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METHOD OF ANNEALING STEEL

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This invention relates to the annealing of steel, and has for its principal object the provision of more efficient and economical methods of annealing than heretofore.

It has been the practise in the steel industry in the annealing of steel, i. e. in order to make it soft, to cool the steel very slowly in an annealing furnace from a temperature above its critical temperature, frequently from about 100° to 200° F. above the critical depending on the analysis, down to temperatures considerably below the critical, for example 300° to 400° F. or more below, i. e. down to temperatures of about 1100° to 800° F. or even lower. For very soft annealing, a cooling rate of 20° F. per hour or less is used, and the total time required to anneal a batch of steel in the manner aforesaid ordinarily amounts to a matter of two to five days.

The annealing furnaces are accordingly tied up for long intervals with each batch, necessitating a large total furnace capacity to care for production during the most active periods. In an effort to reduce the high overhead on furnace construction thus entailed, resort has been made in some instances to the use of exceptionally large furnaces. This, however, introduces additional delays in shipments during slack periods, inasmuch as it is uneconomical to operate the furnaces at substantially less than full load, thereby causing the manufacturer to await the accumulation of sufficient orders to this end.

A method of annealing which would materially decrease the holding time of the steel in the annealing furnace would, therefore, reduce annealing costs and delays in shipments, and also would facilitate the handling of the steel in process of annealing during both active and slack periods.

I have devised methods of annealing which accomplish these desirable objectives and which, moreover, as applied to some steels, permit of efficiently and economically annealing steel in a continuous operation, whereby in such cases an annealing furnace would no longer be tied up for the interval required to anneal a particular batch of steel, and one furnace of the continuous type could replace a number of batch type furnaces.

The methods of annealing constituting my invention are based on my discovery that a large portion, and very often a major portion, of the time consumed by the aforesaid prior process of annealing, is entirely unnecessary, and that the same or a better result can be secured in a much shorter time for reasons and by following the procedure which I shall now explain.

With the prior practise above outlined, the steel is annealed by conversion on slow cooling below the critical temperature, of the austenite formed above the critical temperature on heating, into a relatively soft mixture of ferrite and carbides, such as lamellar pearlite, or spheroidal carbides in a ferrite matrix, or a mixture of these two in varying proportions, depending on the analysis of the steel, the temperature of heating above the critical, the cooling rate, etc. As the steel cools this conversion will commence at a certain temperature below the critical and will thereafter continue to completion with lapse of time as the temperature falls. The cooling rate determines the temperature at which the conversion begins and also the temperature at which it ends; and also determines the time required for the conversion and the resulting hardness of the steel. The slower the cooling rate the higher these temperatures, also the longer the conversion time, and the softer the steel after annealing. Since in continuous cooling, some change occurs at successively lower temperatures throughout the conversion range, the final product will be made up of the products formed at various temperatures, and the resulting softness will depend on the proportions formed at each temperature.

The temperature limits between which the conversion aforesaid is thus effected for any given rate of cooling and for any given analysis of steel, can easily be determined by water quenching small specimens of the steel from various temperatures as the cooling proceeds, and thereafter examining the microstructures of these specimens. In the specimens quenched from above the temperature at which conversion into a relatively soft mixture of ferrite and carbides is initiated, all of the austenite formed above the critical temperature will be transformed on water quenching, into martensite and can be identified as such. On the other hand, no martensite will be found in the specimens quenched from temperatures below that at which conversion is completed, because the conversion itself consists in changing all of the austenite formed above the critical, into the aforesaid relatively soft mixture of ferrite and carbides, so that none of the austenite remains for transformation into martensite on water quenching following the conversion. The specimens quenched from temperatures between those at which conversion is initiated and completed, will, of course, contain a microstructure consisting in part of martensite and in part of a soft mixture of ferrite and carbides, in decreasing and increasing proportions respectively, for specimens

quenched from successively lower temperatures between these temperatures.

In this way it can be shown that no change occurs in the steel during the interval that it is being cooled from the temperature above the critical to which it was heated down to the subcritical temperature at which the conversion into a soft mixture of ferrite and carbides is initiated, and that accordingly, it is unnecessary to cool the steel slowly between these temperatures. And it is likewise unnecessary to continue the slow cooling of the steel to lower temperatures after the conversion is complete, because this also produces no change in the structure of the steel.

I have determined that for proper annealing, substantially complete conversion of the steel should in general be effected within the subcritical range extending from the critical temperature down to about 150° F. below the critical, since if any appreciable conversion occurs at substantially lower temperatures the resulting product will in general be too hard. It will be apparent, therefore, that with the prior practise of annealing by slowly cooling the steel from a temperature of 100° F. or so above the critical down to temperatures of 1100° F. or lower, which is in general about 300° F. or more below the critical, at least three-fourths of the time required for cooling is wasted and only about one-fourth or less is usefully expended in converting the steel into the desired structure consisting of a soft mixture of ferrite and carbides. Thus, for example, if a cooling rate of 20° F. per hour is employed, something in excess of about 25 hours would be required to anneal the steel by the above procedure, of which the steel would be undergoing conversion during only about 5 hours, the remaining 20 hours being unnecessary as the steel would merely be cooling and undergoing no change in structure during this interval.

I, therefore, propose in accordance with my invention, considered in its broader aspects, to cool the steel rapidly, as by air cooling or even by quenching in an appropriate liquid bath, from the heating temperature above the critical down to the subcritical temperature range within which the steel will convert into the aforesaid relatively soft mixture of ferrite and carbides, to thereafter hold the steel within this subcritical range until said conversion is complete, and thereupon to cool the steel rapidly to room temperature, as by air cooling or even by quenching in water, oil, etc., if desired. By following this procedure the only elapsed time is that involved in the actual conversion of the steel into the desired mixture of ferrite and carbides having the requisite degree of softness.

Thus my improved method results in a considerable saving in time in cooling the steel from the heating temperature above the critical to the subcritical temperature at which conversion starts; and also a considerable saving in time in cooling the steel to room temperature after the conversion is completed. Also with my improved method the steel can be removed from the annealing furnace as soon as the conversion is complete, and the furnace thus made available for a further charge in a shorter time and at a higher temperature than formerly. The latter is of importance in that it saves the fuel cost of heating the next load up to this temperature.

In carrying out my invention I rapidly cool the steel from the heating temperature above the critical to an appropriate subcritical annealing temperature, following which: I may hold the steel at or near this temperature until the conversion is complete; or I may allow the steel to cool slowly and more or less continuously during conversion; or I may hold the steel for appropriate intervals at progressively lower temperatures as the conversion progresses. Whichever procedure is followed, however, once the conversion is complete, I cool the steel rapidly to room temperature as aforesaid.

The softest possible anneal is imparted to the steel by allowing the change from austenite to ferrite and carbides to occur at a temperature just below the critical, for example 10° to 25° F. or so below. However, the time required to complete the change at these temperatures is usually quite long, and may be as much as 50 hours or more for certain steels. On the other hand, at a somewhat lower temperature, say 25° to 150° F. below the critical where the product of the change from austenite to ferrite and carbides is still fairly soft, although not as soft as that formed just below the critical, the time required for completion of the change is much shorter, for example ½ to 3 hours or less in typical cases. In order, therefore, to secure an economical compromise between maximum softness and minimum time for conversion, I propose in accordance with a preferred procedure in such cases, to hold the steel for a reasonable time, say no more than about 15 to 20 hours, at a temperature not far below the critical at which the product formed will be very soft, then to cool the steel to a lower temperature at which the conversion will be consummated in a relatively short time, but one at which the product of conversion is nevertheless reasonably soft, and to hold the steel at this latter temperature until the conversion is complete.

Table I below exemplifies this method of annealing as applied to various representative steels as indicated, typical analyses of which are given in the immediately succeeding Table II.

Table I

Type of steel	Critical temp.	Heating temp.	Subcritical conversion				Hardness as annealed Rockwell "B"
			First step		Second step		
			Holding temp.	Holding time	Holding temp.	Holding time	
	° F.	° F.	° F.	*Hours*	° F.	*Hours*	
18-4-1 high speed	1525	1650	1470	3	1450	3	101
14-4-2 high speed	1550	1650	1470	3	1450	3	99
Air hardening high C high Cr	1490	1800	1440	10	1400	1	98
High C stainless	1500	1600	1430	16	1380	2	95
Bearing steel	1385	1450	1365	16	1350	2	92
Oil hardening tool steel	1370	1425	1325	16	1300	2	92
Cr Ni Mo steel	1290	1375	1250	16	1220	3	90

Table II

Type of steel	Typical analyses							
	C	Mn	Si	Ni	Cr	Mo	W	V
18-4-1 high speed	.71	.29	.29	------	3.91	-----	17.65	1.12
14-4-2 high speed	.68	.24	.28	------	4.03	-----	13.96	1.97
Air hardening high C high Cr.	1.63	.33	.23	------	11.25	.69	-------	.23
High C stainless	.93	.49	.43	------	18.40	.55	-------	------
Bearing steel	1.04	.35	.33	------	1.35	-----	-------	------
Oil hardening steel	.85	1.16	.12	------	.50	-----	.46	------
Cr Ni Mo steel	.37	.62	.19	2.07	.95	.34	-------	------

Referring to Table I, the steel is heated in the annealing furnace to the indicated temperature above the critical and held there for a sufficient interval to thoroughly "soak" the steel. Ordinarily a "soaking" of 15 to 30 minutes per inch of thickness of the article will suffice, and seldom is more than one hour per inch of thickness required. The steel is then cooled as rapidly as convenient to the first subcritical holding temperature, as for example by shutting off burners and opening the doors and dampers of the furnace to air cool in batch type furnaces, or by removing to a cooler part of the same furnace or to a different furnace in either a batch type or continuous type furnace, or by quenching in an appropriate liquid bath maintained at the first mentioned subcritical holding temperature. Whatever procedure is followed the steel is maintained at or near the subcritical temperature in question for the duration indicated in the table, following which it is again rapidly cooled in any of the ways above mentioned to the second subcritical holding temperature and held there for the duration shown, i. e. until the conversion is complete. Thereupon the steel is cooled as rapidly as convenient to room temperature, for example by air cooling or even by quenching in water, oil, etc., if desired.

All of the steels in the above table have been generally regarded by the industry as steels difficult to anneal, requiring relatively long times for annealing, i. e. about 30 to 120 hours. By application of the methods of annealing constituting my invention, these steels may be annealed to the same degree of softness as formerly in much shorter times, usually not more than 24 hours. Even with the present invention, however, some of these steels are at present best adapted to batch type annealing. The high speed and the high carbon-high chromium analyses, on the other hand, although heretofore requiring about 30 to 60 hours for annealing, may now be annealed to the same degree of softness in about 4 to 6 hours with the present invention, and thus permit of annealing in furnaces of the continuous type.

The temperature above the critical to which the steel should be heated for best results, depends to some extent on the analysis of the steel. Although the primary purpose of heating above the critical is to convert the ferrite and some of the carbides originally present in the steel into austenite, which may be accomplished by heating just above the critical, it has been found in general and for reasons not clearly understood as yet, that heating to somewhat higher temperatures, depending on the analysis, results in a softer product after annealing. For most steels the most appropriate temperature will be found to be within the range of about 10° to 150° F. above the critical, although for some analyses, such as the air hardening, high carbon-high chromium steel of Table I, higher temperatures up to 350° F., or more above the critical are suitable.

The subcritical holding temperature depends, as above stated, on the softness required of the steel after annealing and also on the time interval within which it is desired to effect conversion of the steel; the higher the conversion temperature the softer the resulting product and the longer the conversion time, and vice versa as explained above. Subject to these general limitations, however, the most appropriate conversion temperature or temperatures for a given softness and conversion time, depends in addition, to some extent on the analysis of the steel, as shown by Table I. For the majority of steels, conversion is best effected at temperatures within the range of about 10° to 150° F. below the critical.

Although a relatively soft product may be obtained by annealing the steel in accordance with the invention as above described, an additional degree of softness may be imparted, other conditions remaining the same, if prior to the regular annealing cycle, the steel is subjected to a preliminary heat treatment consisting either of a tempering heat somewhat below the critical temperature, or of what might be termed a "quick anneal." Such tempering may be effected during the initial heating of the steel to the required temperature above the critical, by arresting the heating below the critical, for example about 50 to 150° F. below, and holding there for about 1 to 3 hours before proceeding above the critical temperature. Or, in the alternative, the steel may be subjected preliminarily to the "quick anneal" referred to, by initially heating as rapidly as convenient above the critical temperature and "soaking" as aforesaid, following which it is cooled as rapidly as convenient, preferably quickly, to a temperature below the critical, for example 50 to 150° F. below, at which it will convert in a relatively short time, i. e. in about 15 minutes to 2 hours or so, into a reasonably soft mixture of ferrite and carbides. The steel is held at this subcritical temperature until the conversion is complete, this constituting the "quick anneal," following which the temperature is again raised above the critical and the annealing completed in accordance with the invention as above described. By the use of this preliminary heat treatment, a steel which would otherwise anneal to say about 102 to 104 "B" Rockwell, may have its hardness reduced to well under 100 "B" Rockwell, as is very often required in order to meet manufacturing specifications.

As an example of an annealing cycle employing the preliminary tempering treatment above referred to, the 18—4—1 high speed steel of Tables I and II may be heated as rapidly as convenient to about 1500° F., i. e. about 50° F. below the critical, and held there for about 2 hours until

thoroughly tempered, following which the temperature is elevated to about 1650° F. and the annealing cycle completed as outlined in Table I. Alternatively, this same steel may be given the preliminary "quick anneal," by initially heating as rapidly as convenient to a temperature above the critical of about 1650° F., held there about ½ to 1 hour and cooled as rapidly as convenient, preferably quickly, to the subcritical temperature of about 1400° F. at which conversion occurs relatively quickly. The steel is held at this temperature until conversion is complete, about 2 hours will suffice, following which it is reheated to 1650° F. and the annealing cycle completed as set forth in Table I.

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 an 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.

I claim:

1. A method of annealing relatively high alloy steels containing upwards of about one and one-half percent of transformation retarding alloying elements other than carbon, which comprises: heating the steel to about 10° to 350° F. above its critical temperature, rapidly cooling the steel to the temperature range of about 10° to 150° F. below the critical and above a temperature of 1050° F., holding within said range until the austenite formed above the critical has been substantially converted into a relatively soft mixture of ferrite and carbides having a room temperature hardness of about 30 Rockwell "C" and under, and thereupon rapidly cooling said steel substantially to room temperature.

2. A method of annealing an alloy steel containing at least an effective amount of a transformation retarding alloying element, which comprises: heating the steel to about 10° to 150° F. above its critical temperature, rapidly cooling to a temperature within the range of about 10° to 150° F. below the critical and holding thereat until the austenite formed above the critical has been converted into a relatively soft mixture of ferrite and carbides, and thereupon rapidly cooling the steel substantially to room temperature.

3. A method of annealing an alloy steel containing at least an effective amount of a transformation retarding alloying element, which comprises: heating the steel to about 10° to 150° F. above its critical temperature, rapidly cooling to a temperature within the range of about 10° to 150° F. below said critical and holding thereat until said steel has been partially converted into a relatively soft mixture of ferrite and carbides, cooling to a lower temperature within said range and holding thereat until said conversion is complete, and thereupon rapidly cooling the steel substantially to room temperature.

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