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PRODUCTION OF HEAT-TREATED SHEETS

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This application is a continuation-in-part of my application Serial No. 847,445, filed October 20, 1959, now abandoned, for Production of Heat-Treated Sheets.

This invention relates to the production of heat-treated sheets, and more particularly, to the production of low-alloy heat-treated sheets characterized by a degree of flatness comparable to that obtained in nonheat-treated steels.

The superior properties in respect to strength, ductility and toughness of steels with microstructures consisting predominantly of tempered martensite or lower bainite is generally recognized and well known to those skilled in the art. The usual practice for heat-treating steels in sheet form to such a microstructure involves heating the sheet to an austenitizing temperature, cooling it to a temperature below that at which transformation to martensite is complete at a cooling rate fast enough to essentially prevent transformation during cooling at temperatures above those at which transformation to martensite or lower bainite occurs, and tempering to the desired strength level. This heat treatment can be done either continuously with the sheet steel in strip form, or sheets of the desired final size can be heat treated singly. The continuous method is, however, preferred for quantity production. Although this method of heat treatment is entirely satisfactory as a method of producing sheets, i.e. .125" maximum gauge with the desired microstructure and mechanical properties, the drastic water quench required to insure the low-temperature transformation in steels of relatively low-alloy content and hardenability leads to a serious distortion in the heat-treated product, both from temperature gradients during cooling, and from stresses set up when transformation occurs at different times along with these temperature gradients. Since the heat-treated sheet is characterized by a relatively high yield strength, i.e. in excess of 75,000 p.s.i., the removal of these distortions, and the production of a flat final sheet product by conventional flattening methods such as roller straightening, stretch straightening, or press flattening is very difficult and time-consuming and requires heavy, high-capacity equipment. These conventional methods, furthermore, all necessitate the occurrence of localized plastic flow in order to produce a flat product, and this results in the development of residual stresses in the product which may be harmful. Although these stresses may be relieved by a thermal stress-relieving heat treatment, this involves an additional operation and additional expense. The distortion occurring in heat-treatment can be minimized by various methods of controlling the cooling so that the resultant temperature gradients are minimized, but, in addition to the difficulties involved in establishing cooling practices which will insure a suitably flat product, particularly in a continuous operation, these methods involve a relatively slow cooling rate from the austenitizing temperature and, therefore, require the use of steels of correspondingly higher hardenability, alloy content, and cost to insure complete transformation to martensite or lower bainite after cooling.

It is accordingly an object of this invention to provide a method of producing flat heat-treated sheets with microstructures of tempered martensite or lower bainite in an efficient and economical manner.

It is a further object of this invention to provide flat heat-treated steel sheets with microstructures of tempered martensite or lower bainite and of relatively low-alloy content which require drastic quenching to produce the desired minimum 75,000 p.s.i. yield strength.

The method of this invention utilizes strip or sheet material, i.e., .250" maximum thickness that has been heat-treated by drastically quenching from above its A_3 temperature, such as by water quenching at a rate in excess of 100° F. per second. Such heat-treated sheet material, preferably in coil form to take full advantage of quantity production, is tempered in accordance with usual practice. According to the teachings of this invention, the heat-treated sheet material is then cold rolled sufficiently to remove all distortions resulting from rolling, so that the strip is returned to a substantially flat condition, and, at the same time, the surface smoothness and the thickness uniformity is improved. The cold-rolled material is then tempered at a temperature higher than its recrystallization temperature but below that of the original heat treatment. This recrystallizing or re-tempering treatment restores the original heat-treated mechanical properties; and, since no further distortion occurs in the final tempering or recrystallizing treatment, a flat product having the desired strength and ductility results.

The quenched and tempered low-alloy steels with tempered martensitic or lower bainitic microstructures which are applicable to the method of this invention are characterized by requiring drastic quenching, i.e. at a rate in excess of 100° F. per second from above their A_3 temperatures to achieve a microstructure consisting essentially of martensite or lower bainite. These low-alloy steels in the quenched and tempered condition will have yield strengths in excess of 75,000 p.s.i. and relatively low rate of work hardening. Because of their low work-hardening rate they can withstand extensive cold reduction by rolling without strain hardening to the extent that a serious embrittlement would occur. This permits cold rolling reductions of 10 to 50% which are required to flatten the drastically distorted sheets. Thus the quality of withstanding such drastic cold reductions permits removing the severe distortions resulting from the drastic quenching required to achieve the desired microstructure of tempered martensite or lower bainite in the economical low-alloy steel.

The yield strengths of the quenched and tempered steels applicable to the method of this invention are much higher and the rate of work hardening is much lower than those of the steels which are cold rolled in conventional production practices. These latter steels usually have microstructures of ferrite and pearlite, and are characterized by much higher work-hardening rates than those of the steels with tempered martensitic or lower bainitic microstructures. Thus in the conventional usage of cold rolling for the production of sheet products, the primary objective is to strengthen the material through work hardening, and the material before cold rolling is necessarily of a relatively low yield strength. In the method of this invention, on the other hand, the primary objective of cold rolling is to obtain a flat product, and the low rate of work hardening makes it possible to do this at the relatively high yield-strength levels of 75,000 to 150,000 p.s.i., characteristic of these quenched and tempered steels.

The use of heavy cold rolling for flattening which is an essential feature of this invention offers the following advantages over prior art methods:

(1) Very severe distortion can be removed, and therefore, a drastic quench can be used in the heat treatment prior to flattening. This permits the use of economical low-alloy low-hardenability steels.

(2) Due to the heavy cold rolling reductions, the entire cross-section flows plastically in the rolling process so that residual stresses are not created by localized strains such as may occur in prior art methods of flattening.

(3) The cold rolling results in an improvement in surface quality and uniformity of thickness in the final product.

(4) The final step in the method of this invention, that of reheating the cold-rolled flat product to a temperature above its recrystallization temperature but lower than the tempering temperature used in the original heat treatment, results in a recrystallization of the cold-worked ferrite and a restoration of the original heat-treated properties.

The method is applicable to steels that (1) can be heat treated to a microstructure consisting substantially of tempered martensite or lower bainite; (2) have a sufficiently low-alloy content that they require drastic quenching to produce a microstructure consisting essentially of martensite or lower bainite and (3) has a recrystallization temperature after cold rolling which is lower than the tempering temperature used in the original heat treatment to achieve the desired strength level. Carbon content of the steel is limited by practical considerations to a maximum of about 0.25 to 0.30%, since higher carbon contents will cause the steel to harden to such an extent that the power requirements for cold reducing become uneconomical. A minimum of .10% carbon is required to achieve the desired strength. Thus, steels containing about 0.15 to 0.25% carbon are preferred.

While numerous steel compositions will provide the desired combination of properties, a preferred combination is that disclosed in United States Patent No. 2,586,042:

	Percent
Carbon	.10 to .20
Manganese	.60 to 1.0
Silicon	.15 to .35
Nickel	.70 to 1.0
Chromium	.40 to .80
Molybdenum	.40 to .60
Vanadium	.03 to .10
Copper	.0 to .50
Boron	.002 to .006

With the balance iron and residual amounts of other elements.

In practicing the teachings of my invention, a heat of steel of the following composition was made:

	Percent
Carbon	.14
Manganese	.86
Silicon	.28
Nickel	.82
Chromium	.53
Molybdenum	.51
Vanadium	.05
Copper	.31
Boron	.003

The steel of this composition was hot rolled to a coil of strip 49 inches wide with a thickness of .10" and transformed to a martensitic structure by heating it to about 1810° F. to austenitize it in a catenary furnace through which it traveled at about 10 feet per minute and then water quenching it. This resulted in considerable distortion in the strip. After quenching, the strip was recoiled and tempered by holding it at a temperature of about 1085° F. for about 4 hours in a box annealing furnace.

The mechanical properties of the quenched and tempered strip were as follows:

Table I

	Yield Strength, .2% Offset, p.s.i.	Tensile Strength, p.s.i.	Elongation in 2", Percent
Longitudinal	143,900	154,000	12.5
Transverse	137,900	140,400	10.5

The strip was then flattened by cold rolling it to reduce the thickness to .05", i.e. about 50% reduction and again tempered in a box annealing furnace by holding for 4 hours at a temperature between 1065 to 1085° F. This temperature is above the recrystallizing temperature of the cold-rolled strip and slightly below the prior annealing temperature. At this stage, the strip was quite flat except for some coil set and had the following mechanical properties:

Table II

	Yield Strength, .2% Offset, p.s.i.	Tensile Strength, p.s.i.	Elongation in 2", Percent
Longitudinal	139,700	145,500	11.0
Transverse	151,600	153,100	9.0

From this it is seen that the material after flattening and recrystallizing had substantially the same mechanical properties as the heat-treated material. To remove coil set, it was cold rolled to produce a reduction of about .004" (i.e., just sufficient to remove coil set), cut into sheets and tempered at a temperature of about 1075° F., i.e. between about 1050 and 1100° F. for 4 hours. Following this, the sheets were flat and exhibited no coil set. The final mechanical properties were as follows:

Table III

	Yield Strength, .2% Offset, p.s.i.	Tensile Strength, p.s.i.	Elongation in 2", Percent
Longitudinal	151,000	154,000	10.5
Transverse	159,100	160,800	8.0

The foregoing is a specific example of the processing steps for producing flat heat-treated sheets, which may be stated generally as follows:

(1) Hot rolling steel of suitable composition to band gage.

(2) Heating the strip to a suitable austenitizing temperature (i.e. above the upper critical temperature of the steel).

(3) Quenching the strip at a rate sufficient to produce or to transform the product to a martensitic or lower bainitic microstructure.

(4) Tempering the strip at a temperature between 1000° F. and the lower critical temperature of the steel.

(5) Cold rolling to the desired finished gage. If the band gage is more than double the desired finished gage, the strip may be cold rolled to an intermediate size, reheated to a temperature not above the tempering temperature and preferably about 50 to 100° F. lower than the first tempering temperature, then cold rolled to the desired finished gage. The strip may be cold rolled and reheated as many times as are necessary to effect reduction from band gage to finished gage while using 10% to 50% reduction.

(6) Heating strip to a temperature above the recrystallizing temperature but below the temperature of tempering in Step 4.

(7) Cooling slowly to ambient temperature. If coil set is not appreciable, the process can end here. If coil set must be removed, the following additional steps must be included.

(8) A light cold reduction, preferably under 2%.

(9) Reheating to temper at a temperature above the lower critical but about 50 to 100° F. below the first tempering temperature as in the range in Step 5 and cooling at such a rate as not to affect the flatness or other properties.

Another example of a low-alloy steel that may be used

in my invention is one having a composition within the ranges as stated above, except that the nickel is omitted and the content of molybdenum is decreased to as little as 0.25%.

While I have shown and described several specific embodiments of my invention, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of my invention, as defined in the appended claims.

I claim:

1. A method of producing flat heat-treated steel sheets comprising drastically quenching from an austenitizing temperature a sheet of hot-rolled steel capable of conversion to martensite or lower bainite to transform the same to a microstructure consisting substantially of martensite or lower bainite, such quenching producing distortion therein, tempering said steel at a temperature above about 1000° F. and below its lower critical temperature, cold reducing said steel between 10 and 50% to the desired thickness and then heating the cold-reduced steel at a temperature above its recrystallization temperature but not above said first-mentioned tempering temperature.

2. A method of producing flat heat-treated low-alloy steel sheet of high strength and toughness comprising drastically quenching a low-alloy hot-rolled steel sheet containing 0.10 to 0.30% carbon to transform the same to a microstructure consisting substantially of martensite or lower bainite, such quenching producing distortion therein, tempering said steel at a temperature above about

1000° F. and below its lower critical temperature, cold rolling said steel to reduce it between 10 and 50% to the desired thickness and then heating the cold-reduced steel at a temperature above its recrystallization temperature but not above said first-mentioned tempering temperature.

3. A method of producing flat heat-treated low-alloy steel sheet of high strength and toughness comprising drastically quenching a low-alloy hot-rolled steel sheet containing 0.10 to 0.30% carbon to transform the same to a microstructure consisting substantially of martensite and lower bainite or mixtures thereof, such quenching producing severe distortion therein, tempering said steel at a temperature above about 1000° F. and below its lower critical temperature, cold reducing said steel between 10 and 50% to the desired thickness and then heating the cold-reduced steel at a temperature above its recrystallization temperature but not above said first-mentioned tempering temperature.

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DAVID L. RECK, *Primary Examiner.*