A method for improving the deep drawing properties of low carbon rimmed steel sheets in which the sheets are cold rolled to at least 80 percent reduction in two stages with an interstage and a final anneal. The annealing steps are carefully selected, depending upon the carbon content of the steel, so that the deep drawing properties are maximized, as exemplified by the Rankford value or Normal Anisotropy and the Planar Anisotropy.
Fig. 1
Fig. 2a

Fig. 2b
Fig. 3a

Fig. 3b

[C] \( \cdot 0.05\% \)

[C] \( \cdot 0.10\% \)
METHOD OF MANUFACTURING STEEL PLATES FOR EXTRA DEEP DRAWING

The present invention relates to a method for manufacturing steel plates for extra deep drawing, and more particularly, it relates to a method for providing steel sheets for extra deep drawing at a relatively low cost but exceeding other methods in yield rate by treating low carbon rimmed steel with cold rollings and annealings in two stages to correspond with the C content of the steel.

Steel sheets to be used for press machines and tool housings, automobile bodies or other similar products by cold working must withstand tough press working. Various attempts and experiments have been carried out to obtain methods most suitable for producing such steel materials. However, it is well known in the art that the problems arising in the course of working to produce products of different shapes and sizes vary widely thus making it quite difficult to establish a uniform method to meet varying requirements. That is, it is a known fact that many and varying defects such as breakage caused by working which exceeds the limit of workability of the material, occurrence of warping or creases due to the non-uniformity in the stress-strain characteristics of the sheet surface or thickness, elastic deformation due to insufficient tensile strength and the like are often seen on this process.

Much effort to obviate these defects has been exerted; however, there is hardly any single method which is capable of improving all of the said defects properly as, although some of the conventional methods may be useful to a particular problem, they may not be effective for others.

Japanese Patent No. 12348/67 presents one method for obtaining low carbon steel sheets by cold rolling which is capable of enduring the tough press working for shaping automobile bodies and the like. The method of this publication utilizes aluminum killed steel as the base material, and with the addition of alloying element Ti, it is intended to produce steel sheets having good deep drawability for an aluminum killed steel. The crux of the invention is that particular case is that if Ti is added to the aluminum killed steel in sufficient quantity for the formation of Ti solid solution therein, said solid solution will assist the development of the face over the entire rolling area of the steel, and if the Ti/C value is selected in the range of 7 to 20, this will give the steel sheet anisotropy of the R values.

The steel thus obtained can be hot rolled at a temperature above 780°C, rinsed with acid, and cold rolled for reduction of more than 30 percent and finally annealed for recrystallization within the temperature of 600°C to 900°C. This method does certainly produce steel having excellent deep drawability; however, the use of Ti in the amount such as Ti/C being 7 to 20 will result in high cost and low yield.

After careful studies and experiments in relation to the conventional methods, the inventors of the present invention have succeeded in providing steel sheet of superior drawability and press formability as compared with the conventional methods with the use of ordinary low carbon rimmed steel as the base material and by improving the characteristics through an appropriate combination of reduction rates in the first and second cold rollings and through suitable annealing cycles that are based upon the amount of C content in the material. Instead of cold rolling in one stage, the inventors repeated examinations of conditions in a two stage cold rolling wherein many different combinations of annealing cycles and reduction rates are possible and whereby many appreciable changes in the characteristics of the steel are caused. An analysis of the data obtained from these studies and experiments indicates that steel sheets of equal composition and thickness differ in the quality thereof depending on the combination of the reduction rates at the time of first and second cold rolling and types of annealing. Thus by selecting the most suitable combination of the steps in the manufacturing process, products of a desired quality to meet the use requirements can be obtained. It was also found that the amount of C contained in the steel sheet influences the drawability of the steel sheets obtained from the two stage cold rolling; therefore, determination of treating conditions which takes the C content of the steel sheets into consideration will result in the production of the steel sheets of desired deep drawability.

One of the objects of the present invention is to provide an inexpensive method for manufacturing steel sheets having excellent deep drawability that is equal or even superior to that of steel sheets including special alloying elements by using ordinary low carbon rimmed steel and without the addition of special alloying elements such as Ti or removal thereof necessitated by said addition.

In the present invention, hot rolled low carbon rimmed steel sheets is treated by a two stage cold rolling and annealing the combinations being selected with due consideration given to the amount of C contained in the rimmed steel. In a more specific embodiment, the present invention uses rimmed steel containing 0.03 to 0.11 percent C; the steel is hot rolled at a finish temperature above 830°C and then coiled at a temperature below 650°C. The steel sheet thus obtained is treated by the two stage cold rolling comprising a first rolling at a reduction rate of 50 to 80 percent and a second rolling at a reduction rate of 40 to 85 percent, the total reduction being more than 80 percent, with annealing in two cycles respective to the two rollings; the schedule being determined in view of the amount of C.

Generally, yield point, tensile strength, and elongation rate are taken into consideration in evaluating the deep drawability of a steel sheet. Today it is agreed that Rankford value r is most indicative of the drawability, a value that is evaluated by the following equation (1) wherein the gauge length and sheet width of a test piece before and after it is given a pull within a determined range of elongation thereof are incorporated.

\[ r = \log(w_0/w)/\log(l_0/l_90) \]

wherein:
- \( l_0, l \) represent gauge length before and after pulling of the test piece at marked points.
- \( w_0, w \) represent sheet width before and after pulling of the test piece.

As the Rankford value is highly directional, it is necessary to measure the same at angles of 0°, 45° and 90° to the rolling direction. The average value of the respective Rankford values at said angles is presented as
the Normal Anisotropy ($\tau$) as shown in the following equation:

$$\tau = r_o + 2r_{\theta\theta} + r_{\phi\phi}/4$$  \hspace{1cm} (2)

This Rankford value $\tau$ is also studied in the present invention along with the yield point, tensile strength and elongation as one of the determining factors of the deep drawability. However, it is found that $\tau$ value along is still insufficient in measuring the deep drawability through the inspection of the steel sheet on the spot. That is, considerable difference in the limit of actual drawability is noted even in the steel materials having the same $\tau$ value. This difference in the drawability is derived from the Planar Anisotropy ($\Delta r$). This Planar Anisotropy is evaluated by the following equation (3) with $r$ values at angles 0°, 45° and 90° that are obtained by the equation (1).

$$\Delta r = r_\theta - r_{\phi\phi} - 2r_{\theta\theta}/2$$  \hspace{1cm} (3)

Depending on the $\Delta r$ value, steel sheets of equal $\tau$ value will vary in their deep drawability. Thus in the present invention the deep drawability of the steel sheets are judged by the $\tau$ and $\Delta r$ values, and by these values the press workability and press formability in the actual drawing operation may also be estimated.

We have already mentioned that the result of various experiments with different reduction rates at the time of first and second cold rolling and different schedules of annealing cycles revealed the fact that considerable differences in the $\tau$ and $\Delta r$ values of the steel sheets are observed, depending on the amount of C contained in the low carbon rimmed steel, due to the close relationship between the C content and the rolling and annealing schedules. For example, a steel sheet was treated in accordance with the present invention comprising two stage cold rolling wherein the reduction rates at the first and second rolling were so determined as to have a total rate of 85 percent, the first annealing following the first cold rolling being a decarburization annealing at 750°C and the second annealing after the second cold rolling being hot annealing at 800°C. Another steel sheet was treated with a different annealing cycle comprising the normal annealing at 700°C as the first annealing and decarburization at 800°C as the second annealing.

The accompanying drawings illustrate the various phases of the steel sheets in accordance with the present invention.

FIG. I shows a graph of the changes in $\tau$ values, in correspondence with the amount of C % content in each steel sheet, at a total reduction rate of 85 percent caused by two types of annealing cycles.

FIGS. 2a and 2b are graphs showing the steel sheets treated by the first type of annealing cycle of the present invention, and the relations, between the reduction rates determined respectively for the first and second cold rollings and the values $\tau$ and $\Delta r$ are evaluated. FIG. 2a shows a steel sheet having 0.05 percent of C; FIG. 2b shows a steel sheet having 0.10 percent of C.

FIGS. 3a and 3b are graphs showing the steel sheets treated by the second type of annealing cycle of the present invention, and the relations between the reduction rates determined respectively for the first and second cold rollings and the values $\tau$ and $\Delta r$ are evaluated. As in the graphs 2a and 2b the steel sheet evaluated in graph 3a contains 0.05 percent of C while the one in graph 3b contains 0.10 percent of C.

Both of the graphs 2a, and 2b, and 3a and 3b also indicate the curves of the total reduction rates. The changes in the normal anisotropy ($\tau$) in correspondence with the C content of the steel sheets are shown in graph 1, in which the first heat treatment schedule was the decarburization annealing at 750°C followed by hot annealing at 800°C as described above and the second schedule was the annealing at 700°C followed by decarburization annealing at 800°C also described above. Both steel sheets of the first schedule and second schedule show orderly change in the $\tau$ value thereof in correspondence with the C content. Consequently, the graph indicates which schedule would be more suitable for a steel sheet of given C content; when the C content in the steel is within the range of 0.07 to 0.08 percent, the $\tau$ value may be substantially the same in steel sheets treated by either schedule, whereas the C content is less than 0.07 percent, the $\tau$ value of the product in accordance with the second type of schedule becomes below 2.0 and tends to still decrease in correspondence with the decrease in the C content while the product in accordance with the first type of schedule shows the $\tau$ value above 2.0 which increases rapidly as the C content decreases when said C content is less than 0.07 percent. It can be said that the annealing schedule of the first type is more effective in producing products of high drawability operated for steels containing less than 0.07 percent C. The annealing schedule of the second type, on the other hand, produces steel sheets which show more moderate change in the $\tau$ value; this means that the schedule is applicable to steel sheets of any C content that it is more effective than the schedule of the first type for steel sheets having more than 0.07 percent C.

The foregoing being taken into consideration, further studies were made into the appropriate range of temperatures for the individual annealings in the two types of schedule. In case of the first schedule wherein the first annealing is for decarburization, the temperature should preferably be between 730°C and 750°C, which is somewhat higher than the modification point $A_r$, whereas the temperature of the first annealing in the second schedule is preferably between about 650°C and 730°C. The second annealing temperature for the first schedule is between 780°C and 820°C, a little higher than that for the second type. The second annealing of the second schedule should be in the range of 750°C to 800°C for decarburization.

Steel sheets containing 0.05 percent C and 0.10 percent C were treated in accordance with the first schedule of wherein the decarburization first annealing was done at 750°C while the second normal annealing was done at 800°C. The relationship of reduction rates for the first and second cold rolling and the relationships between the normal anisotropy ($\tau$) and planar anisotropy $\Delta r$ influenced by the reduction rates are shown in graphs 2a and 2b for comparison of the two example steels. The upper portion on the right of the graphs represents the range where the normal anisotropy $\tau$ is high. When the reduction rate of the first rolling is less than 50 percent, it is not possible to obtain products having good normal anisotropy; likewise when the reduction rate of the second cold rolling is below 45 percent, de-
sirable normal anisotropy value will not be achieved even if the reduction rate of the first cold rolling is set high.

On the other hand, the value of the planar anisotropy becomes relatively high if the desired total reduction rate is achieved by a relatively high rate in the first rolling and a low rate in the second rolling.

Similar relationships among various conditions and values in the steel plates produced in accordance with the schedule of the second type are shown in graphs 3a and 3b. Where both the first and second cold rolling's reduction rates are high, the F value becomes as high as 2.2 or 2.1, while the planar anisotropy value Δα is high when the reduction rate of the first cold rolling is high.

These graphs clearly show the drawability of the steel sheets in correspondence with the different combinations of reduction rates in the cold rollings. Clearly, products with the best possible deep drawability can be obtained if a suitable annealing schedule and combination of reduction rate are selected with due consideration to the C content of the given steel material. For convenience, the graphs also show the relationships in the total reduction rates, whereby the drawability of the steel sheets, as well as the possible combinations of reduction rates in the first and second rollings, for the production of steel sheets of desired thickness from a given thickness of raw material may be ascertained so that reasonable control of the rolling operations becomes possible. Further, modernization and rationalization of the hot rolling treatment for sheet material may be possible by predetermining the thickness of the sheets to be prepared for the hot rolling by estimation of the conditions in the final product or the drawability thereof. The present invention thus establishes conditions that are most effective in the process of manufacturing the steel sheets of this nature and it is advantageous in terms of cost as the addition of special alloying elements or special treatment thereof is not necessary.

As is clear from the studies of the relationships between the diagonal lines in the said graphs and the F values, when the total reduction rate is fixed, a product with better drawability is obtained by two rollings of equal reduction rate.

Examples of the present invention are as follows:

Example 1

Steel sheet containing 0.05 percent C obtained by hot rolling a slab of low carbon rimmed steel produced by the ordinary method was used as the raw material. It was subjected to the annealing cycle of the second type: after cold rolling at a reduction rate of 70 percent, it was subjected to the first annealing for decarburization at 750°C. The reduction rate for the second cold rolling was 77.8 percent and the second annealing temperature was 800°C. The final product had a sheet thickness of 0.4 mm (total red. 93.3 percent).

Example 2

Hot rolled steel sheet as used in the Example 1 was subjected to the decarburization annealing at 750°C after a first cold rolling at 80 percent reduction in accordance with the schedule of the first type given hereinbelow. The temperature of the second annealing was 800°C and the reduction rate for the second cold rolling was 66.7 percent. The final product obtained was 0.4 mm in thickness (total red. 93.3 percent).

Example 3

Steel sheet having a thickness of 6.0 mm obtained by hot rolling low carbon rimmed steel with 0.04 percent was used. The material was subjected to a annealing schedule of the first type: prior to the annealing for decarburization at 750°C the steel sheet was first cold rolled at a reduction rate of 61.7 percent. It was then treated for the second cold rolling at a reduction rate of 65.2 percent. The final annealing temperature was 800°C. The final product obtained was 0.8 mm in thickness (total red. 86.7 percent).

Example 4

Steel sheet of the identical composition as used in Example 3, but having a thickness of 7.0 mm, was used. The material was subjected to a annealing schedule of the first type: prior to the first annealing for decarburization at 750°C, the steel sheet was cold rolled at a reduction rate of 67.1 percent. The reduction rate of the second cold rolling was 65.2 percent and the annealing temperature was 800°C. The final product obtained was 0.8 mm in thickness (total red. 88.6 percent).

Example 5

Steel sheet having a thickness of 6.0 mm obtained from low carbon rimmed steel with 0.07 percent C was used. Prior to a first annealing at 700°C, the steel sheet was first cold rolled at a reduction rate of 61.7 percent. After the second cold rolling at a reduction rate of 65.2 percent it was annealed for decarburization at 800°C. The final product obtained was 0.8 mm in thickness (total red. 88.6 percent).

Example 6

Steel sheet having the identical composition as that used in the Example 5, but having a thickness of 7.0 mm, was used. The steel was subjected to treatment in accordance with the second annealing schedule. Prior to the first annealing at 700°C, the steel was first cold rolled at a reduction rate of 67.1 percent. The reduction rate for the second rolling was 65.2 percent and the decarburization annealing was done at the temperature of 800°C. The final product obtained was 0.8 mm in thickness (total red. 88.6 percent).

The results of the tests in mechanical properties and workability of the products obtained by the examples are given in the following table.

<table>
<thead>
<tr>
<th>Example</th>
<th>Y.P. (kgf/mm²)</th>
<th>Y.P. El. (kgf/mm²)</th>
<th>T.S. (kgf/mm²)</th>
<th>El. (kgf/mm²)</th>
<th>Gr. (°A)</th>
<th>No.</th>
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<td>14.6</td>
<td>27.3</td>
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<td>1.3</td>
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<tr>
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</tr>
<tr>
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<td>30.5</td>
<td>16.5</td>
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</tr>
<tr>
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<td>14.6</td>
<td>31.5</td>
<td>16.5</td>
<td>1.3</td>
<td>2.64</td>
</tr>
</tbody>
</table>

1 Shows steels having only been annealed.

It can be understood from the table that the method of the present invention enables accurate attainment of high Rankford value (normal anisotropy F) of approximately 2.0 or higher in the final product, which is superior in terms of Δα yield point, tensile strength, elongation rate or the ASTM grain size number and has far better deep drawability than any cold rolled steel sheet of low carbon rimmed steel.

Using low carbon rimmed steel as the raw material, the present invention enables the production of steel sheet with excellent extra-deep drawing properties, which is far superior to any rimmed steels of the conventional methods in such values as F and the like which determine the drawability of the steel. The material is subjected to cold rolling in two stages at a total
reduction rate of more than 80 percent and then annealed on a schedule determined in relationship with the cold rollings and the C content of the material so that the drawability potential of the steel will be fully developed. Further more the present invention not only features characteristics which contributes to a reduction in production cost, through the elimination of expensive Ti addition or the like, but it also rationalizes the rolling process to enable smooth performance of the most appropriate and ideal operation. The present invention is thus effective in a wide range of industry.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for producing extra deep drawing steel sheet from low carbon rimmed steel comprising cold rolling said steel in two stages such that the total reduction is greater than 80 percent, annealing said steel between the first and second rolling stage and further annealing said steel after said second stage, wherein the carbon content of said low carbon rimmed steel is below 0.07 percent, said steel is first cold rolled at a reduction of about 50 to 80 percent, decarburization annealed at about 730°-750°C, second cold rolled at a reduction of about 40-85 percent and finally annealed at between 780°-820°C, and wherein the carbon content of said low carbon rimmed steel is from 0.07 percent to 0.11 percent, said steel is first cold rolled to a reduction of about 50-80 percent, annealed at between 650°C and 730°C, second cold rolled at a reduction of 40-85 percent and finally decarburization annealed at 740°C to 800°C.

2. A method as claimed in claim 1 wherein said low carbon rimmed steel contains 0.03-0.07 percent carbon.

3. A method as claimed in claim 1 wherein said low carbon rimmed steel contains 0.07-0.11 percent carbon.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,759,081 Dated September 18, 1973

Inventor(s) KAZUO MATSUO et al

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

Column 3, line 4, replace the formula with the following formula:

\[ r = \frac{r_o + 2r_{45} + r_{90}}{4} \]

Column 3, line 21, replace the formula with the following formula:

\[ \Delta r = \frac{r_o + r_{90} - 2r_{45}}{2} \]

Column 7, line 20, after "wherein" insert --when--.

Signed and sealed this 9th day of July 1974.

(SEAL)
Attest:

McCoy M. Gibson, JR. C. Marshall Dann
Attesting Officer Commissioner of Patents