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[54] **COLD ROLLED STEEL STRIP WITH IMPROVED DRAWING PROPERTIES AND METHOD FOR PRODUCING SAME**

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[63] Continuation of Ser. No. 130,496, April 1, 1971, abandoned.

[52] **U.S. Cl.** ..... **148/12 C,** 148/36

[51] **Int. Cl.** **C21d 9/48,** C22c 39/54

[58] **Field of Search** 148/12, 36

[56] **References Cited**

UNITED STATES PATENTS

3,183,078	5/1965	Ohtake et al.	75/49
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3,492,173	1/1970	Goodenow	148/12
3,560,270	2/1971	Reinbold et al.	148/12
3,607,456	9/1971	Forand, Jr.	148/12

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[57] **ABSTRACT**

Killed steel containing 0.04–0.06 wt. percent carbon, and titanium at least six times the combined carbon and nitrogen contents, is subjected to controlled rolling and annealing steps to improve the drawing properties of the resulting cold rolled strip. No degassing of the molten steel. No decarburizing during annealing.

16 Claims, No Drawings

COLD ROLLED STEEL STRIP WITH IMPROVED DRAWING PROPERTIES AND METHOD FOR PRODUCING SAME

This is a continuation, of application Ser. No. 130,496, filed Apr. 1, 1971, and now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates generally to a method for improving the drawing properties of steel strip, and more particularly to a method for improving the drawing properties of killed, cold rolled steel strip containing between 0.04 and 0.06 wt. percent carbon.

Heretofore, it has been conventional to improve the deep drawing properties of killed, cold rolled steel strip by adding titanium to the steel. However, to obtain the desired deep drawing properties when titanium was added, it was also necessary that the carbon content of the steel be less than 0.02 wt. percent (see Shimizu, U.S. Pat. No. 3,522,110). To obtain this low carbon content, it was necessary to subject the steel to a vacuum degassing operation while the steel was still in a molten condition or that the steel be decarburized after it was rolled into strip.

The deep drawing properties of steel strip are expressed as the "$\bar{r}$ value." The higher the $\bar{r}$ value, the better the deep drawing properties of the steel. The $\bar{r}$ value is the average plastic strain ratio of the material, i.e., it reflects the ratio of percent change in width to percent change in thickness when the strip is pulled to a greater length (see Goodman, U.S. Pat. No. 3,404,047). It is desirable to produce killed, cold rolled steel strip having an $\bar{r}$ value greater than 1.9.

SUMMARY OF THE INVENTION

A method in accordance with the present invention produces killed, cold rolled steel strip containing titanium and having an $\bar{r}$ value greater than 1.9, but without a vacuum degassing operation or a decarburizing operation and with a carbon content between 0.04 and 0.06 wt. percent. The method comprises controlling the rolling and annealing operations, as described more fully below.

DETAILED DESCRIPTION INCLUDING A PREFERRED EMBODIMENT

Steel strip produced in accordance with the present invention has the following typical composition, in wt. percent:

carbon	0.04 – 0.06
manganese	0.29 – 0.35
nitrogen	0.003 – 0.007
titanium	0.30 – 0.65
aluminum	0.026 – 0.040
iron and usual impurities	essentially the balance

Manganese may be present in the permissible range 0.02–0.50. Nitrogen is generally present as an unavoidable impurity and may be present in amounts less than 0.015. The titanium content should be at least six times the combined carbon and nitrogen content. Aluminum is present as a result of killing the steel with aluminum.

Molten steel of the above noted composition is prepared without vacuum degassing, killed in the conventional manner and cast into ingots or slabs. The ingots are broken down into slabs using conventional rolling procedures. The slabs are hot rolled into hot rolled strip. The hot rolling procedure is essentially conventional up to the finishing temperature.

The hot roll finishing temperature is at least 1,645°F. (1,670°–1,710°F. preferred). The hot rolled steel strip is then coiled while at a temperature exceeding 1,100°F. (1,250°–1,290°F. preferred).

After hot rolling, the strip is cold rolled with a minimum cold reduction of about 60 percent (preferably 65–70 percent).

Following cold rolling, the steel strip may be either batch annealed or open coil annealed. In batch annealing, a coil of cold rolled steel strip is heated at a slow heating rate (e.g., 30°–70°F. per hour) to an annealing temperature greater than about 1,285°F. (1,322°–1,350°F. preferred) and soaked at this temperature for at least 20 hours (25–30 hours preferred).

In open coil annealing, the steel strip is heated, without decarburizing, in an inert atmosphere, at the same slow heating rate as described above in connection with batch annealing, to a temperature in the range 1,500°–1,640°F. (1,590°–1,620°F. preferred) for more than 5 hours (25–30 hours preferred).

After annealing, the steel is generally temper rolled.

A hot roll finishing temperature of at least 1,645°F. is necessary to obtain the desired texture at the conclusion of hot rolling. The desired texture is one in which the plane of the strip contains a mixture of crystal planes and no one crystal plane predominates to any significant degree in the plane of the strip. This is a random crystallographic orientation.

A hot roll finishing temperature of at least 1,645°F. also reduces precipitation of compounds containing titanium, carbon and nitrogen, and this is desirable.

The coiling temperature should be no greater than about 1,350°F. because a higher temperature would coarsen precipitated compounds of titanium, carbon and nitrogen, and this is undesirable.

A cold reduction before annealing of at least 60 percent is necessary to obtain a desired $\bar{r}$ value of at least 1.9 after annealing. Generally, the $\bar{r}$ value increases with increased cold reduction. A cold reduction below 60 percent produces an $\bar{r}$ value below 1.9, and a cold reduction above 60 percent generally produces an $\bar{r}$ value greater than 1.9. The $\bar{r}$ value generally increases with increased cold reduction in the range 60–70 percent. The upper cold reduction limit of 70 percent reflects the practical upper limits for cold reduction available with most commercial cold reduction mills. If cold reductions greater than 70 percent are available, then such greater cold reductions may be utilized without departing from the spirit of the present invention.

In the annealing step, 1,285°F. is a critical minimum temperature. Below this temperature the steel will not recrystallize during annealing; and recrystallization during annealing is essential to obtain the desired annealing texture and to get rid of the texture obtained during cold rolling.

More specifically, in order to obtain the desired high $\bar{r}$ value, it is essential to produce, in the annealed cold rolled strip, a crystallographic orientation in which there is a relatively high incidence, in the plane of the strip, of cube or corner (111) crystal planes and a relatively low incidence, in the plane of the strip, of cube on face (100) crystal planes. This texture is not present

after cold rolling, before annealing; but it can be produced with a recrystallizing anneal.

The previously described random orientation of crystal planes produced by the hot rolling step provides a mixture of cube or corner (111) crystal planes, cube on face (100) crystal planes, and all other possible planes, in the plane of the strip.

Not only must there be a recrystallization anneal, as distinguished from merely a recovery anneal (as in Goodenow, U.S. Pat. No. 3,492,173), but, also, recrystallization must be complete in order to obtain the desired strip properties. These properties include not only the desired high $\bar{r}$ value, but also particular strength and ductility levels.

More specifically, a given forming operation including drawing typically also includes stretching. The drawability of the strip is related to the $\bar{r}$ value (the higher the $\bar{r}$ value, the better the drawability). The stretchability of the strip is related to the ductility (elongation). Generally, the higher the ductility the better the stretchability. Moreover, yield strength (or 0.2 percent proof stress afater temper rolling) is also a factor. Too low a yield strength is undesirable in many applications because then the strip is too soft or too weak structurally. Too high a yield strength may be above the limitations of the forming press. A typical desired ductility, expressed as total elongation in a 2 inch gage length, would be greater than 35 percent, for example. A typical desired range for strength, expressed as 0.2 percent proof stress, after a temper roll of ¼–½percent, is 15,000–25,000 p.s.i., for example.

The length of time of the anneal is controlled by the length of time it takes to completely recrystallize the steel and obtain the desired crystallographic orientation and the properties described above including the desired $\bar{r}$ value. Thus, with a minimum annealing temperature of 1,285°F., there should be at least 20 hours of annealing time at this temperature to obtain complete recrystallization. The higher the annealing temperature, the shorter the time required, but a limitation on the annealing temperature for a batch anneal is that, when the temperature is too high, the laps of the coil stick together. This dictates an upper limit on the annealing temperature, when the coil is batch annealed, of about 1,350°F.

When annealing utilizing the open coil method, the laps of the coil don't touch and the steel may be heated to a higher annealing temperature than in the batch anneal method. However, the annealing temperature must be below the temperature at which austenite begins to form in the particular steel composition, and this is so whether annealing with the batch method or the open coil method.

Continuous annealing methods may also be used, the primary consideration being that recrystallization be complete and formation of austenite avoided.

EXAMPLES

Molten steel made by conventional procedures, without vacuum degassing, and having the composition set forth in Table I, was cast into ingots using conventional procedure. The steel was aluminum killed.

TABLE I

STEEL COMPOSITION

C	N	O	Mn	S	Si	P	Al	Ti	Cu
.045	.0045	.0011	.32	.025	.03	.005	.036	.34	.04

The ingots were broken down into slabs using conventional procedure. The slabs were reheated for approximately 2½ hours at 2,300°F., hot rolled and coiled into six coils. The hot rolling finishing temperature, the coiling temperature and the thickness of the coils of hot rolled strip is reflected in Table II.

TABLE II

HOT ROLLING FINISHING AND COILING TEMPERATURES

Coil No.	Hot Rolling Finishing Temperature	Coiling Temperature	Thickness, Inches
1	1680	1255	0.175 — Head 0.177 — Tail
2	1705	1260	0.163 — Hd 0.171 — Tl
3	1690	1255	0.172 — Hd 0.170 — Tl
4	1685	1250	0.170 — Hd 0.169 — Tl
5	1670	1250	0.103 — Hd 0.102 — Tl
6	1645	1290	0.095 — Hd 0.107 — Tl

After hot rolling, the strip was cold rolled. The percent of reduction during cold rolling is reflected in Table IV.

After cold rolling, the cold rolled strip was open coiled annealed at about 1,600°F. for a time in the range 26–30 hours. Details of the annealing treatment are given in Table III.

Some physical properties of the strip after open coil annealing are given in Table IV.

Table IV shows that 4 of the 5 samples of cold rolled strip subjected to a cold reduction of about 60 percent or greater (59.5 – 65.0 percent) before annealing had an r value after annealing greater than 1.9 (and the fifth sample had an $\bar{r}$ value of 1.86) and a grain size at least as fine as 8.0 ; whereas the highest $\bar{r}$ value for the strip samples subjected to cold reduction in the range 46.5 – 57.5 percent was 1.82 (and this was at 57.5 percent cold reduction).

After annealing, the strips was subjected to further cold reduction or temper rolling, as shown in Table V which also gives various physical properties of the strip. For those samples undergoing a total cold reduction of about 65–70 percent, the mean $\bar{r}$ value was about 1.9.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom as modifications will be obvious to those skilled in the art.

TABLE III

DETAILS OF OPEN COIL ANNEALING TREATMENT

Coil No.	Heating Rate	Soak Temp[1]	Soak Time	Cooling Rate
1	60°F./hr.	1600°F. ± 5°F.	26½ hrs.	—
2				
3	60°F./hr.	1590°F. ± [2]5°F.	30 hrs.	60°F./hr. down to 1450°F. then 200°F./hr. down to 830°F. Remainder of cycle at 40°F./hr. or less
4				
5	60°F./hr.	1600°F. ± 5°F.	29 hrs.	—

[1] Taken from hearth thermocouple.
[2] A jump above 1615°F. for approximately 1 hour occurred during the soak. Maximum temperature reached was 1640°F.

TABLE IV

MECHANICAL PROPERTIES AND GRAIN SIZE AFTER OPEN COIL ANNEALING

Coil (1) No.	Test Position	Thickness Inches	Cold Reduction %	Grain Size, ASTM No.	Yield Strength × 10^3 psi (3)	Tensile Strength × 10^3 psi (3)	Elongation Uniform % (2), (3)	Elongation Total % (2), (3)	$\bar{r}$	Hardness, RB
1	Head	.075	53.0	7.5 – 8.5	15.8	46.2	26.2	45.6	1.73	40.6
	Tail	.085	46.5	7.5 – 8.5	15.9	45.4	28.7	46.5	1.65	43.5
2	Hd	.068	57.5	7.5 – 8.5	16.5	47.7	25.5	45.4	1.80	40.1
	Tl	.086	45.8	7.5 – 8.5	16.1	45.2	28.6	47.1	1.59	39.0
3	Hd	.061	62.0	8.5 – 9.5	17.4	48.0	25.1	45.3	1.96	44.3
	Tl	.068	57.5	8.0 – 8.5	17.5	48.1	24.3	44.8	1.82	47.4
4	Hd	.065	59.5	8.0 – 8.5	16.6	47.7	25.3	44.0	1.91	40.2
	Tl	.073	54.5	8.0 – 8.5	17.4	48.2	24.4	45.9	1.79	44.2
5	Hd	.046	54.0	8.5 – 9.0	16.2	47.4	25.2	45.4	1.80	39.0
	Tl	.0355	64.5	8.5 – 9.0	16.8	47.7	25.6	43.1	1.95	43.0
6	Hd	.035	65.0	8.5 – 9.0	16.2	47.5	25.1	42.7	1.86	44.0
	Tl	0.37	63.0	8.5 – 9.0	24.8	43.1	1.97	42.0		

(1) Coils 1 through 4 tandem rolled fromm 0.170 inch Hot Rolled Strip. Coils 5 and 6 tandem rolled from 0.100 inch Hot Rolled Strip
(2) Measured in a 2" gauge length.
(3) Average of 6 samples (2 longitudinal, 2 diagonal and 2 transverse).

TABLE V

MECHANICAL PROPERTIES AFTER TEMPER ROLLING

Coil No.	Test Position	Thickness, Inches	0.2% Proof Stress × 10^3 psi. (2)	Tensile Strength × 10^3 psi. (2)	Elongation, B Uniform (1), (2) %	Elongation, Total (1), (2) %	$\bar{r}$	Total Cold Reduction %
1	Head	.056	24.1	48.0	24.8	43.7	1.89	67.0
	Tail	.059	29.3	47.6	25.0	44.2	1.90	65.2
2	Hd	.058	25.3	48.8	25.0	44.3	1.92	65.8
	Tl	.059	24.1	48.8	24.7	45.4	1.98	65.8
3	Hd	.060	26.2	49.2	24.4	45.0	1.98	64.8
	Tl	.057	26.4	48.5	23.9	44.5	2.03	66.5
4	Hd	.057	24.5	47.8	25.0	44.0	1.89	66.5
	Tl	.058	23.7	47.6	25.0	44.0	1.93	65.8
5	Hd	.040	28.0	47.2	24.6	43.6	1.82	60.0
	Tl	.035	25.8	47.4	24.7	42.8	1.89	65.0
6	Hd	.035	27.2	46.2	24.8	42.3	1.83	65.0
	Tl	.035	25.1	46.3	24.7	43.3	1.83	65.0

(1) Measured in a 2" gauge length.
(2) Average of 6 samples (2 longitudinal, 2 diagonal and 2 transverse).

What is claimed is:

1. A method for producing a finished steel strip with improved deep drawing properties, said method comprising the steps of:

providing a solidified killed steel consisting essentially of 0.04 –0.06 wt. percent carbon, 0.02–0.50 wt. percent manganese, less than 0.015 wt. percent nitrogen, titanium in an amount by weight at least six times the combined carbon and nitrogen content, and a balance consisting essentially of iron;

hot rolling said steel into hot rolled strip, with a hot roll finishing temperature greater than 1,645°F.;

cold rolling said hot rolled strip into cold rolled strip with a cold reduction of at least 60 percent;

annealing said cold rolled strip, at a temperature exceeding 1,285°F. and below the temperature at which austenite begins to form in said steel, without decarburizing, for a time sufficient to completely recrystallize the cold rolled strip and produce a crystallographic orientation in which there is a relatively high incidence, in the plane of the strip, of cube on corner crystal planes and a relatively low incidence, in the plane of the strip, of cube on face crystal planes;

said strip having a grain size, after annealing, at least as fine as 8.0 and a carbon content, after annealing, essentially the same as the carbon content before annealing;

and temper rolling after annealing;

said finished steel strip having an average plastic strain ratio ($\bar{r}$) of at least 1.9 and a strength, expressed as 0.2 percent proof stress, in the range 15,000–25,000 psi.

2. A method as recited in claim **1** and comprising:

coiling said hot rolled strip at the conclusion of said hot rolling step, with a strip temperature, at coiling, of less than 1,350°F.

3. A method as recited in claim **1** wherein said steel is aluminum killed and consists essentially of, in wt. percent:

0.04 – 0.06	carbon
0.29 – 0.35	manganese
0.003 – 0.007	nitrogen
0.30 – 0.65	titanium
0.026 – 0.040	aluminum

and a balance consisting essentially of iron.

4. A method as recited in claim **1** wherein said steel is hot rolled to produce hot rolled strip having a random crystallographic orientation.

5. A method as recited in claim **1** wherein said hot roll finishing temperature is in the range 1,645°F. – **1,710**°F.

6. A method as recited in claim **1** wherein said annealing step is a continuous anneal.

7. A method as recited in claim **1** wherein said temper rolling is in the range ¼–½ percent.

8. A method as recited in claim **1** wherein said steel is produced without vacuum degassing.

9. A method as recited in claim **1** wherein the total cold reduction to which said cold rolled strip is subjected is at least 65 percent.

10. A method as recited in claim **1** wherein said cold rolled strip is coiled and then box annealed for at least 20 hours.

11. A method as recited in claim **10** wherein said cold rolled strip is box annealed at a temperature in the range 1,320°F. – **1,350**°F. for a time in the range 25–30 hours.

12. A method as recited in claim **1** wherein said cold rolled strip is open coil annealed, with an inert atmosphere, at a temperature in the range 1,500°F. – **1,640**°F. for at least 5 hours.

13. A method as recited in claim **12** wherein said cold rolled strip is open coil annealed at a temperature in the range 1,590°F. – **1,620**°F. for a time up to 30 hours.

14. Cold rolled steel strip having deep drawing properties, said strip being composed of killed steel consisting essentially of, in wt. percent:

0.04 – 0.06 carbon,
0.02 – 0.50 manganese,
less than 0.015 nitrogen,
titanium in an amount at least six times the combined carbon and nitrogen content,
and a balance consisting essentially of iron;
said cold rolled steel strip having an average plastic strain ratio ($\bar{r}$) of about 1.9 or more, strength, expressed as 0.2 proof stress, in the range 15,000–25,000 psi, and a grain size of at least 8.0.

15. Cold rolled steel strip as recited in claim **14** and having a steel composition consisting essentially of, in wt. percent:

0.04 – 0.06 carbon,
0.29 – 0.35 manganese,
0.003 – 0.007 nitrogen,
0.03 – 0.65 titanium,
0.026 – 0.040 aluminum,
and a balance consisting essentially of iron.

16. Cold rolled steel strip as recited in claim **14** and having the following physical properties:

ductility, expressed as total elongation in a two inch gage length, of at least 35 percent.

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