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DOUBLE-STEPPED ANNEALING FOR IMPROVEMENT OF SUPER-DEEP DRAWING PROPERTY OF STEEL SHEET

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The present invention relates in general to a practice of improving super-deep drawing property of cold-rolled low carbon steel sheet and in particular to double-stepped annealing to be conducted in two different temperatures, lower and higher, to improve super-deep drawing property of cold-rolled low carbon steel sheet by affording pastic anisotropy. Practice of double-stepped annealing in pursuant to this invention is designed primarily for causing imperfect recrystallization at a lower annealing temperature for development specially of crystallization orientation which best favors deep drawing in a parallel to rolling plane, before softening annealing at a higher in order to achieve decarburization and denitrification of the cold-rolled low carbon steel.

An object of the present invention is to provide a practice of annealing for an adjustment of a refined grain in the cold-rolled low carbon steel plate to an optimum size, which assures no orange peel, resulting from drawing with the press, in other words, improvement of deep-drawing property of the steel which is affected by a realized grain size, namely a technique of annealing the cold-rolled low carbon steel sheet at a lower temperature which assures initial formation and subsequent growth preferentially of such crystal grain as is characterized by the same orientation as that of cold-rolled aggregative structure, which in turn gives rise to intensification of crystal orientation, affecting favorably the deep-drawing property of the annealed steel sheet.

Recently developed soft annealing technique, resorting to decarburization in pursuant to open-coil process has greatly contributed to drastic improvement of deep drawing property of the cold-rolled steel sheet, which may be reasonably considered attributable to:

(1) Successful removal of carbon and nitrogen impurities, present in the structure of the steel, owing to annealing conducted in an atmosphere, containing adequate percentage of hydrogen and steam vapour, which in turn reduces, from the view point of crystal plasticity, presence of matters, impeding the movement of dislocation caused by plastic deformation, resulting from deep drawing, namely, precipitation of carbide, nitride and the likes, and carbon and nitrogen in solid solution, resulting in added ease in making deep-drawing.

(2) Promotion of growth of crystal grain, in accordance with reduction of contents of carbon and nitrogen, described in preceding (1), when treated by open coil process, which never causes inter-sheet sticking trouble at high temperature, as is often the case with conventional batch annealing practice, offering possibility of successful annealing at a very high temperature, that represents another factor assuring reduction of grain boundary one of obstacles to success in deep-drawing, which means an improved ease of the said drawing.

It should, however, be noted that practice of annealing in pursuant to open coil process is liable to cause coarsening of crystal grain which is a predominant cause of orange peel, resulting from drawing on the press. This suggests a great necessity for prior established practice for prevention of orange peel to be caused by drawing on the press by maintenance of crystal grain, adjusted to a proper size, in order to be assured of obtainment of an excellent drawn steel product, by a clever choice of an open coil technique, most acceptable for a particular annealing in embodiment of this invention. That is to say that a means should be sought for which always assures improved drawing property of the steel plate, regardless of the realized size of crystal grain. What must be specially noted in this regard is that it is acknowledged as one of the metallurgical prerequisites for successful deep drawing to adjust the orientation of crystal grain so that deformation, appearing in a direction of plate thickness should be better presented than that in another direction of the plane of the plate, namely to afford the steel sheet the plastic anisotropy. An orientation of crystal grain, meeting the above mentioned requirement, is believed to be preferential orientation, belonging to cube-on-corner (III)[110] type, and it is generally recognized that the steel sheet, characterized by preferred orientation in (III) plane, in parallel to rolling plane-preferred orientation in cold-rolled texture, is featured by an improved drawing property. Being aware of, in conjunction with described plastic anisotropy, the observed fact that the recrystallized aggregate structure of iron often gives rise to preferential crystal orientation, similar to that in cold-rolled aggregative structure when the said structure of iron is annealed at a low temperature, the authors have arrived at a conclusion that improved crystal orientation which is more favorable for successful deep drawing of the steel sheet can be assured by preferential growth of the crystal grain in a particular orientation, caused by annealing for decarburization and denitrification at a higher temperature, conducted immediately after previous annealing at a lower temperature, owing to characteristic mechanism of growth of the crystal grain, because preferential initial formation and subsequent growth of the crystal grain, orientation of which is same as that in cold rolled aggregative structure, achieved by prior annealing at a lower temperature, when metallurgical travel, represented by the fact described above has been allowed in annealing.

Basic idea for the present invention may be justified in an embodiment as will be described later. Definite description will follow hereunder at length with respect to subject matters of the present invention.

No restriction is imposed on the steel plate to which this invention is applicable with respect to the chemical compositions, and accordingly in general any type of steel plate, manufactured as cold-rolled low carbon steel or designed for fabrication by deep drawing, can be covered by scope of application of this invention. But practically in the process of strip rolling, unannealed coil, cold-rolled a usual draft of 40–90% to final design thickness, after pickling, subsequent to hot rolling to a specified thickness, would be treated in accordance with this invention. It should be specially noted that cold-rolling draft of 60–85% is most recommendable to ensure the better achievement of the object of the present invention, providing a technique of heat treatment for annealing. After the said heat treatment, the cold-rolled coil of the steel is heated in a suitable annealing equipment (furnace) wherein atmosphere of inert gas is prevalent, at a temperature of 470°–570° C. below a point where recrystallization is completed (such a temperature is dependent on drafting of the rolled steel, etc.) for a continuous period, exceeding at least 30 minutes to cause slow recrystallization for annealing of the steel until a state of partial recrystallization or immediate before completion of recrystallization is realized metallurgically. This means preferential growth of the crystal grain, simi-

lar to the structure of the cold-rolled sheet with respect to orientation, caused by annealing, conducted at a temperature region, specified above. Rise of annealing temperature above the said region gives rise to initial formation and subsequent growth also of the crystal grain, orientation of which is not similar to that in the cold-rolled aggregative structure, thus wiping out possibility of improvement of the deep drawing property of the annealed steel, and on the contrary, too low an annealing temperature is a cause of lost chance for realization of recrystallization as is desired. But, according to this invention, the strip coil, annealed with a result of imperfect recrystallization, is again annealed for softening, under positive decarburization and denitrification in the atmosphere of such a suitable gas as wet Ax gas, which can not oxidize the iron but purge out the carbon, present in the steel, within the annealing equipment (furnace) for open coil process, this soft annealing is done at a temperature, higher than annealing temperature for imperfect annealing specified above, which, however, may be such that it assures perfect recrystallization of ordinary cold-rolled low carbon steel, namely between 600° C. and A_3 transformation point. In this range of annealing temperature, can be developed the preferential crystal reorientation which is favorably appreciated for successful deep drawing, the first of the objects of this invention. Imperfect recrystallization annealing at a lower temperature (preliminary) and soft annealing (final) may be accomplished stepwise in sequence or in such a manner that the latter is carried out often the preliminarily annealed steel has once been cooled down to around normal room temperature, if formed necessary to do so.

For the latter annealing, such mixture of hydrogen as HNX gas of 3–20% and the rest, primarily of nitrogen, is used when only decarburization is intended for, and another mixture of hydrogen in excess of 70% and rest, primarily of nitrogen, is employed when both decarburization and denitrification must be achieved, by applying steam vapour to be charged into the annealing furnace as soon as the specified temperature has been reached, in order to promote chemical reaction. Denitrification should, preferably be carried out at a lower annealing temperature for success in achieving improvement of super-deep drawing property of the steel sheet. The steel sheet obtained by the double-stepped annealing technique, is appreciably improved with respect to plastic anisotropy or very excellent in regard to drawing result.

Example 1

Steel ingots of specimen with two different chemical compositions A and B as listed below were obtained by means of the test melting furnace and were then forged and hot-rolled into 3 mm. thick plate and finally cold-rolled into 0.8 mm. thick sheet after pickling.

Composition	C	Si	Mn	S	P	Cu	Al	N
Test piece No.:								
A	0.039	0.015	0.43	0.07	0.004	0.095	0.027	0.0045
B	0.036	0.019	0.43	0.07	0.057	0.132	0.019	0.0057

The specimens of cold-rolled steel sheet so prepared were first annealed for slow imperfect crystallization for a continuous period of 2 hours at a temperature of 550° C. in an atmosphere of HNX gas (H_3, 3–10%; CO and CO_2, 0.05% each; rest N_2 dew point —40° C.) and then heated at two different high temperatures of 720° C. and 780° C. in the atmosphere of the same gas. In this heating, steam vapour was charged into the annealing furnace upon achievement of specified soaking temperature. This was followed by decarburization, effected while soaking the specimen at 30° C. dew point of the atmosphere in the furnace for a continuous period of 5 hours at the end of which feed of steam vapour was terminated, being succeeded by charge of dry HNX gas. The specimens were again soaked at the same temperature as before for a continuous period of another 1 hour and then cooled down to room temperature for soft annealing.

The deep drawing property of a steel sheet, realized by the annealing practice described above, and that of another steel sheet, annealed at a temperature of 720° C. or 780° C. are collected in Table 1 to facilitate comparison between them.

TABLE 1

Test piece No.	Previous annealing	Present annealing (final)	Value of conical cup test (mm.)	Ratio of plastic strain (L direction)	A.S.T.M. Grain No.
A	550° C., 2 hours*	720° C., 6 hours	37.70	1,193	7.3
		720° C., 6 hours	37.35	1,230	7.4
	550° C., 2 hours*	780° C., 6 hours	37.42	1,356	6.4
		780° C., 6 hours	36.82	1,390	6.4
B	550° C., 2 hours*	720° C., 6 hours	37.35	1,470	7.3
		720° C., 6 hours	36.87	1,551	7.2
	550° C., 2 hours*	780° C., 6 hours	36.85	1,689	6.4
		780° C., 6 hours	35.58	1,772	6.1

*The present invention.

As is readily known in Table 1, the specimens, annealed in double-step of (preliminary+final) cycles, or in pursuant to this invention, are substantially improved with respect to deep drawing property in comparison with other specimens, annealed only "finally" in accordance with conventional practice. There found hardly any change in chemical compositions of the specimens, both A and B, after heat treatment of annealing, except for carbon, which was found reduced down to below 0.005%.

Example 2

Ingot steel with chemical compositions as expressed by the result of ladle analysis C, 0.04; Si, 0.01; Mn, 0.30; P, 0.029; S, 0.016; Cu, 0.08% were prepared, and finally cold-rolled, after an ordinary process, starting at slabbing or known process, to 0.8 mm. thick plate, which was then preliminarily annealed in the atmosphere of HNX gas at a temperature of 510° C. for a continuous period of 2 hours, and finally annealed in the same manner as described in Example 1, at a temperature of 760° C. for a continuous period of total 6 hours, including soaking comparison of deep drawing property among the first steel sheet, annealed as mentioned above, second steel sheet only finally annealed at 760° C. for 6 hours without prior preliminary annealing and the third steel sheet preliminarily annealed at a temperature and for a period, other than specified in the claim and then finally annealed at 760° C. and for 6 hours are made in Table 2, from which it is apparent that the steel sheet annealed both preliminarily and finally at the proper conditions (in pursuant to this invention) shows much more excellent deep drawing property in comparison with other steel sheets, not preliminarily annealed, and preliminarily annealed but not properly with respect to temperature and period.

TABLE 2

Previous annealing	Present annealing (final)	Ratio of plastic strain				Value of conical cup test (mm.)	A.S.T.M. grain No.
		L direction	45° direction	C direction	Average		
510° C., 20 minutes	760° C., 6 hours	1,435	1,135	2,014	1,528	36.96	7.5
		1,526	1,226	2,033	1,595	36.90	7.4
510° C., 2 hours*	760° C., 6 hours	1,631	1,227	2,329	1,729	35.88	7.4
590° C., 2 hours		1,306	1,314	2,104	1,575	37.01	7.7
450° C., 2 hours		1,304	1,248	1,997	1,516	36.95	7.2

*The present invention.

Although the present invention has been described with a certain degree of particularity, it is understood that present disclosure has been made by way of example and that numerous changes in details of practice may be resorted to without departing from the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. A method of annealing steel in two stages to make it highly deep drawable, which comprises cold rolling low carbon steel sheet intended to be used for deep drawing at a reduction rate ranging from 40 to 90%, annealing the thus cold-rolled steel sheet in an atmosphere of an inert gas at a temperature below the complete recrystallization temperature within the range from 470 to 570° C. for more than 30 minutes, then annealing the low-temperature annealed steel sheet above the complete recrystallization temperature for softening it, said last mentioned annealing being carried out at a temperature above 600° C. and below the A_3 transformation point in an atmosphere of a decarbonizing and denitriding gas.

2. A method of annealing steel in two stages to make it highly-deep drawable, which comprises cold rolling low carbon steel sheet intended to be used for deep drawing at a reduction rate ranging from 40 to 90%, annealing the cold-rolled steel sheet in an atmosphere of an inert gas at a temperature below complete recrystallization temperature within the range from 470 to 570° C. for more than 30 minutes, whereby the orientation which the crystals will take in deep drawing will be with the greatest drawability parallel to the rolling plane of said steel sheet in preference to other orientations, then annealing the low-temperature annealed steel sheet at a temperature above the complete recrystallization temperature for softening it, said last mentioned annealing being at a temperature above 600° C. and below the A_3 transformation point in an atmosphere of a decarbonizing and denitriding gas, thereby accelerating the growth of said oriented crystals in the direction of said orientation in preference to other orientations and giving a strong plastic anisotropy to said steel sheet.

3. A method as claimed in claim **2**, in which the reduction rate of cold rolling is 60–85%.

4. A method as claimed in claim **2**, in which the atmosphere of the inert gas is composed of 3–10% hydrogen, 0.05% carbon monoxide, 0.05% carbon dioxide and the balance nitrogen, and its dew point is −40° C.

5. A method as claimed in claim **2**, wherein the gas for decarbonization and denitrification is HNX gas composed of 3–20% hydrogen and the balance substantially all nitrogen.

6. A method as claimed in claim **2**, wherein the gas for decarbonization and denitrification is a mixture of more than 70% hydrogen and the balance substantially all nitrogen.

7. A method as claimed in claim **2**, wherein the softening annealing is performed as an open coil annealing step.

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