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STEELS AND IMPROVED METHOD OF MANUFACTURE

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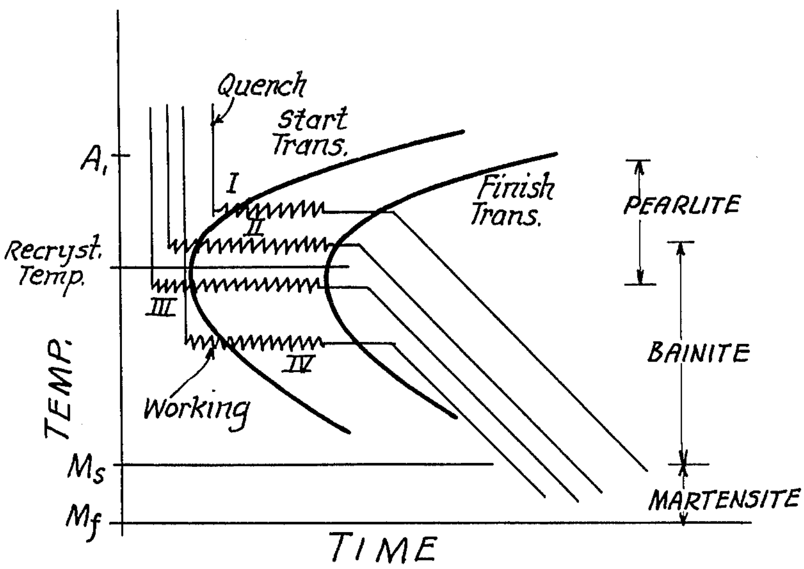

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STEELS AND IMPROVED METHOD OF MANUFACTURE

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This application is a continuation-in-part of my application Serial No. 846,269, filed October 14, 1959, now abandoned, which is a continuation-in-part of my application 617,234, filed October 22, 1956, now abandoned, which was copending with applications Serial No. 518,411, 518,412, 518,413, and 518,414, now U.S. Patent Nos. 2,767,835, 2,767,836, 2,767,837 and 2,767,838.

This invention relates to a new and improved metallurgical process applicable to the cold finishing of steel and it relates more particularly to a metallurgical process capable of use to produce steels having new and different combinations of properties.

It is an object of this invention to produce and to provide a method for producing new and improved steels having a new and improved combination of physical and mechanical properties, some of which constitute improvements of properties heretofore developed by the aforementioned copending applications and patents.

Another object of this invention is to provide a method capable of use in the cold finishing of steels by which the properties and characteristics of the steels can be materially changed to produce steels having new and different combinations of properties; wherein the uniformity of properties and characteristics of the steels of equivalent chemistry are markedly improved from heat to heat by comparison with hot rolled steel; wherein the properties and characteristics of steels are modified to expand the range of physical and mechanical properties capable of being developed in the steels; and to produce steels having new and improved characteristics and improved physical and mechanical properties.

These and other objects and advantages of this invention will hereinafter appear, and for purposes of illustration, but not of limitation, an embodiment of the invention is set forth in the accompanying drawing in which—

The figure is an isothermal transformation diagram of a typical steel which may be used in the practice of this invention, showing the working step in jagged lines.

In the aforementioned issued patents, description is made of a new cold finishing process for the improvement of physical and mechanical properties of steel wherein use is made of a combination of steps which relies upon an elevated temperature reduction (ETD) step wherein, by way of example, the steel is advanced through a die to take a reduction in cross-sectional area while the steel is at a temperature within the range of 200° F. to the lower critical temperature for the steel composition or at a temperature within the range of 200° F. to about 1100° to 1200° F. Depending upon the temperature of the steel advanced through the die for reduction in cross-sectional area or for effecting plastic deformation, various physical and mechanical properties of the steel can be changed by comparison with the same steels given an equivalent reduction while the steel is at about ambient temperature. Thus, by controlling the temperature of the steel advanced through the die, or by controlling the chemistry of the steel, or by controlling the amount of reduction or combinations of the foregoing, it has become possible, in a cold finishing operation (as the term is used in the trade), to produce steel products having new and improved physical and mechanical properties and other characteristics not heretofore available in combination in steels processed by other means.

In a number of applications copending with the application Ser. No. 617,234, now abandoned, description is made of other adaptations of the elevated temperature reduction concept to produce still further modifications and improvements in various of the physical and mechanical properties of steels in a manner to tailor-make the steels to provide a desirable combination of characteristics. In the copending application Ser. No. 617,264, now Patent No. 2,924,543, description is made of a process wherein the steel is heated to austenitizing temperature followed by quenching to produce a phase change to martensite prior to the elevated temperature reduction step whereby elevated temperature reduction is effected on a martensitic steel. In another copending application, Ser. No. 617,266, now Patent No. 2,924,544, description is made of a still further modification wherein the steel, heated to austenitizing temperature and quenched to effect a phase change to martensite, is tempered to provide a tempered martensite prior to elevated temperature reduction so that the elevated temperature reduction step is carried out on a tempered martensitic steel. In a still further copending application, Ser. No. 617,269, now Patent No. 3,088,855, description is made of a still further process wherein the steel is heated to austenitizing temperature and then quenched at a temperature below the temperature for pearlite formation but above the temperature for martensite formation followed by cooling to produce a martempered steel whereby the subsequent elevated temperature reduction step is carried out on a martempered steel to produce a steel having new and improved physical and mechanical properties. In another copending application, Ser. No. 826,413, now abandoned, description is made of a modification wherein the steel is heated to austenitizing temperature and then quenched at a temperature above the nose of the applicable S curve for the steel composition but below the lower critical temperature for a time sufficient to effect or initiate isothermal transformation to pearlite prior to the elevated temperature reduction step. In each of these processes, utilization continues to be made of the characteristics of the steel which causes strain hardening and hardening by some mode of precipitation when the steel is worked at the elevated temperature to produce steels having new and improved combination of physical and mechanical properties.

It has now been found, in accordance with the practice of this invention, that steel having many new and different properties can be fabricated when the elevated temperature reduction step, as previously described, is initiated while the steel structure is in a form which may be defined as unstable austenite or in an unstable austenitic condition. More specifically, steels having new and improved physical and mechanical properties in combination can be produced when, after the steel is heated to austenitizing temperature, the steel is quenched at a temperature at which isothermal transformation to form pearlite and/or bainite can take place but wherein the steel is advanced for working at the elevated temperature before such isothermal transformation has started or progressed to any appreciable extent whereby all or a major part of the isothermal transformation takes place during the plastic deformation of the steel at elevated temperature. Under such conditions, it has been found that all or a major portion of the transformation from austenite to form pearlite, bainite, or mixtures thereof will take place during the elevated temperature reduction step alone or with the major portion of transformation occurring during the elevated temperature reduction step with the small amount of remainder continuing beyond the reduction step. Following the elevated temperature reduction step, the steel can be air cooled or quenched to ambient temperature depending upon the product requirements.

The described process provides a means for taking advantage of the strain hardening as well as the precipitation hardening effects which occur in steels of the type described to produce a new and different combination of physical and mechanical properties in the steel. Added to the described phenomena is a new effect which results from the fact that the structure of the steel undergoes fundamental changes which can be controlled by (1) selection of appropriate temperature for the quench and for the subsequent elevated temperature reduction step which immediately follows, (2) percent reduction, (3) chemistry of the steel, and (4) the period of time that the steel is maintained at the temperature of quench prior to the elevated temperature reduction step.

The described process of austenitizing the steel, quenching the steel at a temperature for isothermal transformation and elevated temperature reduction before isothermal transformation has progressed provides a new and novel cold finishing process which is capable of use to produce steels having properties incapable of being secured by other methods of heat treatment or metallurgical treatment. The physical and mechanical properties influenced by processing steels in the manner described are mainly the strength properties of steel including tensile strength, impact strength, yield strength, flexural strength and the like. Others of the properties most beneficially affected are the ductility of steel, elongation and reduction in area.

The process embodying the features of this invention is capable of being practiced with steels of the type which strain harden and harden by some mode of precipitation. Otherwise defined, use can be made of easy to draw hot rolled steels having a pearlitic structure in a matrix of free ferrite in the hot rolled condition and which are generally cold finished by processes of drawing or extrusion. Because of the difficulty in handling the steel and the time lag between the quench and the elevated temperature reduction step, it is preferred to make use of steels which are relatively slow to reach the point where isothermal transformation starts to take place or in which isothermal transformation takes place at a sufficiently low rate to enable the quenched steel to be advanced to the elevated temperature reduction step before isothermal transformation has progressed by any substantial amount such that, for all practical purposes, it may be considered that isothermal transformation occurs in its entirety during the subsequent elevated temperature reduction step or during the elevated temperature reduction step and the period following. Suitable steels embodying the characteristics described above can be selected from the TTT diagram as set forth in the USS Atlas of Isothermal Transformation Diagrams. Representative of the steels which may be processed in accordance with the practice of this invention are 4340, C1018, C1144, C1080, 4140, etc.

For a typical illustration, reference can be made to the TTT diagram for 4340 steel which shows that when the austenitized steel is quenched at 850° F., isothermal transformation to bainite starts after 12 seconds and is only 50 percent completed in approximately 6 minutes. At this point, the curve reaches a plateau of the bay of the curve which indicates that with slight compositional change, significant differences in the 50 percent completion time may be expected. From the curve, it will also be apparent that temperature will have considerable influence on the time of initiation of isothermal transformation as well as the 50 percent completion time. For example, when the austenitized 4340 steel is quenched at 900° F., the 50 percent completion time for isothermal transformation is in excess of one week. Thus temperature of quench, time of quench, and chemistry are closely interrelated. A suitable time and temperature of quench can be selected from the TTT curves for the steels of each chemistry for the adoption of suitable conditions to be used in the practice of this invention.

While the discussion, to the present, has referred specifically to the preferred isothermal transformation to form bainite after the deformation step, it will be understood that the concepts of this invention are applicable also to quenching at other temperatures for transformation of the steel to form pearlite or mixtures of pearlite and bainite, as illustrated by the diagram in FIG. 1 of the drawing. For pearlite formation, the temperature of quench is selected to be above the M_s range but below the lower critical temperature and preferably above the nose of the applicable S curve to the lower critical temperature for the steel composition. This generally will fall within a temperature range of about 850° F. and above to the lower critical temperature. For bainite formation, the temperature of quench will be between the M_s temperature for martensite formation and the temperature for pearlite formation, which may include a temperature within the range of 450–900° F. It will be understood that transformation will not be limited to the described structure but that pearlitic steel may contain some smaller amounts of bainite and martensite and the bainitic steel may contain some smaller amounts of pearlite and martensite.

Treatment of the steel after the elevated temperature reduction step, as by slow cooling in air or by quenching rapidly to cool the steel, has been found to have but slight effect upon the characteristics and properties developed in the steel with the exception that rapid cooling tends to produce steels having lower levels of stresses and tends to produce steels having a preponderance of compressive stresses to provide steels characterized by negative warpage values, especially when the elevated temperature reduction step is taken when the steel is above 750° F.

As used herein, the term "elevated temperature reduction" is meant to include the step of finishing steels wherein the steel is advanced through a die, as represented by a draw die, an extrusion die or roller die, to effect reduction in cross-sectional area or to effect plastic deformation while the steel is at a temperature within the range of 250° F. to the lower critical temperature of the steel composition and preferably at a temperature within the range of 400° F. to the lower critical. While not equivalent from the processing standpoint, many of the characteristics described are capable also of being developed by other processes for working steel to effect plastic deformation or reduction in cross-sectional area while the steel is at the desired elevated temperature, as by the process, for example, of rolling steels to effect reduction in cross-sectional area while the austenitized and quenched steel predominantly is is the form of unstable austenite and while it is at the temperature of 250° F. to the lower critical temperature for the steel composition. The invention is limited to reduction in cross-section by drawing, extrusion or rolling, at the described temperature conditions, by an amount which does not exceed 30 percent and preferably to reductions in cross-section of less than 20 percent.

The term "austenitizing" is meant to relate to the usual meaning as applied to the term in the steel trade and as defined in the steel handbooks. Briefly described, it relates to the step of heating the steel to austentizing temperature for the steel composition while within the range of about 1450° F. to 1600° F.

In the practice of this invention, elevated temperature reduction follows preferably as a continuous operation after the quenching step whereby the steel may be quenched to the temperature desired for advancement to the elevated temperature reduction step. It will be understood that the steel will cool slightly from the temperature of quench by reason of the brief exposure to ambient temperature between the quenching and reduction step and by reason of the application of lubricant onto the surfaces of the metal in preparation for elevated temperature reduction. Slight deviation from the temperature of quench may otherwise be made for the development of a particular combination of properties in the steel which is subjected to the elevated temperature reduction step.

In the following portions of the specification, data will be given illustrating some of the properties developed by processing steels in accordance with the practice of this invention. The concept will be illustrated by reference to the processing of 4340 steel which will be taken as representative of the steels which may be employed in the practice of this invention. The following is a ladle analysis of 4340 steel in which the major ingredients, other than iron, the set forth.

TABLE 1

Ladle analysis of 4340 steel

C	0.41	Cr	0.85
Mn	0.80	Mo	0.28
P	0.013	Ni	1.76
S	0.019	Cu	0.08
Si	0.31		

PROCEDURE

In the practice of this invention, the hot rolled steel bars, "as received," were descaled by pickling in sulphuric acid and limed to prevent rust.

All of the hot rolled, pickled and limed bar stock was then heated to a temperature of 1550° F. for ½ hour to austenitize the steel.

The austenitized steel was then quenched in a lead bath maintained at 850° F. for 3 minutes in one instance and for 10 minutes in another instance. The quenched steel bars were coated with a suitable drawing lubricant and immediately advanced at the elevated temperature to a draw die to take a reduction in cross-sectional area ranging from 1½ to 20 percent. Use was made of round steel bars having a diameter of ⅝ inch.

TABLE 2

Mechanical properties of ⅝" 4340 bars austenitized and quenched for 3 minutes in a lead bath at 850° F. and deformed at 800° F. from the unstable austenitic condition—air cooled after drawing

Percent reduction in the die	Exit temperature, ° F.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elongation, percent	Reduction of area, percent
0	640	287,500	151,500	5.7	12.9
1½	540	292,000	156,000	9.0	14.5
4	580	205,000	120,000	12.0	36.8
10	750	181,000	118,500	22.9	38.0
15	730	176,500	138,000	20.7	41.5
20	750	188,000	122,400	25.0	38.0

TABLE 3

Mechanical properties of ⅝" 4340 bars austenitized and quenched for 10 minutes in a lead bath at 850° F. and deformed at 800° F. from the unstable austenitic condition—air cooled after drawing

Percent reduction in the die	Exit temperature, ° F.	Tensile strength, p.s.i.	Yield strength, p.s.i.	Elongation, percent	Reduction of area, percent
0	670	275,000	147,000	7	9.9
1½	640	240,000	121,800	(1)	(1)
5	660	231,000	120,000	10.0	19.4
10	700	220,000	119,400	10.0	21.6
15	680	203,000	108,000	21.0	27.0

[1] Broke in shoulder.

The further invention resides in the discovery that a new and improved metallurgical process, which gives new and improved metallurgical products, resides in the quenching of the austenitized steel from austenitizing temperature to a temperature below the M_s range for the steel and working the steel to effect the described elevated temperature reduction while the steel is still in the unstable austenitic state whereby all or the major portion of the transformation from the unstable austenite to martensite occurs during the working step. Again it is desirable to initiate working prior to intiation of transformation and, as in the previously described invention, any small portions of incomplete transformation can be effected after working. In this invention, elevated temperature reduction, as by drawing, extrusion, rolling or working, can include the temperature to which the austenitized steel is quenched below the M_s range down to ambient temperature. As before, reduction in cross-section during transformation is limited to a reduction by an amount up to 30 percent and preferably an amount up to 20 percent. This invention is applicable to the same steels as heretofore described.

It will be apparent from the foregoing that a new and different metallurgical process has been developed which embodies the treatment of a new and different steel by the recently developed elevated temperature reduction concept whereby such different steel, formed primarily of an unstable austenite, is subjected to a different set of reactions to produce a new and different result.

It will be understood that changes may be made in the details of materials and conditions as well as in the processing steps without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. The metallurgical process for treating steel of the type which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, and then, directly from the quenching step and while still in the form of unstable austenite, working the steel to effect plastic deformation while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, the crystallographic isothermal transformation of the steel from its unstable austenitic state being effected almost in its entirety during said elevated temperature working step, and cooling the steel to ambient temperature after the elevated temperature working step.

2. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, and then, while still in the form of unstable austenite, advancing the steel directly from the quenching step to and through a die to effect reduction in cross-sectional area in an amount up to 30 percent reduction while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during said elevated temperature working step, and cooling the steel to ambient temperature after the elevated temperature reduction step.

3. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, then, while still in the form of unstable austenite, advancing the steel directly from the quenching step to and through a die to effect reduction in cross-sectional area by an amount up to 30 percent while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, at least a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during the elevated temperature reduction step, and air cooling the steel to ambient temperature after the elevated temperature reduction step.

4. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, then, while still in the form of unstable austenite, advancing the steel directly from the quenching step to and through a die to effect reduction in cross-sectional area by an amount up to 30 percent while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during the elevated temperature reduction step, and quenching the steel subsequent to the elevated temperature reduction step for reducing the temperature of the steel to ambient temperature.

5. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, and then, while the steel is still in the form of unstable austenite, advancing the quenched steel directly from the quenching step to and through a draw die to effect reduction in cross-sectional area while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during said elevated temperature working step, and cooling the steel to ambient temperature after the temperature reduction step.

6. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, and then, while the steel is still in the form of unstable austenite, advancing the quenched steel directly from the quenching step to and through an extrusion die to effect reduction in cross-sectional area while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during said elevated temperature working step, and cooling the steel to ambient temperature after the temperature reduction step.

7. The metallurgical process for treating steel which strain hardens and hardens by some mode of precipitation when worked at an elevated temperature within the range of 250° F. to the lower critical temperature for the steel composition comprising the combination of steps of austenitizing the steel, quenching the steel to a temperature below the lower critical temperature for the steel composition but above its M_s temperature, and then, while the steel is still in the form of unstable austenite, advancing the quenched steel directly from the quenching step to and through a roller die to effect reduction in cross-sectional area while the steel is at a temperature within the range of 250° F. to the lower critical temperature for the steel composition, a major portion of the crystallographic transformation of the steel from its unstable austenitic state being effected during said elevated temperature working step, and cooling the steel to ambient temperature after the temperature reduction step.

8. A steel prepared in accordance with the process of claim **1.**

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DAVID L. RECK, *Primary Examiner.*