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METHOD OF HARDENING HYPEREUTECTOID STEELS

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ABSTRACT OF THE DISCLOSURE

A method of hardening hypereutectoid steels having less than about 5% total alloy content by heating them to an austenitizing temperature where substantially all carbides are dissolved and then quenching to produce martensite with retained austenite. A substantially austenite-free microstructure is then developed by either (1) quenching to below the M_s temperature to form a mixture of martensite and austenite, reheating to the bainite forming range and then holding for sufficient time to transform all the austenite to bainite and to temper the martensite to a mixture of carbides and ferrite, or (2) quenching to within the bainite forming range and holding therein until substantially all austenite is transformed to bainite. After performing one of (1) or (2) above, the steel is then reheated rapidly to a temperature in the range of 1425 to 1600° F. to convert substantially all ferrite to austenite without causing substantial growth of undissolved carbides. Subsequently, the steel is cooled to harden same and to produce a martensitic structure with an austenite grain size finer than ASTM #10 and a dispersion of uniformly fine carbides.

This application is a continuation-in-part of application Ser. No. 377,534 filed June 24, 1964.

The present invention relates to a method of treating steel to improve mechanical properties. More particularly, the invention concerns a multi-step heat treatment for high carbon steel which develops a unique microstructure. The invention is useful in the treatment of hypereutectoid steels which contain about 0.8% or more of carbon and have a low total alloy content, i.e. less than about 5%. These steels include AISI standard types C1095, E50100, E51100 and E52100 as well as various tool steels of the water and oil hardening types.

Conventionally, steels are hardened by heat treating which involves heating in the range of 1450 to 1600° F. and quenching. The aim in conventional hardening treatments is to dissolve in austenite only part of the total carbon present in the steel. If all or nearly all of the carbon is dissolved, so much austenite is retained after quenching that hardening is reduced considerably and mechanical properties are adversely affected.

It is also customary to harden steels which have been spheroidized by annealing prior to the hardening treatment. In the spheroidized condition, high carbon steels can be readily machined and also respond more satisfactorily to conventional hardening heat treatments. Because of the initial spheroidized microstructure, the carbon remaining undissolved after austenitizing for hardening is generally present as relatively large carbide spheroids. These large undissolved carbides are thought to be undesirable although preferable to large amounts of retained austenite. Thus, conventional hardening of hypereutectoid steels represents a compromise between an undesirably large amount of austenite and the somewhat less undesirable large carbides.

It is an object of the present invention to provide a heat treatment which will result in less retained austenite in the final product than is obtained in conventional hardening treatments and at the same time substantially eliminate large undissolved carbides. In addition, the heat treatment develops a finer grained microstructure that can be obtained by conventional hardening.

According to the invention, hypereutectoid steel having less than about 5% total alloy content is first heated to a temperature of about 1700 to 2000° F. to convert ferrite to austenite and to dissolve substantially all carbides in the austenite. The heating rate is not critical and the steel can be heated in any convenient manner so long as substantially complete dissolution of carbides in austenite is achieved. Following austenitizing, the steel is treated by either of the following two methods to develop a substantially austenite-free microstructure while minimizing distortion and formation of cracks.

One such method to develop a substantially austenite-free microstructure is to quench below the M_s temperature so as to form a mixture of martensite and austenite and then reheat to the bainite forming range and hold therein for a time sufficient to transform substantially all the austenite to bainite and to temper the martensite to a mixture of fine carbides and ferrite. As an alternative to this, however, an austenite-free microstructure can be developed by the second method which comprises quenching directly to within the bainite forming range and holding therein until substantially all austenite is transformed to bainite.

After performing one of the aforementioned methods to produce an austenite-free microstructure, and either cooling to room temperature or reheating immediately, the steel is then reheated rapidly to a temperature in the range of 1425 to 1600° F. for a time sufficient to convert substantially all ferrite to austenite but insufficient to cause substantial growth of the fine undissolved carbides present. Following such heating the steel is cooled to harden same and to produce a fine-grained structure with an austenite grain size finer than ASTM #10 and with a uniform dispersion of fine carbides.

In developing the austenite-free microstructure by the first method described above, the steel is quenched to below the M_s temperature and then immediately reheated into the bainite forming range of 600 to 800° F. The heating time used may vary with the type of steel and the exact temperature selected. Preferably, a time-temperature combination is selected which will result in the transformation of austenite in a conveniently short time. It is necessary in this treatment to transform substantially all the austenite to bainite because any austenite which is not transformed in this step will survive the final heating treatment without having a fine dispersion of carbides. In the conversion to bainite, the fine carbides are distributed throughout the ferrite and retained austenite which if not transformed will not contain the dispersion of carbides required and the result will be an undesirable, non-uniform microstructure.

As discussed above, an alternative to quenching to below the M_s temperature is to quench directly from the austenitizing temperature to within the bainite forming range and hold therein until substantially all austenite is transformed to bainite. This approach avoids the necessity for reheating to the bainite forming range in the previously described treatment and a substantially austenite-free microstructure can be developed with still less risk of distortion and microcrack formation since quenching to lower temperatures, i.e. below the M_s temperature, is avoided.

After elimination of austenite by either of the treatments described above, either with or without intermediate cooling to room temperature, the steel is rapidly reheated to a temperature in the range of 1425 to 1600° F.

to convert any ferrite present to austenite and to uniformly disperse undissolved carbides. It is preferable to maintain the steel at this elevated temperature only sufficiently long enough to convert all ferrite to austenite while leaving the undissolved portion of the carbon in the steel in a state of fine, uniformly dispersed particles. This can be accomplished by maintaining the steel at temperature only until it has achieved substantially uniform temperature throughout. In this way, part of the carbides remain distributed in the austenite to which the ferrite portion of the bainite is converted. By minimizing the time at austenitizing temperatures (1425 to 1600° F.) the portion of the fine carbides undissolved in the austenite will be present as a fine and uniform dispersion. It has been found that depending upon the size of the work it is best in any event to limit the time at austenitizing temperature to not more than 5 minutes after achieving substantially uniform temperature throughout the work.

The rapid heating to austenitizing temperature may be accomplished by any suitable means including immersion in a molten salt or metal bath, induction heating or resistance heating. The total heating time depends on the mass of the work and the mode of heating but as stated above, should avoid dwelling and only be long enough to heat the steel throughout to substantially the predetermined temperature, usually less than 5 minutes.

It has been found that in the foregoing step the temperature range of 1425 to 1600° F. is very important because at temperatures even slightly below 1425° F. erratic results are likely and the hardness falls off considerably. At temperatures above about 1600° F. the grain structure coarsens, too many carbides are dissolved and increasing amounts of retained austenite result. The following data for an AISI 1095 steel at different temperatures illustrate the variation in hardness which results.

Temperature, ° F.:	Hardness, DPH
1370	735
1380	840
1395	895
1425	910
1525	900

The steel after heating as above is subsequently hardened by cooling and a fine-grained structure results which, as a result of the above described heat treatment, contains a minimum amount of retained austenite and a dispersion of uniformly fine carbides. The austenite grain size characteristic of the resulting product is finer than ASTM #10. Cooling to harden may be conveniently accomplished by quenching in oil. After quenching to martensite, the steel can be tempered by heating to 350° F. or higher. However, other hardening methods such as martempering and austempering may be used. Thus, the steel can be cooled to the martempering temperature and held until stabilized after which it can be cooled to room temperature. In the case of austempering, the steel will be held until transformation to bainite is completed.

As a specific example of the invention, a sample of the AISI 52100 steel was heated to 1800° F. and held at the temperature for a time sufficient to convert ferrite to austenite and to dissolve substantially all of the carbide phase in the austenite. The sample was quenched according to the preferred embodiment in oil which was maintained at a temperature of 125 to 150° F. Also according to the preferred embodiment, the sample was held in the oil barely long enough to reach the temperature of the bath before proceeding with the next step in order to minimize microcracks. It has been found that the formation of microcracks is time-dependent and immediate reheating after quenching in warm oil will minimize microcracking. The retained austenite in the sample after quenching was transformed to bainite by heating it at 600° F. for 2 hours. After converting retained austenite to bainite and transforming martensite to fine carbide and ferrite (by heating to 600° F. as above) the steel was rapidly heated by immersion in molten lead to 1475° F. for 40 seconds. The steel was then quenched in oil to harden it and was tempered at 400° F. for 2 hours.

Comparison of the microstructure of the sample heat treated as described above with the sample which was conventionally hardened by heating to 1500° F. and tempering for 2 hours at 400° F. shows that the two microstructures differ markedly from each other.

Comparative tests of samples treated according to the invention and samples conventionally hardened has demonstrated that in accordance with the different microstructures the samples have different mechanical properties as shown in the following table:

TABLE I

Sample (0.3" thick)	Hardness, DPH	Tensile Strength, p.s.i.	Yield Strength, p.s.i.	Retained Austenite, Percent
A[1]	755	326,000	315,900	9
B[2]	735	309,500	297,400	12–15

[1] Treated according to the invention: 1800° F., oil quench; temper 600° F., 2 hours; 1475° F., 40 seconds, oil quench; temper 400° F., 2 hours.
[2] Conventionally hardened: 1500° F., oil quench; temper 400° F., 2 hours.

If greater hardness than resulted in the foregoing example is desired in AISI 52100 steel, the final heating temperature should be higher. Table II shows the variation in hardness with different final heating temperatures. In this example, two sets of similar pieces were prepared. Both sets were heated similarly at 1800° F. for 20 minutes in accordance with the first step of the invention. One set, designated "Treatment A," was quenched from 1800° F. into oil at 140° F. for 1 minute and then heated immediately for 2 hours at 600° F. as specified by one embodiment of the second step of the invention. The other set, designated "Treatment B," was treated by the alternative second-step of the invention. This consisted of quenching rom 1800° F. into a lead bath at 700° F. and holding therein for 3 hours to transform substantially all the austenite to bainite before proceeding as indicated in Table II.

TABLE II

Reheat Temp. (Tx)	Quench	Temper	Product Hardness, DPH	
			Treatment A[1]	Treatment B[2]
1,395° F	Warm Oil	350° F. for 1 hour.	485	520
1,455° F	do	do	785	785
1,490° F	do	do	800	800
1,550° F	do	do	805	805
1,595° F	do	do	805	805
1,650° F	do	do	735	752

[1] Treatment A: 1,800° F., 20 minutes; quench in oil at 140° F.; temper 2 hours at 600° F.; reheat at Tx for 1 minute; quench in warm oil; temper 1 hour at 350° F.
[2] Treatment B: 1,800° F., 20 minutes; quench in lead at 700° F. and hold for 3 hours; reheat at Tx for 1 minute; quench in warm oil; temper 1 hour at 350° F.

Within the reheat range of 1425 to 1600° F. specified in the invention, Treatments A and B both yield equivalent results. Treatment A is the more convenient but alternative Treatment B is less likely to distort or crack the product and consequently might be preferred in treating certain parts. The optimum reheat temperature for this alloyed 52100 steel is higher than indicated previously for a nonalloyed 1095 steel because alloyed carbides dissolve more slowly in austenite than cementite.

As another example of the practice of the invention, pieces of an oil-hardening tool steel containing 1.19% carbon, 0.34% manganese, 0.36% silicon, 0.34% chromium and 1.28% tungsten, in addition to the usual impurity elements in commercial steel, were first heated at 1800° F. for 20 minutes, quenched in a lead bath at

700° F. and held therein for 3 hours to transform substantially all austenite to bainite. They were subsequently reheated at the various temperatures listed in Table III for 1 minute, quenched in warm oil and finally, tempered for 1 hour at 350° F. Hardness developed by each reheat temperature is as follows:

TABLE III

Reheat temperature, ° F.:	Hardness, DPH
1395	615
1455	835
1490	825
1550	820
1595	815
1650	775

Satisfactory hardening resulted in this steel on reheating at temperatures in the 1425 to 1600° F. range but below and above this range the hardness is low.

It is apparent from the foregoing description that various changes and modifications may be made without departing from the invention.

I claim:

1. A method of hardening hypereutectoid steels having less than about 5% total alloy content comprising heating said steel to a temperature in the range of about 1700 to about 2000° F. for a time sufficient to form austenite and to dissolve in said austenite substantially all carbides, rapidly quenching to below the M_s temperature to form a mixture of martensite and austenite, reheating into the bainite forming temperature range and holding therein for a time sufficient to transform substantially all the austenite to bainite and to temper the martensite to a mixture of fine carbides and ferrite, reheating to a temperature in the range of 1425 to 1600° F. for a time sufficient to convert substantially all ferrite to austenite but insufficient to cause substantial growth of any fine carbides present and finally cooling to harden the steel and produce a fine-grained structure with an austenite grain size finer than ASTM #10 and a dispersion of uniformly fine carbides.

2. A method of hardening hypereutectoid steels in accordance with claim 1 wherein said quenching to below the M_s temperature is performed in warm oil at a temperature of 125 to 150° F.

3. A method of hardening hypereutectoid steels in accordance with claim 1 wherein said quenching to below the M_s temperature is for a time just sufficient to achieve uniform temperature throughout the steel and said steel is reheated to the bainite forming range.

4. A method of hardening hypereutectoid steels in accordance with claim 1 wherein said reheating in the range of 1425 to 1600° F. is performed in a manner such as to bring the steel to uniform temperature in not more than about 5 minutes.

5. A method in accordance with claim 1 wherein said reheating in a range of 1425 to 1600° F. is conducted in a manner such as to bring the steel to uniform temperature in not more than about 5 minutes.

6. A method of hardening hypereutectoid steels having less than about 5% total alloy content comprising heating said steel to a temperature in the range of about 1700 to about 2000° F. for a time sufficient to form austenite and to dissolve in said austenite substantially all carbides, quenching directly to within the bainite forming range and holding therein until substantially all austenite is transformed to bainite, subsequently reheating in the range of 1425 to 1600° F. for a time sufficient to convert substantially all ferrite to austenite but insufficient to cause substantial growth of any fine carbides present and thereafter cooling to harden the steel and produce a fine grain structure with an austenite gain size finer than ASTM #10 and a dispersion of uniformly fine carbides.

7. A method of hardening hypereutectoid steels in accordance with claim 6 wherein said reheating in the range of 1425 to 1600° F. is performed in a manner such as to bring the steel to uniform temperature in not more than about 5 minutes.

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