

UNITED STATES PATENT OFFICE

2,188,155

METHOD OF ANNEALING STEEL

Peter Payson, New York, N. Y., assignor to
Crucible Steel Company of America, New York,
N. Y., a corporation of New Jersey

No Drawing. Application December 8, 1938,
Serial No. 244,586

10 Claims. (Cl. 148—21.5)

This invention relates to the production of a non-lamellar or spheroidized, annealed structure in steel, and more particularly, to improved methods of so annealing steels which form lamellar pearlite on relatively slow cooling from above the critical temperature, such as plain carbon and low alloy steels, as well as certain of the higher alloy types.

The invention provides methods of spheroidizing such steels which are far more economical and far less time-consuming than existing methods, and which are superior to certain existing practices in the further respect that, where required, a completely spheroidized structure may be secured with certainty and precision; whereas the practices referred to are apt to result in a product containing an unacceptably high percentage of lamellar pearlite.

There are instances where a mixed lamellar and non-lamellar structure is actually desired in the steel as annealed, provided, however, that these two types of structures are present in a definite ratio, preselected to meet certain requirements. With existing methods of annealing the percentages in which these two types will be present in any particular heat, is uncertain and not accurately determinable in advance. The present invention provides methods of so annealing the steel as to provide any predetermined ratio of lamellar to non-lamellar structure in the annealed product.

Steels which may be hardened, due to formation of martensite, on quenching or cooling with sufficient rapidity from above the critical temperature, may be divided into two classes: those in which, when cooled more slowly from above the critical, the austenite is transformed into lamellar pearlite comprising alternate strata or plates of ferrite and carbides; and those in which the carbides precipitate out only in non-lamellar, rounded or angular particles embedded in a matrix of ferrite. The plain carbon and alloy structural steels, the more simple carbon and alloy tool steels, and the low alloy steels generally, are examples of the first class; while

the high speed, high carbon-high chromium, and the hardenable stainless steels are examples of the second class.

The steels having structures consisting largely of lamellar pearlite when slowly cooled as aforesaid are frequently given a heat treatment to change the distribution of the carbides from a lamellar to a non-lamellar or spheroidal form for one or more of the following reasons: to improve machineability; to improve cold rolling or bending properties; to improve ductility and toughness as measured by tensile and notch impact tests; and to decrease hardenability.

To effect this change from the lamellar to the spheroidal condition of the carbides, the steel industry has heretofore relied on two methods: (1) the "spheroidizing" treatment which consists in a very long heating at a temperature either just below the critical or alternately just above and just below the critical temperature, followed usually by slow cooling, for example furnace cooling, to room temperature; and (2) the "quench and temper" treatment consisting in a normalize or oil quench from a temperature appreciably above the critical, followed by a tempering for a long time at a temperature not far below the critical. The disadvantages of the treatment first referred to are: the long time required—frequently as much as 72 hours—and the uncertainty of the outcome, i. e., that all of the lamellar carbides will be converted into the non-lamellar or spheroidal form. The disadvantages of the method last mentioned are: the expense of the double handling in heat treating; the fuel expense of reheating; the warping incident to quenching, especially of small sized bars, necessitating extra straightening operations; and the restriction of this method to relatively small sized bars of steels which are not inherently "deep hardening."

It has, heretofore, been the generally accepted understanding in the steel industry that when steels of the type under discussion are cooled from a temperature above the critical to room temperature, at rates not sufficiently rapid to

cause the formation of martensite, that structures containing lamellar pearlite will inevitably result, and that this lamellar pearlite will vary in coarseness inversely with the rate of cooling. I have discovered on the contrary, that if the heating of the steel is limited to a temperature which is not too far above the critical temperature at which austenite begins to form, and that if this is followed by a cooling of the steel below this critical temperature and by a holding of the steel for a sufficient interval within a temperature range which is not too far below this critical temperature, that a relatively soft structure consisting exclusively, or substantially so, of spheroidal carbides in a ferrite matrix will result. It is immaterial to the result whether the steel be cooled rapidly or slowly from the temperature of heating above the critical to the temperature range below the critical within which it must be held to effect spheroidization because the steel undergoes no change in structure during the cooling; and it is likewise immaterial once the spheroidization is complete, whether the steel be further cooled rapidly or slowly to atmospheric temperature, because such cooling produces no further change in the steel. The controlling factors in the process are, therefore: (1) limitation of the temperature above the critical to which the steel is heated; (2) restriction of the temperature range below the critical to which it is cooled; and (3) the time interval the steel is held within this range below the critical temperature.

There are accordingly a number of distinctive characteristics of the steel, apparently unappreciated heretofore, all of which must be strictly observed and correctly interpreted and applied if the desired result of a completely spheroidized structure is to be secured, as otherwise a product containing lamellar pearlite will inevitably result. If for example the steel is heated too far above the critical temperature, lamellar pearlite will be produced on cooling to room temperature, no matter how slowly the steel is cooled and irrespective of the holding time within the temperature range below the critical at which spheroidization is effected in accordance with my invention. Also even though the heating is not carried too far above the critical temperature, lamellar pearlite will be formed if the steel is cooled too rapidly through the subcritical spheroidizing range, as might occur by holding the steel within this range for an insufficient interval, or by cooling the steel to too low a temperature before holding.

In carrying out my process of annealing to produce a spheroidized structure, the steel must be heated sufficiently far above the critical temperature and held there for a sufficient interval to produce complete disappearance of all lamellar pearlite initially present. Usually heating to a temperature of less than 100° F. above the critical will suffice. For eutectoid and hypoeutectoid steels, heating just above the critical temperature, for example 10 to 25° F. above the critical, is usually sufficient; while for hypereutectoid steels somewhat higher temperatures of say 50 or 75° F. above the critical, are ordinarily required. Moreover, the heating may be carried somewhat above the minimum temperature above the critical required to produce complete disappearance of the lamellar pearlite initially present without destroying the ability of the steel to change to a spheroidized structure, substantially free from lamellar pearlite, on subsequent cool-

ing to, and holding at, an appropriate subcritical temperature. For eutectoid and hypoeutectoid steels, the heating range may accordingly be extended to about 50° F. above the critical, and for some of the hypereutectoid steels, to 200° F. or more above the critical, consistent with substantially complete conversion to a non-lamellar or spheroidized structure at the subcritical holding temperature.

The duration of holding at heat above the critical will vary with the size of the article, which should be thoroughly "soaked" at the temperature in question. Ordinarily an interval of 15 to 30 minutes per inch of thickness of the article will suffice. Too long a holding at heat, for example, considerably in excess of one hour per inch of thickness of the article, should be avoided.

The most appropriate holding temperature below the critical is dependent on the analysis of the steel and also on the time required for completion of the change from austenite to ferrite and spheroidal carbides, but is ordinarily found to be within the range of about 10 to 100° F. below the critical for the vast majority of steels. The closer the holding temperature is to the critical temperature, the longer is the time required to complete the change. On the other hand, the lower the temperature at which the change is allowed to occur, the greater is the tendency for lamellar pearlite to form. Depending on the analysis of the steel and the particular subcritical holding temperature employed, the time required to complete the change may vary from as little as 15 to 30 minutes to as much as 50 hours or more. Usually, however, the holding time may be limited to a maximum of 15 to 20 hours for even the most difficult steels to anneal, by appropriate selection of the holding temperature.

My preferred method of annealing to produce a completely non-lamellar or spheroidized structure, is to heat the steel to an appropriate temperature above the critical, "soak" at this temperature, and then drop the temperature as rapidly as is convenient, preferably quickly for economy, to the selected subcritical holding temperature, as for example by shutting off burners and opening the doors and dampers of the furnace to air cool, or by removing the steel to a cooler part of the same furnace, or to a different furnace, or to a liquid bath maintained at the subcritical holding temperature. Whatever procedure is employed in cooling to the subcritical temperature, the steel is thereafter held at or close to the selected subcritical holding temperature until the change to a non-lamellar or spheroidized structure is complete, following which the steel is further cooled to room temperature as rapidly as is convenient, preferably quickly for economy, as by air cooling, or even by quenching in water, etc., if desired. Of course complete spheroidization may be secured by merely cooling the steel sufficiently slowly from heating temperature above the critical down through the subcritical range within which the spheroidization is effected, as for example by cooling at a rate of about 5 to 25° F. per hour or less for some steels, but this is wasteful of time in that no spheroidization occurs during the interval that the steel is cooling from the heating temperature above the critical to the subcritical spheroidizing temperature range.

As illustrative of the invention as applied to the production of a non-lamellar, annealed struc-

ture in a wide variety of steels, the following Table I gives for steels of the indicated types and analyses, appropriate heating temperatures and subcritical holding temperatures, together with the resulting hardness of the annealed steel:

hardness of under "B" 94 Rockwell, was obtained in 64 hours by holding at 1275° F. for 48 hours followed by quenching and reheating to the same temperature for an additional 16 hours. A similar bar when spheroidized by the prior art meth-

Table I

No.	Steel Type	Analysis						Critical temp., °F.	Heating temp., °F.	Sub-critical holding temp., °F.	Hardness after annealing, Rockwell "B"
		C	Mn	Si	Ni	Cr	Other elements				
1	SAE-1025	.30	.46	.40	.18	.06		1365	1385	1320	73
2	Water hardening tool	.63	.18	.25	.10	.06		1365	1385	1340	79
3	do.	.81	.36	.18	.14	.13		1360	1385	1340	88
4	do.	1.15	.25	.25	.09	.10		1360	1410	1340	90
5	SAE-1050	.46	.80	.19	.18	.12		1350	1365	1320	81
6	SAE-2340	.38	.68	.29	3.11	.20		1280	1400	1175	82
7	SAE-62100	1.04	.35	.33	.10	1.35		1385	1425	1320	95
8	Machinery	.46	.99	.17	.05	.50	.13 Mo	1350	1390	1325	85
9	Oil hardening	.85	1.16	.12	.04	.60	.46 W	1370	1425	1320	95
10	SAE-4140	.40	.78	.17	.08	.96	.29 Mo	1370	1500	1300	91
11	SAE-6150	.50	.95	.19	.22	1.03	.20 V	1380	1550	1325	87
12	SAE-6140	.36	.73	.47	.12	.89		1395	1500	1325	90
13	SAE-3240	.41	.48	.27	1.68	1.05		1345	1450	1275	89
14	Special alloy	.30	.64	.28	2.62	.68	.60 Mo	1305	1600	1225	93
15	SAE-4340	.37	.47	.21	1.80	1.05	.23 Mo	1295	1450	1275	93

The "critical temperature" referred to in the above table and as applied to my invention generally, is always the temperature at which austenite begins to form when the steel is heated. This temperature is definite for any given steel analysis, and does not depend to any appreciable degree on the rate of heating, or on the previous condition or structure of the steel. It may be determined by heating small specimens of the steel to successively higher temperatures, water quenching from such temperatures, and then examining the microstructures of the quenched specimens, or by testing for increase in hardness. When any such quenched specimen shows martensite, or an increase in hardness as compared to its hardness prior to heating and quenching, it is absolutely established that the specimen has been quenched from a temperature above the critical at which austenite begins to form. It is essential that there be no ambiguity as to what is meant by "the critical temperature" in relation to the present invention and that the above is what is intended, because the literature very often refers to the "critical temperature on cooling" or the Ar point, which is not a constant temperature and can be varied almost at will by changing the temperature from which the cooling is started or by changing the rate of cooling.

In effecting spheroidization of certain steels difficult to anneal, it is sometimes found advantageous, in order to arrive at a compromise between a very long holding time for complete spheroidization at the selected sub-critical temperature, and the extra labor cost of a double heat treatment, to intentionally quench the steel to room temperature before the change from austenite to ferrite and spheroidal carbides is complete, thereby to convert the untransformed austenite into martensite, following which the steel is tempered by reheating just below the critical temperature until the martensite is converted into ferrite and spheroidized carbides. As an example of this procedure a bar of SAE-4335 steel of approximate analysis: 0.4% C, 0.7 Mn, 0.4 Si, 2.0 Ni, 1.0 Cr, 0.3 Mo, was found to require about 100 hours to effect complete spheroidization when held at 1275° F., i. e., 20° F. below the critical after heating above the critical, namely at about 1450° F.; whereas, by following the procedure above outlined, conversion to a completely spheroidized structure having a low

od of quenching to room temperature from above the critical followed by a tempering reheat just below the critical temperature, was found to require 120 hours to effect complete spheroidization for the same low hardness of under "B" 94 Rockwell.

If an annealed steel having a mixed lamellar and non-lamellar structure in specified proportions is desired, the spheroidizing treatment above outlined may be followed by heating about 10 to 200° F., and preferably under 100° F. above the critical, quickly cooling to the spheroidizing temperature of about 10 to 100° F. below the critical and holding thereat for only so long in this instance, however, as to carry the spheroidization to the extent desired, following which the steel is quickly cooled to a somewhat lower temperature, for example 150° to 250° F. below the critical, at which the theretofore unconverted portions of the steel will change into lamellar pearlite. Various alternative procedures may be employed. For example, the steel may be heated, as above, to a temperature within the range of about 10° to 200° F. and preferably under 100° F. above the critical, for just a sufficient time to reduce the lamellar pearlite originally present to the proportion of this constituent desired in the finished product, whereupon the steel may be either: (1) quickly cooled to the spheroidizing range of about 10° to 100° F. below the critical and held there until the austenitized portion has been spheroidized; or (2) quenched from above the critical to room temperature and thereafter reheated below the critical to spheroidize the martensitic portion formed on quenching. These procedures by taking advantage in the final product of the lamellar pearlite originally present, eliminate the step in the method first outlined of holding at a subcritical temperature to form this constituent. Another method is to heat the steel sufficiently high above the critical—150° to 200° F. or more above—to assure that only lamellar pearlite will be formed on slow cooling, cool quickly below the critical and hold at an appropriate subcritical temperature—about 25° to 50° F. below the critical will suffice in this case—until the formation of lamellar pearlite has proceeded to the desired extent, following which the steel is quenched to room temperature to change the unconverted portions into martensite, and thereafter tempered by reheating below the critical to spheroidize the martensite. Still an-

other procedure is to heat to a temperature of about 100° to 200° F. or more above the critical, such that a mixed lamellar and non-lamellar structure will tend to form on cooling, and thereafter to cool quickly to a temperature of about 50° to 150° F. below the critical such as to bring out the mixed structure desired, and to hold thereat until conversion is complete.

Methods of annealing in accordance with the present invention, as above described, depend for their success on accurate control of the steel temperatures, and very frequently it is essential to the successful securing of the results desired, to have thermocouples directly in contact with the steel being treated.

I claim:

1. A method of annealing steel to produce a substantially non-lamellar structure therein, which comprises: heating the steel above the critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, the maximum temperature of said heating being, however, below temperature for which a lamellar structure is again unavoidably obtained on slow cooling below said critical temperature, cooling the steel to the temperature range just below said critical temperature within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides; holding within said range until said conversion is complete; and thereafter cooling the steel to room temperature.

2. A method of annealing steel to produce a substantially non-lamellar structure therein, which comprises: heating the steel within the temperature range of about 10° to 200° F. above the critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, cooling the steel to the temperature range of about 10 to 100° F. below said critical temperature within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides and holding within this range until said conversion is complete.

3. A method of annealing steel to produce a substantially non-lamellar structure therein, which comprises: heating the steel within the temperature range of about 10° to 200° F. above the critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, cooling the steel to the temperature range of about 10 to 100° F. below said critical temperature within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides, holding within this range until said conversion is complete, and cooling the steel to room temperature.

4. A method of annealing steel to produce a substantially non-lamellar structure therein, which comprises: heating the steel within the temperature range of about 10 to 200° F. above the critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, rapidly cooling the steel to the temperature range of about 10 to 100° F. below said critical temperature within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides, holding within this range until said conversion is complete, and thereafter rapidly cooling the steel to room temperature.

5. A method of annealing steel to produce a relatively soft non-lamellar structure therein, which comprises: heating the steel above the

critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, the maximum temperature of said heating being, however, below the temperature for which a lamellar structure is again unavoidably obtained on slow cooling below said critical temperature, cooling the steel to the temperature range below the critical within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides and holding within this range until said conversion is partially complete, thereafter rapidly cooling the steel to room temperature and tempering below said critical temperature to complete the change into said relatively soft, non-lamellar mixture of ferrite and carbides, and cooling the steel to room temperature.

6. A method of annealing steel to produce a non-lamellar structure therein, which comprises: heating the steel within the range of about 10 to 200° F. above the critical temperature at which austenite begins to form until all lamellar structure initially present has disappeared, rapidly cooling the steel to the temperature range of about 10 to 100° F. below said critical temperature within which the steel converts into a relatively soft, substantially non-lamellar mixture of ferrite and carbides and holding within this range until said transformation is partially complete, thereafter rapidly cooling the steel to room temperature and tempering below said critical temperature to complete the change into said relatively soft, non-lamellar mixture of ferrite and carbides, and cooling the steel to room temperature.

7. A method of annealing steel to produce a relatively soft mixture of lamellar and non-lamellar structures therein in preselected proportions, which comprises: heating the steel within the temperature range of about 10 to 200° F. above the critical temperature at which austenite begins to form until all lamellar structure initially present in the steel has disappeared, rapidly cooling the steel to the temperature range of about 10 to 100° F. below said critical temperature within which the steel converts into a relatively soft, non-lamellar mixture of ferrite and carbides and holding within this range until said conversion has been carried to said preselected extent, thereafter rapidly cooling the steel to the slightly lower temperature range within which the previously unconverted portions of the steel will change into lamellar pearlite and holding within this range until said change is complete, and thereafter cooling the steel to room temperature.

8. A method of annealing steel having a lamellar structure initially, to produce a mixed lamellar and non-lamellar structure therein in preselected proportions, which comprises: heating the steel to about 10° to 200° F. above the critical temperature at which austenite begins to form until said original lamellar structure has been reduced to said preselected proportion, thereafter quickly cooling the steel to the temperature range of about 10° to 100° F. below said critical temperature within which the non-lamellar portion of said steel will convert into a relatively soft, non-lamellar mixture of ferrite and carbides and holding within said range until said conversion is complete, and cooling the steel to room temperature.

9. A method of annealing steel to produce a relatively soft, mixed lamellar and non-lamellar structure therein in preselected proportions, which

comprises: soaking the steel at a temperature upwards of about 150° F. above the critical temperature at which austenite begins to form and sufficiently high to assure that only lamellar
5 pearlite will be formed on slow cooling, cooling the steel to about 25° to 150° F. below said critical temperature and holding thereat until said preselected proportion of lamellar pearlite has formed, thereafter rapidly cooling the steel to
10 room temperature and reheating below said critical temperature to spheroidize the non-lamellar portion, and again cooling the steel to room temperature.

10. A method of annealing steel to produce a relatively soft, mixed lamellar and non-lamellar structure therein, which comprises: soaking the steel at a temperature of about 100° to 200° F.
5 above the critical temperature at which austenite begins to form and such as to produce a mixed lamellar and non-lamellar structure on slow cooling below said critical temperature, cooling the steel to about 50° to 150° F. below said critical
10 temperature and holding thereat until formation of said mixed structure is complete, and thereafter cooling the steel to room temperature.

PETER PAYSON.