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THERMALLY HARDENING STEEL

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This invention is a method of thermally hardening a steel article having a portion with a higher carbon content than another portion. An example of such an article is a steel plate having a carburized surface providing the portion of higher carbon content than another portion, the latter being the uncarburized portion of the plate. Other carburized steel articles also may be considered as examples.

When steel is quenched from a temperature where it is austenitic to within the temperature range of from 100° C. to 400° C. and held within this range until all or most of its austenite transforms, the steel possesses greater ductility and impact strength than steel of the same chemical composition hardened to the same hardness by other methods. Also, the austenitic transformation rate of steel varies within this temperature range in accordance with its carbon content, the austenite of a higher carbon steel transforming more slowly than the austenite of a lower carbon steel.

With the above in mind, the present invention is generally characterized by including the heating of an article having a portion with a higher carbon content than another portion, so as to render both these portions austenitic, the article then being quenched to the temperature range of from 100° C. to 400° C. and held within this range until transformation of at least a majority of the austenite of the portion of lower carbon content is effected, whereupon the article is quenched to below the defined temperature range prior to transformation of more than minor amounts of the austenite of the higher carbon portion and at a rate producing martensite.

The result of the above is a steel article having an at least partially martensitic portion and another portion predominantly comprising products resulting from austenite transforming in the temperature range of from 100° C. to 400° C. Thus, the article will be very hard at one portion and will have another portion that is hardened but possesses the ductility and impact strength provided by products resulting from austenitic transformation within the defined temperature range. It is to be understood that metal hardened by quenching to and holding within the defined temperature range, may be recognized by studying its microstructure since this is an acicular type as contrasted to a martensitic structure produced by other hardening methods.

Alloying elements other than carbon also have a decided effect in retarding the austenitic transformation rate of steel at temperatures within the range of from 100° C. to 400° C. Molybdenum, chromium, vanadium, tungsten, silicon, manganese, boron, nickel, tantalum, etc. all have this tendency more or less. In addition to exerting this effect, these elements also function to increase the hardenability of steel to which they are added over that of plain carbon steel of similar carbon content, and for this and other reasons elements of this type are frequently used to produce alloy steels intended for carburization and hardening.

Since the austenitic transformation rate of plain carbon steel is comparatively rapid, the present invention further includes the addition to the steel of the article previously discussed, while the steel is molten, of one or more alloying elements other than carbon, of such a character and used in such amounts as to materially retard the austenitic transformation rate of the steel in the defined range as compared to that of plain carbon steel of similar carbon content. The element or elements used may be any of the broad class hereinbefore mentioned. When such a steel is carburized to produce an article having a portion of higher carbon content than another portion, the higher carbon portion has a slower austenitic transformation rate than that of the portion of comparatively lower carbon content, and the transformation rates of both portions are considerably retarded as compared to similar portions in the case of plain carbon steel. Therefore, the carrying out of the method hereinbefore described is made easier in that a greater time is provided for manipulation of the work during the various steps involved.

During the time the steel is held at the temperature range of from 100° C. to 400° C., the austenite of the lower carbon portion is continuously transforming to the particular products produced within this range. The portion of higher carbon content during that time does not harden due to transformation of its austenite and, therefore, is in a relatively malleable and ductile state. Consequently, during the period while austenite transformation is going on in the case of the portion of the lower carbon content, the steel article may be plastically formed as desired, such as by curving it, so that it will have a predetermined shape at the end of the method.

Austenitic transformation effected in the stated temperature range results in a minimum of distortion during the hardening of the steel, and the higher carbon portion subsequently hardened to martensite with consequent expansion cannot distort the article being hardened as

much as usual, because this expansion is resisted by the steel of the lower carbon portion which is completely hardened about the time austenitic transformation of the higher portion is initiated. In the case of certain articles such as a plate having one carburized surface, it is possible to plastically form the plate while its lower carbon portion is undergoing austenitic transformation, so as to cause its carburized face to be concave to a degree sufficient to result in subsequent hardening of this surface to a martensitic condition causing this surface to flatten. Also, the plate may be produced by such forming with its carburized surface convex so as to be placed in compression during flattening of the plate. Usual hardening of carburized plate may result in the carburized face being concave so that flattening places this face in tension so as to involve the possibility of rupturing it.

In some instances it may be desirable to temper the higher carbon portion to relieve some of the strain resulting from its conversion to a martensitic condition by the second described quenching. This tempering may be done by heating the higher carbon portion to any temperature less than the temperature range wherein transformation of the austenite of the lower carbon portion took place. In other words, the article should be tempered only by the use of temperatures less than from 100° C. to 400° C., the exact temperature depending on the temperature where the mentioned transformation of austenite occurred.

Although the principles of this invention are applicable to the production of a great many carburized articles, such as dies, gears, tools, shafts, bearings, rolls, etc., a specific example of the invention as it has been commercially applied to the hardening of light armor plate will now be disclosed.

The armor plate is rolled from steel to which alloys are added while it is molten so it contains .25% carbon, .50% manganese, 4.5% nickel and .40% molybdenum, the balance being iron excepting for immaterial amounts of those elements normally classed as impurities in the case of the product under discussion. The resulting plate is then carburized on one surface in the prior art manner. Tests have shown that at 250° C. it requires about two hours to effect austenitic transformation producing the desired hardness in the case of the low carbon portion of this plate, whereas no austenitic transformation occurs in the case of the carburized surface over a period of five hours. Such information must be developed experimentally in the case of steels of different chemical compositions, but the desired retardation of the austenitic transformation rate is obtained in the case of a wide range of alloy steels.

The carburized plate is then heated to a temperature above the upper critical temperature of both its higher and lower carbon portions, this being done in a conventional heat treating furnace in a nonoxidizing atmosphere. The time of this heating is sufficient to assure complete carbide solution whereby the plate is rendered completely austenitic.

The completely austenitic plate is next quenched to a temperature within the stated range of from 100° C. to 400° C. This quenching is accomplished by means of a short oil or water quench or in the case of thin sections, by immersing the plate directly into the bath used to hold its temperature within the stated range. This bath is composed of either lead or a lead alloy adapted to give the desired fluidity at the holding temperature used, but oil or salt baths may be used for this purpose. Care is taken in all events to control the temperature of the bath to keep it constant, it being preferable to hold the temperature of the plate at a constant value within the stated range since this provides better control of the method.

During the time the temperature of the plate is being held, the austenite of the uncarburized portion is transforming to the particular products formed in the temperature range used, the austenite of the carburized surface failing to transform to any great extent during this period because of its higher carbon content and, therefore, its much slower rate of austenitic transformation. As soon as the austenitic transformation of the uncarburized portion is complete, the plate is quenched by means of oil or water to approximately atmospheric temperature and at a rate hardening the untransformed austenite of its carburized surface to martensite, this producing a very hard surface. As just stated, the second quenching is carried out after the lapsing of sufficient time to assure substantially complete transformation of the austenite of the uncarburized portion of the plate, and in all cases the second quenching must be performed prior to transformation of more than 25% of the austenite of the carburized surface to obtain a properly hardened surface. The time period of the first quenching and the time for initiating the second quenching are easily determined factors.

If the plate is flat at the termination of the period effecting austenitic transformation of the uncarburized portion, the second quenching converting the carburized surface to martensite, causes a consequent expansion of this surface so that it becomes convex. This is contrary to what usually occurs in the case of conventional hardening methods and is important in that subsequent flattening of the plate throws the hardened surface in compression so that it cannot rupture.

To obtain a flat plate, the plate is plastically formed prior to completion of the transformation of the austenite of its uncarburized portion in such a manner as to make its carburized surface concave. Then, upon the subsequent quenching transforming the austenite of the carburized surface to martensite, the expansion incidental to this transformation flattens the plate. In this way, a flat piece of armor plate is produced which requires little or no subsequent flattening.

The plastic forming is done in various manners, a roller leveler, pressure jig, or other forming device being usable. The plate is removed from the bath for the forming operation or, if desired, the forming device itself may be immersed directly in the bath. Any such forming, of course, is done prior to complete hardening of the uncarburized portion of the plate.

The armor plate produced by this method has a properly hardened or martensitic carburized surface with its remainder comprising those products recognized as resulting from austenitic transformation practically entirely within the temperature range of from 100° C. to 400° C. If necessary, the hardened surface is tempered by reheating to temperatures less than the transformation temperature for suitable periods of time. As previously mentioned, transformation products of austenite produced in the range stated are microscopically recognizable. Further-

more, physical tests show greater ductility and impact strength than can be obtained by conventional hardening methods in the case of steel of similar chemical composition.

We claim:

1. A method of thermally hardening a steel article having a portion with a higher carbon content than another portion, said method including heating said article to render both said portions austenitic, quenching said article to the temperature range of from 100° C. to 400° C., holding said article in said range until transformation of at least a majority of the austenite of the second named portion is effected and quenching said article to below said range prior to transformation of more than minor amounts of the austenite of the first named portion and at a rate producing martensite.

2. A method of thermally hardening a steel article having a portion with a higher carbon content than another portion, said method including heating said article to render both said portions austenitic, quenching said article to the temperature range of from 100° C. to 400° C., holding said article in said range until transformation of at least a majority of the austenite of the second named portion is effected and quenching said article to below said range prior to transformation of more than minor amounts of the austenite of the first named portion and at a rate producing martensite, said method further including the addition to the steel of said article while it is molten of at least one alloying element other than carbon and which is of such a character and used in such amount as to materially retard the austenitic transformation rate of said steel as compared to plain carbon steel of similar carbon content.

3. A method of thermally hardening a steel article having a portion with a higher carbon content than another portion, said method including heating said article to render both said portions austenitic, quenching said article to the temperature range of from 100° C. to 400° C., holding said article in said range until transformation of at least a majority of the austenite of the second named portion is effected and quenching said article to below said range prior to transformation of more than minor amounts of the austenite of the first named portion and at a rate producing martensite, said method further including plastically forming said article after the starting of but prior to complete transformation of the austenite of the second named portion.

4. A method of thermally hardening a steel article having a portion with a higher carbon content than another portion, said method including heating said article to render both said portions austenitic, quenching said article to the temperature range of from 100° C. to 400° C., holding said article in said range until transformation of at least a majority of the austenite of the second named portion is effected and quenching said article to below said range prior to transformation of more than minor amounts of the austenite of the first named portion and at a rate producing martensite, said method further including tempering the first named portion at a temperature less than the temperature where the austenite of the second named portion occurred.

5. A method of hardening an allow steel plate with a carburized surface, comprising heating said plate to render it entirely austenitic, quenching said plate to the temperature range of from 100° C. to 400° C., holding the plate in said range until austenitic transformation of its uncarburized portion is practically complete and quenching said plate prior to transformation of more than 25% of the austenite of said carburized surface and at a rate producing martensite, said plate being plastically formed to render its carburized surface convex to a degree preventing said surface from becoming concave when rendered martensitic, said plastic forming being done after the starting of but prior to complete transformation of the austenite of the uncarburized portion of said plate.

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