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CARBURIZING THIN GAUGE ARMOR PLATE  
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Signed by Bishop
The invention relates to thin gauge armor plate, such as \(\frac{1}{4}''\), \(\frac{3}{8}''\), \(\frac{1}{2}''\), \(\frac{3}{4}''\), \(\frac{5}{8}''\) and up to \(1''\) thick steel armor plate, and more particularly to a carburizing compound and method for uniformly carburizing such armor plate.

During the last few years there has been an increase in the demand for thin gauge steel armor plate having a hard case at one surface merging into a softer backing at the other surface. Moreover, there have been demands recently for tremendous increases in the rate of production of thin gauge armor plate for use in the construction of land, sea or air, offensive and defensive weapons, equipment, materials and armament without sacrifice to the required physical and ballistic properties, or the uniformity of the same.

The development of uniform physical and ballistic properties by heat treatment of carburized armor plate material is ultimately dependent upon the uniformity of carburizing the hard or case side of the armor plate. A number of complicating conditions arise in connection with carburizing light gauge armor plate, which do not arise in the art of case hardening other common articles. In the latter art there is a wealth of knowledge and experience, but it has been said that each article presents its own problem as to carburizing conditions, and that book recipes are of little avail in solving particular problems.

Initially, the size of armor plate complicates the carburizing problem such that one authority has said that the average heat treater does not have to deal with so difficult a problem as securing the proper gradation of hardness and toughness in pieces of the size of armor plate.

Thus, the prior art indicates that when a large carburizing box is used, the material in the center lags behind the indicated furnace temperature as much as several hundred degrees; that the greater the size of the box, the larger will be this error, and the greater the actual difference in the thickness of case taken on by steel near the sides of the box as compared with that near the center of the box; and that this condition can be remedied only by altering the dimensions of the box itself.

Unfortunately, the large sizes of armor plates desired or required, as to length or breadth, or both, do not permit this condition to be remedied by altering the dimensions of the carburizing box to make them smaller so as to obtain more uniform carburization.

Another complicating factor is the thinness of the armor plate, one surface and one surface only of which is to be carburized; because thin gauge material may warp.

Moreover, the conservation of vital raw materials has required a reduction in the percentages of alloying metals used in making carburizing steel plates for carburization; so that phases of the problem which might otherwise be satisfied by increasing the percentages of certain alloying metals are in fact increased by the required reduction in the percentages of certain alloying metals used.

In the general prior art of carburizing, the usual solid carburizers are made up essentially of hard wood charcoal and barium carbonate; and these types of carburizing compounds have to a great extent replaced earlier types based principally on bone, or charred leather with bone, or bone with charcoal. Sometimes small amounts of coke are used as a diluent.

A compound containing a large amount of charred bone, a smaller amount of charcoal, with some barium carbonate as an energizer, and oil as a binder, was somewhat satisfactorily used by us for carburizing thin gauge armor plate.

This prior carburizing material used by us for carburizing thin gauge armor plate was sluggish in operation, because it was in fact a good heat insulator and sometimes resulted in over-carburized edges and under-carburized centers. This lack of uniformity of carburizing was kept at a minimum by very careful and slow heating.

Attempts to speed up the rate of heating with this carburizing compound were not practical, and alterations in the relative percentage of materials used in the compound were of no avail in reducing the overall time of carburizing, because of the large size of the boxes required, and the temperature heating lag incident thereto.

We have discovered, however, by eliminating the bone, and by using a carburizing compound containing a large percentage of coke, a smaller percentage of charcoal, an energizer and a binder, that it is possible to reduce to substantially one-half, the total time required for carburizing and yet obtain a uniform carburized depth having the desired gradient throughout, in thin gauge armor plate so carburized; while at the same time utilizing carburizing steel plate raw
material containing smaller amounts of alloying metals than were heretofore used. These new results accordingly assist in conserving raw materials, speed up production by as much as 75 per cent or more with available equipment for carburizing light gauge armor plate, and produce a more uniform product in which extremely uniform and high physical and ballistic properties can be developed by subsequent heat treatment.

Accordingly, it is an object of the present invention to conserve vital raw materials such as nickel and chromium in the manufacture of thin gauge armor plate. It is also an object of the present invention to substantially decrease the time required for carburizing thin gauge armor plate.

Also, it is an object of the present invention to provide a carburizing compound for carburizing thin gauge armor plate with which a carburized case side may be provided on one side only of thin gauge armor plate, of very uniform depth and gradient throughout the extent of plates of various sizes carburized in relatively large carburizing boxes.

Also it is an object of the present invention to provide a new carburizing compound for uniformly carburizing one side only of very thin gauge material of relatively great length or breadth, or both.

And finally, it is an object of the present invention to provide a carburizing compound for carburizing thin gauge steel armor plate which avoids prior difficulties and enables the speedy production of armor plate having uniform high ballistic properties.

These and other objects may be obtained by the methods, procedures, steps, operations and compounds hereinafter described in detail, and set forth in the appended claims.

In the drawing, the figure illustrates somewhat diagrammatically the carbon gradient desired in the case side of thin gauge armor plate.

The raw material used for the manufacture of thin gauge armor plate is carburizing alloy steel plates as received from the steel mill, of a type commonly used in the manufacture of armor plate, but in which the percentage of alloying metals may be materially lowered from those percentages previously used in order to conserve vital alloying metals such as chromium, nickel, molybdenum, vanadium and manganese.

The plates are laid off and sheared or cut generally to size in accordance with specifications, which size may be a matter of a number of feet in length or breadth, or both, with the plate as thin as ¼" up to 1" in thickness.

Because extremely large quantities of ¼" armor plate are used, and because the manufacture of ¼" armor plate perhaps presents a greater problem than any other gauge in the range of ¼" to 1" thick thin gauge armor plate, the invention will be described in detail with particular reference to ¼" thin gauge armor plate.

No holes are drilled in the plates which have been cut generally to size, but two matched plates are placed face to face, and the edges of the plates are welded together completely around the periphery thereof so as to completely seal off the inside or contacting faces or surfaces of the matched plates and to leave only one face or surface of each plate exposed.

The procedure usually renders it unnecessary to apply and remove an anti-carburizing material to the inner face or surface of each of the plates for preventing carburization thereat, and thereby reduces the cost of production of light gauge armor plate, which is face hardened on one side only.

After matched plates have been welded together, they are packed in carburizing boxes which may be as large as 96 inches in length and breadth, and up to about 32 inches in depth, or larger, and the plates are surrounded by a carburizing compound, the constitution of which comprises one of the principal features of the present invention.

The carburizing material, in accordance with usual practice, may be used over and over with the addition of some new material, and the depth of the carburizing compound between plate layers when packed ordinarily ranges from 1 ½" to 3".

In packing the plates in the carburizing boxes, all edges of all plates are kept away from the sides of the box and from touching each other.

The box is covered with a lid and sealed with fire clay in the usual manner, and is then placed in a carburizing furnace, wherein the temperature is raised to from 1680° F. to 1720° F. furnace temperature as fast, as it is possible to do so. The plates in the boxes are thus treated at the stated temperature in the carburizing furnace for a total furnace on to furnace off time of from 28 to 32 hours, usually about 28 hours for ¼" plate.

Small variations in the furnace time and temperature are determined by the depth of case desired; the hardness desired; the ballistic properties to be developed; the steel analysis; and the grain size; and these matters are known in the art of carburizing where small variations are ordinarily left largely up to the skill of the operator.

The sealed boxes are then removed from the carburizing furnace and are permitted to cool, whereupon the boxes are unpacked, the welds which are brittle are struck in order to separate the matched or paired plates. The plates are then machined, or sheared, or bent or drilled to required size, shape, and specification, following which the plates are heat treated to develop the required physical and ballistic properties in the hard case and softer backing sides.

Referring more particularly to the drawing, a .18% to .24% carbon, carburizing alloy steel plate is normally used for making thin gauge armor plate, and in armor plate of this gauge, it is usually desired to have the carbon content of the carburized side of slightly hyper-eutectoid composition at or near to the surface. The curves of per cent carbon to case depth illustrate somewhat diagrammatically the approximate conditions desired in finished carburized heat treated armor plate made from .22% carbon base material.

Normally it is desired to have a uniform depth of carbon penetration, which is gauged by a visible line of demarcation between a fine siliceous grain structure of the case and a coarser grain structure of the core. Normally this line is at a place where the carbon content is approximately .35% to .40% carbon; and for ¼" armor plate it is normally desired to have this line at a depth of about .005", indicated generally at B in curve 1 of the drawing.

The curves, as stated, show diagrammatically the approximate desired finished conditions, curve 1 being for ¼" thick armor plate and curve 2 being for ½" thick armor plate. In curve 1, A
indicates the desire slightly hyper-eutectoid composition near to the surface of the finished heat treated armor plate made from .23% carbon base material. Similarly, A—1 in curve 2 indicates the hyper-eutectoid composition near to the surface of 3/4" thick armor plate and B—1 indicates the location of the visible line between fine and coarse grain structures where the carbon content is approximately .35% to .40% carbon at a desired depth of about .10", for 3/4" armor plate.

Thus, the carbon gradient A—B in curve 1 for 3/4" armor plate is relatively steep from approximately the surface to the line of demarcation B between the fine and coarse grain structures, after which the gradient tapers off and merges into the .23% carbon of the base.

The optimum desired characteristic of thin gauge armor plate having a hard case side and a softer backing side is a plate having a carbon gradient in the carburized portion thereof substantially uniform throughout the length and breadth of the plate and substantially as shown in the drawing.

We have been able, by using the improved carburizing compound now to be specifically described, to provide such uniform carburized conditions in thin gauge armor plate. At the same time we have materially decreased the time required for carburizing, thus enabling increased production.

The improved carburizing compound may be made up in accordance with the following specifications, by volume:

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>By-product coke</td>
<td>50 to 58</td>
</tr>
<tr>
<td>Hardwood charcoal</td>
<td>28</td>
</tr>
<tr>
<td>Barium carbonate</td>
<td>4 1/2 to 5 1/2</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>1 1/2 to 2 1/2</td>
</tr>
<tr>
<td>Shrap molasses or other binder</td>
<td>6</td>
</tr>
</tbody>
</table>

The coke is preferably a by-product coke of good structure with a maximum of .3% sulphur; and its size should be about 3 mesh with not more than 20% passing through a 6 mesh screen. The coke forms the major portion of the compound, and functions to transmit the furnace heat at a very fast rate into the interior of the large carburizing boxes so that there is only a very small lag in temperature, even though the carburizing box size is relatively large. The large coke content of the carburizing compound is quite contrary to that of usual mixtures of carburizing compounds of the prior art wherein coke has been used.

The coke also functions to maintain porosity in the packed boxes so as to permit free circulation of the carburizing gases evolved. In this connection, the size of the coke is important, because in the large boxes wherein a large number of relatively large sized pieces of armor plate are packed, the dead weight of the material being treated is considerable and the carburizing compound must be able to sustain the load and yet leave passages for the circulation of carburizing gases. Thus, the coke, because of its strength and indicated size, also functions to sustain the load and to leave passages for the circulation of carburizing gases close to the faces of the material being carburized without a compacting of the carburizing compound, which would reduce such circulation.

The charcoal is hardwood charcoal and its size should be about 3 mesh with not more than 20% passing through a 6 mesh screen.

The barium carbonate and calcium carbonate act in a somewhat typical manner as the energizers or catalysts so that CO gas gives up carbon as a slow, even and controlled rate to the metal to be carburized and so that the carbon at the surface is not too high, but is absorbed and migrates so as to produce the somewhat typical gradients shown in the drawing. The energizer content of the improved compound is somewhat lower than that usually used in the prior art. Even so, with the improved compound, we obtain uniform results and materially reduce the carburizing time in carburizing thin gauge armor plate.

There have been a number of theories as to the mechanism of carburization, and it is believed unnecessary to explain herein what we believe to be the proper theory as to the action of the energizer and the charcoal and the chemical reactions which take place. We may, however, state that we believe that the bulk of the CO gas, which gives up carbon to the metal, comes from the charcoal; and we believe that a slight amount of effective CO gas is produced by the energizer, and also by the coke.

Regardless of the explanation of the mechanism of carburization, we have found that by using the carburizing compound just described, thin gauge armor plate may be carburized in large boxes in a relatively short period of time to produce a case or carburized layer on one side of 3/4" thick armor plate having a carbon content at or near the surface of slightly hypereutectoid composition, and having approximately a .35% to .40% carbon content as a case depth of approximately .065" substantially uniformly throughout relatively large sized plates having a length or breadth, or both, as large as say 90 inches.

The same carburizing compound may be used for carburizing plates heavier than 3/4" thick within the range of up to 1" thick, thin gauge armor plate; but in carburizing heavier plates in this range, a somewhat longer time of treatment in the carburizing furnace will be employed in order to obtain a thicker carburized layer having a slightly less steep carbon gradient curve as indicated by curve 2 in the drawing for finished 3/4" armor plate.

In its broadest aspects, the invention comprises a radical change in the composition of usual carburizing compounds, which materially simplifies and speeds up the manufacture of thin gauge armor plate and produces a more uniform thin gauge armor plate satisfying present day requirements.

Moreover, the welding of plate pairs together, entirely around the periphery, enables carburization on one side only of each plate usually without the application or removal of an anti-carburizing material; which is also a radical change in armor plate manufacture.

Thus, the present invention provides for overcoming difficulties and eliminating disadvantages and operations involved in the prior practice of making thin gauge armor plate.

The invention is not limited to the production of 3/4" thick armor plate, because armor plate of substantially any thickness in the thinner gauges up to approximately 1" in thickness, may be processed in accordance with the described invention, without departing from the scope of the invention.
Having now described the features of the invention, the preferred steps used in carburizing thin gauge armor plate, the improved carburizing compound used, and the advantages and results obtained thereby; the new and useful methods, method steps, operations and compounds are set forth in the appended claims.

We claim:

1. In the manufacture of uniformly carburized steel armor plate of the thinner gauges of the order of up to 1" in thickness having a hard case side and a softer backing side, the steps of welding the edges of paired plates together entirely around the periphery thereof; packing the paired welded plates in large carburizing boxes with a carburizing compound containing a major portion of coke by volume, and the balance charcoal, an energizer and a binder; and then heating the same at about 1680° F. to 1720° F. to uniformly carburize the outer face of each plate of each pair.

2. In the manufacture of uniformly carburized steel armor plate of the thinner gauges of the order of up to 1" in thickness having a hard case side and a softer backing side, the steps of welding the edges of paired plates together entirely around the periphery thereof; packing the paired welded plates in large carburizing boxes with a carburizing compound containing approximately by volume 50% to 58% coke, 28% to 38% charcoal, a small amount of an energizer, and a binder; and then heating the same at about 1680° F. to 1720° F. to uniformly carburize the outer face of each plate of each pair.

3. In the manufacture of uniformly carburized 3/4" steel armor plate having a hard case side and a softer backing side, the steps of welding the edges of paired plates together entirely around the periphery thereof; packing the paired welded plates in large carburizing boxes with a carburizing compound containing approximately by volume 50% to 58% coke, 28% to 38% charcoal, 4 1/2% to 5 1/2% barium carbonate, 1 1/2% to 2 1/2% calcium carbonate and 6% a binder; and then heating the same at about 1680° F. to 1720° F. for about 28 to 32 hours to uniformly carburize the outer face of each plate of each pair.

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