3 is one obtained with respect to a comparative powder forged article prepared from a prealloyed steel powder comprising 0.17% of carbon and 3.0% of nickel, curve 4 is one obtained with respect to a test piece which was cut from structural wrought alloy steel, JIS G4104 SCr 21 (comprising 0.13–0.18% of carbon, 0.15–0.35% of silicon, 0.60–0.85% of manganese, and 0.9–1.20% of chromium) and subjected to carburizing, quenching and tempering treatments, and curve 5 is one obtained with respect to the composition of Example 3 of this invention.

Powder forged articles of this invention include those articles obtained by the powders incorporating in iron powder alloying elements separately or in the form of composite metals and powders prepared by combining iron powder with alloying element metals by plating, coating or cementations.

A powder forged structural article prepared from the prealloyed steel powder of this invention has, as described above, excellent carburizing and quenching characteristics and other mechanical properties. In addition, since it is prepared by employing cheap copper, and the amount of nickel which is expensive and which involves a problem concerning scanty sources is very low, the powder forged structural article of this invention can be manufactured at low cost. This is an economic advantage of this invention.

The powder forged structural article of this invention can be used as case hardening steel materials for automobiles, sewing machines, etc., and can be applied to fields to which structural wrought alloy steel articles cut from conventional wrought alloy steel materials such as nickel-chromium, nickel-chromium-molybdenum, chromium, chromium-molybdenum, manganese, manganese-chromium and aluminum-chromium, molybdenum steel materials, are applied.

This invention will now be illustrated in more detail by reference to Examples.

EXAMPLE 1

Low carbon steel scrap was melted in a high frequency induction furnace, and prescribed alloying elements were added to the melt so as to attain a desired chemical composition. The molten steel was then let to

fall from small holes, and the molten prealloyed steel streams were atomized under a pressure of 65 Kg/cm² by means of high pressure water projected from nozzles. The resulting powder was dried and subjected to the reduction annealing for 2 hours at 730°C. The annealed powder had a chemical composition comprising 0.02% of carbon, 2.32% of copper, 0.50% of molybdenum, 0.84% of nickel, 0.11% of manganese, 0.013% of phosphorus and 0.010% of sulfur, and was characterized by a micro Vickers hardness of 175, an oxygen content of 0.15%, the following particle size distribution:

20 to 80 mesh	36.0%
80 to 100 mesh	17.7%
100 to 150 mesh	20.2%
150 to 200 mesh	17.2%
200 to 250 mesh	5.9%
250 to 325 mesh	1.0%
smaller than 325 mesh	2.0%

an apparent density of 3.4 g/cm³ and flow rate of 18.5 sec/50g. The above powder was mixed with graphite powder and incorporated with 1% of zinc stearate, and the mixed powder was subjected to the compaction forming under a pressure of 4.5 tons per square centimeter to have a cylindrical shape having a diameter of 58 mm and a height of 40 mm. The green density was 6.2 g/cm³ at this time. The so-formed compact was dewaxed in a dissociated ammonia gas, and sintered for 30 minutes at 1120°C in a dissociated ammonia gas. Then, it was heated in a nitrogen inert gas (NX gas) at 900°C for 30 minutes and forged under a pressure of about 13 tons per square centimeter with use of a mechanical press. The resulting powder forged article has a carbon content of 0.17% and a density of 7.87 g/cm³. Then, this powder forged article was heated at 900°C for 30 minutes in a nitrogen inert gas (NX gas), and quenched in oil and tempered at 600°C for 30 minutes. The resulting powder forged, heat treated article was characterized by a tensile strength of 113.5 Kg/mm², an elongation of 16.7%, a Rockwell C hardness of 31.3 and an impact strength with U notch of 8.6 Kg.m/cm², and these mechanical properties were those satisfying the regulation of a JIS G4105 SCM 21 chromium-molybdenum steel article cut from a conventional wrought alloy steel. The optical microscopic structure of the product was a quenched and tempered one. When a specimen cut from this powder forged article was subjected to the Jominy test, it was found, as seen from curve 1 of FIG. 1, that at a point of 2.5 mm from the quenched end the Rockwell C hardness was 46, at a point of 10 mm from the quenched end the Rockwell C hardness was 34, and at a point of 40 mm from the quenched end the Rockwell C hardness was 24. Such excellent quench hardenability corresponded substantially to one shown in curve 2 drawn by connecting the upper values in the Jominy band of JIS G4052 SCM21H steel. For comparison, a powder forged article was prepared in the same manner as above from a prealloyed steel powder comprising 0.19% of carbon, 1.85% of nickel, 0.30% of molybdenum and 0.6% of manganese. When this comparative article was subjected to the Jominy test, Jominy curve 3 of FIG. 1 was obtained. As is seen from this curve, the quench hardenability of this comparative powder forged article was very poor.

EXAMPLE 2

A molten prealloyed steel having the same chemical composition as in Example 1, except that the carbon content was relatively high, was similarly water-atomized and subjected to the reducing annealing treatment to obtain a prealloyed steel powder having a carbon content of 0.17%, and a size distribution of 25% of particles of 32 to 100 mesh and 75% of particles of a size smaller than 100 mesh. Zinc stearate was coated on the side walls of a mold, and the powder was packed in the mold and subjected to the compaction forming under a pressure of 4.5 tons per square centimeter at a green density of 6.1 g/cm³ so as to obtain a compact having a dimension of 10 mm × 12 mm × 55 mm. The so formed compact was sintered at 1120°C for 30 minutes in a hydrogen gas and heated at 900°C for 10 minutes in a nitrogen gas, followed by forging by means of a mechanical press. The forged article had a density of 7.84 g/cm³. This sample was subjected to surface grinding and the surface region was carburized at 920°C for 2.5 hours in a gas carburizing furnace, following which the sample was quenched in oil at 80°C, then tempered at 200°C for 1.5 hours and air-cooled. The relation between the distance from the oil quenched surface and the hardness in the so heat treated sample is shown in curve 1 of FIG. 2. For comparison, a sample of a powder forged body prepared from a prealloyed steel powder having a chemical composition comprising 0.18% of carbon, 1.70% of nickel and 0.51% of molybdenum was treated and tested in the same manner as above to obtain results shown in curve 2 of FIG. 2. Test results of a sample of powder forged carburized, quenched and tempered body from a prealloyed steel powder having a chemical composition comprising 0.17% of carbon and 3.0% of nickel are shown in curve 3 of FIG. 2. Further, a test piece cut from JIS G4104 SCr21 wrought alloy steel was similarly carburized, quenched and tempered, and test results are shown in curve 4 of FIG. 2.

As is seen from curve 1 of FIG. 2, the powder forged body prepared from the prealloyed steel powder of this invention had carburizing and quenching abilities giving sufficient hardness after quenching and tempering, sufficient depth of quench hardening and sufficient core hardness, and its carburizing and quenching characteristics were comparable or superior to those of the conventional wrought alloy steel (JIS G4104 SCr21 steel) shown in curve 4. The powder forged body prepared from the prealloyed steel powder containing nickel and molybdenum, which is shown in curve 2, was deficient in that the depth of quench hardening was shallow and the core hardness was low. Further, in the powder forged body comprising 3% of nickel shown in curve 3, the depth of quench hardening was much shallower and the core hardness was much lower, and thus, this powder forged body was very poor in the carburizing and quenching abilities.

EXAMPLE 3

Prealloyed steel powder was produced by the same method as in Example 1. The annealed powder had a chemical composition comprising 0.01% of carbon, 3.10% of copper, 0.5% of molybdenum, 0.08% of manganese, 0.010% of phosphorus, and 0.012% of sulfur, and was characterized by a micro Vickers hardness of

190, an oxygen content of 0.08%, the following particle size distribution:

20 to 80 mesh	29.0%
80 to 100 mesh	20.1%
100 to 150 mesh	18.0%
150 to 200 mesh	15.3%
200 to 250 mesh	7.2%
250 to 325 mesh	5.4%
smaller than 325 mesh	5.0%

an apparent density of 3.3 g/cm³, and a flow rate of 17.9 sec/50g.

This powder was compacted, sintered and forged by the same method as in Example 1.

The resulting powder forged article had a carbon content of 0.19% and a density of 7.87 g/cm³. Then this powder forged article was heated at 900°C for 30 minutes in a nitrogen inert gas and quenched in oil and tempered at 560°C for 30 minutes. The resulting powder forged, heat treated article was characterized by a tensile strength of 109.4 Kg/mm², an elongation of 15%, a Rockwell C hardness of 30.6, and an impact strength with U notch of 6.7 Kg.m/cm². The result of Jominy end quench tests on a specimen cut from this powder forged article which is shown by the curve 4 of FIG. 1, showed the Rockwell C hardness of 48 at a point 2.5 mm from the quenched end, 32 at a point of 10 mm, and 26 at a point of 40 mm, corresponded substantially to the upper value in the Jominy band of JIS G4052 SCM21H steel. The carburizing and quenching characteristics of this powder forged article were measured on the sample which was subjected to the same treatment as in Example 2. The result is shown in curve 5 of FIG. 2. The result is rather superior to that of the conventional wrought SCM21 alloy steel. The toughness showed by the impact value and elongation is lower compared with that of the powder forged article from the steel powder in Example 1. However, it is adequate for practical use in which the required toughness is not so high.

What is claimed is:

1. A prealloyed steel powder for formation of structural parts by powder forging, which consists essentially of up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, 0.3 to 1.3% by weight of nickel, and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process, and which exhibits excellent quench hardenability and excellent mechanical properties after powder forging.

2. A prealloyed steel powder set forth in claim 1, wherein the copper content is from 1.0 to 5.0% by weight.

3. A powder forged article for structural parts, which consists essentially of 0.1 to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, 0.3 to 1.3% by weight of nickel, and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process.

4. A powder forged article set forth in claim 3, wherein the copper content is from 1.0 to 5.0% by weight.

5. A powder forged article set forth in claim 3, which has a density ranging from 7.60 to 7.93 g/cm³.

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6. A prealloyed steel powder for formation of structural parts by powder forging, which consists essentially of up to 0.5% by weight of carbon, 0.8 to 5.0% by weight of copper, 0.1 to 0.7% by weight of molybdenum, and up to 0.6% by weight of manganese, the balance being iron and unavoidable impurities incorporated during the manufacturing process, and which ex-

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hibits excellent quench hardenability after powder forging.

7. A prealloyed steel powder set forth in claim 6, wherein the copper content is from 1.0 to 5.0% by weight.

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