

March 25, 1958

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2,828,202

TITANIUM TOOL STEEL

Filed Oct. 8, 1954

2 Sheets-Sheet 1

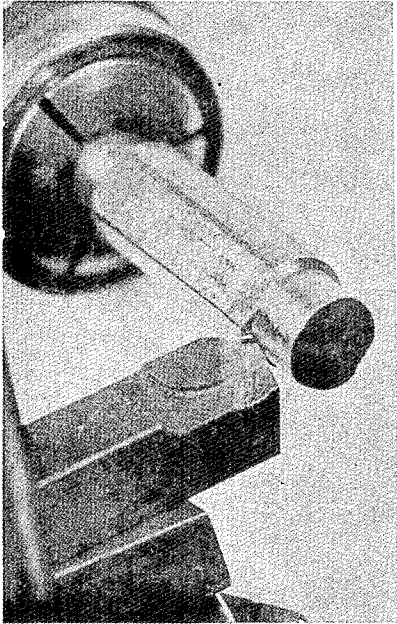


Fig. 1.

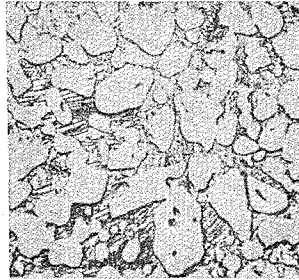


Fig. 2.

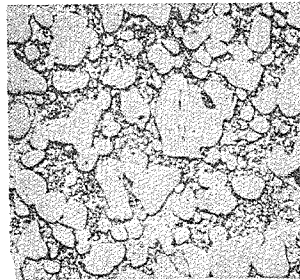


Fig. 3.

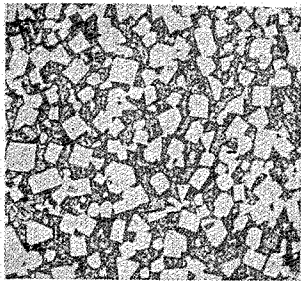


Fig. 5.

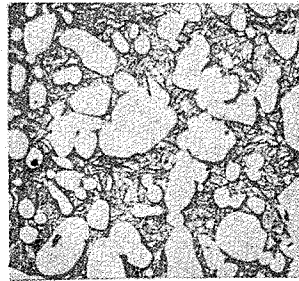


Fig. 4.

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2 Sheets-Sheet 2

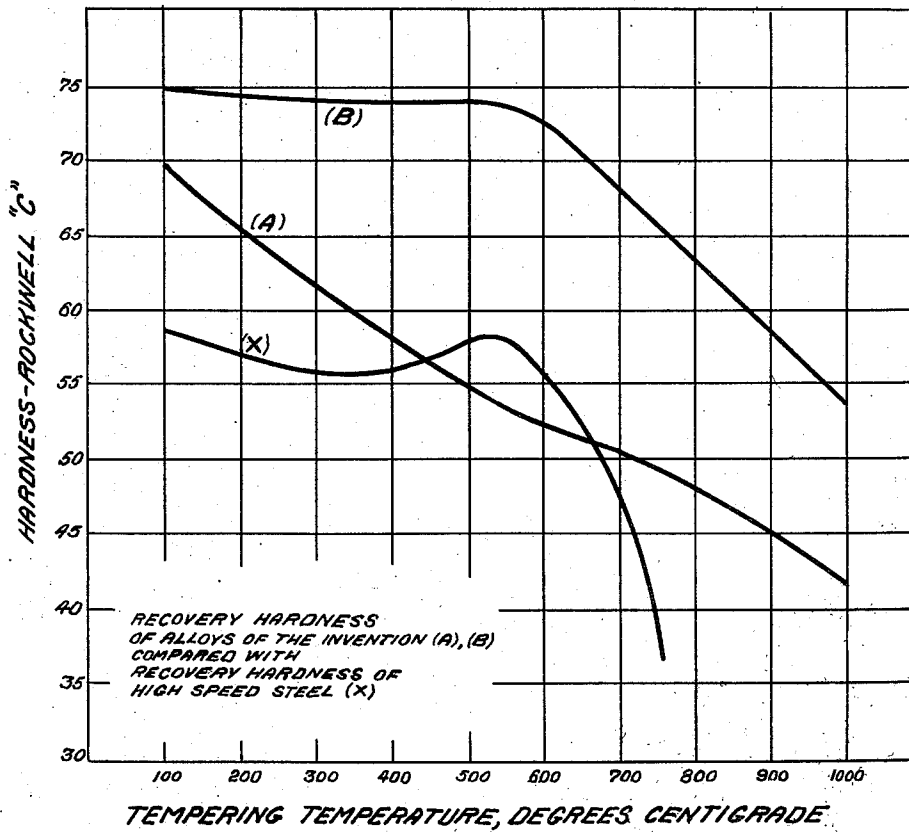


Fig. 6.

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TITANIUM TOOL STEEL

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Application October 8, 1954; Serial No. 461,143

14 Claims. (Cl. 75-123)

The present invention relates to a titanium-containing steel and more particularly to a high carbon titanium tool steel bar stock capable of being heat treated to high hardness combined with high toughness.

Titanium as a strong carbide former has certain attributes which make it attractive as an alloying ingredient in ferrous materials, especially in the production of tool steels. Titanium combined with carbon is very hard, is substantially resistant to wear and galling, is substantially resistant to corrosion, has a low coefficient of friction, has a relatively high heat conductivity and also has a relatively low specific gravity compared to other carbides, such as tungsten carbide, molybdenum carbide, etc. In addition, titanium, unlike tungsten, is non-strategic, is available domestically in very large quantities and is not affected by national emergencies arising from unstable world situations. Yet, with all these attractive features in its favor, it has not been possible to utilize titanium in large amounts commercially in the production of tool steels in the sense that tungsten and heavy refractory metals are employed in the production of high speed and tool steels. The addition of titanium to a molten ferrous metal in amounts exceeding about 5% has been known to have such an embrittling effect on the resulting ferrous alloy as to make the alloy unworkable and unsuitable for the commercial production of useful products. Particular care must be taken in using titanium as an alloying ingredient in view of its high propensity to react chemically with oxygen and nitrogen, which elements, when combined with titanium, are known to have deleterious effects on the properties of the alloy.

When titanium is added to a molten bath of a carbon-containing ferrous metal by conventional melting procedures, titanium carbide or a titanium compound based on carbon is formed, generally as large dendritic aggregates during solidification. Because of the relatively low specific gravity of the carbide, it has a tendency to form large undesirable aggregates which make it difficult to obtain a uniform product having a controlled carbide size and uniform carbide distribution. These aggregates and segregates often form an undesirable continuous phase which cannot be broken up into discrete small particles by working, and therefore impart extreme brittleness to the alloy. The aforementioned disadvantages which accrue from using titanium as an alloying ingredient in steels have militated against its use in the production of hard tough alloys, particularly in the production of high titanium, high carbon tool steels. Furthermore, the usefulness of such types of steel was not known owing to the fact that they were not available.

A special high titanium, high carbon ferrous alloy has now been discovered containing substantial amounts of titanium, i. e., at least about 10% by weight, said alloy being characterized by substantial freedom from undesirable large dendritic aggregates and segregates of titanium carbide and also characterized by high hardness combined with high heat and corrosion resistance, strength and resistance to wear and abrasion.

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The expression "ferrous alloy" as employed herein is meant to include an alloy containing at least about 10% titanium by weight substantially as titanium carbide uniformly distributed through a ferrous matrix which may comprise carbon steel, medium alloy steel or high alloy steel. The titanium containing ferrous alloy has the heat treatable characteristics of steel.

It is an object of the present invention to provide a heat treatable ferrous alloy containing high amounts of titanium and carbon, yet characterized by a substantially non-continuous carbide phase.

Another object of the invention is to provide as ingot or bar stock an annealable tool steel-type composition containing high amounts of titanium and carbon and capable of being machined to various shapes in substantially the annealed condition.

A further object of the invention is to provide a ferrous alloy rich in titanium and carbon and capable of being hardened to hardnesses of an order of magnitude comparable to cemented tungsten carbides.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a reproduction of a photograph showing bar stock of the titanium and carbon rich ferrous alloy being machined in the conventional manner with a cutting tool;

Fig. 2 depicts a reproduction of a photomicrograph taken at 1000 diameters showing an annealed structure of the ferrous alloy provided by the invention;

Fig. 3 shows a reproduction of a photomicrograph taken at 1000 diameters illustrating a variation of an annealed structure of the ferrous alloy;

Fig. 4 is a reproduction of a photomicrograph taken at 1000 diameters showing the hardened structure of the ferrous alloy provided by the invention;

Fig. 5 is a reproduction of a photomicrograph taken at 1000 diameters showing another hardened structure of the ferrous alloy provided by the invention; and

Fig. 6 is a diagram comparing the recovery hardnesses of two ferrous alloys of the invention with the recovery hardness of a prior art steel.

Broadly stated, the present invention provides a high titanium, high carbon ferrous alloy having the heat treatability of commercial high alloy tool steels, such as high speed steels, and at the same time having some of the desirable attributes of cemented tungsten carbides. The ferrous alloy contains titanium and carbon as essential ingredients in amounts substantially in excess of those usually considered detrimental in steel. By utilizing these two elements in a cooperative manner, a heat treatable and useful ferrous alloy product can be produced containing at least about 10% and generally up to about 70% by weight of titanium, provided the titanium is present in the alloy in a special form.

The product of the invention is achieved by employing titanium and carbon together in a combined form comprising substantially titanium carbide as an alloying ingredient with a steel which cooperates with the titanium carbide in producing the desired results. The steel employed in the invention contains iron as the major alloying element which generally comprises at least about 60% by weight of the steel. Thus, in carrying out the invention, the steel may be an alloy steel, a carbon steel or may comprise pure iron which in practicing the invention, will combine with carbon to form a steel. When the steel is employed in forming the high titanium, high carbon ferrous alloy containing about 10% to 70%, and preferably about 20% to 58%, by weight of titanium, the total amount of carbon in the alloy must be at least sufficient to be in combination with the titanium as titanium carbide and also be sufficient to confer heat treatability to the ferrous matrix. The expression "ferrous matrix"

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as employed herein is one which crystallographically at ordinary temperatures is characterized by a substantially ferritic or body centered cubic structure and which at an elevated temperature below the melting point of the ferrous alloy is transformed to a substantially austenitic or face centered cubic structure.

The ferrous alloy product of the invention containing the aforementioned amounts of titanium over the broad range of 10% to 70% by weight corresponds to titanium carbide of about 20% to 90% by volume, with the balance substantially steel in amounts ranging from about 80% to 10% by volume. The preferred range of 20% to 58% by weight of titanium corresponds to about 40% to 80% by volume of titanium carbide, with the balance substantially about 60% to 20% by volume of the steel. By employing titanium carbide as the alloying ingredient in place of metallic titanium, massive carbide dendrites and continuous segregates are avoided and a useful product is obtained.

The following examples are indicative of useful compositions provided by the invention.

Example 1

An alloy useful for single point cutting tools and other similar applications requiring high hardness has the following composition:

About 65% by weight titanium
About 10.9% by weight iron
About 2% by weight cobalt
About 0.7% by weight chromium
About 0.3% by weight vanadium
About 3.0% by weight tungsten
About 18.1% by weight carbon

Example 2

A composition which is very useful where toughness along with high resistance to wear and galling is required is as follows:

About 39% by weight titanium
About 10.3% by weight carbon
About 0.7% by weight chromium
About 50% by weight iron

The foregoing examples illustrate that titanium in high amounts can be utilized in the ferrous alloy provided by the invention. By utilizing titanium in the form of titanium carbide, rather than metallic titanium, beneficial rather than adverse results are obtained. Tests have indicated that titanium carbide when employed in combination with a steel, for example low carbon steel, reacts with the latter due to a partial solution of the titanium carbide therein during high temperature heating involving liquid and solid phase reactions, whereby the ferrous matrix of the resulting ferrous alloy is provided with additional alloy and carbon content for improving the hardenability, resistance to tempering, hot hardness, resistance to deformation and wear, etc. Even when the ferrous matrix is derived from a high alloy steel, an improvement in the final properties of the ferrous alloy is effected.

The partial solubility of titanium carbide in the ferrous matrix is particularly desirable as it results in microstructures which are beneficial to the properties of the alloy, particularly resistance to wear and deformation. Such microstructures may comprise well rounded or partially rounded or substantially angular grains of titanium carbide dispersed uniformly throughout the ferrous matrix, whether the matrix comprises pearlite, spheroidite, martensitic decomposition products, or martensite or bainite. Examples of such microstructures are illustrated in Figures 2, 3, 4 and 5 of the drawing. Figure 2, which is a reproduction of a photomicrograph taken at 1000 diameters, shows the microstructure of the ferrous alloy in the annealed condition comprising partially rounded titanium carbide grains distributed substantially uniformly

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through a pearlite ferrous matrix. Fig. 3, also taken at 1000 diameters, shows partially rounded titanium carbide grains dispersed through a similar ferrous matrix containing substantial amounts of spheroidite. The microstructure of Fig. 4, taken at 1000 diameters, shows well rounded titanium carbide grains also dispersed through a similar ferrous matrix comprising primarily martensite resulting from a water quench treatment from a temperature of about 985° C. Figure 5 is similar to Figure 4, except that it shows angular titanium carbide grains dispersed through a martensitic ferrous matrix. This structure is advantageous in cutting tools.

Figure 6 is a diagram showing the recovery hardness of two alloys of the invention (curves A and B). By recovery hardness is meant the room temperature hardness of an alloy which had previously been hardened and preheated to the temperatures indicated in the diagram. For comparison, a curve of the recovery hardness of a conventional 18-4-1 type high speed steel is presented (curve X). Curve A represents the recovery hardness of a ferrous alloy of the invention comprising approximately 50% titanium, carbon sufficient to combine with the titanium, with the balance substantially iron. The recovery hardness of this alloy is superior to that represented by curve X at temperatures above approximately 670° C. It is also superior in recovery hardness at temperatures below approximately 440° C. Curve B represents the recovery hardness of a ferrous alloy of the invention comprising approximately 50% titanium, 10% tungsten, 2% chromium with small amounts of vanadium and sufficient carbon to combine with substantially all the titanium and to confer heat treatability to the ferrous matrix. The recovery hardness of this ferrous alloy is superior to that of the conventional alloy at all temperature ranges up to about 1000° C.

It will be appreciated from the foregoing that the high titanium, high carbon ferrous alloy provided by the invention can be heat treated like conventional steels to provide hard or annealed structures. But unlike the conventional steels, certain ferrous alloys of the invention exhibit their maximum toughness in the fully hardened condition. For example, a ferrous alloy comprising about 35% by weight of titanium with the balance substantially iron and carbon combined with the titanium generally exhibits in the annealed condition an impact resistance of about 8 inch-pounds when tested in Izod on an unnotched $\frac{3}{16}$ inch square specimen. However, when the same alloy is rendered fully hard by water quenching from about 985° C. the resistance to impact improves to about 13 inch-pounds. Thus, the impact resistance in the fully hardened condition is better than in the annealed condition, whereas, the reverse is true for most conventional steels.

Examples of steels which may be employed in combination with titanium carbide in producing the ferrous alloy of the invention include low, medium and high carbon steels. Such steels include SAE 1010 steel, SAE 1020 steel, SAE 1030 steel, SAE 1040 steel, SAE 1080 steel, etc. Pure iron may be used, since it combines with carbon to form a steel during the process of producing the ferrous alloy of the invention. Low, medium and high alloy steels may also be employed, including the following: about 0.8% chromium, 0.2% molybdenum, about 0.30% carbon, and iron substantially the balance; about 5% chromium, 1.4% molybdenum, 1.4% tungsten, 0.45% vanadium, 0.35% carbon, and iron substantially the balance; about 8% molybdenum, 4% chromium, 2% vanadium, 0.85% carbon, and iron substantially the balance; about 18% tungsten, 4% chromium, 1% vanadium, 0.75% carbon, and iron substantially the balance; about 20% tungsten, 12% cobalt, 4% chromium, 2% vanadium, 0.80% carbon, and iron substantially the balance; and generally other types of steels characterized crystallographically by a body centered cubic structure at ordinary temperatures and by being transformable to a face cen-

tered cubic structure at an elevated temperature below the melting point of the steel.

The titanium carbide employed in the alloy may contain limited amounts of other carbides, preferably in solid solution therewith, without departing from the scope of the invention. Thus, the titanium carbide may be replaced in part by up to about 35% of tungsten carbide, up to about 35% vanadium carbide, up to about 25% zirconium carbide, up to about 10% columbium carbide, up to about 10% tantalum carbide, etc., the total amount of these carbides not exceeding about 50% by weight of the total carbides present. In other words the carbide employed in the ferrous alloy may comprise titanium-base carbides which include titanium carbide per se.

As has been stated hereinbefore, the ferrous alloy of the invention is amenable to heat treatment. Thus, to anneal the alloy, it is cooled slowly through the A_1 temperature so as to produce a microstructure in the ferrous matrix consisting of pearlite and spheroidite. By A_1 temperature is meant that temperature at which the face centered cubic crystal is transformed to a body-centered cubic crystalline structure. In hardening, the alloy is heated to an austenitization temperature sufficient to convert substantially the matrix to a face centered cubic structure and for a time sufficient to effect a uniform structure and then subsequently quenched by cooling in air, oil or water, depending upon the hardenability of the ferrous alloy, thus decomposing austenite to martensite. The austenite may also be transformed into bainite by isothermally quenching to a bainite formation temperature from the aforementioned austenitizing temperature.

One of the main advantages to be gained from the invention is that the annealed high titanium, high carbon ferrous alloy is to a large extent machinable by conventional means. For example, bar stock comprising about 35% by weight of titanium and the balance substantially carbon steel and carbon combined with the titanium machined easily on a lathe to the desired shape, utilizing a steel cutting grade of cemented tungsten carbide, when annealed to as low as 40 Rockwell C. The machined bar stock was then hardened to about 72 Rockwell C by oil quenching from a temperature in the order of about 870° C. Figure 1 illustrates the ease with which the annealed alloy of the invention can be machined by an ordinary cutting tool. This alloy had a titanium content of about 35% by weight which was combined with carbon, the balance being a pearlitic matrix.

The novel ferrous alloy of the invention can be produced substantially free from massive carbide dendrites and segregation, preferably by interstitially casting molten steel into the interstices of a coherent porous structure comprising substantially titanium carbide grains. This is achieved by coalescing titanium carbide grains into a coherent porous body by briquetting followed by firing at an elevated temperature, generally from about 1000° C. to 1600° C. for about 1/4 hour to 6 hours, preferably at a vacuum or a sub-atmospheric pressure not exceeding about 200 microns of mercury. As an alternative method, the coalescence may be achieved by simultaneously briquetting and firing at the indicated temperature range under non-oxidizing conditions for about 10 minutes to about 2 hours. The fired porous body is then prepared for the casting process by encasing it in a mold of refractory material substantially inert to the ferrous alloy, for example stabilized zirconia, with provisions made for the molten steel to enter the mold and contact the porous carbide structure. The mold of refractory material and the porous carbide structure supported therein is then placed into a suitable casting furnace. Sufficient amount of steel to produce the casting is placed at the mold opening and the whole brought to a temperature of generally up to about 100° C. above the melting point of the steel so that the molten steel flows intersti-

tially into the porous body, completely filling it and providing excess feed for shrinkage cavities, pipes, etc. The casting is achieved in vacuum or at a sub-atmospheric pressure generally not exceeding about 200 microns of mercury. After the steel has interstitially filled all of the voids in the porous titanium carbide structure, and then allowed to reach equilibrium with it, the carbide is modified by partial solution in the liquid phase, whereby it is disrupted into discrete and uniformly distributed grains. The interstitially cast ferrous alloy body is cooled in vacuum, is removed from the furnace and is finally separated from the refractory mold. The product is then annealed, e.g. by heating in a furnace at a temperature of at least about 700° C. and to up to about 1050° C. for up to about 4 hours under non-oxidizing conditions, for example a reducing atmosphere comprising about 93% nitrogen and about 7% hydrogen, followed by controlled cooling of less than about 15° C. per hour down to a temperature of about 540° C. or lower. As has been pointed out hereinbefore, the microstructure of the annealed ferrous alloy generally comprises hard grains of titanium carbide distributed substantially uniformly through an annealed ferrous matrix, for example a matrix having a microstructure of pearlite, spheroidite, or martensitic decomposition products. The following examples illustrate in greater detail how the foregoing method may be employed in producing alloys and products of the invention:

Example 3

A hot heading tool for severe impact applications had the following alloy composition:

- About 43% by weight titanium
- About 45.3% by weight iron
- About 11% by weight carbon
- About 0.4% by weight chromium
- About 0.2% by weight manganese
- About 0.1% by weight molybdenum

The tool was manufactured by the following technique:

A batch of titanium carbide with the following analysis: 78.0% titanium, 20.68% total carbon, 3.11% free carbon, 0.22% iron, 0.037% hydrogen, 1.09% oxygen, 0.503% nitrogen, was treated in a carbon crucible, in air, at about 1900° C. After this treatment the free carbon was 3.78% and the total carbon 20.51%. The agglomerated heat treated cake was then crushed to minus 140 mesh. About 2000 grams of this crushed product was placed in a one gallon stainless steel mill which was charged with 11,500 grams of 1/2 in. steel balls and then half filled with trichlorethylene. The product was milled for 100 hours, carefully dried and screened through a 140 mesh sieve.

A 2 1/2 inch diameter porous cylindrical briquette, 1 1/4 inch high, was then pressed at 4 tons per square inch. It was placed on a graphite carrier and fired at about 1250° C. for 1/2 hour in a vacuum of less than 100 microns mercury column. The fired porous briquette comprised approximately 65% by volume of titanium carbide. It was then placed into a refractory mold consisting of granular stabilized zirconia. A predetermined quantity of metal calculated to completely fill all interstices between the carbide grains contained in the mold plus a liberal quantity in the order of 50% excess was placed above the mold. This excess was necessary to fill the mold completely to allow feeding of shrinkage cavities as in conventional foundry practices. The metal in this case consisted of molybdenum-chrome steel SAE #4130. The charge was placed in a vacuum casting furnace and heated slowly to a temperature of about 1530° C. Melting of the steel occurred at a pressure of approximately 200 microns of mercury column at a temperature of approximately 1480° C. The molten metal was cast interstitially into the porous carbide structure. The temperature was maintained at about 1530° C. for one hour so as to permit high fluidity of the metal

so that all voids would be completely filled and solubility and rounding of the carbide grains could occur. The melt was then allowed to cool under vacuum, then removed from the furnace, and the casting stripped from the mold.

The rough casting was then annealed by placing it in a furnace at about 870° C. in a protective atmosphere consisting of about 93% nitrogen and about 7% hydrogen. The annealing period was 2 hours, followed by a controlled cooling at a rate of less than 15° C. per hour down to a temperature of about 540° C. The annealed structure then had a hardness of approximately 45 Rockwell C. The casting could then be turned on a lathe to the desired shape, utilizing a steel cutting grade of tungsten carbide. Usual tolerances for grinding after hardening were permitted. The machined slug was hardened by austenitizing at about 980° C. and quenched into an oil bath. The slug was then tempered for 1 hour at about 205° C. The hardened structure had a hardness of approximately 70 to 71 Rc. Its modulus of rupture was approximately 300,000 pounds per square inch in transverse rupture and its impact strength 12 inch-pounds on an unnotched $\frac{3}{16}$ inch square specimen tested in Izod. It was then ground to finish size, cased in an alloy steel holder and was ready for use.

Example 4

A useful alloy for cutting purposes had the following composition:

About 61% by weight titanium
About 18% by weight iron
About 15.5% by weight carbon
About 4.3% by weight tungsten
About 0.9% by weight chromium
About 0.2% by weight vanadium

It was produced as follows:

The titanium carbide product, as treated in Example 3, was briquetted into a rectangular slab at a pressure of 10 tons per square inch. The slab was now cut with a rubber bonded wheel into small rectangles $\frac{1}{4}$ inch x $\frac{3}{8}$ inch x $\frac{3}{8}$ inch, a useful size for a single point cutting tool. Similar rectangles of smaller size were briquetted directly with an automatic pill press. The bodies were fired at about 1350° C. in a vacuum of less than 100 microns of mercury column. The fired porous structures comprised approximately 85% by volume of titanium carbide. The fired bodies were placed in an open mold of beryllia, with an allotment of metal on the top of each of the porous structures. The alloy in this case consisted of an 18-4-1 type high-speed steel and the quantity allotted was 50% in excess of that required to fill the void volume of the porous structure. The excess was necessary for reasons explained in Example 3. The interstitial casting was conducted in vacuum at a pressure of less than 200 microns of mercury column and a temperature of about 1490° C. The castings were allowed to soak at this temperature for 40 minutes. After cooling and removal from the vacuum furnace, there was no adherence of the cast bits to the supporting ceramic mold, and the shape and size were close to that of the original porous body. The bits were hardened by quenching in oil or air from about 1040° C. and were finish ground as tool tips. The hardness was approximately 74 Rockwell C; the modulus of rupture was 230,000 pounds per square inch; and the impact on a $\frac{3}{16}$ inch square Izod specimen was 5 inch-pounds.

While it is preferred to produce the alloy of the invention by means of interstitial casting, it will be appreciated that other methods can be employed. For example, the titanium carbide grains may be mixed with the steel in particulate form and briquetted into the desired shape and this shape then fired at an elevated temperature, generally not exceeding about 100° C. above the melting point of the steel phase. By heating the car-

bide in the presence of the liquid phase, the cooperative effects of the two constituents are achieved, whereby a heat treatable ferrous alloy is obtained.

The foregoing procedure for producing alloys of the invention is detailed in the following example:

Example 5

An alloy useful for extrusion dies had the following composition:

About 29.5% by weight titanium
About 58% by weight iron
About 7.5% by weight carbon
About 1.2% by weight molybdenum
About 1.2% by weight tungsten
About 0.3% by weight vanadium

In producing this composition, 3700 grams of titanium carbide, as treated in Example 3, was mixed thoroughly with 6,300 grams of a tool steel in a form all passing through 325 mesh, by milling in a stainless steel mill. The product was then briquetted at a pressure of 100 tons per square inch. This briquette was then fired in vacuum at a pressure of less than 200 microns mercury column and at a temperature of about 1470° C. for 3 hours. After cooling, the alloy in vacuum, it was annealed at about 870° C. in a protective atmosphere consisting of about 93% nitrogen and 7% hydrogen. The annealed structure had a hardness of approximately 40 Rockwell C and could then be turned on a lathe to the desired shape utilizing a steel cutting grade of tungsten carbide. Usual tolerances for grinding after hardening were permitted. The machined slug was hardened by austenitizing at about 980° C. and quenching into an oil bath. The slug was then tempered for one hour at about 200° C. Its hardness was then approximately 70 Rockwell C and after grinding and finishing, an extrusion nib of this alloy proved excellent insofar as resistance to erosion and galling were concerned.

The invention provides a high titanium, high carbon ferrous alloy which in the form of bar stock, rounds, squares, blocks, ingots and other shapes can be utilized in the fabrication of cutting tools, blanking dies, forming dies, drawing dies, rolls, hot extrusion dies, forging dies, upsetting dies, broaching tools, and in general all types of wear and/or heat resisting elements, tools or machine parts.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. A heat treatable, high titanium, high carbon ferrous alloy comprising at least about 10% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as the major alloying constituent and containing combined carbon, said matrix characterized by a microstructure comprising an austenitic decomposition product.

2. A heat treatable, high titanium, high carbon ferrous alloy comprising about 10% to 70% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element and also containing combined carbon, said matrix being characterized by a microstructure comprising any one of the austenitic decomposition products pearlite, bainite and martensite.

3. A heat treatable, ferrous alloy as in claim 2, wherein the titanium content comprises about 20% to 58% by

weight of the alloy substantially all combined as a titanium-base carbide phase.

4. A high titanium, high carbon ferrous alloy comprising at least about 10% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a soft ferrous matrix containing iron as a major alloying element and also containing combined carbon, said matrix being characterized by a pearlitic structure.

5. A high titanium, high carbon ferrous alloy comprising about 10% to 70% by weight of titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a soft ferrous matrix containing iron as a major alloying element and also containing combined carbon, said matrix being characterized by a structure of pearlite.

6. The ferrous alloy as in claim 5, wherein the titanium content comprises about 20% to 58% by weight of the alloy substantially all combined as a titanium-base carbide phase.

7. A hardened, wear resistant, high titanium, high carbon ferrous alloy comprising at least about 10% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element, said matrix being characterized by a microstructure comprising martensite.

8. A hardened, wear resistant, high titanium, high carbon ferrous alloy comprising about 10% to 70% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element, said matrix being characterized by a microstructure comprising martensite.

9. A hardened, wear resistant, ferrous alloy as in claim 8, wherein the titanium content comprises about 20% to 58% by weight of the alloy substantially all combined as a titanium-base carbide phase.

10. A hardened, wear resistant, high titanium, high carbon ferrous alloy comprising at least about 10% by weight titanium substantially all combined as a titanium-

base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element, said matrix being characterized by a microstructure comprising bainite.

11. A hardened, wear resistant, high titanium, high carbon ferrous alloy comprising about 10% to 70% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element, said matrix being characterized by a microstructure comprising bainite.

12. A hardened, wear resistant, ferrous alloy as in claim 11, wherein the titanium content comprises about 20% to 58% by weight of the alloy substantially all combined as a titanium-base carbide phase.

13. As an article of manufacture, heat treatable bar stock of a high titanium, high carbon ferrous alloy comprising about 10% to 70% by weight titanium substantially all combined as a titanium-base carbide phase distributed substantially uniformly through a ferrous matrix containing iron as a major alloying element and also containing combined carbon, said matrix being characterized by a microstructure comprising any one of the austenitic decomposition products pearlite, bainite and martensite.

14. The heat treatable bar stock of claim 13, wherein the alloy composition comprises 20% to 58% by weight titanium substantially all combined as titanium-base carbide phase.

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