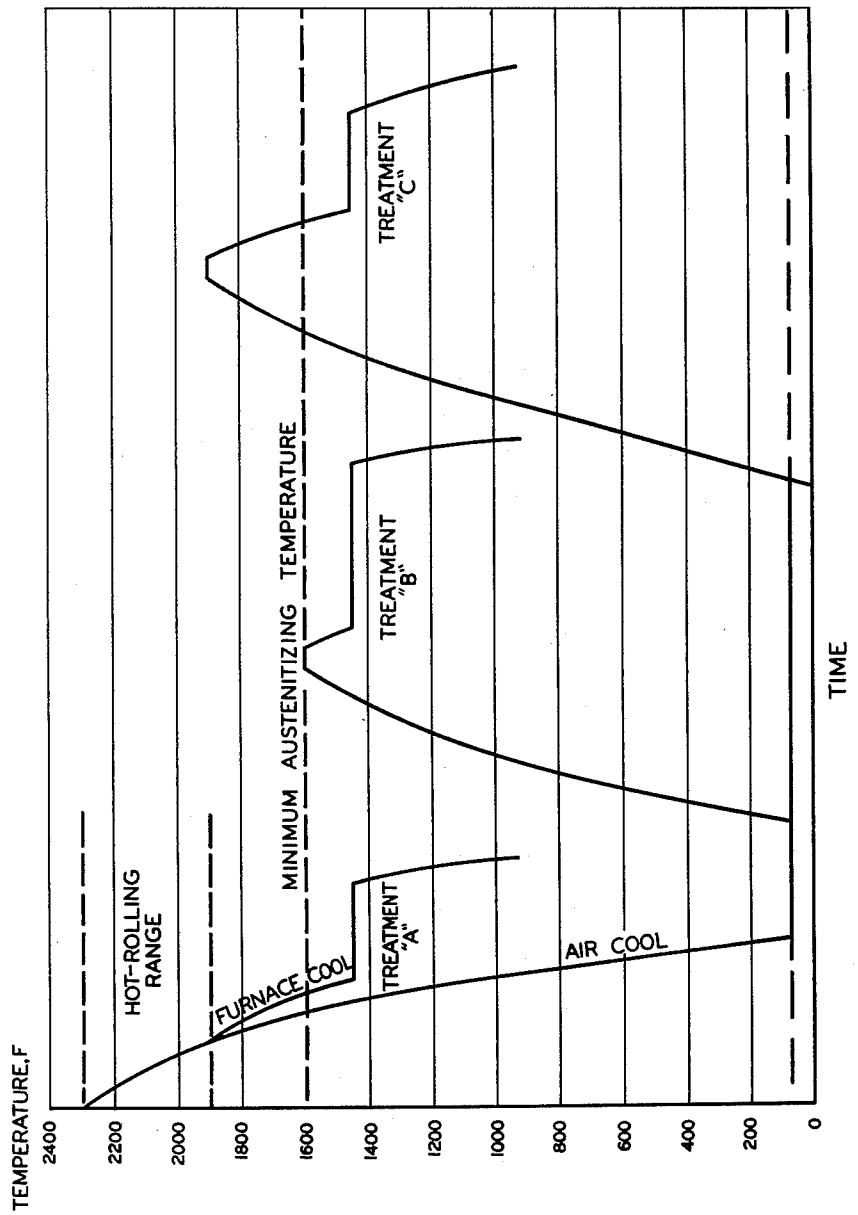
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METHOD OF ANNEALING TYPE 430 STAINLESS STEEL

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METHOD OF ANNEALING TYPE 430 STAINLESS STEEL

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The invention relates to the preparation or treatment of AISI Type 430 stainless steel strip. More particularly, it pertains to a method of annealing hot rolled Type 430 stainless steel strip preliminary to subsequent cold rolling.

Type 430 stainless steel is a ferritic alloy of a group of alloys having the basic chemical constituents of 0.12% maximum carbon and of from 14.0 to 18.0% chromium. Such alloys, which are also referred to as ferritic stainless steels or chromium steels, are non-hardening and ferritic at temperatures up to about 1650° F.; and, being somewhat easily formed, are used for automobile trim, chemical equipment, and the like. Indeed, the alloys can be hot or cold worked without undue detriment to their physical properties, grain structure, and corrosion resistance.

An outstanding characteristic of Type 430 stainless steel is that it is ferritic at temperatures up to 1650° F. Above that temperature it partiallyy transforms into austenite which upon air cooling to room temperature transforms into martensite. Prior to cold rolling, the stainless steel strip must be annealed because of the relatively high hardness of about Rockwell B 100 that results from air cooling the hot rolled material.

The conventional method for annealing Type 430 stainless steel has been somewhat complicated, time-consuming and costly. In this conventional method, the hot rolled strip, after being air cooled to room temperature, is reheated into a temperature range of 1550° F. to 1600° F. where it is held for approximately thirty minutes. The material is then furnace cooled to 1450° F. where it is held for four hours until spheroidization is complete. Higher temperatures of annealing are avoided because of the hazard of pearlite formation rather than spheroidized crabides. Thereafter the material is cooled to 1100° F. and then air cooled to room temperature. That annealing procedure is not only time-consuming but it wastes heat and it is therefore costly.

We have found a more efficient and less costly annealing process, in which the heat present in the steel after hot rolling at a finishing temperature of about 1900° F. and before other cooling, is utilized to anneal the strip by a controlled cooling cycle from the hot rolling finishing temperature to a temperature within the transformation range, the strip temperature being maintained for a period of time below austenizing temperature and above 1400° F. to perform isothermal annealing. More particularly, the material is transferred immediately after hot rolling to a furnace for controlled isothermal annealing at a lower temperature of about 1450° F. (below the austenizing temperature) and held for a sufficient time to insure complete transformation of austenite to ferrite and spheroidized carbides and then air cooled to room temperature. Isothermal annealing has been defined as a process in which a ferrous alloy

is heated to produce a structure that is partly or wholly austenitic, and then cooled to and held at a temperature that causes transformation of the austenite to a relatively soft ferrite-carbide aggregate. Such a procedure, if properly integrated with hot rolling facilities, reduces processing time by several days and saves most of the fuel that is otherwise normally required to reheat the cold strip as in conventional annealing.

Type 430 stainless steel responds to heat treatment in a manner different from other types of steel. Some steels are not susceptible to isothermal annealing. Low carbon steels are usually air cooled as fast as possible after hot rolling. High carbon steels will form the familiar lamellar pearlite structure upon cooling from hot rolling temperatures. Similarly, Type 406 steel, a ferritic stainless steel, having about 13% chromium, cannot be compared with Type 430 stainless steel because Type 406 has a completely ferritic matrix during hot rolling and forms a more soft ferrite-carbide aggregate upon annealing than does Type 430 stainless steel.

Type 446 steel, which is a ferritic stainless steel, also cannot be compared with Type 430 steel because of the higher (23.0 to 27.0%) chromium content of Type 446 which renders this steel completely ferritic at hot rolling temperature. Moreover, since Type 446 contains no austenitic phase at hot rolling temperatures as does Type 430, annealing of the hot strip presents an entirely different problem. Accordingly, because of the varying characteristics of stainless steels such as Types 406, 430 and 446, a prediction as to the behavior of one of them, based upon behavior of another, cannot be made.

Nor can the conventional practice of box annealing hot rolled strip be compared with isothermal annealing procedure immediately following hot rolling. Furthermore, all known methods of slow cooling after hot rolling are not sufficient to produce the particular results obtained by isothermally annealing Type 430 steel directly after hot rolling. Such slow cooling methods simply do not hold the heat in the strip in the required temperature range long enough to permit the isothermal transformation to occur. Such a transformation is the process of transforming austenite in a ferrous alloy to a ferrite-carbide aggregate at a constant temperature within the transformation range.

Accordingly, it is a general object of this invention to provide an isothermal annealing method in which Type 430 stainless steel is isothermally annealed immediately after hot rolling at a temperature within the transformation range for a sufficient length of time to produce a spheroidal carbide structure.

It is another object of this invention to provide an isothermal annealing treatment for Type 430 steel which results in physical properties more conducive to subsequent cold working.

It is another object of this invention to provide hot rolled Type 430 stainless steel strip products having lower strength and higher ductility for subsequent cold working, as well as more uniform tensile properties measured in the transverse and longitudinal directions than heretofore present in Type 430 stainless steel strip products.

It is another object of this invention to provide an isothermal annealing procedure for Type 430 stainless steel which saves time and fuel, thereby substantially reducing production costs.

Finally, it is an object of this invention to provide a method of annealing Type 430 stainless steel which eliminates prior art difficulties in conventional annealing methods, which improves the ultimate cold working procedures and products and which obtains the foregoing advantages and desiderata in a simple and effective manner.

These and other objects may be accomplished by the methods, steps, procedures, principles, and treatments comprising the present invention, the nature of which is set forth in the following general statement, and a preferred embodiment of which—illustrative of the best mode in which applicants have contemplated applying the principles—is set forth in the following description and illustrated in the accompanying drawing, and which is particularly and distinctly pointed out and set forth in the appended claims forming a part hereof.

The improvements, in a method of providing cold working Type 430 stainless steel strip products, of the present invention, may be stated in general terms as comprising holding the temperature of the hot rolled steel, immediately after hot rolling to strip form of the desired thickness, and while still retaining heat from the heating for hot rolling, in a temperature range of from 1400° F. to 1500° F. in a furnace for a minimum of three hours, and then air cooling to room temperature to provide a ferrite stainless steel having a spheroidized carbide structure in a ferrite matrix.

Generally the chemical analysis of Type 430 stainless steel material treated in accordance with the invention may be as follows:

Carbon	.12% max.
Manganese	1.00% max.
Silicon	1.00% max.
Nickel	.50% max.
Chromium	14% to 18%.

In addition, traces of other elements such as P, S and possibly small amounts of Ti, N, Mo, etc. may exist as incidental impurities. A typical Type 430 analysis is as follows:

	Percent
Carbon	.055
Manganese	.35
Silicon	.27
Nickel	.19
Chromium	16.54

Conventional operations heretofore used for producing Type 430 cold rolled steel strip include the following steps:

(1) Hot roll at from 2300° F. to 1900° F.
(2) Air cool to room temperature.
(3) Reheat to 1550° F. to 1600° F. for 30 minutes.
(4) Furnace cool to 1450° F. and hold for four hours.
(5) Furnace cool to 1100° F. and then air cool to room temperature.
(6) Pickle in hot nitric-hydrofluoric acid.
(7) Cold roll by 10% reduction passes from .150 to .060 inch thick strip.
(8) Stress relief anneal at 1400° F.
(9) Pickle.

This conventional procedure is altered in accordance with the invention as follows:

(1) Hot roll at from 2300° F. to 1900° F.
(2) While still retaining hot rolling heat, furnace cool to and isothermally furnace anneal at a temperature between 1400° F.–1500° F. for at least three hours.
(3) Air cool to room temperature.
(4) Pickle in hot nitric-hydrofluoric acid.
(5) Cold roll by 10% reduction passes from .150 to .060 inch thick strip.
(6) Stress relief anneal at 1400° F.
(7) Pickle.

In accordance with the invention, Type 430 stainless steel after melting and casting in the usual manner is processed by hot rolling to form the desired semi-finished hot rolled strip product. For instance, ingots of the alloy are hot rolled to coils of semi-finished strip having thicknesses of .090" to .120" in a temperature range of 1900° F. to 2300° F. The coils of strip are then transferred immediately while still retaining hot rolling heat to an annealing furnace and treated as outlined in Treatment "A" below.

Hot rolled Type 430 strip steel was subjected to three different annealing treatments, shown diagrammatically in the drawing, in order to evaluate and compare the properties of material treated in accordance with the invention and material treated by conventional procedures. These treatments are referred to herein as treatment "A," treatment "B" and treatment "C" as follows:

(A) Isothermal annealing treatment in accordance with the invention, wherein the strip was transferred, immediately after hot rolling and while still retaining hot rolling heat, to a gas-fired tunnel furnace where it was isothermally annealed for three hours at 1450° F.±25° F., then air cooled to room temperature.

(B) Conventional annealing treatment wherein the strip was air cooled after hot rolling, then reheated to 1600° F. for 30 minutes, then furnace cooled to 1450° F. for four hours, then furnace cooled to 1100° F., and then air cooled to room temperature.

(C) Special isothermal annealing treatment wherein the strip was air cooled after hot rolling, then reheated to 1900° F. for 30 minutes, then transferred to an annealing furnace at 1450° F. for three hours, and then air cooled to room temperature.

After being subjected to each of the three treatments "A," "B" and "C," the strip material was pickled in a solution containing 20% nitric and 5% hydrofluoric acid. Thereafter the strip was cold rolled to .060–.065 inch thick strip, after which it was annealed for stress relief at 1400° F. for one hour, and pickled. The strip was then cold rolled to about .020 inch thick, annealed for stress relief at 1440° F., and pickled. Finally, the strip was cold rolled from .020 to .010 inch, and stress relief annealed for 15 minutes at 1450° F.

The results of hardness tests on the isothermally (treatment "A") and conventionally (treatment "B") annealed Type 430 strip in various conditions are shown in Table I:

TABLE I

Hardness of Isothermally and Conventionally Annealed Type 430 Strip in Various Conditions

Condition of strip	Rockwell B hardness	
	Isothermally annealed	Conventionally annealed
Hot rolled to 0.120 inch, air cooled	----------	96.5
Hot rolled and annealed	79.5	81.0
Cold rolled to 0.060–0.070 inch	97.5	98.0
Stress relieved at 1,400° F	72.5	76.0
Cold rolled to 0.035 inch	99.0	99.0
Cold rolled to 0.020 inch	[1] 101	[1] 100
Stress annealed at 1,400° F	[1] 82	[1] 82
Cold rolled to 0.010 inch	[1] 102	[1] 103
Stress relieved at 1,450° F	[1] 85	[1] 88

[1] Hardness measured on Rockwell 15T scale and converted to Rockwell B values.

In general, the isothermally annealed strip in both the as-rolled and as-annealed conditions is softer than the conventionally annealed strip. In the as-rolled condition the hardness increases gradually as the strip thickness is decreased by cold rolling. In the annealed or stress-relieved condition, lower hardness values are obtained for .060–.070 inch cold rolled strip than for the .105–.115 inch hot rolled strip. Subsequent reduction by cold rolling from .060–.070 inch to .010 inch thickness, however,

results in successively higher hardness values for stress-relieved material. This gradual increase in hardness was probably caused by a decrease in grain size.

The results of tensile tests on the isothermally (treatment "A") and conventionally (treatment "B") annealed Type 430 strip in various conditions are given in Tables II and III below, the data being the average for four test specimens in each instance:

TABLE II

Tensile Properties of Isothermally Annealed Type 430 Stainless Strip (Treatment "A")

HOT-ROLLED (0.100-0.110 IN.) ISOTHERMALLY ANNEALED (1,450° F.)

Direction of testing with respect to rolling	Yield strength 0.2 percent offset, p.s.i.	Tensile strength, p.s.i.	Elongation, percent in 2 inches
Longitudinal	42,400	63,600	26
Transverse	43,250	66,150	24
COLD-ROLLED (0.056 IN.), STRESS-RELIEVED (1,400° F.)			
Longitudinal	38,000	63,000	34
Transverse	37,200	65,400	32
COLD-ROLLED (0.020 IN.), STRESS-RELIEVED (1,440° F.)			
Longitudinal	45,400	66,300	33
COLD-ROLLED (0.010 IN.), STRESS-RELIEVED (1,450° F.)			
Longitudinal	39,900	64,700	31

TABLE III

Tensile Properties of Conventionally Annealed Type 430 Stainless Strip (Treatment "B")

HOT-ROLLED (0.090-0.100 IN.) CONVENTIONALLY ANNEALED

Direction of testing with respect to rolling	Yield strength 0.2 percent offset, p.s.i.	Tensile strength, p.s.i.	Elongation, percent in 2 inches
Longitudinal	45,600	68,150	24
Transverse	50,100	75,400	19
COLD-ROLLED (0.065 IN.), STRESS-RELIEVED (1,400° F.)			
Longitudinal	41,200	68,400	30
Transverse	42,000	71,000	28
COLD-ROLLED (0.020 IN.), STRESS-RELIEVED (1,440° F.)			
Longitudinal	43,100	67,600	31
COLD-ROLLED (0.010 IN.), STRESS-RELIEVED (1,450° F.)			
Longitudinal	41,200	65,700	28

In general, the isothermally annealed strip exhibits (Table II) lower yield strength and tensile strength and higher ductility than does the conventionally annealed strip (Table III) for any given strip thickness. Moreover, in both cases the strengths are higher and the ductility is lower when measured in the direction transverse to cold rolling.

The data in Tables II and III further reveals that the most pronounced difference in the tensile properties of isothermally and conventionally annealed strip occurs in the hot rolled and annealed specimens, and that subsequent cold rolling and stress relieving gradually reduces the differences to an almost insignificant degree. For example, in the hot-rolled and annealed condition, the isothermally annealed strip shows average tensile strength values of 63,600 p.s.i. in the longitudinal direction and 66,150 p.s.i. in the transverse direction with corresponding values for ductility of 26 and 24%. The conventionally annealed strip shows appreciably higher tensile strength values of 68,150 p.s.i. in the longitudinal direction and 75,400 p.s.i. in the transverse direction with respective ductility values of 24 and 19%.

After cold rolling to about 0.064 inch thick strip and stress relieving at 1400° F., the isothermally annealed specimens show nearly the same tensile strength values in both directions as before, but ductility had increased to 34% in the longitudinal and to 32% in the transverse direction. Conventionally annealed strip shows about the same tensile strength in the longitudinal direction as before (68,000 p.s.i.), a significantly lower tensile strength in the transverse direction (71,000 p.s.i.), and higher ductility values of 30% in the longitudinal and 28% in the transverse direction. After further cold rolling to 0.020 inch thick strip and strand annealing at 1400° F., only slight differences are found in tensile strength (66,300 p.s.i. and 67,000 p.s.i.) and ductility (33% and 31%) values of isothermally and conventionally annealed strip.

In order to determine whether there would be a distinguishable difference in tensile properties of Type 430 strip which, instead of being annealed isothermally at 1450° F. immediately after hot rolling, was allowed to cool to room temperature, then reheated to within the austenitic range of 1900° F., and finally annealed isothermally at 1450° F., a group of samples were tested after treatment in this manner, the treatment being referred to heretofore as treatment "C." The tensile data (each value being the average of four tests) on 0.060 inch thick cold rolled and stress relieved strip are shown in Table IV.

TABLE IV

Tensile Properties of Hot-Rolled, Air-Cooled Isothermally-Annealed Type 430 Stainless Strip [1]

COLD-ROLLED (0.060-INCH) STRESS-RELIEVED (1,400° F.)

Direction of testing with respect to rolling	Yield strength 0.2 percent offset, p.s.i.	Tensile strength, p.s.i.	Elongation, percent in 2 inches
Longitudinal	37,150	61,700	33
Transverse	37,700	64,300	32

[1] Reheated to 1900° F. for 30 minutes, isothermally annealed for 3 hours at 1,450° F.

When the data in Table IV is compared with the results of otherwise similarly processed strip in Table II, no significant difference in tensile properties is present. Thus, similar tensile properties would apparently result if Type 430 strip were isothermally annealed either immediately after hot rolling (treatment "A") or after cooling to room temperature and then reheating (treatment "C") to 1900° F., the finishing temperature for hot rolling. However, treatment "C" involves a reheating operation and is therefore more costly and time-consuming.

Metallographic studies made to compare the structures of Type 430 stainless steel in the hot rolled and isothermally and conventionally annealed conditions, as well as in the stress-relieved condition after cold rolling to .065, .020, and .010 inch thick strip reveal structural similarities and differences which appear to be related either to the annealing treatment or to the rolling practice, or both.

Structural similarities consist of ferrite grains (which were the result of austenite transformation), a matrix of delta ferrite, and carbide particles which had precipitated at prior austenite grain boundaries and within the delta ferrite matrix. Structural differences exist in the sizes of the ferrite grains and the amount and distribution of the precipitated carbide particles.

In the hot rolled and annealed condition, the prior austenite grains in isothermally annealed strip are noticeably larger than those in the conventionally annealed

strip. In both cases the ferrite grains appear as thin, elongated grains surrounded by carbides, and randomly oriented with respect to the rolling direction. No distinguishable difference exists in the nature of the precipitated carbides that could be attributed to annealing practice.

A visual comparison of isothermally and conventionally annealed Type 430 stainless strip after cold rolling and subsequent strip relieving and pickling shows no distinguishable differences in surface appearance which can be attributed to either of the two annealing practices.

Briefly, in accordance with the invention and on the basis of hardness data, tensile properties, microstructure and behavior during subsequent cold rolling, Type 430 stainless strip should be isothermally annealed immediately after hot rolling within the temperature range of 1400° F. to 1500° F. for at least three hours. Under those conditions the hardness is low (about Rockwell B75), the tensile and yield strengths are low, ductility is high, the structure consists of ferrite (delta ferrite plus ferrite produced from decomposition of austenite) and precipitated carbides, and cold rolling behavior is very satisfactory as evidenced by a relatively low degree of work hardening.

When strip is isothermally annealed at a lower temperature of say 1300° F., pearlite is found in the prior austenite grains. Annealing for less than three hours at 1400° F. or 1450° F. results in an incomplete decomposition of austenite. In both instances the hardness after annealing is higher and the degree of work hardening and susceptibility to cracking during cold rolling are greater than for the preferred conditions.

In accordance with the invention, an isothermal annealing treatment for AISI Type 430 stainless steel strip within a temperature range of 1400° F. to 1450° F. immediately after hot rolling can be effectively employed in processing Type 430 strip. The optimum treatment for isothermal annealing is in the temperature range of 1400° F. to 1450° F. for three hours or more. Isothermally annealing strip immediately after hot rolling results in lower hardness than is produced by conventional annealing. At the same time, lower strengths and higher ductility result from isothermal annealing as compared with conventional annealing. Although the isothermally annealed strip has lower hardness and strength and higher ductility than conventionally annealed strip, the differences in properties diminishes as the strip is further cold rolled from .065 to .01 inch thick strip and stress relieved.

Moreover, isothermally annealed strip may be cold rolled as easily as conventionally annealed strip, resulting in a surface quality equal to that of conventionally annealed strip at thicknesses ranging from .125 to .010 inch.

Finally, the isothermal annealing procedure of the invention for Type 430 steel strip is commercially desirable because it results in a savings in operating costs and time with no sacrifice in rolling behavior, tensile properties, or surface characteristics.

In the foregoing description, certain terms have been used for brevity, clearness and understanding; but no unnecessary limitations are to be implied therefrom beyond the requirements of the prior art, because such terms are utilized for descriptive purposes herein and not for the purpose of limitation and are intended to be broadly construed.

Moreover, the description of the improvements is by way of example and the scope of the present invention is not limited to the exact details illustrated.

Having now described the features, discoveries and principles of the invention, the procedures or steps necessary to accomplish the objectives, the characteristics of the new products obtained thereby, and the advantageous, new and useful results provided; the new and useful methods, steps, operations, procedures, discoveries and principles, and mechanical equivalents obvious to those skilled in the art, are set forth in the appended claims.

What is claimed is:

1. The method of making hot rolled annealed Type 430 stainless steel at hot rolling temperature range of 2300° F. to 1900° F. to form hot rolled, soft, ductile, fully spheroidized strip that is completely free of martensite; furnace cooling the hot rolled strip from the hot rolling temperature range immediately after hot rolling and while still retaining hot rolling heat to a temperature in the range of 1400° F. to 1500° F., maintaining the strip at said 1400° F. to 1500° F. temperature for at least three hours; and then cooling the hot rolled strip to room temperature.

2. The method set forth in claim 1 in which the hot rolled strip is furnace cooled to and maintained at 1450° F. for at least three hours.

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