**United States Patent** [11] **3,607,456**

[72] Inventor **James L. Forand, Jr.**
**Bethlehem, Pa.**
[21] Appl. No. **816,239**
[22] Filed **Apr. 15, 1969**
[45] Patented **Sept. 21, 1971**
[73] Assignee **Bethlehem Steel Corporation**

[54] **DEEP DRAWING STEEL AND METHOD OF MANUFACTURE**
**5 Claims, 2 Drawing Figs.**

[52] **U.S. Cl.** .......... **148/12,** 148/12.1, 148/36
[51] **Int. Cl.** .......... **C21d 9/48**
[50] **Field of Search** .......... 148/12, 12.1

[56] **References Cited**

UNITED STATES PATENTS

3,522,110 7/1970 Shimizu et al. .......... 148/12

*Primary Examiner*—L. Dewayne Rutledge
*Assistant Examiner*—W. W. Stallard
*Attorney*—Joseph J. O'Keefe

**ABSTRACT:** A ferrous metal sheet having an $\bar{r}$ in the range of 2.5 to 3.3 and an ASTM grain size of 6.0 to 9.0 is produced by hot rolling to intermediate gauge strip ferrous metal containing 0.15 to 0.30 wt. percent titanium and small amounts of oxygen, carbon and nitrogen, the weight ratio of the titanium to the sum of the carbon and nitrogen being a minimum of 7:1. The steel is finished hot, coiled cold, cold reduced and batch annealed at temperatures approaching the alpha-gamma transformation temperature.

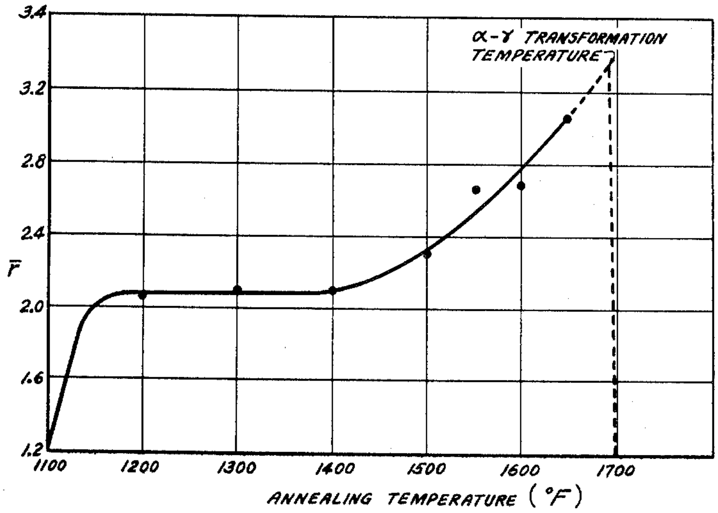
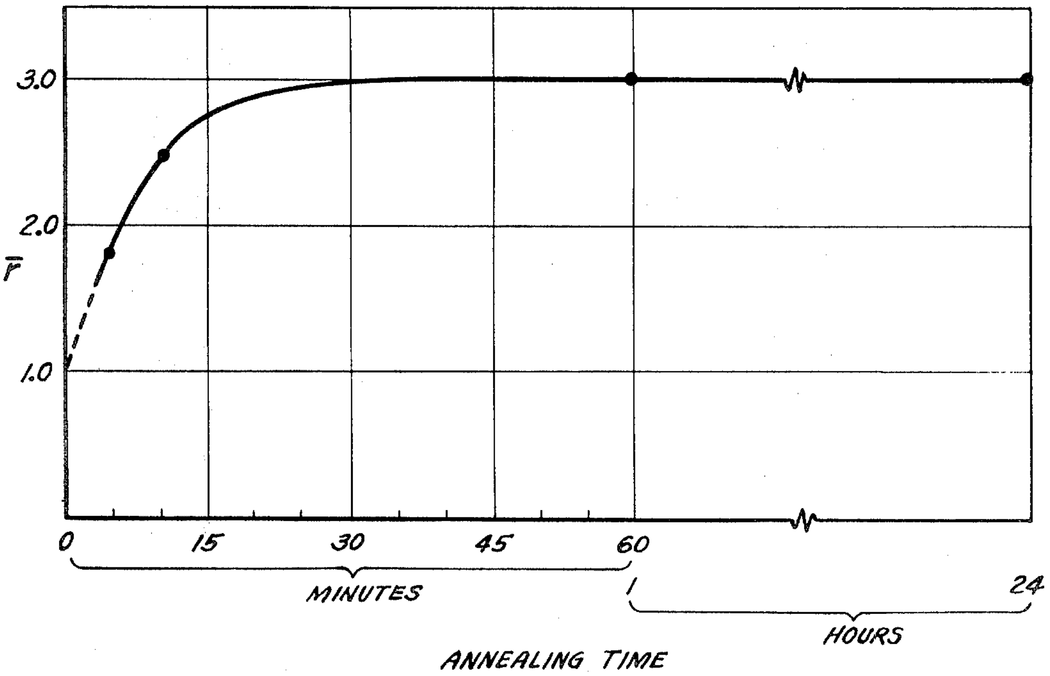


FIG. 1



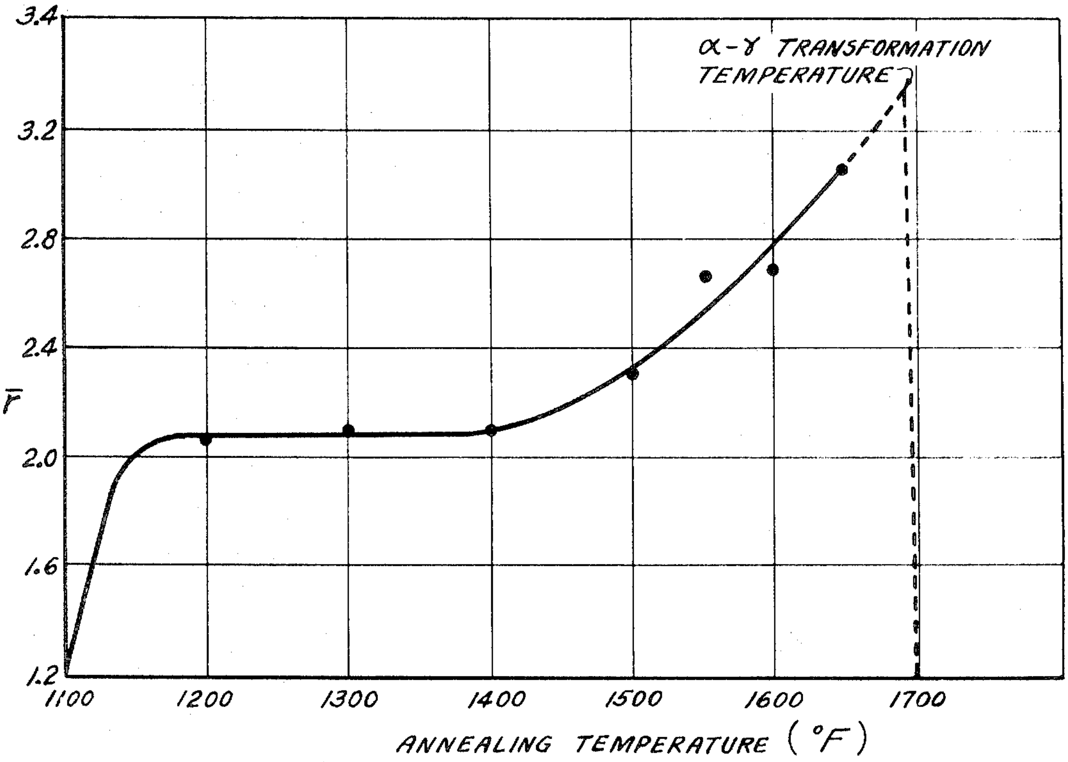


FIG. 2

INVENTOR
James L. Forand Jr.

# DEEP DRAWING STEEL AND METHOD OF MANUFACTURE

## BACKGROUND OF THE INVENTION

This invention relates to a ferrous metal sheet having very good deep drawing properties, and more particularly to a ferrous metal sheet characterized by the combination of an $\bar{r}$ of at least 2.5 and an ASTM grain size of 6.0 to 9.0. It further relates to a method of manufacturing such a sheet.

Ferrous metal sheets are widely used in the manufacture of products which are formed into intricate shapes in presses or the like. During the forming of said sheets, the metal is stretched, drawn or, as is usually the case, is deformed by a combination of both stretching and drawing.

It has been found in recent years that the drawability of a metal sheet is dependent upon the degree of normal anisotropy of the metal crystals in the sheet. Best drawability occurs when the crystals are so oriented that the strength in the thickness of the sheet greatly exceeds the strength in the plane of the sheet.

The degree of normal anisotropy is determined by calculating the ratio of strains in the width and thickness directions in a simple tensile test. This ratio is called the strain ratio, $r$, and is measured in the rolling direction, at 45° to the rolling direction and transverse to the rolling direction to provide data for calculating the average strain ratio, $r$, of the metal sheet.

It is known that ferrous metal sheets having $r$'s from about 2.15 to 2.47 can be obtained by treating metal of a particular composition in a particular fashion. According to the prior art, the metal must contain less than 0.020 wt. percent carbon, less than 0.015 wt. percent oxygen, from 0.02 to 0.5 wt. percent titanium (with the exception of titanium in the form of titanium oxides), less than 0.45 wt. percent manganese, balance iron and impurities, the weight ratio of said titanium to the carbon being more than 4:1. The metal is then hot rolled so as to finish hot, e.g. at 1,652° F., coiled cold, e.g. 1,022° F., cold rolled and continually annealed for about 5 minutes, preferably at about 1,328° F. to about 1,800° F.

In addition to being characterized by high $\bar{r}$'s, it is desirable for drawing quality ferrous metal sheets to have an ASTM grain size of from 6.0 to 9.0. While coarser grain sizes result in higher $\bar{r}$'s, the appearance of sheets having such a grain size is unsatisfactory for most purposes. It is desirable for drawing quality ferrous metal sheets to have a grain size no finer than ASTM 9.0, as the yield strength of the sheet increases as the grains thereof become finer. Preferably, an ASTM grain size of 6.5 to 8.5 is desired.

It is an object of this invention to provide a deep drawing ferrous metal sheet having an $\bar{r}$ of at least 2.5 and an ASTM grain size of from 6.0 to 9.0. It is a further object to provide a method of manufacturing such a sheet.

## SUMMARY OF THE INVENTION

I have discovered that the foregoing objects can be attained by hot rolling to intermediate gauge strip ferrous consisting essentially of carbon 0.020 wt. percent max., manganese 0.60 wt. percent max., titanium 0.15 to 0.30 wt. percent, nitrogen 0.010 wt. percent max., oxygen0.015 wt. percent max., balance essentially iron, the weight ratio of titanium to the sum of the carbon and the nitrogen being a minimum of 7:1. The hot rolling is finished above 1,550° F., and the strip is rapidly cooled to a temperature within the range of 900° to 1,200° F., and coiled. The strip is then cooled to room temperature and cold reduced by 50 to 85 percent. Subsequently, the strip is batch annealed within the range of 1,550° F., to the alpha-gamma transformation temperature for a time sufficient to develop an $\bar{r}$ of at least 2.5 and an ASTM grain size of 6.0 to 9.0.

This process differs from the above-described prior art primarily in the following three respects:

1. The weight ratio of the titanium to the carbon plus nitrogen, rather than to the carbon alone, must be a certain minimum, this minimum being 7:1.
2. The ferrous metal strip must be batch annealed rather than continuously annealed.
3. During the anneal, the strip must be held at a temperature within the range of 1,550° F. to the alpha-gamma transformation temperature, rather than between 1,382° F. and 1,800° F.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing $\bar{r}$ as a function of annealing time.

FIG. 2 is a graph showing $\bar{r}$ as a function of annealing temperature.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Broadly, the ferrous metal sheets of the invention consist essentially of:

| | Wt. % |
|---|---|
| carbon | 0.020 max. |
| manganese | 0.60 max. |
| titanium | 0.15 to 0.30 |
| nitrogen | 0.010 max. |
| oxygen | 0.015 max. |

balance essentially iron, the weight ratio of the titanium to the sum of the carbon and the nitrogen being a minimum of 7:1.

By "balance essentially iron," I do not wish to exclude residual impurities and incidental elements which may be present in amounts which do not substantially detract from the novel properties of the ferrous metal sheets of the invention. For example, the metal usually contains up to about 0.01 wt. percent phosphorus and up to about 0.03 wt. percent sulfur as impurities. In addition, small amounts of silicon or aluminum may be added to the melt to control the oxygen content thereof.

The $\bar{r}$ of a ferrous metal has been found to decrease with increasing carbon. In addition, the yield strength of a ferrous metal sheet increases with increasing carbon. Since a high $r$ and a low yield strength are desirable for good formability, carbon should be as low as is feasible, and should in no event be higher than 0.020 wt. percent. Preferably, carbon should be no higher than **0.010** wt. percent.

Manganese is not essential to the ferrous metal sheets of the invention, insofar as the forming properties thereof are concerned. However, from an economic viewpoint it is desirable to add manganese to the ferrous metal melt prior to the addition of titanium thereto. The manganese combines with the sulfur as well as certain other impurities in the melt which would otherwise be available to combine with the titanium which is subsequently added. No more than 0.60 wt. percent manganese is normally added, and the preferred manganese content is 0.20 to 0.50 wt. percent.

A minimum of 0.15 wt. percent titanium is essential for $\bar{r}$'s of at least 2.5, provided that the weight ratio of the titanium to the sum of the carbon and the nitrogen is equal to at least 7:1. More than 0.30 wt. percent titanium produces insufficient improvement in properties to justify the increased costs. The preferred range of titanium is 0.15 to 0.20 wt. percent.

Nitrogen and oxygen have been found to have an adverse effect on $r$'s, and therefore should be kept as low as is feasible. The nitrogen and the oxygen should in no event be higher than 0.010 and 0.015 wt. percent respectively, and preferably should be no higher than 0.005 and 0.010 wt. percent, respectively.

It has been found that, in order to get high $\bar{r}$'s, the weight ratio of the titanium to the sum of the carbon and the nitrogen must be at least 7:1. Preferably, said ratio is about 12:1.

The ferrous metal sheets of the invention are produced as follows. A melt of the proper composition is prepared in the usual manner, vacuum deoxidized to lower the carbon and oxygen contents to the desired level, and poured into ingot molds provided with hot tops.

The ingots are then slabbed and hot rolled into intermediate gauge strip. In order for the final product to have a high $\bar{r}$, the hot rolling must be finished above 1,500° F., e.g. in the range from 1,550° to 1,700° F., rapidly cooled, e.g., by water sprays, to a temperature within the range of 900° to 1,200° F., coiled at said temperature, and allowed to cool to room temperature.

The hot-rolled strip is then pickled in the usual manner and may be slit to any desired width. Subsequently, said strip is cold reduced to final gauge. In order for the final product to have the highest $\bar{r}$'s, it is essential for said cold reduction to be in the range of 50 to 85 percent.

The cold-reduced strip is then annealed to develop *$\bar{r}$'s greater than* 2.5 therein. As is shown in FIGS. **1** and **2**, such $\bar{r}$'s can only be developed as a result of specific annealing times and temperatures. For example, FIG. **1** shows $\bar{r}$ as a function of annealing time for a series of ferrous metal samples, having compositions within the ranges of the metal of the invention, which were annealed at 1,600° to 1,650° F. It can be concluded from FIG. **1**, which is meant to be more qualitative than quantitative, that the crystallographic texture responsible for high $\bar{r}$'s begins to form in less than 5 minutes at annealing temperatures. Between 5 and 10 minutes $\bar{r}$'s continue to improve, but at a constantly decreasing rate. The maximum $r$ occurs somewhere between 10 minutes and 1 hour, after which time there is no additional improvement in $\bar{r}$. It can further be concluded from FIG. **1** that, in order to have an $\bar{r}$ approaching the maximum attainable value, ferrous metal strip must be held at annealing temperatures for at least 10 minutes and preferably for at least 1 hour. Continuous annealing of the strip is therefore precluded.

FIG. **2** is a graph qualitatively showing $\bar{r}$ as a function of annealing temperature. Each of the samples tested had a composition within the ranges of the ferrous metal of the invention and was held at the annealing temperature for 24 hours. As shown, the $\bar{r}$ initially increases rapidly from about 1,100° to 1,200° F. This initial increase is caused by the ferrous metal passing through the recrystallization temperature range, during which time a high degree of preferred crystallographic orientation occurs. The $\bar{r}$ levels off at about 2.1 to 1,200° F. and remains at this value up to about 1,400 F. From 1,400° F. to the alpha-gamma transformation temperature the $r$ gradually increases from 2.1 to about 3.1. Above said transformation temperature the crystallographic orientation becomes random, and the $\bar{r}$ rapidly decreases toward its initial value.

By batch annealing above about 1,550 ° F., $\bar{r}$'s of 2.5 and higher can be obtained. The ferrous metal strip should either be open coiled, or tight coiled with an inert powder such as magnesium oxide applied to at least surface thereof, to prevent adjacent laps of the coil from sticking together at such temperatures.

The following table shows the compositions of a number of samples of ferrous metal sheets for which $\bar{r}$'s were determined.

| Sample No. | C | Mn | Ti | N | O | Ti/C | Ti/C+N |
|---|---|---|---|---|---|---|---|
| A, wt. percent | .018 | .47 | .19 | .0073 | .0052 | 11:1 | 8:1 |
| B, wt. percent | .011 | .30 | .17 | .0034 | .0076 | 15:1 | 12:1 |
| C, wt. percent | .005 | .30 | .06 | .0045 | .0095 | 12:1 | 6:1 |

Samples A and B are illustrative of the invention, while Sample C is illustrative of the prior art.

The following table shows $\bar{r}$'s and ASTM grain sizes for samples A and B for annealing temperatures varying from 1,500° to 1,650° F. It also shows the $\bar{r}$ and ASTM grain size for sample C when annealed at 1,600° F. All samples were open coil annealed for 24 hours in 100 percent hydrogen.

| Sample No. | Annealing Temp. (° F.) | ASTM Grain Size | *r* |
|---|---|---|---|
| A | 1,500 | 8.2 | 2.7 |
| B1,550 | | 8.4 | 2.8 |
| A | 1,600 | 6.5 | 2.6 |
| B | 1,600 | 8.5 | 2.8 |
| C | 1,600 | 8.2 | 1.9 |
| A | 1,6500 | 6.0 | 2.8 |
| B | 1,650 | 6.0 | 3.1 |

The above table shows that the $\bar{r}$ of sample C was relatively low, as compared to the $\bar{r}$ of samples A and B, despite the fact that sample C had a Ti/C of 12:1, which is far in excess of the minimum specified in the prior art to be necessary for good $\bar{r}$'s. The Ti/C+N, however, is only 6:1 for sample C, this ratio being less than I have found to be the minimum for good $\bar{R}$'s. These data appear to confirm that the Ti/C+N, rather than Ti/C, is critical for high $\bar{r}$'s, and that the minimum Ti/C+N should be 7:1.

As a specific example of the invention, a heat of ferrous metal was prepared, vacuum deoxidized in an R–H vacuum unit, and cast into a plurality of 10-ton hot top ingot molds. The composition of the ferrous metal ingot of the instant example was:

| | Wt. percent |
|---|---|
| C | .011 |
| Mn | .29 |
| Ti | .19 |
| N | .0042 |
| O | .013 |
| Balance essentially iron. | |

The ingot was reduced in the usual manner into a slab 6¾ inches by 37 inches by slab length. The slab was then hot rolled into a coil 0.090 inches by 37 inches by coil length. In the hot mill, the hot finish rolling was started at 1,680° F. and completed at 1,600° F. After leaving the finishing stands, the strip was sprayed with cold water on the runout table to lower the temperature of the strip to 1,000° F. as it was being coiled. The strip was then permitted to cool to room temperature.

The hot-rolled strip was pickled in the usual manner, slit to a width of 36 inches, and cold reduced by 60 percent to a thickness of 0.0359 inches. Samples of the cold-reduced strip were then placed in an annealing furnace, adjacent samples being spaced apart to simulate open coil annealing. Said samples were then heated in a 100 percent hydrogen atmosphere, at a heating rate 400° F./hour, to a temperature of 1,650° F. The samples were held at 1,650° F. for 24 hours and then allowed to cool in the furnace. The resultant ferrous metal was found to have an ASTM grain size of 6.5 and an $\bar{r}$ of 3.1.

I claim:

**1**. A sheet of ferrous metal having an $\bar{r}$ of at least **2.5** and an ASTM grain size within the range of 6.0 to 9.0, said ferrous metal consisting essentially of carbon 0.020 wt. percent max., manganese 0.60 wt. percent max., titanium 0.15 to 0.30 wt. percent, nitrogen 0.010 wt. percent max., oxygen 0.015 wt. percent max., balance essentially iron, the weight ratio of the titanium to the sum of the carbon and the nitrogen being a minimum of 7:1.

**2**. An article as recited in claim **1**, in which said sheet has an ASTM grain size of 6.5 to 8.5, said ferrous metal consisting essentially of carbon 0.010 wt. percent max., manganese 0.20 to 0.50 wt. percent, titanium 0.15 to 0.20 wt. percent, nitrogen 0.005 wt. percent max., oxygen 0.010 wt. percent max., balance essentially iron, the weight ratio of the titanium to the sum of the carbon and the nitrogen being at least about 12:1.

**3**. A method of producing ferrous metal strip comprising:

a. hot rolling to intermediate gauge strip ferrous metal consisting essentially of carbon 0.020 wt. percent max., manganese 0.60 wt. percent max., titanium 0.15 to 0.30 wt. percent, nitrogen 0.010 wt. percent max., oxygen 0.015 wt. percent max., balance essentially iron, the weight ratio of the titanium to the sum of the carbon and the nitrogen being a minimum of 7:1,

b. finishing said hot rolling at a temperature above 1,550° F.,

c. rapidly cooling the hot-rolled strip to a temperature within the range of 900° F. to 1,200° F., coiling said strip at said temperature, and cooling said strip to room temperature,

d. cold reducing said strip by 50 to 85 percent, and

e. batch annealing said strip at a temperature within the range of 1,550° F. to the alpha-gamma transformation temperature for a time sufficient to develop an $\bar{r}$ of at least 2.5 and an ASTM grain size within the range of 6.0 to 9.0.

**4**. The method as recited in claim **3**, in which during said batch annealing said strip is held at said temperature within the range of 1,550° F. to the alpha-gamma transformation temperature for a minimum time of 1 hour.

**5**. The method as recited in claim **3**, in which said strip is open coiled during step (e).