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(54) **CARBURIZED LOW SILICON STEEL ARTICLE AND PROCESS**

ZEMENTIERTER STAHL MIT NIEDRIGEM SILIZIUMGEHALT UND VERFAHREN ZU SEINER
HERSTELLUNG

ARTICLE EN ACIER CEMENTE A FAIBLE TENEUR EN SILICIUM ET PROCEDE

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(73) Proprietor: **CATERPILLAR INC.**
Peoria Illinois 61629-6490 (US)

(72) Inventors:

- **TIPTON, Sheryl, A.**
East Peoria, IL 61611 (US)
- **KEIL, Gary, D.**
Elmwood, IL 61529 (US)
- **HOLLOWAY, Gregory, S.**
Metamora, IL 61548 (US)
- **GROMER, Dave, R.**
Morton, IL 61550 (US)
- **BILTGEN, Gary, L.**
Peoria, IL 61614 (US)

(74) Representative: **Wagner, Karl H., Dipl.-Ing.**
WAGNER & GEYER
Patentanwälte
Gewürzmühlstrasse 5
80538 München (DE)

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Description**Technical Field**

5 This invention relates generally to metal heat treatment and more particularly to case hardening with a gas containing carbon and a resulting article.

Background Art

10 Carburizing is an effective method of increasing the surface hardness of low carbon, unalloyed, or low carbon, low alloy steels. Typically, steel articles are placed in an atmosphere containing carbon in an amount greater than the base carbon content of the steel and heated to a temperature above the austenite transformation temperature of the steel. After the desired amount of carbon has been diffused into the article, hardness is induced by quenching.

15 Gas carburizing is efficient, controllable, and one of the most widely used methods of generating a carbonaceous atmosphere for carburizing. However, most commonly used gas mixtures typically contain small amounts of oxygen which tend to form surface oxides with one or more of the steel elements which have a strong affinity for oxygen, such as silicon, chromium and manganese. Oxides that form along grain boundaries, i.e., intergranularly, extend inwardly from the surface and have a harmful effect on the mechanical properties of the carburized article.

20 Conventional carburizing processes typically avoid the formation of case carbides, and generally produce an essentially carbide free martensitic structure. Even when case carbides are involuntarily formed, characteristically there is a thin surface layer void of carbides. This is due to the oxidation of carbide forming elements in the surface layer.

The detrimental effects of oxidation during gas carburizing have been known for a long period of time. Heretofore, when designing a carburized article, it has been necessary to consider the reduction in bending fatigue strength attributable to intergranular surface oxides. To avoid reduction in bending fatigue properties, it has been necessary to 25 physically remove intergranular surface oxides formed during carburizing by machining or grinding, or prevent such surface formations by removing oxygen compounds from the carburizing media. These alternatives are costly. A 1978 article authored by Ruth Chatterjee-Fischer, "Internal Oxidation During Carburizing and Heat Treating," Metallurgical Transactions A, published by American Society for Metals and the Metallurgical Society of AIME, Vol. 9A, November 1978, pp. 1553-1560, reported that, when employing conventional carburizing processes, the presence of silicon in 30 the parent metal is a prime contributor to the formation of oxides at the surface of the article. However, while identifying that lowering silicon is a solution to the problem of surface oxidation, the paper fails to recognize any interrelationship between low silicon amounts and the enhanced formation of surface carbides by nonconventional carburizing methods.

A low silicon carburizing steel, developed by Sanyo Special Steel Co., Ltd. is described in Japanese Patent Publication No. 57-23741. The Sanyo reference teaches that low silicon, i.e., 0.06% to 0.12%, when combined with relatively 35 high carbon and chromium amounts will accelerate carbon diffusion and thereby reduce carburizing time. This reference limits the amount of chromium in the steel composition to intentionally avoid the formation of case carbides. Furthermore, this reference fails to link the influence of a low silicon composition with the formation of surface oxides and carbides during carburizing. The Sanyo low silicon steel composition described in the above publication is no longer in commercial production.

40 Another low silicon carburizing steel intended for use in applications wherein the formation of case carbides is purposefully avoided, was developed by Kobe Steel, Ltd. Kobe's composition is described in Japanese Patent Publication No. 61-253346 and, as described therein, was developed for use in a gear that is heat treated after carburizing to improve the hardness of the root areas of gear teeth. To assure favorable surface hardenability after carburizing, Kobe intentionally limits the amount of carbide forming elements in the steel composition to prohibit the formation of 45 surface carbides during carburizing. Also, the amounts of silicon, manganese and chromium in the composition are restricted to prevent the formation of granular oxides which lower the heat treatability of the carburized surface layer. This reference also does not disclose any interrelationship between low silicon amounts and the beneficial formation of surface carbides.

50 A low silicon steel composition intended for carburized articles in which near surface carbides are formed is disclosed by Daido Special Steel Co. in Japanese Patent Publication No. 61-104065. Daido, like the above references, recognizes that restricting the amount of silicon in the steel composition is beneficial for reducing intergranular oxides. However, this reference also teaches that more than 1.2% chromium is essential to form carbides at or near the surface. This reference also fails to recognize that in addition to its effect on oxidation, silicon effects surface carbide formation and, by limiting the amount of silicon in a carburizing steel as taught by the present invention, surface carbides may 55 be easily formed with significantly smaller amounts of chromium.

Conventional gas carburizing processes, as discussed above, generally attempt to prevent the formation of case carbides. A nonconventional carburizing process for intentionally forming carbides in the case is described in Canadian Patent 610,554, "Carburization of Ferrous Alloys," issued Dec. 13, 1960, to Orville E. Cullen. Cullen teaches a method

for carburizing low alloy steel by repeatedly carburizing and rapidly cooling the steel article. However, Cullen's method is very lengthy, requiring on the order of about 42 hours to complete, and is therefore quite expensive. Further, Cullen's process does not suggest a solution to the problem of surface oxide formation.

More recently, a two stage carburizing process was described in U. S. Patent 4,202,710, issued May 13, 1980, to Takeshi Naito, et al. That process forms spheroidal carbides within a region between 0.1 mm and 0.4 mm below the case surface, but fails to provide a high density of carbides on the outer surface of the carburized case. As a result, articles formed by this teaching must initially wear, or be machined, down to the carbide rich zone beginning 0.1 mm below the surface before the enhanced wear and contact fatigue properties of the carbide microstructure, such as pitting and spalling resistance, can be advantageously utilized. Also, like Cullen, this process fails to offer a solution to the problem of surface oxide formation.

JP-A-61 253 346 refers to steels for gears with high-strength teeth.

The purpose of JP-A-61253346 is to produce high strength gear superior in dedendum strength, by controlling contents of Si, Mn to require min. limit, suppressing S content and decreasing sulfide inclusion, at manufacturing the titled steel. The steel material has a composition containing by weight 0.15~0.40% C, 0.45~1.0% Mo, 0.5~2.0% Cr, <0.10% Si, <0.50% Mn, <0.010% P, <0.010% S, <15ppm O. A gear is produced with gear steel of the composition, carburization treated 900°C for 1~2hr, then cooled in furnace, held at 850°C for 10min, and oil quenched. Successively, the gear is held at about 200°C for 2 hr, then air cooled. High strength gear having superior surface hardness, surface residual stress, remarkably improved fatigue limit, high dedendum strength, without breakage can be produced.

Metallurgical transactions A, Vol.9A, November 1978, pages 1553-1560 discusses the internal oxidation of the surface layers of ferrus engineering components during carburizing.

HÄRTEREI-TECHNISCHE MITTEILUNGEN (HTM) Vo. 42, No. 3, May/June 1987, pages 139-146; DE T. RETI e al.: "Vereinfachtes mathematisches Modell für zweistufige Aufkohlungsverfahren" is directed to a model and prediction method for controlling the depth and carbon content of the carburized case (i.e. the surface layer).

The present invention is directed to overcoming the problems set forth above. It is desirable to have a carburized steel article which is essentially free of surface intergranular oxides and which has a high ratio of carbides on the surface. It is also desirable to provide a process which will form this article in a short treatment time, and is economical and controllable.

Disclosure of the Invention

The present invention is directed to a process for forming a steel article as set forth in claim 1. The invention is also directed to a process for carburizing a low silicon steel article as set forth in claim 12. Preferred embodiments of the invention are disclosed in the dependent claims.

In accordance with one aspect of the present invention, a process for forming a carburized steel article includes carburizing an article made of a steel having no more than 0.10% silicon and less than 1.1% chromium at a temperature sufficient to form, on a surface of the article, austenite having a high density of carbides dispersed therein. After carburizing, the article is quenched to transform the carburized surface microstructure to martensite, retained austenite and carbides, whereby the article has a carburized surface substantially free of intergranular oxides and has carbides comprising at least 20% of the carburized surface.

Other features of the process of forming a carburized steel article include carburizing in a first stage to form about 75% to 95% of the desired case depth, which may be advantageously followed by a second stage wherein the high density of surface carbides are formed.

In another aspect of the present invention, there is provided a carburized low silicon steel article characterized by having not more than 0.10% silicon and less than 1.1% chromium, by having an outer surface substantially free of intergranular oxides, and by having a high percentage of carbides on the outer surface. Preferably the carbides on the outer surface comprise at least 20% thereof.

Other features of the carburized low silicon article include a composition, by weight, of 0.08% to 0.35% carbon, 0.3% to 1.7% manganese, 0.2% to 2.5% carbide forming elements including said chromium, less than 6% additional hardenability agents, less than 1% grain refining elements, not more than 0.10% silicon, not more than 0.15% copper, and iron and trace elements.

Brief Description of the Drawings

Fig. 1 is a photomicrograph, at 750X, showing an unetched section of a carburized low silicon steel article containing less than 0.10% silicon according to the present invention.

Fig. 2 is a photomicrograph, at 750X, of an etched section of the article shown in Fig. 1.

Fig. 3 is a photomicrograph, at 750X, showing an unetched section of an article carburized with the article in Fig. 1, but formed of a typical carburizing grade low alloy steel containing 0.26% silicon.

Fig. 4 is a photomicrograph, at 750X, of an etched section of the article shown Fig. 3.

Fig. 5 is a photomicrograph, at 500X, showing an etched section of an article formed of a typical carburizing grade low alloy steel containing 0.26% silicon and carburized by a conventional carburizing process.

Fig. 6 is a graph showing the relationship between silicon content in the steel composition, and the amount of oxides and carbides formed on the surface of an article carburized according to the present invention.

Fig. 7 is a graph illustrating the time and temperature relationship of the carburizing process embodying the present invention.

Best Mode for Carrying Out the Invention

A process for forming a steel article includes the steps of selecting a low silicon steel, shaping the steel, carburizing, controllably cooling to the hardening temperature, and quenching. As used herein the term "low silicon steel" means a steel material containing from 0% silicon to no more than 0.10% silicon, and whose composition in all other respects is recognized as generally suitable for carburizing. Restricting, or eliminating, the amount of silicon in the steel not only represses the formation of silicon oxides but also inhibits the oxidation of chromium and manganese on the surface of the carburized article. Furthermore, when low silicon steel articles are processed in accordance with the present invention, the formation of a high ratio of carbides on the surface is assured. Accordingly, selection of an appropriate steel composition is an important step.

Commercially produced low alloy carburizing grade steels typically have a composition, by weight, within the following ranges:

Carbon	0.08% - 0.35%
Manganese	0.3 % - 1.7%
Carbide forming elements such as Chromium, Molybdenum or Vanadium (total)	0.2% - 2.5%
Additional Hardenability agents	0.0% - 6%
Silicon	0.15% - 0.35%
Grain refining elements	0.0% - 1.0%
Iron and residual elements -	Balance

The above steel composition, if silicon is deleted or restricted to 0.10% or less, is suitable for the formation of carburized articles according to the present invention.

The accepted steel industry standard allowable residual amount of copper in steel compositions is 0.35%. It has been found that low silicon steels having copper toward the upper limit of such amount are sometimes inconsistent in the formation of carbides on the carburized surface. It is theorized that copper may inhibit the formation of surface carbides. Accordingly it is desirable, though apparently not essential in all cases, to limit the amount of copper in the composition to not more than 0.15%.

More specifically, a low alloy carburizing grade steel, such as one of the SAE 4110 to 4130 series, all modified particularly to limit silicon to no more than 0.10%, are particularly suited for the formation of carburized articles such as gears, bearings and shafts. Therefore, commercial low alloy carburizing grade steels containing relatively small but essential amounts of carbide forming elements such as chromium, molybdenum or vanadium, may be modified to be a low silicon steel composition. Additional hardenability agents may be included but should be limited to amounts less than about 6%. Grain refining elements in amounts less than 1% are often added to promote fine grain size. As noted above, it is also desirable to limit residual or trace amounts of copper to no more than 0.15% to further enhance surface carbide formation. Deleterious elements such as phosphorus and sulfur, often present in trace amounts, are preferably limited to no more than 0.05% and 0.08% respectively.

Articles having any of the above described compositions are shaped to a predetermined form by machining from rolled steel, by casting or forging, by consolidating steel powder, or by a combination of forming operations.

After shaping, the article is placed into a carburizing furnace and heated to a temperature sufficient to diffuse carbon from the furnace atmosphere into the article and to form a high density of carbides on the surface of the article. Preferably, the carburizing operation is carried out in two stages. In the first carburizing stage, the carbon potential of the gas atmosphere in the furnace is maintained at a level about equal to the saturation limit of carbon in austenite. The saturation level of carbon in austenite, generally designated as " A_{cm} ", is temperature dependent. The shaped article is preferably placed directly into a continuous type furnace having a temperature within the carburizing chamber of from about 1550°F (843°C) to about 1850°F (1010°C) and an atmosphere about equal to the A_{cm} corresponding the specific steel composition of the article.

As shown graphically on Fig. 7, the first stage of the carburizing process includes holding the article in the carburizing chamber for a period of time sufficient to develop about 75% to 95% of the desired final case depth. As used

herein, "case depth" is the distance below the surface where the carbon content is at 0.40%. The time required to achieve the desired case depth of the article is dependent on a number of parameters, such as the chemical composition of the article, and composition and temperature of the gas atmosphere. Hence the length of time that the article is held in the carburizing chamber in this first stage may vary from about 2 to about 25 hours. When the article has the low silicon composition described above, the furnace atmosphere is maintained as close as possible to the A_{cm} of the particular steel, and the carburizing temperature is maintained at about 1700°F (927°C), an initial case depth of about 1.0 mm can be achieved by holding the article in the furnace for about 4 to 5 hours. After completion of the second stage carburizing operation, described below, the final case depth is about 1.1 mm.

After the first stage carburizing operation, the article is cooled, preferably by gas quenching, to a temperature below that at which bainite and pearlite begin to form. This temperature is commonly designated as " A_1 " and is represented by the dashed horizontal line on Fig. 7. It is desirable to cool the surface of the article rapidly in this operation to suppress network carbide formation. This results in the formation of a supersaturated, metastable, solid solution of iron and carbon. If excessively slow cooling rates are used, carbides will form at grain boundaries, and not provide effective intragranular nuclei for the formation of carbides.

After cooling the article to a temperature sufficiently below A_1 to assure the substantially complete transformation to bainite or pearlite, the article is quickly reheated by placing it into a preheated carburizing furnace. This causes a homogenous carbide precipitation from the metastable solid solution, and results in a dispersion of carbides in the case microstructure.

During the second stage carburizing operation, the carbon potential of the furnace atmosphere is maintained at a level above the A_{cm} , i.e., the carbon potential of the atmosphere is above the saturation limit of carbon in austenite of the article. For example, an atmosphere having a carbon potential of about 1.5% to 2% can be provided by a gas having a composition of 0.055% CO_2 , 1% CH_4 , 20% CO , 40% H_2 and the balance N_2 . Typically, the temperature of the second stage carburizing chamber is maintained between about 1550°F (843°C) and 1850°F (1010°C), and preferably at about 1700°F (927°C). In the second stage it is only necessary to reaustenitize the case of the article in a supersaturated gas environment, and thereby increase the surface carbon to a level above 1.5%. The article need be held for only about 15 to 60 minutes at 1700°F (927°C) to achieve the desired case carbon content. Although lower temperatures may be used, it will require holding the article in the furnace for a corresponding longer time. Also, it has been found that the size and volume fraction of the surface carbides present in the carburized article can be controlled by selection of the second stage carburizing temperature and the rate of cooling in the subsequent cooling step described below. For example, higher second stage carburizing temperatures tend to produce more carbides, i.e., a higher volume fraction of larger carbides, on the surface of the article.

Upon completion of the second stage carburizing operation an austenitic microstructure having a high density of well dispersed surface carbides has been formed. The article, preferably while still in the furnace, is then controllably cooled to the hardening temperature of the steel core. By way of example, the hardening temperature of SAE 4118 steel having a low silicon composition, is about 1540°F (838°C). During the cooling operation, the previously formed carbides increase in size and volume fraction. To achieve this, the cooling rate of the article from the carburizing to hardening temperature is carefully controlled. Advantageously, the cooling rate is about 1 F° (0.6 C°) to 20 F° (11 C°) per minute.

After cooling the surface of the article to the hardening temperature, it is desirable to maintain the article at the hardening temperature for a length of time sufficient to permit the temperature in the core of the article to cool to the hardening temperature. This process, known as equalizing, is identified in the process diagram shown in Fig. 7. Although desirable to minimize distortion, equalizing is not essential to obtain the desired surface microstructure. Depending on the article's mass and geometry, equalizing typically takes about 5 to 60 minutes to complete.

A carbonaceous gas atmosphere is advantageously maintained about the article during the preceding cooling and equalizing operations to prevent carbon depletion at the surface of the article. Both cooling and equalizing may be carried out in the second stage carburizing furnace, or in an interconnecting chamber, so that the same gas atmosphere used in carburizing may be simply cooled and circulated about the article.

After equalizing, the article is preferably directly quenched from the hardening temperature at a rate sufficiently rapid to transform the surface microstructure to martensite, retained austenite and carbides. For this, an oil medium is used with a quench rate high enough to assure the desired surface transformation.

If it is not convenient to directly quench the article immediately after equalizing, alternative steps represented by the dashed line in Fig. 7 have been developed. In one alternative, the article may be cooled and then reheated to the hardening temperature of the steel, equalized and quenched. In another alternative, if the mass and geometry of the article are sufficiently small, and the controlled cooling rate sufficiently slow, equalizing may not be required. If these conditions are present, the article may be quenched directly after the controlled slow cooling step.

Shafts and gears are exemplary of articles subjected to high bending loads, surface wear and contact fatigue. Samples of these articles have been successfully formed in accordance with the above described process. The total time required to complete the carburizing process, including the final quench, was typically only about 7 hrs. Thus, the

described process not only forms articles having improved metallurgical surface characteristics, but it is also much faster than prior art methods for forming desirable surface carbide structures.

Photomicrographs of a representative sample of an article embodying the present invention are shown in Figs. 1 and 2. Advantages of the present invention are emphasized by contrasting it with Figs. 3 to 5 which are photomicrographs of representative samples of articles formed differently as described below. Figs. 1 and 3, are photomicrographs of polished and unetched samples in which intergranular oxides are identified. Figs. 2 and 4 are the same samples as Figs. 1 and 3, but etched with a conventional 1% nital solution to better define the carbides in the microstructure. Fig. 5 is a sample of an article given a conventional heat treat, and polished and etched with 1% nital solution. In the photomicrographs, intergranular oxides appear as elongated black areas in the unetched samples. Typical intergranular oxide formations are identified by the reference numeral 10. Carbide structures appear in the photomicrographs of the etched samples as white areas, typical ones of which are identified by the reference numeral 12.

EXAMPLE 1

A representative sample of an article formed according to one embodiment of the present invention has a microstructure as shown in section, at 750X, in Figs. 1 and 2. The sample was cut from a modified wrought SAE 4118 steel having the following specific composition:

Carbon	0.23%
Manganese	0.99%
Phosphorus	0.009%
Sulfur	0.010%
Silicon	0.04%
Chromium	0.40%
Molybdenum	0.13%
Aluminum	0.029%
Copper	0.03%
Iron and residual elements	Balance

The sample was placed in a carburizing furnace having a conventional endothermic gas carburizing atmosphere comprising about 0.07% CO₂, 0.6% CH₄, 20% CO, 40% H₂, and the balance N₂. The furnace was preheated to a temperature of about 1700°F (927°C). The carbon potential of the atmosphere was maintained as close as the furnace control system permitted to the A_{cm}, the carbon in austenite solubility limit of the above described steel composition. The article was held in the furnace, at the same temperature and atmosphere for 4 1/2 hrs, and then gas quenched to 200°F (93°C). After cooling subsequent to the first carburizing operation, the article was placed in a carburizing furnace, preheated to about 1700°F (927°C), and the gas atmosphere controlled so that the carbon potential of the gas was greater than the saturation limit of carbon in the steel material's austenite phase. The article was held in the carbon rich atmosphere, at the same temperature, for about 30 minutes, and then slowly cooled over a period of about 60 minutes, i.e., at a rate of about 2.7 F°/minute (1.5 C°/minute) to 1540°F (838°C), the hardening temperature of the steel. The article was held at 1540°F (838°C) for about 40 minutes to allow the temperature of interior portions of the article to equalize to the hardening temperature. After equalizing, the article was directly quenched in an oil medium.

As may be seen in the photo of a micrographic sample of the article in Fig. 2, the article has a high volume ratio of carbides 12 formed on the surface. Direct measurement of the carbides on the surface immediately adjacent the band of black bedding material observable along the very top of the photomicrograph shows that carbides comprise about 50% of the article's surface area. Furthermore, as best shown in the unetched section shown in Fig. 1, the carbide rich area formed on the surface of the article is essentially free of intergranular oxides.

EXAMPLE 2

A second article, a micrographic sample of which is shown in Figs. 3 and 4, was formed from modified wrought SAE 4118 steel having a silicon content within the typical range of silicon for commercially produced heats of similar material. Specifically, the article in this example has the following composition:

Carbon	0.22%
Manganese	0.76%
Phosphorus	0.009%

(continued)

Sulfur	0.016%
Silicon	0.26%
Chromium	0.78%
Molybdenum	0.24%
Aluminum	0.033%
Copper	0.12%
Iron and residual elements	Balance

The material in this example has a silicon content of 0.26%, representative of silicon amounts normally present in conventional carburizing grade steels having a similar composition. The article formed of the above material was heat treated simultaneously with the article described in Example 1, i.e., according to the process of the present invention.

Fig. 4 illustrates the influence of increased amounts of silicon on surface carbide formation. There are virtually no carbides 12 on the surface of this sample. Furthermore, the carbide free surface layer is commensurate with the depth of the intergranular oxides 10. Therefore, even when employing a case carbide forming, nonconventional carburizing process, it is necessary to limit the amount of silicon in the base steel to assure the formation of significant carbide structures on the surface of the carburized article. Further, as best seen in Fig. 3, intergranular oxides 10 are present in significantly greater quantity than in the low silicon material of Fig. 1. The ratio of intergranular oxides to length of article surface shown in the field of view is about .50:1. That is, when measured along their major axes, the length of the intergranular oxides visible in Fig. 3 total about 50% of the length of the surface in the same field of view.

EXAMPLE 3

A sample of an article having a modified SAE 4118H composition with 0.26% silicon, and given a conventional single stage carburizing treatment, is shown in Fig. 5. The article has the following composition:

Carbon	0.21%
Manganese	0.93%
Phosphorus	0.011%
Sulfur	0.013%
Silicon	0.26%
Chromium	0.95%
Molybdenum	0.34%
Aluminum	0.032%
Copper	0.06%
Iron and residual elements	Balance

This example illustrates the metallurgical surface characteristics of conventionally treated standard carburizing grade steel in which case carbides were formed. In particular, there is a typical carbide depleted zone extending about .02 mm below the surface of the article. Within this zone there are a significant number of oxide formations, both intergranular and intragranular. As is well known, intergranular oxides 10 have a deleterious affect on bending fatigue properties. Furthermore, because there are no carbides on the surface, about .02 mm of the article's outer surface must be worn away before the benefit of the carbide structures can be used advantageously.

As can be seen from the above examples there are several features of the described embodiment. First, the steel material from which an article is formed must contain no more than 0.10% silicon. Limiting the silicon content to this amount not only inhibits the formation of intergranular oxides, but also promotes and enhances the formation of desirable carbide structures on the surface. Secondly, a high ratio of carbides are formed on the outer surface of the article, and not at some finite depth, e.g. 0.1 mm or more, below the surface. To accomplish this most advantageously, the article is carburized in the manner described to assure the formation of a high density of carbides well dispersed in austenite on the article surface prior to growth by controlled cooling. As seen from Examples 2 and 3, if either of these two features are missing, the carburized article will not have an outer surface which is essentially free of intergranular oxides and on which a high volume ratio of carbides are formed.

EXAMPLE 4

A number of samples having similar base compositions except for silicon amounts, and in two examples, chromium, were prepared and heat treated by the carburizing process described in Example 1, above. The samples were then cut, polished, and analyzed for the presence of intergranular oxides and surface carbides. Specifically, nine samples having compositions as listed below were tested:

Sample No.	-----COMPOSITION-----							*SURFACE RATINGS*	
	(Balance Fe and residual elements)							Intgr. Oxides	Carbides
	%C	%Mn	%Cr	%Mo	%Al	%Cu	%Si	% ratio	% ratio
a	0.22	0.67	0.89	0.19	0.003	0.02	0.01	0%	51%
b	.23	.98	.43	.13	.040	.03	.04	1	45
c	.23	.89	.45	.21	.033	.03	.06	6	42
d	.23	.84	.45	.20	.029	.03	.09	8	27
e	.23	.83	.44	.20	.027	.03	.11	13	10
f	.22	.80	.44	.20	.030	.03	.12	17	17
g	.22	.78	.44	.20	.025	.03	.14	26	12
h	.23	.77	.45	.20	.023	.03	.18	25	8
i	.22	.76	.78	.24	.033	.12	.26	37	0

The total length of intergranular oxides, measured along the major axes of the oxides in three equally-sized representative fields in a section of each sample, were averaged and expressed as a % ratio to the length of the article's outer surface in the field of view. Similarly, the percent of linear surface at which carbides are present was measured in three equally-sized representative fields in a section of each sample, averaged, and expressed as a % ratio to the length of the article surface in the representative field of view.

The results of the above measurements are shown in a graphical form in Fig. 6. The % ratio of oxides for each of the above samples is represented on the graph by a small circular symbol. The scale for % silicon is shown along the base of the graph, and the scale for % ratio of oxides is shown along the right vertical side. As shown by the solid line representing a reasonable fit for the plotted data points, the amount of intergranular oxides increases with increasing silicon content in the samples. The data indicates that for these particular samples, the silicon content may be as high as .11% or .12% and still yield less than about a 15% ratio of intergranular oxides with respect to a representative surface length.

In similar fashion, the % ratio of carbides for each of the above samples is represented on the graph by a small triangular-shaped symbol, and plotted according to the scale shown along the left vertical side of the graph. A line, representing a reasonable fit of the individual data points, readily shows that the % ratio of carbides with the respect to the surface generally decreases with increases in silicon in the samples. Sample e appears to have a lower carbide ratio than either sample d or f, respectively representing lower and higher silicon amounts on each side of sample e. For this reason, although the integrated data suggests that, for the above representative group of samples, a silicon content of about .11% or .12% will provide a desirable carbide level of about 20%, a preferred limit of about .10% silicon will more consistently assure that the carbide to surface ratio in the carburized article will be above 20%.

Industrial Applicability

Articles formed according to the above are particularly useful as gears, couplings, shafts, bearings, and similar articles subjected to a combination of high bending loads, surface wear and contact fatigue.

It has been found that low silicon steel with restricted residual amounts of copper is priced about the same as conventional carburizing grade alloy steels. Accordingly, since the process is more economical than many conventional processes, it is felt that the process may have wide applicability and the resulting articles may also be widely used where carburized articles are required.

It is now deemed apparent that there has been described a carburizing process for low silicon steel material to form a high ratio of carbides on the outer surface of an article substantially free of intergranular surface oxides. It is known that intergranular surface oxides reduce the bending fatigue strength of articles. It is also known that high density carbide structures have high hardness and contribute to increased wear and contact fatigue life. As a result of preventing undesirable surface oxide formations and simultaneously providing beneficial surface carbide structures, the bending fatigue strength, wear properties, and contact fatigue properties of articles formed as described are greatly enhanced.

Claims

1. A process for forming a steel article having a carburized surface that does not require any additional finishing or machining, the steel article being formed of a composition having, by weight percent, from about 0.08% to about 0.35% carbon, from about 0.3% to about 1.7% manganese, not more than 0.10% silicon, not more than 0.15% copper less than 1.1% chromium, from about 0.2% to about 2.5% carbide forming elements including said chromium, less than 6% additional hardenability agents, less than 1% grain refining elements, and the balance iron and trace impurities, said process comprising the steps of:
 - carburizing said article at a predetermined temperature and for a period of time sufficient to form a surface comprising austenite and a high density of carbides dispersed in said austenite;
 - quenching said carburized article to transform the surface microstructure to martensite, retained austenite and carbides; and,
 - controlling the steps of carburizing and quenching so that said carbides constitute at least 20% of said surface, and said surface is free of any detrimental intergranular oxides.
2. A process for forming a carburized steel article, as set forth in Claim 1, wherein the step of quenching the carburized article includes quenching in an oil medium.
3. A process for forming a carburized steel article, as set forth in Claim 1, including prior to quenching, the step of controllable cooling at least said predefined surface of the carburized article from a predetermined carburizing temperature to a predetermined hardening temperature at a rate sufficient to assure that said carbides increase in size and form a higher surface fraction of carbides.
4. A process for forming a carburized steel article, as set forth in Claim 3, wherein the step of cooling said carburized article to the hardening temperature includes reducing the temperature of the furnace atmosphere at a rate of from about 1 °F/minute (0.6 °C/minute) to about 20 °F/minute (11 °C/minute).
5. A process for forming a carburized steel article, as set forth in Claim 3, including after cooling to the hardening temperature, the step of maintaining said carburized article at the hardening temperature of the steel material for a time sufficient to permit the core temperature of the article to equalize a said hardening temperature.
6. A process for forming a carburized steel article, as set forth in Claim 5, wherein the step of maintaining said carburized article at the hardening temperature of the steel material includes maintaining the article at a temperature of about 1540 °F (838 °C) for from about 5 minutes to about 60 minutes.
7. A process for forming a carburized steel article, as set forth in Claim 1, wherein the step of carburizing said article includes a first stage in which the article is placed in a preheated furnace having a temperature of from about 1550 °F (843 °C) to about 1850 °F (1010 °C) and an atmosphere in which the carbon content is maintained in equilibrium with austenite saturated with carbon at the furnace temperature, and held in said furnace for a period of time sufficient to form from about 75% to about 95% of the final case depth.
8. A process for forming a carburized steel article, as set forth in Claim 7, wherein during said first stage the furnace temperature is maintained at about 1700 °F (927 °C) and said article is held in said furnace from about 4 to about 5 hours.
9. A process for forming a carburized steel article, as set forth in Claim 7, wherein the step of carburizing includes gas quenching said article after the first stage carburizing, said quenching being at a rate sufficient to suppress carbide nucleation in the carburized case and maintaining said rate until the case temperature is below the temperature at which the transformation of austenite is essentially complete.
10. A process for forming a carburized steel article, as set forth in Claim 7, wherein the step of carburizing the article includes a second stage in which the article is placed in a preheated furnace having a temperature of from about 1550 °F (843 °C) to about 1850 °F (1010 °C) and an atmosphere in which the carbon content is maintained at a level greater than the saturation limit of carbon in austenite at the furnace temperature, and held in said furnace for a period of time sufficient to transform the surface to an essentially austenitic microstructure having a high density of surface carbides dispersed in said austenite.

11. A process for forming a carburized steel article, as set forth in Claim 10, wherein during the second stage, the furnace temperature is maintained at about 1700 °F (927 °C) and the article is held in said furnace for from about 15 minutes to about 60 minutes.

12. A carburized low silicon steel article having a composition containing by weight percent, from about 0.08% to about 0.35% carbon, from about 0.3% to about 1.7% manganese, not more than 0.10% silicon, less than 1.1% chromium, from about 0.2% to about 2.5% carbide forming elements including said chromium, less than 6% additional hardenability agents, less than 1% grain refining elements, and a copper content of not more than 0.15%, and having a carburized surface that, without any material removal therefrom, is free of any detrimental intergranular oxides and has carbides on said carburized surface which constitute at least 20% of the area of the carburized surface, and does not require further finishing or machining.

13. A carburized low silicon steel article, as set forth in Claim 13, wherein the total length of any intergranular oxides in a representative cross-section of the article is not more than about 15% of the length of the outer surface of the article in said cross section.

Patentansprüche

1. Verfahren zum Bilden eines Stahlgegenstands mit einer carburierten Oberfläche, die keine zusätzliche Endbearbeitung oder maschinenmäßige Bearbeitung erfordert, wobei der Stahlgegenstand aus einer Zusammensetzung gebildet ist, der in Gewichtsprozent folgendes aufweist: von ungefähr 0,08 % bis ungefähr 0,35 % Kohlenstoff, von ungefähr 0,3 % bis ungefähr 1,7 % Mangan, nicht mehr als 0,10 % Silicium, nicht mehr als 0,15 % Kupfer, weniger als 1,1 % Chrom, von ungefähr 0,2 % bis ungefähr 2,5 % carbidbildende Elemente, und zwar einschließlich dem Chrom, weniger als 6 % zusätzliche Härtungsmittel, weniger als 1 % kornverfeinernde Elemente, und wobei der Rest Eisen und Spurenverunreinigungen ist, wobei das Verfahren folgende Schritte aufweist:

Carburieren des Gegenstands bei einer bestimmten Temperatur und für eine Zeitperiode, die ausreicht, um eine Oberfläche zu bilden, die Austenit aufweist und eine hohe Dichte von Carbiden, die in dem Austenit verteilt bzw. dispergiert sind;

Abschrecken des carburierten Gegenstandes, um die Oberflächen-Mikrostruktur zu Martensit, zurückgehaltenem Austenit und Carbiden umzuwandeln; und

Steuern der Schritte des Carburierens und des Abschreckens, so daß die Carbide mindestens 20 % der Oberfläche aufbauen, und die Oberfläche frei von irgendwelchen schädlichen intergranularen Oxiden ist.

2. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 1, wobei der Schritt des Abschreckens des carburierten Gegenstands das Abschrecken in einem Ölmedium aufweist.

3. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 1, das vor dem Abschrecken folgenden Schritt aufweist: Steuerbares Abkühlen von wenigstens der vordefinierten Oberfläche des carburierten Gegenstandes von einer vorbestimmten Carburierungs-Temperatur zu einer vorbestimmten Härtungs-Temperatur, und zwar bei einer Rate, die ausreicht, um sicherzustellen, daß die Carbide in Größe zunehmen und einen höheren Oberflächenbruchteil von Carbiden bilden.

4. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 3, wobei der Schritt des Abkühlens des carburierten Gegenstands auf die Härtungs-Temperatur folgendes aufweist: Reduzieren der Temperatur der Ofen-Atmosphäre bei einer Rate von ungefähr 1°F/Minute (0,6°C/Minute) bis ungefähr 20°F/Minute (11°C/Minute).

5. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 3, das ferner nach dem Kühlen auf die Härtungs-Temperatur folgenden Schritt aufweist: Halten des carburierten Gegenstands bei der Härtungs-Temperatur des Stahlmaterials, und zwar für eine Zeit, die ausreicht, es der Kern-Temperatur des Gegenstands zu gestatten, die Härtungs-Temperatur auszugleichen.

6. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 5, wobei der Schritt des Haltens des carburierten Gegenstands bei der Härtungs-Temperatur des Stahlmaterials folgenden Schritt aufweist: Halten des Gegenstands bei einer Temperatur von ungefähr 1540°F (838°C) für von ungefähr 5 Minuten bis ungefähr 60 Minuten.

7. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 1, wobei der Schritt des Carburierens des Gegenstands folgendes aufweist: eine erste Stufe, in der der Gegenstand in einem vorgeheizten Ofen mit einer Temperatur von ungefähr 1550°F (843°C) bis ungefähr 1850°F (1010°C) und einer Atmosphäre, in der der Kohlenstoffgehalt im Gleichgewicht mit kohlenstoffsaturiertem bzw. -gesättigtem Austenit gehalten wird, und zwar bei der Ofentemperatur, plaziert wird, unter dem Ofen für eine Zeitperiode gehalten wird, die ausreicht, um von ungefähr 75 % bis ungefähr 95 % der schließlichen Falltiefe zu bilden.
8. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 7, wobei während der ersten Stufe die Ofentemperatur bei ungefähr 1700°F (927°C) gehalten wird, und der Gegenstand in dem Ofen von ungefähr 4 bis ungefähr 5 Stunden gehalten wird.
9. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 7, wobei der Schritt des Carburierens folgendes aufweist: Gasabschrecken des Gegenstands nach dem Carburieren der ersten Stufe, wobei das Abschrecken bei einer Rate erfolgt, die ausreicht, um Carbide-Nukleation bzw. -Kernbildung in dem carburierten Fall zu unterdrücken und Halten der Rate, bis die Falltemperatur unterhalb der Temperatur ist, bei der die Umwandlung von Austenit im wesentlichen vollständig ist.
10. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 7, wobei der Schritt des Carburierens des Gegenstands folgendes aufweist: eine zweite Stufe, in der der Gegenstand in einem vorgeheizten Ofen mit einer Temperatur von ungefähr 1550°F (843°C) bis ungefähr 1850°F (1010°C) und einer Atmosphäre, in der der Kohlenstoffgehalt auf einem Niveau größer als die Sättigungsgrenze von Kohlenstoff in Austenit bei der Ofentemperatur gehalten wird, plaziert wird, und in dem Ofen für eine Zeitperiode gehalten wird, die ausreicht, um die Oberfläche in eine im wesentlichen austenitische Mikrostruktur umzuwandeln, und zwar mit einer hohen Dichte von Oberflächen-Carbiden, die in dem Austenit verteilt bzw. dispergiert sind.
11. Verfahren zum Bilden eines carburierten Stahlgegenstands gemäß Anspruch 10, wobei während der zweiten Stufe die Ofentemperatur bei ungefähr 1700°F (927°C) gehalten wird, und wobei der Gegenstand in dem Ofen für von ungefähr 15 Minuten bis ungefähr 60 Minuten gehalten wird.
12. Carburiertes Niedrig-Silicium-Stahlgegenstand mit einer Zusammensetzung, die an Gewichtsprozent folgendes aufweist: von ungefähr 0,08 % bis ungefähr 0,35 % Kohlenstoff, von ungefähr 0,3 % bis ungefähr 1,7 % Mangan, nicht mehr als 0,10 % Silicium, weniger als 1,1 % Chrom, von ungefähr 0,2 % bis ungefähr 2,5 % carbidbildende Elemente, und zwar einschließlich dem Chrom, weniger als 6 % zusätzliche Härtungsmittel, weniger als 1 % kornverfeinernde Elemente, und einen Kupfergehalt von nicht mehr als 0,15 %, wobei der Gegenstand eine carburierte Oberfläche besitzt, die ohne irgendeine Entfernung von Material davon frei von irgendwelchen schädlichen intergranularen Oxiden ist und Carbide auf der carburierten Oberfläche besitzt, die mindestens 20 % des Gebiets bzw. der Fläche der carburierten Oberfläche aufbauen, und was nicht eine weitere Endbearbeitung oder maschinenmäßige Bearbeitung erfordert.
13. Carburiertes Niedrig-Silicium-Stahlgegenstand nach Anspruch 13, wobei die Gesamtlänge von irgendwelchen intergranularen Oxiden in einem repräsentativen Querschnitt des Gegenstands nicht mehr als ungefähr 15 % der Länge der Außenoberfläche des Gegenstands in dem Querschnitt ist.

Revendications

1. Procédé de formation d'un produit en acier ayant une surface cémentée qui ne nécessite pas de finition ou d'usinage supplémentaire, le produit en acier ayant une composition comportant, en pourcentage pondéral, d'environ 0,08 % à environ 0,35 % de carbone, d'environ 0,3 % à environ 1,7 % de manganèse, pas plus de 0,10 % de silicium, pas plus de 0,15 % de cuivre, moins de 1,1 % de chrome, d'environ 0,2 % à environ 2,5 % d'éléments formant des carbures incluant le chrome, moins de 6 % d'agents de durcissement supplémentaires, moins de 1 % d'éléments d'affinage de grain, et le reste en fer et en traces d'impuretés, le procédé comprenant les étapes suivantes :

cémenter le produit à une température prédéterminée et pendant une durée suffisante pour former une surface comprenant de l'austénite et une haute densité de carbures dispersés dans ladite austénite ;
tremper le produit cémenté pour transformer la microstructure de surface en martensite, en austénite maintenue et en carbure ; et

contrôler les étapes de cémentation et de trempe de sorte que les carbures constituent au moins 20 % de ladite surface, et que la surface soit exempte de tout oxyde nuisible intragranulaire.

- 5 2. Procédé de formation d'un produit en acier cémenté selon la revendication 1, dans lequel l'étape de trempe du produit cémenté comprend une trempe dans de l'huile.
- 10 3. Procédé de formation d'un produit en acier cémenté selon la revendication 1, comprenant, avant la trempe, l'étape consistant à refroidir de façon contrôlable au moins la surface prédéfinie du produit cémenté à partir d'une température de cémentation prédéterminée jusqu'à une température de durcissement prédéterminée, à une vitesse suffisante pour assurer que les carbures augmentent en dimension et forment une fraction superficielle plus élevée de carbure.
- 15 4. Procédé de formation d'un produit en acier cémenté selon la revendication 3, dans lequel l'étape de refroidissement du produit cémenté jusqu'à la température de durcissement comprend l'étape de réduction de la température de l'atmosphère du four à une vitesse allant d'environ 1°F/minute (0,6°C/minute) jusqu'à environ 20°F/minute (11°C/minute).
- 20 5. Procédé de formation d'un produit en acier cémenté selon la revendication 3, comprenant, après le refroidissement à la température de durcissement, l'étape consistant à maintenir le produit cémenté à la température de durcissement de l'acier pendant une durée suffisante pour permettre à la température du coeur du produit d'être égale à la température de durcissement.
- 25 6. Procédé de formation d'un produit en acier cémenté selon la revendication 5, dans lequel l'étape consistant à maintenir le produit cémenté à la température de durcissement de l'acier comprend l'étape consistant à maintenir le produit à une température d'environ 1540°F (838°C) d'environ 5 à environ 60 minutes.
- 30 7. Procédé de formation d'un produit en acier cémenté selon la revendication 1, dans lequel l'étape de cémentation du produit comprend une première étape pendant laquelle le produit est placé dans un four préchauffé ayant une température d'environ 1550°F (843°C) à environ 1850°F (1010°C) et une atmosphère dans laquelle le contenu en carbone est maintenu en équilibre avec l'austénite saturée en carbone à la température du four, et maintenu dans le four pendant une durée suffisante pour former d'environ 75 % à environ 95 % de la profondeur de cémentation finale.
- 35 8. Procédé de formation d'un produit en acier cémenté selon la revendication 7, dans lequel, pendant ladite première étape, la température du four est maintenue à environ 1700°F (927°C) et le produit est maintenu dans le four pendant environ 4 à 5 heures.
- 40 9. Procédé de formation d'un produit en acier cémenté selon la revendication 7, dans lequel l'étape de cémentation comprend une trempe dans un gaz du produit après la cémentation de première étape, la trempe étant faite à une vitesse suffisante pour supprimer la nucléation de carbure dans la zone cémentée et maintenir la vitesse jusqu'à ce que la température de cémentation soit inférieure à la température à laquelle la transformation d'austénite est sensiblement complète.
- 45 10. Procédé de formation d'un produit en acier cémenté selon la revendication 7, dans lequel l'étape de cémentation du produit comprend une seconde étape pendant laquelle le produit est placé dans un four préchauffé ayant une température d'environ 1550°F (843°C) à environ 1850°F (1010°C) et une atmosphère dans laquelle le contenu en carbone est maintenu à un niveau supérieur à la limite de saturation du carbone dans l'austénite à la température du four, et maintenu dans le four pendant une durée suffisante pour transformer la surface en une microstructure essentiellement austénitique ayant une densité élevée de carbures superficiels dispersés dans l'austénite.
- 50 11. Procédé de formation d'un produit en acier cémenté selon la revendication 10, dans lequel, pendant la seconde étape, la température du four est maintenue à environ 1700°F (927°C) et le produit est maintenu dans le four pendant environ 15 à environ 60 minutes.
- 55 12. Produit en acier cémenté à faible teneur en silicium ayant une composition contenant, en pourcentage pondéral, d'environ 0,08 % à environ 0,35 % de carbone, d'environ 0,3 % à environ 1,7 % de manganèse, pas plus de 0,1 % de silicium, moins de 1,1 % de chrome, d'environ 0,2 % à environ 2,5 % d'éléments formant des carbures comprenant le chrome, moins de 6 % d'agents de durcissement supplémentaires, moins de 1 % d'éléments d'af-

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finage de grain, et un contenu en cuivre non supérieur à 0,15 %, et ayant une surface cémentée qui, sans aucun revêtement de matériau, est exempte de tout oxyde intragranulaire néfaste et comporte des carbures sur la surface cémentée qui constituent au moins 20 % de la zone de surface cémentée, et ne nécessite pas de finissage ou d'usinage ultérieur.

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- 13.** Produit en acier cémenté à faible teneur en silicium selon la revendication 12, dans lequel la longueur totale des oxydes intragranulaires dans une section représentative du produit n'est pas supérieure à environ 15 % de la longueur de la surface externe du produit dans la section.

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Fig. 1

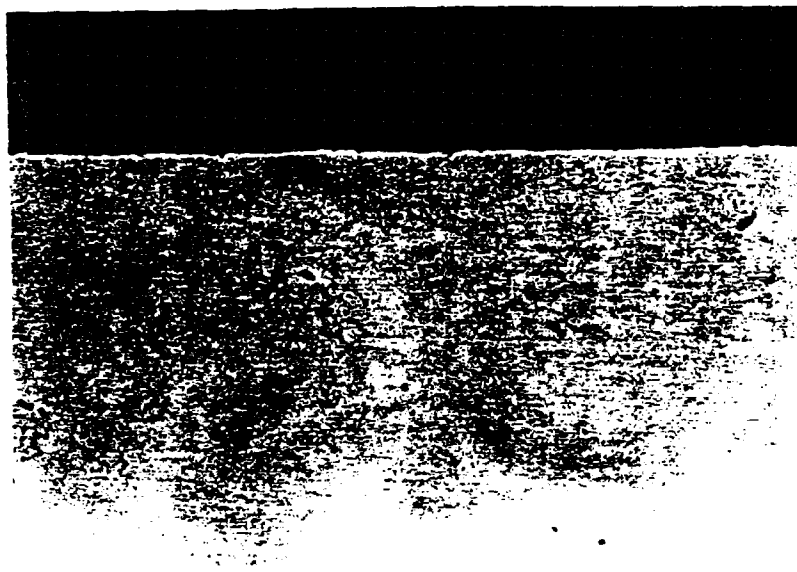
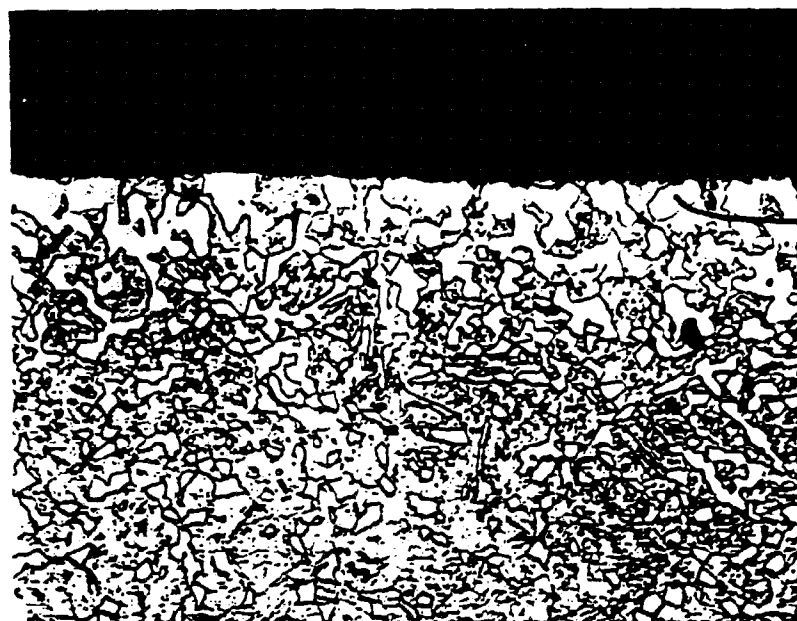


Fig. 2



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FIG. 3.

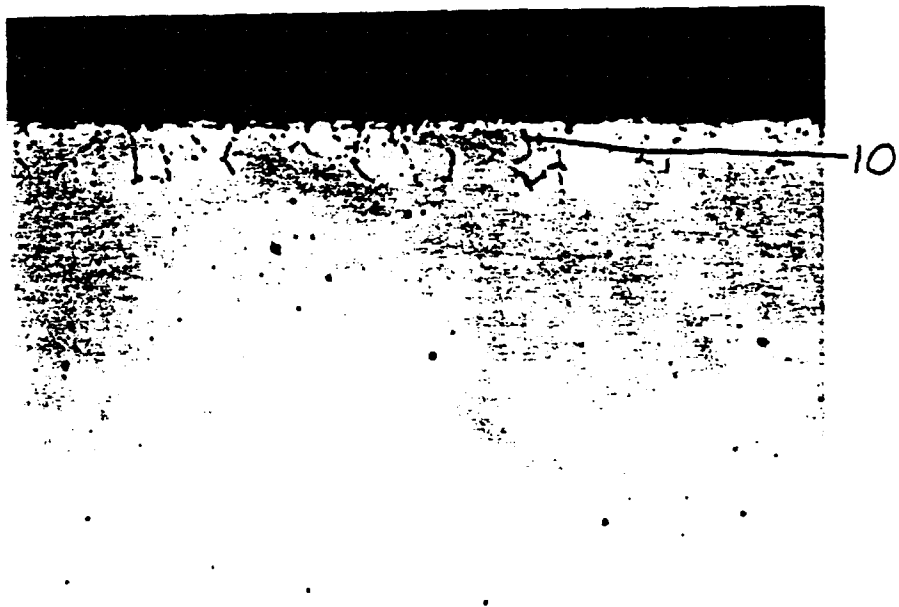
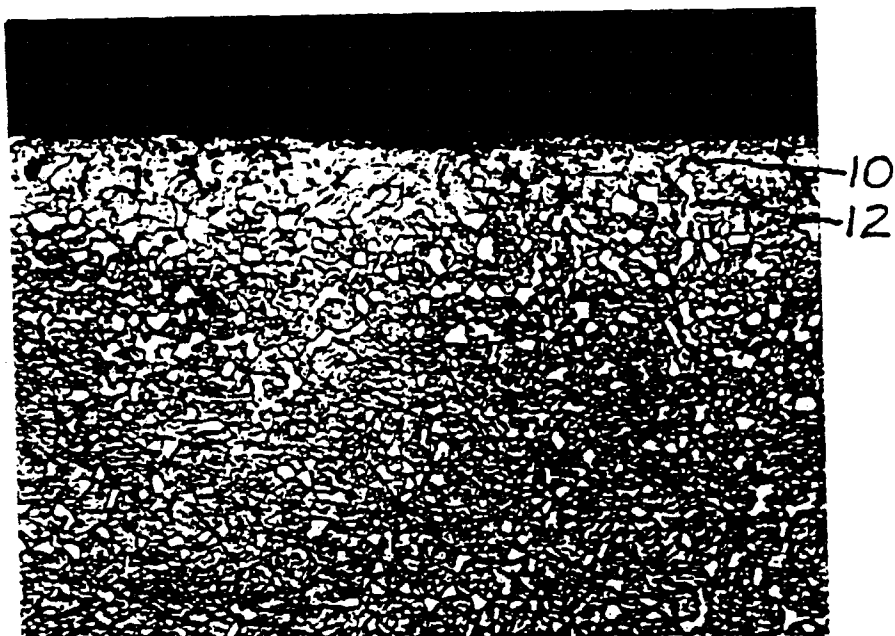


FIG. 4.



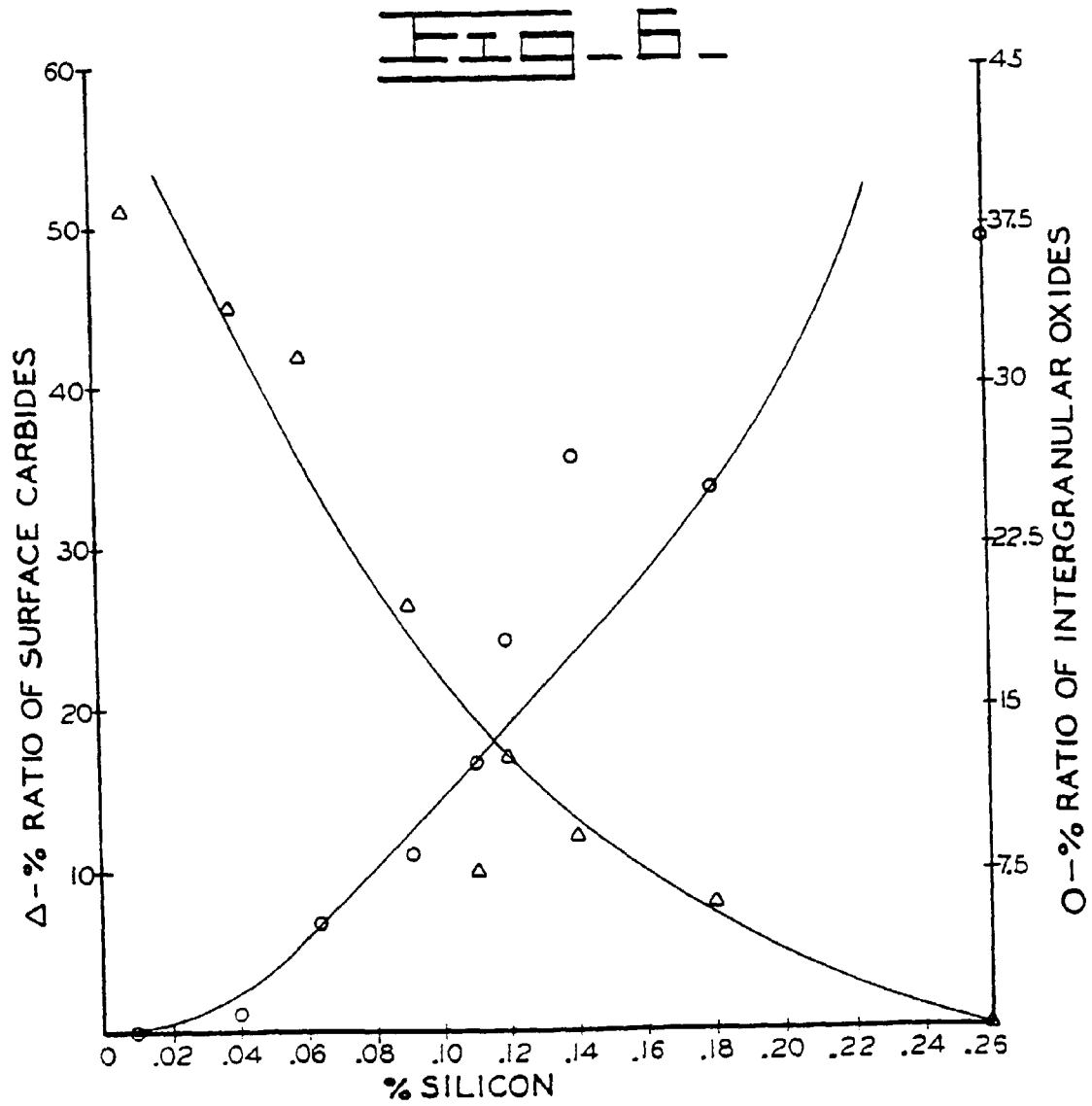
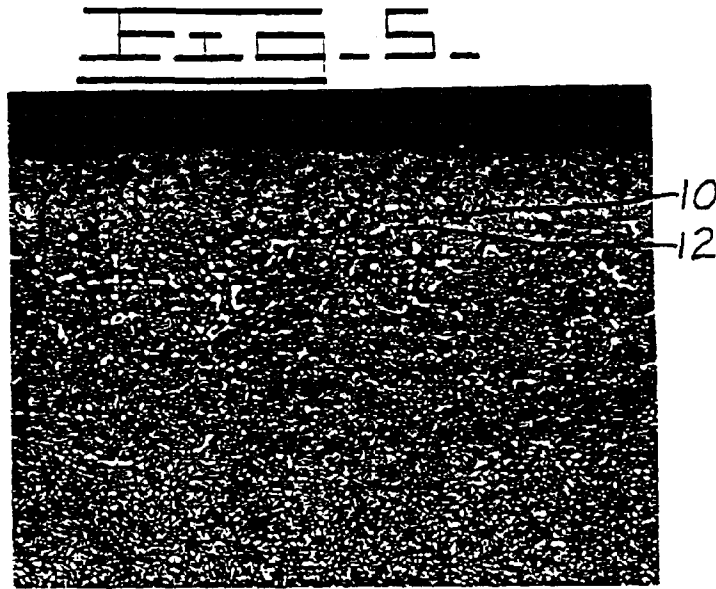


FIG - 7 -

