Aug. 3, 1954 S. J. SINDEBAND 2,685,543

PRODUCTION OF CHROMIUM CARBIDE SURFACED WEAR RESISTANT FERROUS BODIES

Filed Jan. 17, 1951 3 Sheets-Sheet 1

Fig 1



Fig 2

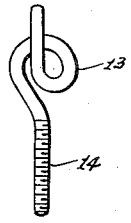
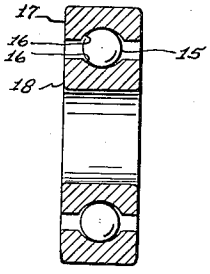


Fig 3



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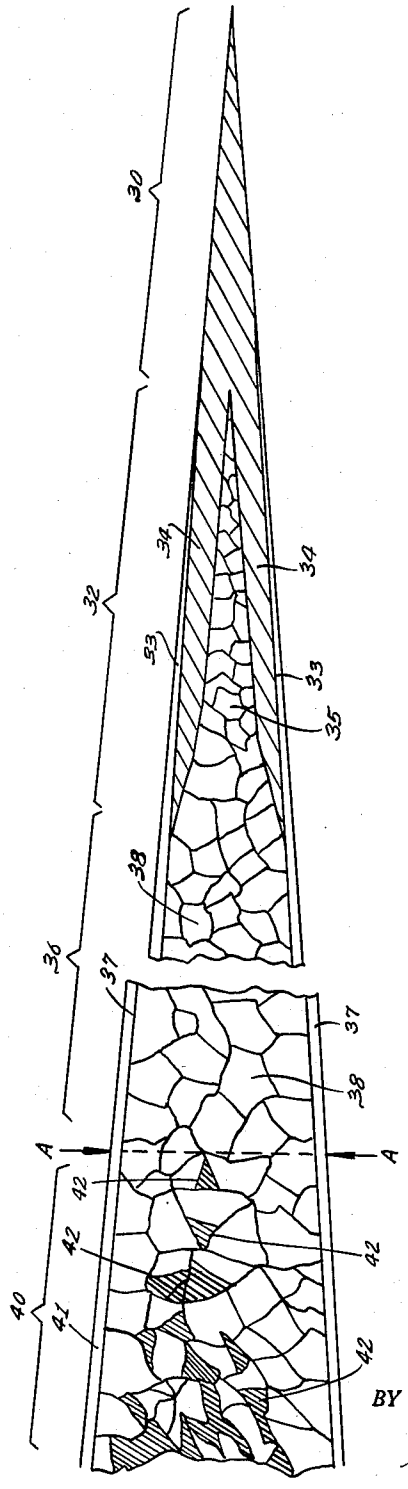


FIG. 4.

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PRODUCTION OF CHROMIUM CARBIDE SURFACED WEAR RESISTANT FERROUS BODIES

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FIG. 5.

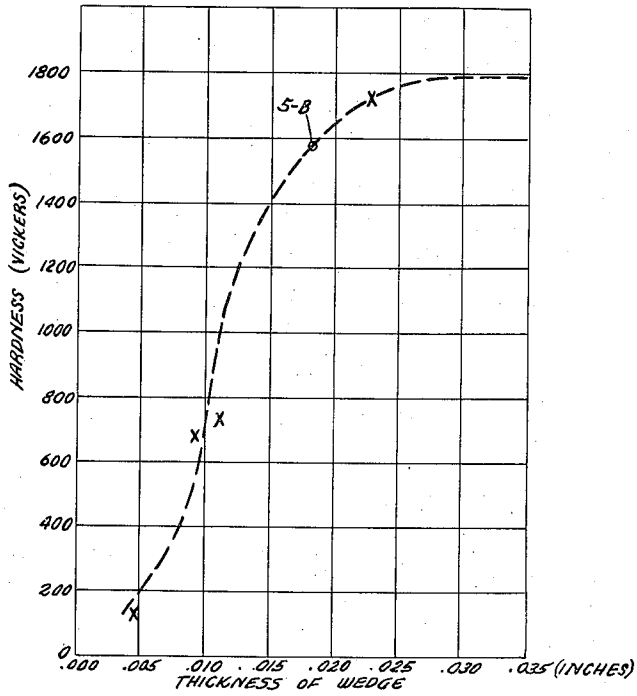
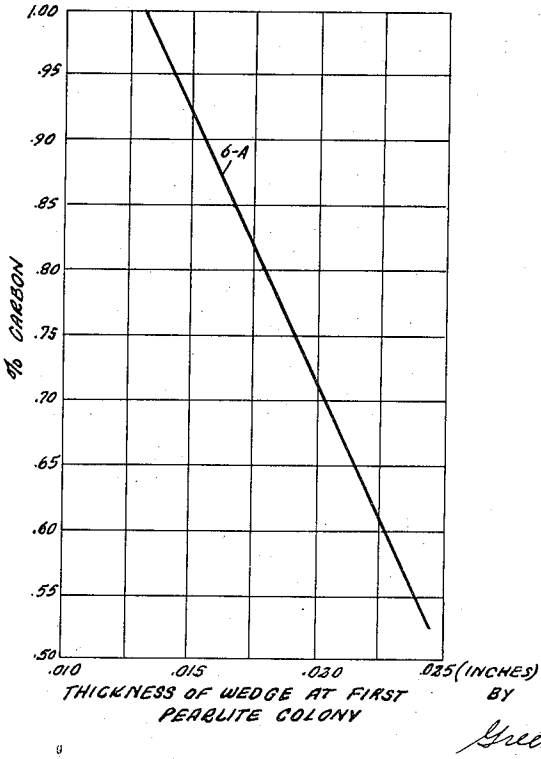


FIG. 6.



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Patented Aug. 3, 1954

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2,685,543

PRODUCTION OF CHROMIUM CARBIDE SURFACED WEAR RESISTANT FERROUS BODIES

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Application January 17, 1951, Serial No. 206,380

4 Claims. (Cl. 148—6)

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This invention relates to wear-resistant bodies or articles of the type having a ferrous or steel base provided on its exterior with a hard wear-resistant continuous surface layer and to methods of producing such bodies.

Among the objects of the invention is a ferrous body or article provided with a wear-resistant continuous surface layer or casing of chromium carbide for use in applications requiring bodies or articles having exposed surfaces which are subject to wear.

A distinct object of the invention is a provision of a ferrous body or article provided with a wear-resistant surface layer or casing of chromium carbide having a Vickers hardness of about 1500 to 1600 or higher.

A particular object of the invention is a ferrous body or article provided with such wear-resistant chromium surface layer on only certain surface portions thereof, with other surface portions of the article being free from such chromium carbide surface layers.

According to the invention, a ferrous body or article having at least in the surface layer thereof at least about 0.4 percent available carbon is provided with a wear-resistant continuous surface layer of chromium carbide having a Vickers hardness of at least about 1500 to 1600, by causing chromium—deposited at an elevated temperature on the surface of the body from a gaseous or liquid chromium compound—to diffuse into the surface layer of the ferrous body and to combine with the carbon content thereof to produce a wear-resistant chromium surface layer of a thickness of at least about 8 microns having such high hardness.

As used herein in the specification and claims, "Vickers hardness" means hardness in numbers determined by Vickers diamond pyramid hardness tests, such as described for instance in the Metals Handbook, 1939 Edition, published by the American Society for Metals.

The foregoing and other objects of the invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings wherein:

Fig. 1 is an enlarged photomicrograph of a section of a surface region of an article made according to the invention;

Fig. 2 and Fig. 3 are views of two typical ferrous articles provided with wear-resistant chromium carbide surface layers in accordance with the principles of the invention;

Fig. 4 is a cross-sectional view of adjacent portions of a wedge of carbon steel which was treated in accordance with the invention to form thereon a chromium carbide surface layer or casing to show how the character of the casing depends on the cross-sectional thickness of the steel body on which the chromium carbide casing was formed.

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Fig. 5 is a plot indicating in a generalized way how the hardness of the carbide casing formed on the wedge of Fig. 3 increases with the thickness of the cross-sectional area of the steel body; and

Fig. 6 is a graph obtained from wedge-shaped ferrous bodies of different carbon content provided with a chromium carbide casing of the invention to show how the thickness of the wedge at which the first pearlite formation appears depends on the carbon content of the ferrous body.

For years past ferrous bodies or articles with hard wear-resistant surfaces have found many applications in the arts as for example the moving parts of machinery subject to wear and shock. Heretofore, it has been generally believed that the most satisfactory wear-resistant hard surface for a ferrous article is that provided by electrodeposition of a layer of chromium from an electrodeposition bath on the surface of the body. However, such chromium surface layer, even if formed under the most favorable conditions, exhibits at most about 800 Vickers hardness and has only a limited wear-resistance.

It has also been known that a ferrous article could be provided with a surface layer of chromium by an exchange reaction with a chromium compound at an elevated temperature. However, as described, for instance, in U. S. Patent 2,415,078, Becker et al., when producing such chromium surface-alloyed ferrous bodies, it was found that the carbon content of the ferrous body caused serious difficulties, as carbon of the base material formed carbides with deposited chromium, the carbides checking the penetration of chromium into the surface layer of the body. This difficulty was overcome by keeping the carbon content of the surface layer of the body below 0.1% and/or alloying with the ferrous body a small percentage of alloying metals such as titanium, columbium, molybdenum, tungsten, vanadium, and/or manganese, which have a greater affinity for carbon than chromium.

The present invention is based on the discovery that under certain critical conditions of a carbon content of the ferrous body and the thickness of its cross-sectional area it is possible to provide the entire or only a limited exposed surface region of such body with a wear-resistant

chromium carbide layer forming an integral part of the body and exhibiting a Vickers hardness of 1500 to 1600 or even more, thus multiplying the life of such wear-resistant bodies or articles compared to the prior art chromium coated wear-resistant bodies.

In accordance with the invention a ferrous or steel body containing at least 0.4% carbon having a certain minimum thickness in relation to its carbon content will, when subjected at an elevated temperature to a surface alloying action in which chromium from a chromium compound is deposited on the surface of the body, cause the deposited chromium to diffuse into the surface layer of the body and combine with carbon migrating from the interior to form a chromium carbide surface layer which permits continued deposition of chromium on the exterior surface of the body, the additional deposited chromium continuing to combine with the carbon in the surface layer until a chromium carbide surface layer of a thickness of at least about 8 to 16 microns having at least about 1500 Vickers hardness has been formed on the surface of the body as an integral part thereof.

Important factors affecting the nature of a chromium carbide casing formed on the surface of a ferrous article are the percentage of its carbon content, the thickness of the ferrous body in relation to its total carbon content, and the percentage of alloying elements having a greater affinity for carbon than chromium. The ferrous or steel article should have an available carbon content of at least 0.4% and should be of substantial thickness of at least about .020 inch so that carbon of the interior can diffuse from relatively deep areas below the surface to combine with chromium deposited on the surface of the article at an elevated temperature from a gaseous or liquid chromium compound into a wear-resistant chromium carbide surface layer of substantial thickness. It has been found that highly satisfactory chromium carbide surface layers form on ferrous articles containing 0.60 to 1.20% carbon.

A feature of the invention is the discovery that—for a ferrous body having a carbon content of at least 0.4% and a certain minimum thickness—the chromium carbide casing formed on its exterior by the treatment of the invention will increase in hardness as the thickness of the ferrous body increases until it reaches a maximum hardness which does not increase with a further increase in thickness of the ferrous body. The increase of the hardness of the chromium carbide casing caused by the increase in the thickness of the ferrous body shows that chromium carbides of greater carbon content and greater hardness are formed on ferrous bodies having a certain minimum thickness than in ferrous bodies of lesser thickness on which carbides of lower carbon content and lesser hardness appear to form. In other words in order to form on a ferrous body containing at least 0.4% carbon a chromium carbide casing having a minimum of 1500 to 1600 Vickers hardness, the ferrous body must have a minimum thickness of at least 0.20 inch so that the carbon from the interior may diffuse into the surface layer of the body on which the chromium is deposited to provide the additional carbon required for causing the deposited chromium to combine with the carbon of the body into a chromium carbide layer of relatively high carbon content and a minimum of at least about 1500 to 1600 Vickers hardness.

It is known that a number of chromium carbides exist, and there is every indication that, at least up to chromium carbide of the formula Cr_3C_2 (which may be called "trichromium dicarbide"), the hardness of the chromium carbide increases with the increase of the carbon content of the carbide. Furthermore, there are indications that the hard carbide surface layer or casing of the invention of a thickness of at least about 8 microns and of at least 1500 Vickers contains or consists, at least to some extent, of a multiple carbide containing carbon combined with the deposited chromium and with iron of the base or article.

As used herein in the specification and claims, the expression "chromium carbide surface layer" and "chromium carbide casing" are intended to mean a metal carbide surface layer or casing consisting essentially either of a carbide of the deposited chromium or of multiple carbide of the deposited chromium and of iron from the article base or of a mixture or combination of said carbides.

When forming on the exterior of a ferrous body a chromium casing of the invention the interior of the ferrous body or its core is depleted of carbon or decarburized. If such ferrous body is thin and has been depleted of its carbon content by the formation of a chromium carbide casing on its exterior, the decarburized core of such body will lose its ability to be hardened through subsequent heat treatments of the type generally used for hardening steel bodies.

According to the invention, ferrous articles which are to be provided with a chromium carbide casing of the invention are chosen to contain sufficient carbon and to be of sufficient thickness so that—after forming on the exterior of the body the chromium carbide casing of a minimum thickness of at least 8 microns and at least 1500 to 1600 Vickers hardness—the ferrous core of the body will retain a carbon content of at least 0.2% so that it may be subjected to known heat treatments by which similar carbon-containing steel bodies are hardened. It is thus possible to provide ferrous bodies with a wear-resistant chromium carbide casing of the invention, which may be subjected to known heat treatment whereby the ferrous articles are given enhanced strength as well as other desired characteristics.

Among the various ferrous articles whose surfaces have been provided with a wear-resistant continuous surface layer of chromium carbide in accordance with this invention are thread guides, cylinders, pistons, dies, drills, cutters, ball and roller bearings with associated races, phonograph needles, etc. In general, the invention may be applied to any ferrous article having a surface which is subjected to wear.

Any of the known methods for depositing chromium from a gaseous or liquid chromium compound on the surface of a ferrous body heated to an elevated temperature below the melting temperature of the body may be employed for depositing chromium on and diffusing chromium into the surface layer of the ferrous body to combine with carbon and for forming a wear-resistant surface layer of chromium carbide.

These methods include chemical reduction or reaction of the chromium compound at the surface of the ferrous article as exemplified by hydrogen reduction of chromium halides and by displacement or reaction of the ferrous base metal with one of the constituents of the gaseous

chromium compound. Another method that may be used for depositing chromium on and diffusing chromium into the surface layer of the ferrous body to combine with carbon and for forming a wear-resistant surface layer of chromium compound is thermal decomposition of a chromium compound at the surface of the ferrous article as exemplified by thermal decomposition of chromium halides at the surface of the ferrous article at high temperatures and by thermal decomposition of chromium carbonyl at the surface of the ferrous article at low temperatures.

Among such known chromium surfacing processes, one that was found particularly suitable for practicing the invention involves an exchange or displacement reaction of the ferrous metal of the treated body with the chromium constituent of a gaseous or vapor phase of a chromium halide, such as chromous chloride, at an elevated temperature in the range between about 900° to 1200° C. in accordance with the equation:

$$CrCl_2+Fe \rightarrow Cr+FeCl_2$$

Chromium of the chromous chloride gas replaces ferrous metal on the surface of the body and combines with carbon diffusing to the surface into chromium carbide while the gaseous chloride compound of the displaced metal escapes. Successive strata of chromium carbide are thus formed until a casing of desired thickness is obtained. It has been discovered that the chromium carbide surface-forming process continues after the formation of the initial chromium carbide stratum which encases the ferrous article and that the ferrous particles of the body have the property of forming solid solutions with particles of the chromium carbide layer thus permitting the displacement or exchange reaction between the ferrous particles and chromium of the gaseous chromium compound to continue.

Instead of chromous chloride, other chromium halides may be used for effectively carrying out the chromium carbide surface-forming process in accordance with the principles of the invention.

The ferrous articles which are to be treated by the chromium-exchange reaction may be brought into contact with the chromium exchange compound in various ways. For example, the ferrous or steel articles to be treated are packed in a pack containing ferro-chromium and a stream of a gaseous mixture of hydrogen and hydrogen chloride is passed through the pack in which case the chromizing agent, that is chromous chloride gas, is produced within the pack. Alternatively the pack may be impregnated with separately prepared chromous chloride, in which case the hydrogen chloride gas may be at least partially omitted from the gaseous stream and only hydrogen passed through the pack. As another alternative procedure, the ferrous body is packed in a pack of porcelain powder, ferro-chromium powder, and a chromium chloride compound and enclosed within a sealed envelope which is heated to produce the desired chromium carbide surface formation. As a still further alternative procedure, the ferrous article may be immersed in a molten salt bath containing chromous chloride and subjected therein to a chromium carbide surface forming treatment at an elevated temperature.

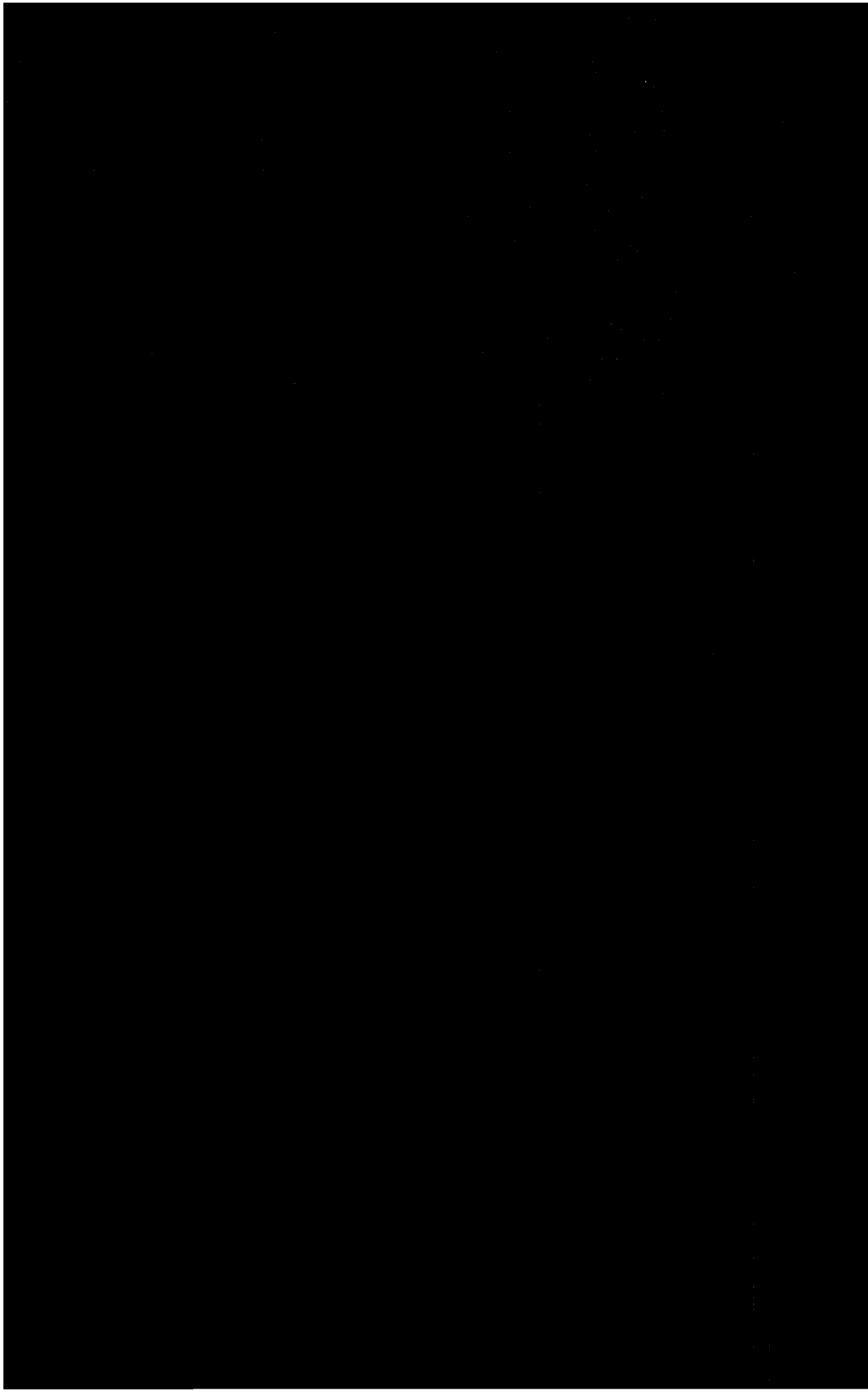
It should be noted that the deposition of chromium by an exchange reaction with the surface layer particles of the ferrous body is of particular advantage in forming a chromium carbide surface layer on interior surfaces of hollow bodies such as a hollow thread guide or the interior race surface of a roller bearing.

According to the invention, it is also possible to provide ferrous bodies or articles which have a low carbon content with a wear-resistant chromium carbide layer by first forming on the surface thereof, by a known carburizing process, a carburized surface layer or casing of high carbon content, and thereafter subjecting the so carburized surface region to the chromium deposition and chromium carbide forming treatment.

In practicing the invention to produce a chromium carbide surface on a smoothly ground polished or other mechanically worked surface of a ferrous article, it was found that surface imperfections arranged in a fashion suggesting scratches, tool marks, grinding marks, machining patterns, and/or welts appear on the exterior surface of the chromium carbide layer. The formation of these protuberances and welts appears to occur to a lesser extent in low carbon steels. It seems that such protuberant swellings or growths appear at portions of the chromium carbide surface layer formed on worked or work-affected surface portions of the ferrous base. As used herein in the specifications and the claims, the expression "work-affected surface portions" means surface portions of a ferrous article the material of which was worked upon as by grinding, polishing, rolling, etc., thereby giving its surface structure a characteristic distinct from underlying portions with respect to the tendency to form the chromium carbide surface layer of the invention. It has been observed that the chromium carbide surface layer of the invention, when formed on work-affected surfaces of a ferrous article, exhibits such objectionable surface irregularities even when the article is subjected to a heating or annealing treatment in the initial stages of or prior to the chromium carbide forming process.

According to another phase of the invention, the objectionable surface irregularities of the wear-resistant chromium carbide layer are eliminated, prevented or suppressed by removing the work-affected exterior surface stratum of the article before treating the article to form thereon the chromium carbide surface layer. Any known processes, such as etching, deplating and the like which are effective in removing a surface stratum from the exterior of a ferrous body without forming a new surface of the same kind, may be used for removing the work-affected surface layer of the article so as to suppress surface irregularities on the chromium carbide layer formed on the exterior of the ferrous article.

By way of example, the work-affected surface stratum of the ferrous article may be removed by treating the surface with a solution of HCl containing 50% by volume concentrated hydrochloric acid HCl, balance water, while heated at about 85° C. for 2 to 10 minutes. Other known etching compounds may be used for removing the work-affected surface layer from the surface portions of the article which are to be provided with the chromium carbide wear-resistant surface layer. Alternatively, the ferrous article which has a work-affected surface may be placed in an electrolyte bath of suitable concentration and connected as anode in an electrodeposition circuit for removing the work-affected surface layer by the electrodeposition process. Any known electrolytic deposition baths may be used



layer remains soft, and that the hardness increases as the carbide surface layer of relatively greater carbon content is formed along the somewhat thicker wedge regions **32** and **36**. The desired great hardness of about 1600 Vickers is reached only in the region of the thickness A—A, where the casing of chromium carbide of great carbon content is formed, the hardness curve leveling off and approaching the maximum for greater thickness.

Fig. 6 shows a curve 6–A of thickness plotted against carbon content and illustrates how the thickness of an article can be reduced as the carbon content thereof increases.

As explained above, the processes of the invention involving the formation of a surface layer of chromium carbide on a ferrous article are not limited to the displacement of the ferrous base metal with the chromium constituent of the gaseous chromium compound. Another process for forming a surface layer of chromium carbide on a ferrous article involves the thermal decomposition of a chromium compound at the surface of the ferrous article. In this type of chromium carbide surface forming treatment the chromium compound is decomposed and chromium deposited at surface regions of the ferrous article heated to an elevated temperature, and the deposited chromium diffuses into the surface layer of the article and combines with carbon migrating to the surface into a chromium carbide surface layer of substantial thickness. In such chromium carbide surface-forming treatment the chromous chloride gas may be passed through a retort of ceramic or like insulating refractory material containing the ferrous article. Selective induction heating of the exposed surfaces of the ferrous article—on which formation of the chromium carbide layer is desired—may be employed to cause decomposition of the chromous chloride gas, the deposition of chromium at said exposed surfaces, and the formation of a surface layer of chromium carbide on the exposed surfaces of the ferrous article.

Without thereby limiting the scope of the invention in order to enable those skilled in the art to readily practice the invention, there will now be described specific examples of satisfactory procedure for providing ferrous articles, such as thread guides in Fig. 2, with a chromium carbide layer on its looped guide part 13.

The ferrous articles to be treated are first dipped in an acid etching bath, for example, a bath containing 50%, by volume, of concentrated HCl, at about 80° C. for 2 to 10 minutes until the work-affected exterior surface stratum has been removed from the exposed surfaces on which the wear-resistant chromium carbide layer is to be formed. After removal from the etching bath, the ferrous articles are packed within a chromous-chloride-producing pack mass and placed within baskets of suitable heat-resistant metal such as a chromium-nickel-iron alloy. The pack may consist, for instance, of 50% by volume ceramic lumps, such as porcelain pieces, and the balance a chromium alloy such as ferro-chromium. An alternative chromium carbide-forming pack which was found highly effective consists of a mixture of titanium oxide with ferro-chromium. Good results are obtained with such pack consisting of about 20% titanium oxide by volume, the balance consisting of ferro-chromium containing about 70% chromium.

The treating baskets containing the ferrous metal are then placed in a retort and heated to a temperature in the range of between 900° and 1200° C. and a stream of hydrogen and hydrogen halide gas, such as hydrogen chloride gas is passed through the retort for producing reactions causing chromium atoms to be deposited on the ferrous metal surface and to diffuse into the interior of the ferrous metal surface and combine with carbon present and/or diffusing toward the surface into a wear-resistant continuous chromium carbide surface layer or casing.

In such chromium carbide surface-forming treatment, the hydrogen chloride gas passing through the retort interacts with the ferro-chromium to form chromous chloride gas. The chromium of the chromous chloride gas replaces the ferrous metal on the surface of the heated ferrous body primarily by the exchange reaction. Part of the chromous chloride gas is absorbed by the packing material such as the ceramic material or the titanium oxide in the pack.

In the particular example herein described, a retort having a volume of approximately 16 cubic feet which is substantially completely filled with the packed baskets was employed. The packing material consisted of TiO_2, 20% by volume, the balance ferro-chromium containing 70% chromium. During the initial part of the chromium carbide surface-forming treatment, purified dry hydrogen gas was caused to flow through the enclosed retort space at a rate of 40 cubic feet per hour, while the temperature was raised to about 950° C. The flow of purified dry hydrogen gas was thereafter continued at the same rate for four hours at the same temperature of about 950° C. Thereafter the baskets within the retort were subjected to a succession of five treatment sequences at about 950° C., each treatment sequence lasting 6 hours, and consisting of: (*a*) passing through the retort at a rate of 20 cubic feet per hour a mixture of 20 parts of hydrogen and 3 parts of HCl gas for one hour, followed by (*b*) passing pure hydrogen at the same rate for one hour, followed by (*c*) passing the same mixture of hydrogen and HCl gas as in (*a*) for one hour, followed by (*b*) passing pure hydrogen at the same rate for three hours. After a succession of six such treatment sequences of six hours duration each, the treatment was ended by turning off the heat and permitting the retort with its contents to cool while continuing the flow of hydrogen through the retort space until the temperature of its contents was brought down to room temperature. The chromium carbide surfaced article was then removed from the retort and subjected to an air blast removing adhering packing materials from the exterior surface of the article.

As an alternative procedure, the ferrous articles to be treated are etched as in the previous example and are then immersed in a molten salt bath containing chromous chloride and subjected therein to a chromium carbide surface-forming treatment at an elevated temperature. A suitable bath composition for the latter treatment may consist of 30% $CrCl_2$, 50% $BaCl_2$, and 20% NaCl. By keeping the bath heated to a temperature in the range from about 900° C. to 1500° C. for about 3 to 10 hours the desired chromium carbide surface-forming action will be produced. The $CrCl_2$ content of such bath may be replaced by substances which generate $CrCl_2$, in which case an equivalent amount of $CrCl_3$ and chromium metal is included in the bath.

As described previously, ferrous bodies or articles which have a low carbon content are

provided with a wear-resistant chromium carbide layer by first forming on the surface thereof, by a known carburizing process, a carburized surface layer or casing of high carbon content, and thereafter subjecting the so carburized surface region to the chromium deposition and chromium carbide forming treatment.

A low carbon ferrous article is first packed in a conventional carburizing pack mass and placed within a carburizing furnace and heated to a temperature of about 925° C., causing carbon to be deposited on the ferrous metal surface and to diffuse into the interior of the ferrous metal surface until a carburized layer of substantial thickness containing, for example, about 0.95% carbon is formed on the surface of the article. The pack may consist, for instance, of a mixture of approximately 20% $BaCO_3$, bound to a hardwood charcoal with oil, tar, or molasses.

As an alternative carburizing procedure, the low carbon ferrous article is first packed in a retort and heated to a temperature of about 925° C. and a stream of a gaseous mixture of O_2, CO, CH_4, C_2H_6, and N_2 is passed through the retort for producing reactions causing the CO and hydrocarbons to break down almost completely to carbon, oxygen and hydrogen, the carbon depositing on and diffusing into the surface layer of the ferrous body forming a surface layer of high carbon content.

The carburized ferrous articles are etched as in the previous examples and are then packed within a chromium-chloride-producing pack mass and placed within baskets of suitable heat-resistant metal such as a chromium-nickel-iron alloy. The heating baskets containing the ferrous metal are then placed in a retort and heated to a temperature in the range of between 900° and 1200° C. and a stream of hydrogen and hydrogen halide gas, such as hydrogen chloride gas is passed through the retort for producing reactions causing chromium atoms to be deposited on the ferrous metal surface and to diffuse into the surface layer of the body and combine with carbon into a chromium carbide surface layer which permits further continued deposition of chromium, the additional deposited chromium continuing to combine with the carbon present into a wear-resistant continuous chromium carbide surface layer or casing of substantial thickness.

Without in any way limiting the scope of the invention, and in order to enable those skilled in the art to readily practice the invention, there are given below the results obtained by subjecting a ferrous article to the chromium carbide surface-forming treatment as described above.

Ferrous articles provided with a chromium carbide surface layer in the manner described above exhibited a hardness of 1800 Vickers as compared with a hardness of 800 Vickers for hard chrome plated articles. It should be noted that the hardness of 1800 Vickers exhibited by the chromium carbide layer so formed is considerably higher than the hardness of 1400 Vickers exhibited by known cemented carbides. The carbon content and thickness of the articles of the present invention are so correlated as explained above, to produce a chromium carbide layer with a hardness of at least 1600 Vickers.

In an article such as a thread guide of Fig. 2 provided with such chromium carbide surface layer which was subjected to 4430 hours of normal operation, the thickness of the chromium carbide surface layer which was originally 10 microns was reduced to about 7.5 microns. In addition, it was observed that the chromium carbide surface layer of such article is self-polishing in service.

As explained hereinbefore, after producing the chromium carbide surfaced ferrous articles in which the core retains enough carbon to have a pearlite structure, they may be subjected to further heat treatment of the type applied to steel for imparting thereto high mechanical strength such as required by drills, cutters, and like articles. Such further heat treatment may be readily carried out without affecting the chromium carbide surface layer previously formed on the article.

The principles of the invention described above in connection with specific exemplifications thereof, will suggest various other modifications and applications of the same. It is accordingly desired that the present invention shall not be limited to the specific exemplifications shown as described above.

I claim:

1. In the method of making articles having an exposed wear-resistant surface region consisting essentially of metal carbide forming an integral part of said article and constituting only a small fraction of the mass of said article, the procedure comprising the steps of providing a ferrous body containing carbon and having a mechanically worked exposed surface, said ferrous body having a thickness of at least 0.020 inch and containing adjacent the surface thereof at least 0.4% of available carbon, removing the stratum of work-affected metallic surface particles of said body from said surface region depositing chromium on the exposed surface region of said body from a gaseous chromium compound at an elevated temperature causing the deposited chromium to react with available carbon of said surface region and to produce out of an integral surface layer of said surface region a surface layer of a chromium containing carbide, and continuing said deposition of chromium from said chromium compound and the carbide forming reaction of the so deposited chromium with the available carbon of said surface region until an integral chromium containing carbide layer of at least about 8 microns thickness having a surface hardness of at least about 1500 Vickers is integrally formed on said surface region.

2. In the method as claimed in claim 1, the procedure of applying to another exposed surface region of the ferrous body on which formation of carbide is to be prevented with a stop cover prior to the step of depositing chromium on another surface region on which chromium is to be deposited.

3. In the method of making articles having an exposed wear-resistant surface region consisting essentially of metal carbide forming an integral part of said article and constituting only a small fraction of the mass of said article, the procedure comprising the steps of providing a mechanically shaped ferrous body containing carbon and including a portion of at least about 0.020 inch thickness containing adjacent a surface region thereof at least 0.4% of available carbon, removing the stratum of work-affected metallic surface particles of said body from said surface region depositing chromium on said surface region of said body from a chromium compound at an elevated temperature by an exchange reaction between chromium of the compound and iron of said body, and causing the deposited chromium to react with available carbon of said surface region and to produce out of

an integral surface layer of said surface region a surface layer of a chromium containing carbide, and continuing said deposition of chromium from said chromium compound and the carbide forming reaction of the so deposited chromium with the available carbon of said surface region until an integral substantially uniform chromium carbide layer of at least about 8 microns thickness of at least about 1500 Vickers hardness is integrally formed on said surface region.

4. In the method as claimed in claim 3, the procedure of applying to another exposed surface region of the ferrous body on which formation of carbide is to be prevented with a stop cover prior to the step of depositing chromium on another surface region on which chromium is to be deposited.

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