PROCESS FOR CARBURIZING HIGH ALLOY STEELS


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References Cited
OTHER PUBLICATIONS

ABSTRACT
A process for carburizing high alloy steels comprises heating the steel at a high temperature in an oxidizing atmosphere to form a high temperature oxide on the steel surface and carburizing the steel containing the high temperature oxide. Once the high temperature oxide is formed on the steel surface, the steel can be carburized at any time thereafter.

9 Claims, No Drawings
PROCESS FOR CARBURIZING HIGH ALLOY STEELS

This invention relates to a process for carburizing high alloy steels, and more particularly relates to an improved process for carburizing such steels which overcomes the problems caused by the passive metal oxide layer that is usually associated with such steels.

The hardenability of a steel, or the ability to obtain hardness below the surface of the steel, is a function of its alloy content. When the alloy content is below 2 percent, a steel is commonly referred to as low alloy; above 2 percent, a steel is commonly referred to as high alloy. When the combination of carbon and alloy content are sufficient to achieve 90-95 percent martensite at the center of a section when the steel is heat treated by normal means, the steel alloy is said to be through hardened.

The residual stress pattern generally exhibited by throughhardened steels comprises tensile stresses on the surface and to a great depth and compressive stresses near the center of the section.

Bearings, gears and other metallic members which move in contact relative to other members are subject to alternating stresses and are commonly said to be loaded in fatigue. It is recognized that the fatigue strength of parts is enhanced by the presence of compressive stresses at the surface. Gears, bearings and similar parts ideally should have a residual stress pattern of compressive stresses on their surfaces and tensile stresses in the core or center section. The surface of such parts should exhibit good resistance to surface and bending fatigue and have good strength and toughness. Thus, the stress pattern developed in throughhardened steels is reverse of that required for bearing and gear applications.

Specifically, the surface tensile stresses developed in throughhardened steels are deleterious to rolling contact and bending fatigue life requirements normally associated with bearings and gears. The stress pattern developed in through-hardened steel thus detracts rather than enhances the fatigue life of bearings and gears made from them.

It is well known that alloys which possess very high hardness and are through-hardening tend to be brittle and susceptible to rapid fracture under load. An article or part made entirely from such an alloy therefore might not perform satisfactorily under impact or other types of rapidly applied stresses. This is particularly true in steels where high carbon contents are employed to obtain high hardness.

The process of case hardening by carburizing steel and then hardening it has been developed to overcome the inherent problems caused by high carbon contents in steels used for bearing, gear, and similar applications. In one process for case hardening steels, the surface of an article or part made from a low-carbon steel is enriched in carbon by heating the article or part in contact with a carburizing medium. During this treatment, carbon diffuses into the low-carbon steel to produce an enriched layer, usually between 0.005 inch and 0.150 inch deep depending upon the ultimate use for the article or part. The carbon-enriched layer, known as the case, usually contains about 0.6 percent to about 1.3 percent carbon, while the low-carbon portion remaining, known as the core, usually contains only about 0.05 percent to about 0.30 percent carbon.

The actual hardening of the case is effected by cooling the carburized article or part from a temperature at which the carburized case is completely or substantially austenite (austenitizing temperature) to a temperature at which the case transforms to martensite. The attainment of this austenitizing or hardening temperature may be effected in several ways. The article or part can be carburized at the austenitizing temperature or at a high temperature and cooled directly to cause transformation to martensite; or the article or part can be reheated to an austenitizing temperature from room temperature after previous carburizing or refining heat treatments.

The aim in cooling from the austenitizing temperature is to produce a hard martensitic microstructure in the carbon-enriched zone at the surface. Most case-hardened steels need to be quenched in oil, water or molten salts at low temperatures in order to minimize or suppress the transformation of austenite in the case to undesirably soft microstructures which occur at intermediate temperatures. The resulting martensitic case is very hard, having a hardness above Rockwell C 50 and usually above Rockwell C 60.

On the other hand, the low-carbon core remains at a lower hardness level after quenching and thereby retains a high resistance to impact and good toughness. The effect of case hardening is, therefore, to produce a very hard, wear and score resistant surface (case) and to combine this with a core which has good ductility and toughness, although lower hardness. Carburized steel parts have a residual stress pattern of compressive stresses on their surfaces and tensile stresses in the core or center section and are thus especially useful in gear, bearing, and similar applications.

Where a high surface wear resistance and a high degree of toughness are required in steel, the steel is usually alloyed with a percentage of alloying elements, usually at least 2 percent alloying elements. High alloy steels normally contain chromium in amounts of from about 2 percent by weight to about 25 percent by weight or higher to improve toughness and wear resistance. Other alloying ingredients can be added to high alloy steels to improve their usefulness for particular purposes. For example, such metals as vanadium, tungsten, and molybdenum can be added to produce steels which retain their hardness at high temperatures, commonly referred to as hot hardness steels.

In the past, attempts to case-harden high alloy steels by conventional carburizing techniques to make them useful in bearing, gear, and similar applications have been largely unsuccessful because of the formation of a heterogeneous passive metal oxide on the steel surface which prevents the uniform diffusion of carbon into the steel. Carburization, to be effective, must be accomplished in such a manner that a layer of carbon is diffused uniformly throughout the exposed surface.

The passive metal oxide, believed to be a chromium oxide, forms at room temperature and, unless the high alloy steels are given special preliminary treatments, causes the formation of a case that is too shallow or spotty or of too low a degree of hardness. Thus, carburized high alloy steels are generally unsatisfactory for use in gear or bearing applications because they con-
tain localized surface areas that are much softer than required for these applications.

The prior art has often sought to overcome this problem by pre-treating the high alloy steel to remove the passive film by various techniques and then immediately carburizing. Prior art methods of removing the passive films, however, have suffered from numerous disadvantages. For example, one such method involves cleaning the steel surface with abrasive particles. In this process, the cleaned steel pieces must be introduced into the carburizing furnace immediately following the cleaning treatment because failure to do so will result in the passive film reforming upon exposure to air.

The passive oxide film will usually reform in about one or two hours, and the carburizing treatment must be begun within this short period of time to avoid adverse effects. Most prior art processes for removing the passive film suffer from this disadvantage. Still other methods for removing passive films involve extra operations, additional equipment, and increased costs.

Accordingly, it is a primary object of this invention to provide a new and improved method for carburizing high alloy steels.

Another object of this invention is to provide a method for carburizing high alloy steels which overcomes the problems caused by the formation of a low temperature passive oxide film on such steels.

A further object of the invention is to provide a method for carburizing high alloy steels that allows the steel to be stored for a considerable length of time before it is carburized.

A still further object of this invention is to provide a carburizing method that does not require any special equipment and which makes use of conventional carburizing equipment and techniques.

Additional objects and advantages of the invention will be set forth in part in the description which follows and in part will be obvious from the description or can be learned by practice of the invention. The objects and advantages are achieved by means of the instrumentality, processes, and combinations particularly pointed out in the appended claims.

To achieve the foregoing objects and in accordance with its purpose, this invention provides a method for carburizing a high alloy steel which comprises heating the steel at a high temperature in an oxidizing atmosphere to form a high temperature oxide on the steel surface and carburizing the steel containing the high temperature oxide.

It has been found, in accordance with the present invention, that a high temperature oxide formed on steel surfaces is not resistant to carburization and permits carbon to uniformly diffuse into the surface of the steel during carburization to provide a hard, uniform case. Further, the high temperature oxide prevents reformation of the low temperature passive film which inhibits the carburization process. The high temperature oxide formed on the steel is stable in air and remains on the steel for long periods of time, for example, at least one week or longer. The high temperature oxide thus permits carburization to be deferred to a convenient time.

Preferably, the steel is oxidized at a temperature of about 1750°F to 1850°F, and most preferably at about 1800°F. The steel is oxidized for about 30 minutes to about 4 hours, preferably from 30 minutes to 1 hour. The carburizing medium used in the carburization has a carbon potential of from 0.6 to 1.5 percent preferably from 0.85 to 0.95 percent.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory but are not restrictive of the invention.

In accordance with the invention, a high alloy steel is heated at a high temperature in an oxidizing atmosphere to form a high temperature oxide on the steel surface. The oxidizing atmosphere can be air or a combination of gases which maintain an oxidizing potential and result in the formation of an oxide scale on high alloy steels when heated at the temperature range described hereafter. The oxidizing atmosphere can be provided by conventional furnace equipment. The furnace preferably is provided with a lid which can be closed after the steel is placed in the furnace to insure that a uniform temperature is obtained throughout the furnace. The furnace can be provided with forced or positive pressure air during the oxidation to insure satisfactory oxidizing conditions. It also can operate under normal, still-air conditions.

The steels treated in accordance with this invention are heat hardenable, high alloy steels generally having an alloy content of at least 2 percent, and preferably at least 5 percent, to impart wear resistance and increased toughness. The steels generally contain chromium in a range of from 2 percent to 25 percent or greater as a basic alloying element. They contain 0.05 percent to 0.3 percent carbon.

Steels used in the present invention preferably are martensitic type steels and include the Vasco X2 and modified Vasco X2 steels sold by Teledyne Vasco, Latrobe, Pennsylvania, modified H11 tool steel; and stainless steels, such as 416 stainless steel. These steels, in addition to being high alloy steels, are hot hardness steels having the ability to retain a large percentage of their room temperature strength at elevated temperature. Typical compositions of a number of steels useful in the present invention are listed in Table 1 below.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Modified Vasco X2</th>
<th>Vasco X2</th>
<th>Modified H11 Tool Steel</th>
<th>416 Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>.13</td>
<td>.16</td>
<td>.20</td>
<td>.25</td>
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<tr>
<td>Silicon</td>
<td>.80</td>
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<td>Manganese</td>
<td>.20</td>
<td>.40</td>
<td>.20</td>
<td>.40</td>
</tr>
<tr>
<td>Sulphur</td>
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<td>max.</td>
<td>.015</td>
<td>max.</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>.015</td>
<td>max.</td>
<td>.015</td>
<td>max.</td>
</tr>
<tr>
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<td>-1.50</td>
<td>1.20</td>
<td>-1.50</td>
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<tr>
<td>Vanadium</td>
<td>.40</td>
<td>- .50</td>
<td>.40</td>
<td>- .50</td>
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<td>Molybdenum</td>
<td>1.30</td>
<td>-1.50</td>
<td>1.30</td>
<td>-1.50</td>
</tr>
</tbody>
</table>

*When selenium is absent, the sulphur content shall be 0.15-0.40.
Other high alloy steels that can be used in the present invention include high speed and tool steels which contain greater than 2% chromium.

The steels useful in the present invention are produced and processed in accordance with well known procedures. The steels are preferably melted in electric furnaces or vacuum melted followed by forging, annealing and rough machining into gears, bearings, and other parts. The steels are generally carburized after rough machining. In accordance with the present invention, the rough machined steels are introduced into the high temperature oxidizing atmosphere before carburization.

During the oxidation step of the present invention, the temperature of the oxidizing atmosphere usually is maintained at between about 1000°F and 1900°F to produce the high temperature oxide on the steel surface. In a preferred embodiment of the oxidizing step, the oxidizing atmosphere is maintained between about 1750°F and 1850°F, with a temperature of 1800°F presently considered to be optimum. When using a temperature of between 1750°F and 1850°F, it has been found that a shorter time is needed to form a satisfactory high temperature oxide, as determined by subsequent uniform carburization, and that the steel can be oxidized directly without preliminary cleaning treatment.

Although it is not essential to pre-clean the steel when using oxidizing temperatures of 1750°F to 1850°F, it is preferred to employ such a step to provide a clean working surface. The preliminary cleaning of the steel can be accomplished in a conventional manner, such as by using a blast of aluminum oxide grit or garnet grit. Aluminum oxide is presently preferred because of its more effective cleaning ability.

When using oxidizing temperatures of 1750°F to 1850°F, the steel can be kept in the oxidizing atmosphere from about 30 minutes to 4 hours. Usually, at these temperatures, a satisfactory high temperature oxide film forms on the steels in about 30 minutes to 1 hour. The steel is preferably kept in the oxidizing atmosphere for as short a time as possible, such as 30 minutes to 1 hour, because the steel has a tendency to decarburize during the oxidation treatment.

The steel must be left in the furnace for a sufficient time to bring the entire steel part to the temperature of the furnace. Generally, the steel is soaked in the high temperature oxidizing furnace for a period of 1 hour for each inch of its thickness.

Temperatures higher than 1850°F are effective in producing a satisfactory high temperature oxide, but such temperatures speed the decarburization of the surface of the steel which occurs during the oxidizing step and may result in undesired grain growth at the surface of the part. On the other hand, as the temperature of the oxidation step decreases below 1750°F, the time needed for forming a satisfactory high temperature oxide increases.

At lower oxidizing temperatures in the range of 1000°F to below about 1750°F, it becomes necessary to use a preliminary cleaning step, and to place the clean steel in the oxidizing atmosphere before the passive film can reform. Although a preliminary cleaning is necessary to insure subsequent uniform carburization when using oxidizing temperatures of 1000°F to below about 1750°F, this step does present the problems associated with the prior art technique of cleaning immediately before carburization. Carburization time is usually several hours in length, for example 6 to 30 hours, and once carburization has begun, the carburizing furnace cannot be opened to receive more parts. Thus, the prior art cleaning of the parts could only be accomplished in accordance with the availability of the carburizing furnace. Further only those number of parts that could be cleaned in the short time that it takes for the passive oxide film to reform could be placed in the carburizing furnace. The high temperature oxidation time of the present invention, however, is relatively short and steel parts can be placed in an air furnace and oxidized at any time during its operation.

Thus, the preliminary cleaning step used in the present invention is not limited as to when it can be accomplished or by the number of parts that can be prepared in the short time that it takes for a passive film to reform.

After the steel is heated in the oxidizing atmosphere to form the high temperature oxide on its surface, it is removed from the furnace and preferably is allowed to air cool. The steel can be slowly air cooled to room temperature or can be cooled by a combination of air cooling followed by water cooling. Once the high temperature oxide has been formed on the steel, the steel can be left in the air for long periods of time before the carburization treatment is begun. Thus, the steel can be left in air for longer than the one to two hours that it takes for reformation of the passive oxide film, and can be left in the air for a period of at least a week.

The process of the present invention is thus unlike prior art pre-treatment methods where the carburization must immediately follow the pre-treatment step.

The steels of the present invention can be carburized immediately upon their removal from the oxidizing furnace, if desired, but because of the presence of the high temperature oxide on their surface, they can be carburized at a later time, thus affording the manufacturer greater flexibility in conducting the carburization.

The present invention enables large numbers of parts to be prepared for carburization whereas prior art pre-treatment methods enable only those number of parts that could be cleaned in the short time that it takes for the passive oxide film to reform to be carburized.

Preferably before carburizing, the steel is provided with a protective covering in those areas that are not to be carburized. This is conventional in carburizing, and only those areas that require a hard case because of contact with other surfaces are carburized. The protective covering is preferably a copper plate and is provided by first masking the areas that are to be carburized with a heavy wax and leaving those areas that are not to be carburized uncleated and receptive to copper plate. The steel is then copper plated in accordance with conventional techniques to form a minimum 0.001 inch thick layer of copper in those areas that are not to be carburized. The heavy wax mask is then removed by conventional means, such as by a hot alkaline clean, to expose the areas to be carburized.

As stated above, steel has a tendency to decarburize during the high temperature oxidation, and if the steel is given a copper plate to mask certain areas from carburization, the masked areas may have a lower carbon content than desired. To overcome this problem, the
steel parts can be made oversize in those areas that are not to be carburized. The oversize thickness which is
decarburized during the oxidation step can be removed
after hardening to leave a surface having the proper
carbon content.

Alternatively, the entire steel part can be carburized,
restoring the carbon lost during the high temperature
oxidation step and, in fact, forming an enriched carbon
case around the entire part. Or, the steel can be given
a protective coating in those areas that are not to be
carburized prior to the oxidation step to prevent decar-
burization. The protective covering preferably is a ce-
ramic coating formed by applying the material
“Ceram-Guard”, sold by A. O. Smith Corp., Glass
Coating Div., Milwaukee, Wisconsin. The Ceram-
Guard can be applied by brushing, spraying or dipping.
A base coat of Ceram-Guard CG-11 is first applied fol-
lowed by a sealer coat of Ceram-Guard CG-16.

In accordance with the invention, the steel provided
with the high temperature oxidation surface is carburized
by conventional carburizing techniques. Thus, the car-
burizing is carried out in a conventional carburizing
furnace or chamber containing a conventional carbu-
rizing agent, such as a solid, a liquid, or a controlled at-
mosphere composed of a carrier gas and an enriching
gas. Preferably, a controlled atmosphere is used.
The carburization temperature used can vary from 1550°F
to 2100°F, with 1700°F being preferred.

The term “enriching gas”, as used herein, denotes a
CH₄ gas, and includes natural gas, relatively pure meth-
ane, ethane, propane and other hydrocarbons and ox-
yhydrocarbons that are methane equivalents in that
they are known as enriching gases for carburizing.

The carbon potential of the carburizing furnace is
kept at about 0.6 to 1.5 percent. This is controlled by
measuring the dew point of the incoming gases and/or
by a carbon dioxide infrared analysis of the actual gases
in the carburizing furnace. The carbon potential of a
fluid, as used herein and in the appended claims, indi-
cates the carbon content to which that gas will carbu-
rize steel if equilibrium is reached. Carbon potential is
customarily measured in percent of carbon in thin
strips of low carbon steel (0.10 percent or less) which
have been brought to substantial equilibrium with the
gaseous atmosphere and have a substantially uniform
carbon content throughout the strip. Carbon potential
is also a function of temperature and, at least within the
austenitic temperature range, the carbon potential of a
gas of a given composition increases inversely with
temperature.

The carbon potential used in the practicing of the
process of the present invention is preferably between
about 0.85 and 0.95 percent. This carbon potential is
easier to attain and control than higher carbon poten-
tials, and also substantially avoids objectionable car-
bide networks that have a tendency to form on the steel
surface when higher carbon potentials are used. Such
carbide network formations are also lessened by de-
creasing the oxidation time and/or increasing the harden-
ing time used in the process.

During the carburization step of the present inven-
tion, carbon diffuses into the steel and produces a car-
bon enriched layer or case. The carbon enriched layer
or case usually is formed to provide an “effective case
depth” in the finished part of between 0.005 inch and
0.150 inch depending on the ultimate use for the article
or part. Preferably, the effective case depth of the
finished part is between 0.020 inch to 0.120 inch deep.
The carburizing time is dependent upon the effective
case depth desired. As used herein, the term effective
case depth refers to the perpendicular distance from
the surface of the case to a point where the hardness is
equivalent to Rockwell C 50. Thus, the steels can be
carburized for as little as 4 hours or less or as much as
30 hours or more. Typically, when using a carbon po-
tential of 0.85 to 0.95 percent, and a carburizing tem-
perature of 1700°F, carburization for 6 hours produces
an effective case depth of 0.030 to 0.040 inches, carbu-
rization for 12 hours produces an effective case depth of
0.055 to 0.065 inches, and carburization for 30 hours
produces an effective case depth of 0.090 to 0.100 inches.

The furnace used in the carburizing step can be a
standard batch type furnace, such as a pit furnace or a
box-type furnace. Conventionally, steel is placed in the
carburizing furnace at a temperature of 1500°F, and
then raised to a temperature of 1700°F in the absence of
the enriching gas. When the carburizing temperature is
attained, the enriching gas is introduced into the fur-
nace.

While this procedure can be used in the present in-
vention, the oxidized steel parts preferably are charged
to a carburizing furnace maintained at the carburizing
temperature and the enriching gas is introduced into the
furnace immediately thereafter. After carburization
is completed, the steel is cooled to 1500°F in the carbu-
rizing furnace, and removed from the furnace and air
cooled. The steel is then subjected to a conventional
post-carburizing hardening treatment suited to the par-
ticular steel used.

For example, with a Vasco X2 or modified Vasco X2
steel, a typical hardening treatment would be to first
temper the steel at 600°F for 2 hours to relieve stress,
strip the copper plate and then blast clean with alumi-
nium oxide or garnet particles. The steel is blast-cleaned
to prepare it for a new copper plate over its entire sur-
face to prevent decarburization during subsequent
hardening. After the blast clean, a thin layer of nickel,
(0.0003 inch maximum) is plated onto the steel to acti-
vate its surface and prime it for the copper plate. The
copper plate, preferably at 0.001 inch minimum, is
then applied to the entire surface of the steel. The steel
can then be heated at 1150°F for 3 hours to check the
adherence of the copper plate. After heating, the steel
is subjected to a glass bead blast to further evaluate the
quality of the copper plate. Any blistering, or break-
down of the copper plate during the glass bead blast,
indicates that the plate is defective and should be re-
placed.

After the copper plate has been tested, the steel is
brought to the hardening temperature. For example, a
Vasco X2 steel can be preheated to 1450°F for 30 min-
utes and then heated at 1850°F for 30 minutes to trans-
form the entire steel to austenite. The steel is then sub-
jected to an oil quench to transform the austenitic
phase to martensite. Within 30 minutes after the oil
quench, the steel is preferably deep frozen at a tempera-
ture of −100°F to −120°F. The steel is kept in the deep
freeze for 3 hours to insure the transformation of all or
at least 95 percent of the austenite to martensite. The
steel is removed from the deep freeze and is given a
double temper at 600°F, with each temper lasting 2
hours. This reduces internal stresses and increases the
toughness and ductility of the steel. The steel is then blast-cleaned, the copper plate is stripped, the article is re-blasted, and given a final machining.

The present invention thus provides a process for carburizing high alloy steels exhibiting high load capabilities. These steels can be utilized for both gear and bearing application and have significantly longer part life. No unique or special heat treating equipment, such as furnaces or atmospheres are required and conventional carburizing equipment can be used. The cost of carburizing in accordance with the method of this invention is essentially the same as the cost of conventional carburization.

The following examples are given by way of illustration to further explain the principles of the invention. These examples are merely illustrative and are not to be understood as limiting the scope and underlying principles of the invention in any way. All percentages referred to herein are by weight unless otherwise specifically indicated.

**EXAMPLE 1**

A modified Vasco X2 steel machined into a gear test slug is cleaned using an aluminum oxide grit, and then heated at 1800°F for one hour in the oxidizing atmosphere of a laboratory air furnace. The gear slug is removed from the furnace and air cooled to room temperature. After 21 hours in the room air atmosphere, the slug is carburized at 1700°F for 12 hours using a carbon potential of 1.25 – 1.35 percent. The gear slug is removed from the furnace and plated by first nickel striking to a thickness of 0.0003 inch maximum, immediately followed by copper plating to a thickness of 0.001 inch minimum. The steel gear slug is hardened by preheating the plated slug for 30 minutes at 1450°F and then heating to a hardening temperature of 1850°F and maintaining it at this temperature for 30 minutes. The steel is then oil quenched and placed in a deep freeze within 30 minutes at −100°F to −120°F for 3 hours. The steel is then given a double temper at 600°F, with each temper lasting two hours. The copper plate is removed and the part is abrasively blast cleaned. The gear slug is then given a final machining. The hardened slug is tested for hardness at its root and flank positions. The hardness of the gear slug at various depths below its surface is given in Table 2 for each of the sections tested.

**EXAMPLE 2**

A gear made of modified Vasco X2 steel is cleaned by mechanical abrasive blasting using aluminum oxide grit, and then heated at 1800°F for one hour in an oxidizing atmosphere in a commercial production air furnace. An air line is connected to the furnace and a positive air pressure of 400 cubic feet per hour is flowed through the furnace. The gear is removed from the furnace and air cooled to room temperature. After 18 hours in the room air atmosphere, the gear is carburized at 1700°F for 10 hours using a carbon potential of 0.85 – 0.95 percent.

The gear is removed from the furnace and plated by first nickel striking to a thickness of 0.0003 inch maximum, immediately followed by copper plating to a thickness of 0.001 inch minimum. The gear is hardened by preheating the steel for 30 minutes at 1450°F, and then heating the steel to a hardening temperature of 1850°F and maintaining it at this temperature for 30 minutes. The steel is then oil quenched. The steel is placed in a dry box within thirty minutes and given a deep freeze to −100°F to −120°F for 3 hours. The steel is then given a double temper at 600°F, with each temper lasting two hours. The copper is then removed by ordinary chemical means. After removal of the copper, the part is given a glass bead blasting. The gear is then given a final machining. Table 3 shows the results of hardness tests taken at various depths below the surface of the gear at its left flank, right flank, and root positions.

A graph prepared from this data shows that the gear test slug is substantially uniformly carburized throughout its surface and does not exhibit any spotty carburization.

**EXAMPLE 3**

A series of test specimens are cleaned by abrasively blasting using aluminum oxide grit, and are then heated at 1800°F for one hour in the oxidizing atmosphere of
3,885,995

a production furnace supplied with 400 cubic feet per hour of positive air pressure. The specimens are removed from the air furnace, air cooled to room temperature, and left in the room air atmosphere overnight for about 24 hours before they are carburized. The specimens are three sets of \( \frac{4}{5} \) inch round ground rollers. Each set contains five ground rollers and is hardened at a different temperature. Each of the five rollers of each set is carburized for different periods of time at a carburizing temperature of 1700°F and a carbon potential of 1.25 – 1.35 percent. The first rolled in each set is carburized for five hours, and each succeeding roller is carburized for five hours longer than the preceding roller. One set of rollers is hardened at a temperature of 1800°F for 30 minutes, a second set at 1850°F for 30 minutes, and a third set at 1900°F for 30 minutes. The Rockwell C50 and Rockwell C60 depth for each roller is determined and shown in Table 4 below which also indicates the ratio of Rockwell C60 depth to Rockwell C50 depth. This ratio gives an indication of the carburization efficiency.

<table>
<thead>
<tr>
<th>Hardening Temperature</th>
<th>Carburizing Time (Hours)</th>
<th>Rockwell C60 Depth</th>
<th>Rockwell C50 Depth</th>
<th>Ratio Rockwell C60/50</th>
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</thead>
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<tr>
<td>1800°F</td>
<td>5</td>
<td>.0215</td>
<td>.043</td>
<td>500</td>
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<td>.0745</td>
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<tr>
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<tr>
<td>1900°F</td>
<td>25</td>
<td>.049</td>
<td>.092</td>
<td>489</td>
</tr>
</tbody>
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The carburizing uniformity of all specimens is acceptable. The results of the five-hour carburizing is particularly interesting because it shows that approximately 0.25 inch of Rockwell C60 hardness is obtained on each specimen. This means that in an area where a shallow case depth is required that a maximum of .020 inch of metal can be removed during succeeding grinding and/or finishing operations with the part still maintaining a Rockwell C60 hardness at the surface.

**EXAMPLE 4**

A test specimen taken from a housing of a clutch shaft and having an approximately 2\( \frac{1}{4} \) inch square cross-section and a test specimen taken from a clutch shaft and having an approximate one inch cross-section are oxidized, carburized, and hardened in accordance with the general procedures of Example 3. Both test specimens are made of modified Vasso X2 steel. The specimens are oxidized at 1800°F for one hour, and are carburized at 1700°F for 30 hours using a carbon potential of 0.85 – 0.95 percent. The specimens are hardened by preheating at 1450°F for two hours and then heated at 1850°F for 45 minutes. The specimens are then oil quenched to transform the austenite structure to martensite. Tests show that the test specimen of the clutch shaft carburized uniformly, but that the test specimen of the clutch shaft housing did not carburize uniformly. The poor results obtained with the clutch shaft housing is attributable to its large mass which never reached and stabilized at the oxidation temperature of 1800°F for the one hour cycle. Oxidation of such larger masses requires a longer time, and a repeat test on a clutch housing specimen done at an oxidation time of two to three hours produced a satisfactory result.

The invention in its broader aspects is not limited to specific details shown and described and departures may be made from such details without departing from the principles of the invention and without sacrificing its chief advantages.

What is claimed is:

1. A process for carburizing a high alloy steel having a carbon content of 0.05 to 0.3 percent and a chromium content of from 2 to 25 percent or greater comprising:

   a. heating the steel at a temperature of 1000°F to 1900°F in an oxidizing atmosphere for a period of time of about 30 minutes to 4 hours and sufficient to form a high temperature oxide on the steel surface; and

   b. carburizing the steel containing the high temperature oxide in a gas having a carbon potential of about 0.6 to 15 percent at a temperature of about 1550°F to 2100°F.

2. The process of claim 1 wherein the oxidizing atmosphere is air.

3. The process of claim 1 wherein the steel is oxidized at a temperature between about 1750°F and 1850°F.

4. The process of claim 1 wherein the steel is pre-cleaned with a particle grit blast and is oxidized at a temperature of between about 1000°F and 1850°F before a passive film forms on the steel surface.

5. The process of claim 1 wherein the steel is carburized more than two hours after it is subjected to the high temperature oxidizing atmosphere.

6. The process of claim 1 wherein the steel is oxidized at a temperature between about 1750°F and 1850°F and is carburized with a gas having a carbon potential of between about 0.85 and 0.95 percent.
7. The process of claim 1 wherein the steel is carburized to provide an effective case depth of Rockwell C 50 hardness of from 0.005 to 0.150 inch.
8. The process of claim 7 wherein the steel is carburized to provide an effective case depth of Rockwell C 50 hardness of from 0.020 to 0.120 inch.
9. The process of claim 8 wherein the steel is oxidized at a temperature of about 1750°F and 1850°F.

* * * * *
UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,885,995
DATED : May 27, 1975
INVENTOR(S) : Roy J. Cunningham, Warren Lieberman

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 12, line 51 - Change "15 percent" to "1.5 percent"

Signed and Sealed this fifteenth Day of June 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks