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METHOD OF MAKING DEEP DRAWING STAINLESS STEEL

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This invention relates to the preparation of chromium alloy steels for deep drawing operations. More particularly, it pertains to the heat treatment of these steels to obtain improved ductility and a minimum tendency to forming a surface banded structure, sometimes called "roping," during such operations.

In the fabrication of deep drawn articles from stainless steels, the austenitic grades of 18–8 type, containing approximately 18% chromium and 8% nickel, have generally been preferred because of their superior corrosion resistance, excellent drawing quality and bright finish. The term "stainless steel" is used not only to refer to the above mentioned 18–8 type, but also to include straight chromium steels, such as A. I. S. I. types 410, 430 and 442.

Due to Government restrictions on the use of nickel in recent years, the use of straight chromium stainless steels has been prevalent particularly for civilian purposes. For many applications it has been possible to substitute straight chromium steels, such as 12% Cr (type 410, containing about 12% Cr) or 17% Cr grades (e. g. type 430 containing 14% to 18% Cr, the optimum being about 17% Cr; or type 440 containing 18% to 23% Cr, in accordance with A. I. S. I. commercial designations). Type 442 is very similar in metallographic structure and physical properties to type 430 but has slightly better corrosion resistance, and both are transforming, stainless steels. The most popular substitute for the 18–8 type is the type 430 straight chromium steel containing approximately 17% chromium. Its corrosion resistance approaches that of the 18–8 type, and in formations requiring relatively light plastic deformations, it can be easily polished to a high luster. Moreover, improvements in die design and lubrication have made possible the use of 17% chromium alloy steel strip for deep drawn formations which were formerly regarded as too severe for such grades of steel.

In formations requiring relatively light plastic deformations, such as moldings and ornamental trim, the 17% chromium strip steel is very satisfactory. However, in deep drawn parts which have been severely stretched or strained, this type of steel has the disadvantage of forming directional lines or bands, sometimes called "roping" or "washboard." These directional lines are ridges on the surface of the metal and are due to a warpage of the metal during plastic flow in forming. They are very unsightly and they are both difficult and expensive to remove by polishing. Accordingly, attempts have been made to increase the ductility of the straight chromium stainless steel strip of the 17% chromium type and to minimize the effect of directional lines or bands, the ultimate aim being to find an economical substitute for the 18–8 type of stainless steel.

It is one object of this invention to provide a corrosion resistant grade of steel strip with a minimum amount of directional lines or banded structure and thereby minimize costs of polishing and improve appearance.

It is another object of this invention to provide a corrosion resistant steel having improved ductility and workability.

It is a further object of this invention to provide a corrosion resistant steel having a homogeneous micro-structure which in turn is conducive to improved ductility and appearance.

Another object of this invention is to provide a corrosion resistant steel having increased elongation properties which in turn are conducive to greater deformations for a given operation.

Finally, it is an object of the present invention to solve existing problems in the art, to eliminate prior art difficulties in the deep drawing of straight chrome stainless steels, to generally improve straight chrome stainless steel cold working procedures and products, and to obtain the foregoing advantages and desiderata in a simple and effective manner.

These and other objects and advantages apparent to those skilled in the art from the following description and claims, may be obtained, the stated results achieved, and the described difficulties overcome by the methods, steps, operations and procedures which comprise the present invention, the nature of which is set forth in the following statement, a preferred procedure of which—illustrative of the best mode in which applicants have contemplated applying the principles—is set forth in the following description, and which are particularly and distinctly pointed out and set forth in the appended claims forming part hereof.

The nature of the improvements in method of making deep drawing straight chrome stainless steel of the present invention may be stated in general terms as comprising subjecting the steel, after hot rolling to strip form of the desired thickness and prior to annealing the same, to a phase redistribution heat treatment by passing the strip through and heating it in a continuous furnace at from 1700° F. to 2100° F. long enough to promote complete heating of the strip and to effect a break up of the prismastic grain structure in the hot rooled strip resulting from directional hot rolling of a material—straight chrome stainless steel—in which two metallic phases coexist at hot rolling temperatures but not at room temperature, said heating time being about one to ten minutes at temperature, and then air cooling the thus heated strip material.

The material treated by the discoveries of the invention is straight chromium stainless steel (types 430 and 442) which has a composition whereby the metal contains two phases in the temperature range where hot working or rolling operations take place; that is, at temperatures where the metal can be readily worked, between approximately 1600° F. and 2400° F. The two phases are the delta and gamma iron phases which are present in substantially equal proportions in said temperature range.

For the purpose of the present invention the chemical analysis of the steel used is as follows:

C	Mn	Si	Ni	Cr
.25% max.	1.00% max.	1.00% max.	.50% max.	14% to 23%

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

C	Mn	Si	Ni	Cr
.08%	.40%	.35%	.12%	17.00%

When steel of this analysis cools, it solidifies with a dendritic pattern at a temperature of approximately 2600° F. to 2750° F. As the temperature drops below the

solidification temperature the solid metal consists of crystals of delta iron and gamma iron. As the metal cools below about 1650° F., substantially the delta iron phase retains its body-centered cubic crystal structure which is the same as alpha iron at room temperature, whereas the gamma iron phase is substantially transformed into a product consisting of carbides in a matrix of alpha iron.

Upon heating the ingots in the soaking pits at temperatures approaching 2300° F., the delta and gamma phases return. Subsequently, the ingots are rolled into blooms between the temperatures of 2000° F. and 2300° F., and the gamma and delta phases, which exist substantially independently of each other, are rolled out longitudinally in the direction of rolling by virtue of the directional stresses imparted by the hot working operation.

Normally, the blooms are then cooled to room temperature for the removal of surface defects by usual surface conditioning operations; and when the blooms are so cooled, the delta and gamma phases transform in the manner previously described. However, when the blooms are again reheated for rolling into slabs, the delta and gamma phases again reappear in their directional alignment. If the blooms do not require surface conditioning prior to slab rolling, the blooms may be rolled directly to slabs without cooling, surface conditioning and reheating. This, however, is the exception and not the rule because seldom is the surface condition of a bloom such as not to require conditioning.

The rolling temperature in rolling blooms to slabs is usually in the range from about 2300° F. to 1600° F., and further directional characteristics are imparted to the metal during hot working in rolling the slabs. When the slabs are cooled, for surface conditioning as by grinding and the like, the delta and gamma phases again undergo transformation as previously described. However, when the slabs are again reheated for hot rolling into strip form, the delta and gamma phases again reappear.

During the hot rolling of the slabs to form hot rolled strip, the metal in the slabs, which may be from 2" to 3" thick, is rolled out to a thickness of .100" to .250" thick, again in a temperature range of from about 2300° F. down to 1600° F., in which temperature range the delta and gamma phases again reappear and are further elongated in the direction of rolling due to the hot working.

If microsections of the hot rolled strip are made along planes parallel to and at various angles to the direction of rolling, examination of such sections discloses that the strip has a duplex structure consisting of low carbon ferrite, originating substantially from the delta iron phase; and a decomposition product, possibly containing pearlite or martensite depending upon the rate of cooling, this constituent having been transformed from the gamma iron phase. This duplex structure has the arrangement of a cluster of small bands running in the direction of rolling; while at right angles to the direction of rolling there is no banding or directional structure. A microscopic specimen cut along any plane parallel to the rolling direction (such as a plane parallel to the mill edge, or parallel to the surface) shows the directional structure.

The foregoing constitute the major operations normally carried out in producing hot rolled stainless steel strip. Where cold rolled strip is produced the usual operations include the following:

1. Hot roll at from 2300° F. to 1600° F.
2. Box anneal between 1400° F. and 1600° F.
3. Pickle to remove scale.
4. Cold roll to some lighter gauge.
5. Continuous anneal between 1350° F. and 1500° F.
6. Pickle to remove scale.
7. Pinch pass if desired for very light reduction.

Where the operating conditions or the dimensions of the final product require, steps 4, 5 and 6 may be repeated in that order after operation 6.

In the above procedure, step 1 has been described and includes those hot rolling operations that are necessary to reduce the metal to usual hot rolled strip thicknesses ranging from .100" to .250". At this stage, the metal is in the form of long coils which should be annealed. For this purpose it is preferred that the coils be box annealed by placing the same in a suitable closed container with or without packing material in order to minimize oxidation at a temperature range of 1400° to 1600° F. After cooling the metal is subjected to pickling to remove scale. It is then cold rolled to a lighter gauge, annealed at a temperature between 1350° and 1500° F. and pickled again to remove scale. This may be followed by a so-called "pinch pass" through cold rolls in order to impart a cold rolled surface.

If the cold rolling and annealing operations are properly carried out and controlled, the finished cold rolled strip product has no apparent visible directional properties until it is stretched or drawn. If, however, a sample of the cold rolled strip is heated somewhat above 1650° F. and slow cooled, microscopic examination reveals a duplex structure which has a directional orientation corresponding to that in the hot rolled strip, indicating that the directional properties induced by hot rolling are still inherent in and present in the cold rolled product despite the various processing operations performed in reducing the hot rolled strip to finished cold rolled strip. If the finished product in the annealed or soft state is severely stretched, as in a tensile test, or formed into deep drawn parts, such as pans, or cups, directional lines of the character described develop and appear on the surface of the stretched or deep drawn product.

We have established from another standpoint that these directional lines are directly related to the duplex hot rolled structure imparted by directional hot working, by determining that the condition can be altered by changing the direction of hot rolling at some appropriate stage of hot working. For example, if an ingot is rolled into a sheet bar, say ½" thick, and short lengths of the sheet bar are cross rolled to form .060" thick sheets, hot rolling in the sheet mill being done at right angles to the direction of the prior hot working operations, the product has distinctly different properties from material produced from hot or directional rolled strip. Then if the cross rolled sheet product is box annealed, pickled, cold rolled to say .020" gauge sheets, annealed and electro-pickled, stretching or cold drawing does not tend to form the directional lines or roping characteristics of material produced from strip hot worked entirely in one direction.

Instead of "roping" in cross rolled sheets, a pebbled effect may appear or be visible on the surface of a pan or cup deep drawn therefrom. These results establish that the cold rolling does not produce the directional lines. Microscopic samples of cold rolled material produced from cross rolled sheet, heated above 1650° F., slow cooled, and examined for structure, disclose that the directional pattern differs from material originating from hot rolled strip. The latter, shows a banded structure in any direction parallel to the hot rolling direction; while transverse to the rolling direction there is no banding. In contrast, material originating from cross rolled sheet discloses no banding in a plane parallel to the surface, but discloses a checkerboard pattern. There is banding, however, in planes perpendicular to the surface.

These investigations indicate that the directional orientation produced by hot rolling to sheet bar in one direction, followed by cross rolling at right angles in the sheet mill, persists after subsequent cold rolling and annealing operations. In material produced from cross rolled sheet, the checkerboard, hot rolled structure seems to be related to the pebbled surface obtained after stretching or drawing the finished product, just as the hot rolled banding is related to the directional lines or roping on material produced from hot rolled strip.

Although cross rolling in a sheet mill is a partial solution to the problem, it is less economical to produce large

quantities of short sheets than long coils and it is more difficult to produce a cold rolled surface in sheets. Suffice it to say, it is more desirable to produce strip in large coils.

We have found it possible to produce a strip product having a minimum of directional tendency and also better ductility by subjecting hot rolled strip to a new and special heat treating procedure after hot rolling and prior to box annealing the same.

Accordingly, the hot strip is heated in a continuous furnace to a temperature substantially above the finishing temperature on the hot mill for a time sufficient to effect a partial breakdown of the directional banding. This temperature range is from 1700° to 2100° F., for a sufficient time to permit thorough heating. The optimum temperature range is 1900° F. to 2000° F., the preferred temperature being 1950° F. The time required is one to ten minutes at temperature depending on the strip mass or thickness. Lower temperatures are not effective, while higher temperatures may cause undesirable grain growth.

This heat treating operation is not a "normalizing" operation inasmuch as the temperature must be substantially above that required for a phase change, nor is it an annealing or softening operation for the reason that no softening or annealing occurs. In fact, the hardness may be slightly increased sometimes from 94 to 98 RB, Rockwell hardness. Rather the operation is a partial homogenizing procedure, the purpose of which is to promote diffusion between the gamma and delta phases in a temperature range where they coexist and in the absence of mechanical stress.

As a result, the banded structure is partially broken up and the grains, which are approximately polygonal prisms after hot rolling, are converted to irregular polyhedrons of many faces. Thus there is a partial breakup of banding which greatly facilitates softening and equiaxing of the grain structure in subsequent operations. After this heat treating operation the strip is air cooled.

The process of manufacturing the new deep drawing 17% chromium strip in accordance with the invention and beginning with a slab is as follows:

1. Hot roll at from 2300° F. to 1600° F.
2. Phase redistribution heat treatment between 1700° F. and 2100° F. (preferably 1950° F.).
3. Air cool to room temperature.
4. Box anneal between 1400° F. and 1650° F.
5. Pickle to remove scale.
6. Cold roll to form lighter gauge.
7. Continuous anneal between 1350° F. and 1500° F.
8. Pickle to remove scale.
9. Repeat steps 6, 7 and 8, after step 8, if desirable, or pinch pass.

The phase redistribution heat treatment is, of course, the crucial feature of this invention. Inasmuch as it is neither a softening nor a hardening operation, but is concerned with the arrangement of two metallic phases which coexist at hot rolling temperatures but not at room temperatures, this heat treatment is believed to be unique in metallurgical practices. This is believed to be particularly true owing to the position in which the operation is placed in the sequence of operations.

By carrying out the new procedure of the present invention, a new deep drawing grade of chromium alloy stainless steel, such as 17% chrome stainless steel, may be made, the phase redistribution heat treatment being performed on the hot rolled strip after hot rolling and before box annealing. The allowable range of heating is 400° F. between from 1700° F. to 2100° F., preferably 1950° F. The time-temperature cycle must be sufficient to effect a redistribution and reshaping of the grains, converting them from polygonal prisms to irregular polyhedrons and effecting a partial breakup of the hot rolled banded structure.

In the metallurgical control of the phase redistribution heat treatment, the usual hardness and ductility tests are

of no value and no testing method seems adequate excepting microscopic examination, the effectiveness of the phase redistribution heat treatment being determined by metallurgical examination of microscopic samples.

Even microscopic examination has its limitations. For instance, if type 430 stainless steel is subjected to the phase redistribution heat treatment of the present invention, but the cooling is at a rapid rate, although the benefits of diminished "roping" are obtained, yet microscopic examination does not disclose the irregular polyhedrons with the grains of bainite approaching approximately spherical shape, even though they may be present. Instead, with rapid cooling the phase changes originating from the delta and gamma iron phases both show a needlelike pattern of martensitic structure.

However, if the fast cooled material is reheated to say 900° F. and then cooled, that is to say if the material is drawn by reheating and cooling, the grain structure becomes more evident.

In other words, even though the breakup of the banded structure occurs from heat treatment of the material in accordance with the invention, it may possibly not be possible to see the effectiveness thereof by microscopic examination if the material has been rapidly cooled.

Cold rolled straight chrome stainless steel produced in accordance with the procedure of the present invention has many improved properties. It has a more homogeneous microstructure; microscopic tests made after various annealing operations disclosing a much better equiaxed microstructure than is common to usual straight chrome stainless steel strip. Ductility of the finished product is much improved, showing an increase of about 20% in the values obtained from usual straight chrome stainless steel strip. For example, an average of about 25% elongation in 2" is obtained in conventional type 430 stainless steel while an elongation of about 30% in 2" is obtained in steel products made in accordance with the invention.

The tendency toward directional lines in the finished product is greatly reduced. Thus when the finished product made in accordance with the present invention is severely stretched or deep drawn, it forms a minimum of directional lines or "roping." After deep drawing, the material is much easier to polish to a high luster, because of the diminished "roping" effect, so that polishing costs are greatly reduced and appearance of the finished deep drawn part is improved.

Accordingly, the present invention provides a new procedure for making cold rolled straight chrome stainless steel strip; provides improved characteristics or properties in the finished product; satisfies the foregoing objectives, advantages and desiderata in a simple and effective manner; and overcomes prior art difficulties and solves long standing problems in the art.

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 or discoveries is by way of example and the scope of the present invention is not limited to the exact details described provided that the new procedure is carried out at the time and in the manner described in the manufacture of straight chrome stainless steel.

Having now described the features, discoveries and principles of the invention, the procedures of preferred method steps thereof, 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.

We claim:

1. The method of making deep drawing quality, cold rolled, 14% to 23% straight chromium, transforming, stainless steel strip capable of being deep drawn with a minimum of directional lines imparted by directional hot rolling of the delta and gamma iron phases which exist at hot rolling temperatures but not at room temperature in 14% to 23% straight chromium transforming stainless steel, and which delta and gamma iron phases transform upon cooling to a duplex structure consisting of ferrite substantially originating from the delta iron phase and a decomposition product originating from the gamma iron phase, arranged in a cluster of small bands running in the direction of rolling; the steps of hot rolling slabs of 14% to 23% straight chromium, transforming, stainless steel at hot rolling temperatures of from about 2300° F. to 1600° F. in one direction to form hot rolled strip; continuously heating the hot rolled strip to a temperature in the range of from 1700° F. to 2100° F. for from one to ten minutes to promote a redistribution between the gamma and delta phases in a temperature range where they coexist and in the absence of mechanical stress, to effect a breakup of the banded structure and to redistribute, reshape and convert the grains which are approximately polygonal prisms after hot rolling into irregular polyhedrons of many faces tending to approach a spherical shape upon cooling; then annealing the strip at from 1400° F. to 1650° F., then cold rolling the strip to desired gauge, and then continuously annealing the cold rolled strip at a temperature between 1350° F. and 1500° F. to provide annealed cold rolled stainless steel strip material having elongation of about 30% in two inches.

2. The method of making deep drawing quality, cold rolled, 14% to 23% straight chromium, transforming, stainless steel strip capable of being deep drawn with minimum roping resulting from banding produced by longitudinal hot rolling directional stresses imparted to the delta and gamma iron phases which exist at hot rolling temperatures but not at room temperature in 14% to 23% straight chromium transforming stainless steel; the steps of hot rolling slabs of 14% to 23% straight chromium, transforming, stainless steel at hot rolling temperatures of from about 2300° F. to 1600° F. in one direction to form hot rolled strip, continuously heating the hot rolled strip to a temperature in the range of from 1700° F. to 2100° F. for from one to ten minutes to effect a breakup of directional banding present in the directionally hot rolled strip as a result of hot rolling the delta and gamma iron phases at hot rolling temperatures, then annealing the strip at from 1400° F. to 1650° F., and then cold rolling the strip to desired gauge, and then continuously annealing the cold rolled strip at a temperature between 1350° F. and 1500° F.

3. The method set forth in claim 2 in which the hot rolled strip is continuously heated to a temperature between 1900° F. and 2000° F., and in which the strip is air-cooled after such heating.

4. The method set forth in claim 2 in which the hot rolled strip is continuously heated to a temperature of 1950° F.

5. The method of making cold rolled, 17% straight chromium, transforming, stainless steel strip having a minimum of directional lines when severely stretched or deep drawn, including the steps of hot rolling slabs of 17% straight chromium, transforming, stainless steel strip in one direction at hot rolling temperatures of from about 2300° F. to 1600° F. where delta and gamma iron phases coexist to form hot rolled strip, continuously heating the hot rolled strip to a temperature in the range of from 1700° F. to 2100° F. for from one to ten minutes to effect a breakup of directional banding present in the directionally hot rolled strip as a result of hot rolling the delta and gamma iron phases at hot rolling temperatures, then annealing the strip at from 1400° F. to 1650° F., then cold rolling the strip to desired gauge, and then continuously annealing the cold rolled strip at a temperature between 1350° F. and 1500° F.

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