United States Patent Office 3,513,036 Patented May 19, 1970

3,513,036

PROCESS FOR PRODUCING COILED, HOT-ROLLED, PICKLED STEEL STRIP

William H. McFarland, Hobart, and Henry M. Tietz, Gary, Ind., assignors to Inland Steel Company, Chicago, Ill., a corporation of Delaware

No Drawing. Filed May 2, 1967, Ser. No. 635,371
Int. Cl. C21f
U.S. Cl. 148—12 14 Claims

ABSTRACT OF THE DISCLOSURE

Coiled, hot-rolled, pickled steel strip containing 0.02–0.25 wt. percent carbon and 0.04–0.60 wt. percent manganese. Surface and interior grain size no greater than 5 ASTM. Hardness no greater than 55 Rockwell B. Drawable without orange peel. Thickness between 0.060 and 0.25 inch, all widths.

Process includes heating slab above A_3, hot-rolling, lubricating hot-rolled strip and finishing at no greater than 1450° F., coiling at no greater than 950° F., cooling, uncoiling, pickling without avoiding cold-working, abrading to remove scale, recoiling, annealing without avoiding recrystallization, temper rolling before or after anneal.

BACKGROUND OF THE INVENTION

The present invention relates generally to hot-rolled, pickled steel strip, in coiled form, and more particularly to a soft, ductile, readily drawable, hot-rolled, pickled steel strip in coiled form, and to a process for producing this product.

As used herein, the term "strip" refers to flat steel having a thickness between 0.060 and 0.25 inch, in all widths.

Hot-rolled, pickled strip having the desired softness, ductility and drawability has heretofore been available in relatively short, separate, discrete pieces. More recently, there has been a demand for hot-rolled, pickled strip in coil form, for convenience in materials handling and in fabricating the ultimate product. In the manufacture of hot-rolled, pickled strip in coil form, problems arise, in connection with producing the desired softness, ductility and drawability, which do not arise when this strip is provided as relatively short, separate, discrete pieces. These problems can best be understood from the following description of a conventional process for producing hot-rolled, pickled strip in coil form.

Steel slabs to be hot-rolled into strip are conventionally heated to an elevated temperature above the A_3 for the steel (e.g., around 2300° F.) and subjected to hot-rolling. The strip undergoing rolling arrives at the finishing train of rolls (which imparts the desired final thickness to the strip) at a conventional finishing temperature of 1950–2100° F. After the finishing train, the strip moves on rollers along a table upon which the strip is cooled by water sprays following which the strip is coiled at a conventional strip-coiling temperature of 1100–1250° F. The coils of hot-rolled strip are then cooled to room temperature. Thereafter, the hot-rolled strip is uncoiled and run through a pickling bath of acid to remove scale from the surface of the steel. Following pickling, the strip is recoiled. The steps of uncoiling, pickling and recoiling are continuous.

Unless precautions are taken, a strip will undergo cold-working during the continuous steps of uncoiling, pickling and recoiling; and it is not uncommon for the strip to undergo 3% cold deformation during these steps.

As rolled, the steel strip is not ductile enough to be drawn, and requires annealing to improve softness and drawability. A steel strip which was cold-worked during the pickling operation will soften during annealing, but the grain size of the steel will become relatively large (e.g., 4 or larger on the ASTM scale). This is undesirable because, in a steel undergoing drawing, relatively large grains product undesirable surface imperfections which resemble orange peel.

Grain coarsening can be prevented by annealing at a relatively low temperature (e.g., 1100–1150° F.), but the resulting product is less ductile than if annealed at a higher temperature.

Conventional processes, for producing hot-rolled strip in coiled form, took precautions to minimze cold-working before annealing. Temper-rolling the strip before annealing, was avoided; and the use of rollers, around which the strip could be run through the pickling bath, was minimized. Abrading of the steel strip in connection with pickling (e.g., by passing the strip through pinch rolls or by striking the strip), to remove scale, was avoided.

In addition to minimizing cold-working of the strip during the pickling operation, the recoiled strip was annealed at a relatively low temperature to minimize recrystallization of such grains as were cold-worked. In the conventional processes, recrystallization caused coarse grains. The problems of recrystallization and coarse grains were particularly severe at the surface of the strip.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is produced a hot-rolled strip, in coiled form, having the desired softness and ductility, a relatively small grain size and improved drawability. No precautions are taken to avoid cold-working during pickling or recoiling, no precautions are taken to prevent recrystallization during annealing; and annealing may be conducted at relatively high temperatures.

Essentially, the process for producing the product of the present invention involves finishing hot-rolling at a relatively low temperature (e.g., 1450° F. or lower) and coiling at a relatively low temperature (e.g., 950° F. or lower).

Because cold-working during the pickling operation need not be avoided, the strip may be abraded in connection with pickling, to facilitate the removal of scale from the surface of the strip; and the strip may be temper-rolled before annealing.

Because the strip may be annealed at higher temperatures, without worrying about the effects of recrystallization, shorter annealing times may be employed, thus increasing the utilization of annealing equipment.

A hot-rolled strip produced by the process of the present invention is softer and has a smaller grain size, without coarse grains on the surface, than the strip produced in accordance with conventional processes. Accordingly,

the strip of the present invention may be readily drawn, and the resulting drawn product is devoid of surface defects such as "orange peel."

Other features and advantages are inherent in the product and process claimed and disclosed or will become apparent to those skilled in the art from the following detailed description.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A hot-rolled steel strip in coil form, in accordance with the present invention, has a composition consisting essentially of 0.02–0.25 wt. percent carbon, 0.04–0.60 wt. percent manganese, phosphorus and sulphur in residual amounts and the balance consisting essentially of iron. Preferably, sufficient manganese is included to prevent hot shortness. A preferable embodiment has between 0.05–0.10 wt. percent carbon and 0.20–0.40 wt. percent manganese. The steel may be rolled from rimmed, semi-killed, killed or mechanically capped ingots. If the ingot has been killed, aluminum and/or silicon are present in amounts up to 0.08 wt. percent aluminum and 0.35 wt. percent silicon.

A steel slab, having a composition described above, is heated to an elevated temperature, above the A_3 for the steel, e.g., to 2300° F., and subjected to hot-rolling. The slab is substantially reduced in thickness before it is subjected to the finishing train of rolls in the hot-rolling mill. The temperature of the strip is controlled, as it leaves the finishing train, to a temperature no greater than 1450° F. In a more preferable embodiment, the finishing temperature for the hot-rolling operation is controlled within the range 1300–1400° F.

The finishing temperature may be controlled by reducing the initial temperature of hot-rolling; or by holding the strip, before finishing, on a run-out table until the temperature of the strip drops to the desired level.

Because the friction between the strip and the rolling mill increases as the temperature of the strip drops, it may be desirable to apply lubricant to the strip before it enters the finishing train of the hot-rolling mill, to decrease the friction and decrease the work load on the mill.

Between the finishing train and the coiling reel, the strip is cooled by water sprays until the temperature of the strip, before coiling, is reduced to 950° F. or less. In a more preferable embodiment, the temperature is reduced to 650–900° F.

The temperature at which the strip passes through the finishing train of the hot-rolling mill is a temperature at which ferrite grains are cold-worked. The temperature at which the strip is coiled is a temperature below the recrystallization temperature for cold-worked ferrite. Between the hot-roll finishing step and the coiling step, the strip is cooled at a rate which prevents significant recrystallization of ferrite.

Following coiling, the hot-rolled strip of steel, in coiled form, is allowed to cool (e.g. to room temperature) before pickling. After cooling, the strip is uncoiled and run continuously through a pickling bath, and then recoiled. During pickling, no precautions are taken to prevent cold-working. Typically, during the uncoiling, pickling and recoiling steps, the strip may undergo 3 percent elongation or cold-working and at least 1 percent cold-working.

The uncoiled strip may be abraded prior to entering the pickling bath and while in the bath, to facilitate removal of scale from the strip. Abrading includes passing the strip through pinch rolls or striking the strip. Moreover, because the hot roll finishing temperature is relatively low, the scale is more readily removable from the strip than would be the case if the finishing temperature was relatively high.

After the strip has been recoiled, it is annealed utilizing, for example, conventional box-annealing apparatus. If desired, the strip may be temper-rolled, before annealing, which gives an improved surface with maximum softness compared to a strip temper-rolled after annealing.

Annealing may be conducted at a temperature of 1000–1400° F. for a time of 1–48 hours. The lower the temperature, the longer the annealing time and vice versa. In a more preferable embodiment, the annealing temperature is 1100–1300° F. and the time is 6–24 hours.

A hot-rolled, pickled strip, in coiled form, in accordance with the present invention, subjected to an annealing operation as described above, has a final grain size no larger than 5 on the ASTM scale; and this is true of both the interior and the surface grains. The same strip has a final Rockwell B hardness no greater than 55. A preferable embodiment of hot-rolled, pickled strip, in coiled form, in accordance with the present invention, has a grain size between 6 and 8 on the ASTM scale and has a Rockwell B hardness no greater than 50.

Following annealing, the strip may be subjected to a temper-roll, which gives an improved surface to the strip and suppresses the yield point in the steel, thereby eliminating what are known as stretcher strains (surface defects manifest by unsightly surface lines). Temper-rolling after annealing produces a product which is slightly harder than one which has been temper-rolled before annealing.

The following tables reflect the properties of hot-rolled, pickled steel strip, in coiled form, in accordance with the present invention, compared to essentially the same steel prepared in accordance with conventional processes. In each table, a coil identified as A undergoes conventional processing while coils identified as B, C and D undergo processing in accordance with the present invention.

Table I gives the composition and dimensions of the respective coils.

Table II reflects the mechanical properties of the respective coils after pickling but before annealing.

Table III reflects the hardness and grain size of the strip in the respective coils, as a function of annealing temperature, for an annealing time of 6 hours.

Table IV reflects the hardness and grain size of the strip in the respective coils, as a function of annealing temperature, for an annealing time of 10 hours.

Table V reflects the hardness and grain size of the strip in the respective coils, as a function of annealing temperature, for an annealing time of 14 hours.

Table VI reflects the hardness and grain size of the strip in the respective coils, as a function of annealing temperature, for an annealing time of 24 hours.

Table VII reflects the mechanical properties of the strip in the respective coils after a given anneal.

TABLE I.—CHEMICAL ANALYSES AND DIMENSIONS

	C, wt. percent	Mn, wt. percent	P, wt. percent	S, wt. percent	Thickness, inches	Width, inches
Coil A:						
Head	.06	.38	.008	.024	.114	35
Tail	.05	.38	.008	.017		
Coil B:						
Head	.04	.38	.009	.017	.115	35
Tail	.04	.38	.008	.012		
Coil C:						
Head	.05	.39	.008	.025	.115	35
Tail	.06	.39	.009	.027		
Coil D:						
Head	.06	.40	.009	.027	.122	35
Tail	.06	.38	.008	.023		

TABLE II.—MECHANICAL PROPERTIES AFTER PICKLING AND WITHOUT ANNEALING

Coil and hot mill practice	Hardness Rockwell Rb-average		Yield strength, p.s.i.[2]		Tensile strength, p.s.i.[2]		Percent elongation in 2" [2]		Percent yield elongation [2]		Average Olsen, inches [2]
	As hot rolled and pickled	Aged 35 days	Long'l.	Transverse	Long'l.	Transverse	Long l.	Transverse	Long'l.	Transverse	
A:											
Finish, 1,560° F., Head	59	60	34,800	39,900	46,200	47,600	29	36	0	2.0	----------
Coil, 1,140° F., (Standard Practice) Tail	60	62	35,500	44,500	48,900	50,300	39	37	0.1	1.6	.573
B:											
Finish, 1,460° F., Head	61	64	38,700	45,600	51,400	50,300	36	34	0.5	2.7	----------
Coil, 850° F., Tail	69	64	39,000	42,500	50,900	52,600	82	31	0	0.6	.544
C:											
Finish, 1,410° F., Head	68	61	34,300	45,100	47,000	54,300	33	[1] 17	0	1.8	----------
Coil, 785° F., Tail	72	68	45,300	50,800	56,100	59,100	[1] 22	[1] 13	0	0.5	.533
D:											
Finish, 1,340 ° F., Head	78	80	52,100	60,800	58,600	68,600	18	18	0	0.7	----------
Coil, 660° F., Tail	83	81	54,600	62,400	60,400	69,300	[1] 11	12	0	0	.498

[1] Fracture outside gauge lines.
[2] Aged 35 days.

TABLE III.—HARDNESS AND GRAIN SIZE VERSUS ANNEALING TEMPERATURE ANNEALING TIME 6 HOURS PACK COOLED, TAIL TESTS

	Hardness after hot rolling, Rb	Annealed 1,150° F.		Annealed 1,225° F.		Annealed 1,300° F.		Annealed 1,350° F.	
		Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM. grain size
Coil:									
A	60	59	7.9	54	[1] 7.4	47	(1)	45	(2)
B	69	48	6.6	42	5.3	39	6.6	52	5.0
C	72	55	7.6	47	6.4	42	6.2	46	5.6
D	83	48	(3)	48	5.4	38	5.7	44	6.9

[1] Coarse surface grain.
[2] Coarse grain through sample thickness.
[3] Material showed elongated cold-worked grain.

TABLE IV.—HARDNESS AND GRAIN SIZE VERSUS ANNEALING TEMPERATURE ANNEALING TIME 10 HOURS PACK COOLED, TAIL TESTS

Coil	Hardness after hot rolling, Rb	Annealed 1,150° F.		Annealed 1,225° F.		Annealed 1,350° F.	
		Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size
A, Tail	60	54	[1] 7.7	53	[1] 7.7	47	(2)
B, Tail	69	43	6.0	42	5.8	41	6.1
C, Tail	72	47	6.9	45	6.7	46	6.3
D, Tail	83	42	5.6	41	6.1	40	5.2

[1] Coarse surface grain.
[2] Coarse grain through sample thickness.

TABLE V.—HARDNESS AND GRAIN SIZE VERSUS ANNEALING TEMPERATURE ANNEALING TIME 14 HOURS PACK COOLED, TAIL TESTS

	Hardness after hot rolling, Rb	Annealed 1,150° F.		Annealed 1,225° F.		Annealed 1,300° F.		Annealed 1,350° F.	
		Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM grain size
Coil:									
A, Tail	60	50	(1)	48	(1)	39	(2)	48	(2)
B, Tail	69	41	6.3	45	6.3	44	5.3	43	6.3
C, Tail	72	42	6.0	43	6.5	45	5.8	46	6.3
D, Tail	83	37	4.7	40	6.2	43	5.0	35	5.6

[1] Coarse surface grain.
[2] Coarse grain through sample thickness.

TABLE VI.—HARDNESS AND GRAIN SIZE VERSUS ANNEALING TEMPERATURE ANNEALING TIME 24 HOURS PACK COOLED, TAIL TESTS

	Hardness after hot rolling, Rb	Annealed 1,150° F.		Annealed 1,225° F.		Annealed 1,300° F.		Annealed 1,350° F.	
		Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM, grain size	Hardness, Rb	ASTM. grain size
Coil:									
A	60	47	[1] 7.7	46	(1)	29	(2)	15	(2)
B	69	44	5.8	39	5.3	41	4.9	31	6.9
C	72	43	7.3	46	6.7	46	5.6	35	5.8
D	83	40	5.8	42	5.1	41	4.8	27	5.2

[1] Coarse surface grain.
[2] Coarse grain through sample thickness.

TABLE VII.—MECHANICAL PROPERTIES AFTER ANNEALING

	Process temperatures, ° F.		Annealing cycle [1]		Rockwell hardness, Rb	Average Olsen, inches	Grain size
	Finish	Coil	Temp., ° F.	Time, (hrs.)			
Coil:							
A	1,560	1,140	1,150	10	57	.586	8.8
B	1,460	850	1,225	10	44	.588	6.5
C	1,410	785	1,225	10	46	.576	6.7
D	1,340	660	1,225	10	43	.600	6.0

	Yield Strength, p.s.i.		Tensile Strength, p.s.i.		Percent Elongation in 2 inches		Yield Point Elongation	
Coil	Long'l.	Transverse	Long'l.	Transverse	Long'l.	Transverse	Long'l.	Transverse
A	31,300	30,300	42,800	43,800	38	[2] 31	3.6	3.5
B	34,700	36,300	42,300	44,600	44	24	5.5	5.0
C	31,100	31,300	41,800	44,200	42	[2] 36	3.5	2.5
D	28,200	32,350	39,500	43,800	44	36	3.4	3.0

[1] Furnace cooled.
[2] Fractured outside gauge marks.

The foregoing tables illustrate the improvement in softness and decrease in grain size resulting from a process in accordance with the present invention, compared to conventional processing. Improved softness and decreased grain size result in improved drawing properties for the coil of hot-rolled, pickled strip.

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.

We claim:

1. In a proces for producing a coil of hot-rolled strip steel, said process comprising the steps of, in sequence, hot-rolling a strip, cooling said strip, coiling the strip, cooling the coil, uncoiling, pickling, recoiling and annealing, the features of:

finishing said hot-rolling step at an elevated temperature no greater than 1450° F.;

cooling said strip, between said finishing of said hot-rolling step and said coiling step, at a cooling rate sufficiently rapid to prevent substantial recrystallization of ferrite;

and performing said coiling step at a temperature no greater than 950° F. and which is below the recrystallization temperature for cold-worked ferrite;

whereby there is produced a coil of soft, ductile strip steel having a relatively fine grain size both in the interior and at the surface of the steel.

2. In a process as recited in claim **1** wherein:

said annealing step comprises heating said steel at a temperature and for a time which gives a Rockwell B hardness no greater than 55 with a grain size no larger than 5 on the ASTM scale.

3. In a process as recited in claim **2** wherein:

said annealing step is performed at a temperature between 1000° F. and 1400° F. for a time between one hour and 48 hours.

4. In a process as recited in claim **2** wherein:

said annealing step is performed at a temperature greater than 1150° F. and up to 1300° F.

5. In a process as recited in claim **2** wherein:

said steel, after said annealing step, has a Rockwell B hardness no greater than 50, and a grain size between 6 and 8 on the ASTM scale.

6. In a process as recited in claim **1** wherein:

said hot-rolling step is finished at a temperature between 1300° F. and 1400° F.

7. In a process as recited in claim **1** wherein:

said coiling step is performed at a temperature between 650° F. and 900° F.

8. In a process as recited in claim **1** wherein:

said hot-rolling step is finished at a temperature between 1300° F. and 1400° F.;

and said coiling step is performed at a temperature between 650° F. and 900° F.

9. In a process as recited in claim **1** wherein said steel has a composition consisting essentially of:

0.02–0.25 wt. percent carbon;

0.04–0.60 wt. percent manganese;

and the balance consisting essentially of iron.

10. In a process as recited in claim **1** wherein:

said steel is subjected to 1%–3% cold working following said hot-rolling step.

11. In a process as recited in claim **1** wherein said steel is temper-rolled after pickling and before annealing.

12. In a process as recited in claim **1** wherein said steel undergoes an abrading step in connection with pickling and before annealing, to remove scale.

13. In a process as recited in claim **1** wherein:

said annealing step is performed without avoiding recrystallization.

14. In a process as recited in claim **1** wherein:

the steps following said hot-rolling step and preceding said annealing step are performed without minimizing cold working.

References Cited

UNITED STATES PATENTS

2,597,979	5/1952	Darmara	148—12
2,606,848	8/1952	Farling et al.	148—12
3,245,844	4/1966	Weber	148—12
3,248,270	4/1966	Laidman et al.	148—12
3,320,099	5/1967	Weber	148—12 X

FOREIGN PATENTS

762,127	11/1956	Great Britain.
773,071	4/1957	Great Britain.

OTHER REFERENCES

Making, Shaping and Treating of Steel, 1957, pp. 593–94.

L. DEWAYNE RUTLEDGE, Primary Examiner

G. K. WHITE, Assistant Examiner

U.S. Cl. X.R.

148—12.4, 36

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,513,036 Dated May 19, 1970

Inventor(s) William H. McFarland and Henry M. Tietz

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 14, "product" should be --produce--.

Column 6, Table 2, 7th column of numbers, 4 rows down, "82" should be --28--.

Column 7, Table 7, last column of numbers (Coil B), "5.0" should be --4.0--.

SIGNED AND
SEALED
SEP 15 1970

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents