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DEEP DRAWING STEEL AND METHOD OF MANUFACTURE

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This invention relates to an improved deep drawing quality steel sheet having a novel combination of composition and crystallographic texture, and to a method of making the same.

Steel sheet is widely used in the manufacture of products which are formed into intricate shapes in presses or the like. For such purposes, steel sheet should have high ductility and high formability, that is, it should be easily formable in a press and it should stretch uniformly, with a minimum of variation in thickness between various parts of the formed sheet.

In addition, such steel should have good drawability. Strictly speaking, the term drawability refers to that property which enables a sheet of material to be drawn, or pulled, over the edges of a die.

Ideally, a sheet of steel having the optimum drawability could be formed into shape with very little change in the thickness of the sheet. That is, the sheet could be pulled over the edges of a die, for example, with a consequent deformation in the width and length of the sheet but with very little deformation in the thickness thereof.

To determine the drawability of a sheet, on the basis of the foregoing, a test has been developed which yields a number indicative of drawability as hereinbefore defined. This test broadly comprises cutting four rectangular samples from the sheet to be tested. Each sample is ¾ inch wide and 8 inches long. One sample is cut with its long axis parallel to the direction of rolling, one sample with its long axis transverse to the direction of rolling, and two samples with their long axes at 45° to the direction of rolling.

Each sample is then placed in a testing machine and is longitudinally stressed, in tension, within the limit of uniform elongation, said limit being that amount of stress beyond which the sample necks. Measurements are then made to determine the strain in the thickness and the strain in the width of each sample. The ratio of the strain in the width to the strain in the thickness is called the "strain-ratio." The average of the strain ratios of the four samples is called the average R-value of the steel sheet.

Based upon the foregoing definition of drawability, it can be seen that a steel sheet having optimum drawability would have an R-value approaching infinity as an upper limit, inasmuch as the denominator of the strain ratio should ideally be zero. However, from a practical standpoint, a steel sheet having an R-value above about 1.20 has been found to have excellent drawability.

We have determined, on the basis of mathematical analyses, laboratory tests, and commercial draws, that the R-value of a steel sheet is an accurate indication of its ability to be deep drawn.

It has been determined that the crystallographic orientation of a steel sheet has an important bearing on its deep drawing qualities, i.e., its R-value. More specifically, a sheet with optimum deep drawing qualities should have a high degree of a specific type of preferred crystallographic orientation.

A steel sheet, the crystals of which are randomly oriented, has an R-value equal to unity. This indicates that the flow strength in directions parallel and perpendicular

to the plane of the sheet are equal. Thus the steel will strain equally in its thickness and in its width and length when stressed, e.g., during a deep draw.

It has been found that crystals of iron have different resistances to deformation in different crystallographic directions. For example, an iron crystal is most resistant to deformation when a force is applied parallel to its cube diagonal. In addition, an iron crystal is least resistant to deformation when a force is applied parallel to a cube face.

It has been found that in order to minimize deformation in the thickness of the sheet a maximum number of crystals should be oriented with a cube diagonal perpendicular to the plane of the sheet and a minimum number of crystals should be oriented with a face parallel to the plane of the sheet. Stated differently, the steel sheet should have, in its plane, a larger number of "cube-on-corner" crystals and a smaller number of "cube-on-face" crystals than would be present if the crystals were randomly oriented.

A steel sheet in which the crystals are so oriented has an R-value greater than unity. Conversely, a steel sheet having, in its plane, a smaller number of cube-on-corner crystals and a larger number of cube-on-face crystals than would be present if the crystals were randomly oriented has an R-value less than unity.

We have discovered that it is possible to produce steel sheets having a high R-value by proper control of the analysis of the steel from which the sheet is formed and by proper control of the steps used in its manufacture.

Accordingly it is an object of our invention to produce a steel sheet having a novel combination of analysis and crystallographic texture and having improved deep drawing qualities.

Another object of our invention is to produce a steel sheet having a particular kind of preferred crystallographic orientation and a high degree of ductility.

A further object of our invention is to produce unkilled steels having R-values of 1.20 or greater. By unkilled steels is meant rimmed, capped, and semi-killed steels.

Another object is to provide a process for producing such sheets.

These and other objects will be apparent from the following description.

In the broad sense, our invention is based on the discovery that a specific type of preferred crystallographic orientation which results in an improved R-value can be obtained by a particular combination of composition and method of treatment. More specifically, it has been found that a sheet of unkilled steel containing 0.03% minimum phosphorus will develop a crystallographic orientation which results in a substantially improved R-value if, after cold reduction, the steel is heated to a temperature within the range of 1100–1400° F. at a maximum rate of 500° F. per hour through the range 950–1100° F., and decarburized to a carbon content of 0.010% maximum. The steels of the invention consistently have R-values of 1.20 and higher and have deep drawing qualities superior to those of prior unkilled steels, the R-values of such prior steels generally averaging about 1.15.

The carbon content of the steel should be 0.010% maximum, and preferably 0.004% maximum because both the R-value and the ductility of the steel sheet vary inversely with the carbon content. The minimum phosphorus content which results in any substantial improvement in R-value over that of ordinary sheet steel, i.e. steel containing about 0.01% phosphorus, is 0.03%. While the R-value improves with increasing phosphorus content, the ductility and degree of uniform elongation are adversely affected, and the steels of the invention are thus limited to a maximum phosphorus content of about

0.09%. Steels containing phosphorus above about 0.09% are generally not suitable for deep drawing.

The other elements in the steels of the invention may be within the limits ordinarily found in rimmed, capped, and semi-killed sheet steels. For example, the manganese content may vary from 0.15 to 0.60%. The lower limit is based upon the minimum amount of manganese necessary to prevent hot shortness during hot rolling, and is also the minimum amount necessary for recrystallization during a sub-critical anneal. Inasmuch as manganese is costly and detracts from ductility, an upper limit of 0.60% is considered practical.

The silicon content of the steel must be limited to 0.10% maximum and preferably 0.02% maximum, as silicon is detrimental to ductility. The sulfur content should be limited to 0.04% maximum.

Variations in the percentages of manganese and sulfur, as well as incidental impurities, e.g., copper, are not critical insofar as the R-value of the steel is concerned. However, the amounts of these and other elements which are present in the steel should be determined on the basis of their effects on ductility.

The steel sheets of the invention are produced by the following method. An open hearth heat is melted to the desired composition range. The heat is poured into ingot molds and treated according to standard rimmed, capped, or semi-killed steel-making practice. The resulting ingots are then rolled into slabs. The slabs are then re-conditioned to remove surface defects.

The slabs are reheated and hot rolled to strip approximately 0.1 inch thick. The rolling is usually finished at about 1500°–1750° F. The steel is then coiled at about 1100° F. and cooled in air to room temperature.

The steel is next pickled to remove the hot mill scale and then cold reduced to final gauge. The cold reduction is above 40%, and is preferably 55–75%. The cold reduced strip is open wound, placed in an open coil annealing furnace, and heated to within an annealing temperature range of from 1100–1400° F. in a dry 4% H_2, balance N_2 protective atmosphere. The heating rate through the range of 950–1100° F. is a maximum of 500° F. per hour, and preferably between 50–200° F. per hour.

When the temperature of the steel reaches about 1100° F. the protective atmosphere is discharged from the furnace and a decarburizing atmosphere comprising 18% H_2, balance N_2, and having a dew point of 65–70° F. is introduced into the furnace. The steel is then decarburized until its carbon level is less than 0.010%. The dew point of the atmosphere is then reduced to —40° F. and the steel is soaked at the annealing temperature for about 24 hours. Following the soak, the atmosphere is changed to one comprising 4% H_2, balance N_2, and substantially dry, and the steel is cooled slowly to room temperature. For example, the cooling rate may be 50 to 150° per hour.

Unkilled sheet steel containing 0.03–0.09% phosphorus has been found to have exceptionally high R-values when processed in accordance with the foregoing method. The critical steps of the process comprise the cold reduction followed by slow heating through a specific temperature range and decarburizing the steel until the carbon is less than .010%.

As a specific example of our product and the method of producing it, a basic open hearth heat of the following analysis was melted.

C, percent	Mn, percent	P, percent	S, percent	Cu, percent	Fe
0.10	0.49	0.042	0.021	0.08	Balance

The heat was poured into ingot molds and treated according to standard practice for capped steels. The ingots from this heat were hot rolled into slabs and said slabs were cooled and surface conditioned to remove defects. The slabs were then reheated and hot rolled to 0.125 inch thick steel strip. The rolling was finished with the steel at a 1500° F. minimum temperature and the strip was coiled within a temperature range of 1050° F.–1150° F. and cooled in air to room temperature. The hot-rolled steel strip was then pickled and cold reduced to a thickness of 0.0598 inch, a reduction of 52%. The steel strip was then open wound, placed within a batch annealing furnace and heated to 1290° F., the rate of heating being 150° F. per hour through the temperature range 950–1100° F. This steel was decarburized in accordance with the aforementioned practice. When the CO content of the gas under the cover had decreased to 0.37%, a dry 18% H_2, balance N_2, atmosphere was substituted for the decarburizing atmosphere and the coil was soaked for 24 hours. At the end of this time, the atmosphere was changed to a dry 4% H_2, balance N_2 gas and the coil was cooled to room temperature.

The decarburized steel strip was then tight wound and skin rolled, effecting a 1% increase in length.

The decarburized steel strip had the following composition analysis:

C, percent	Mn, percent	P, percent	S, percent	Cu, percent	N, percent	Fe
0.004	0.49	0.042	0.016	0.05	0.005	Balance

The R-value of a sheet made from this steel was 1.21.

As a second specific example of our product and the method of making it, a basic open hearth heat of the following ladle analysis was melted.

C, percent	Mn, percent	P, percent	S, percent	Cu, percent	Fe
0.10	0.41	0.039	0.021	0.06	Balance

The heat was poured into ingot molds and treated in accordance with standard capped steel practice. The ingots were processed into hot rolled strip in the manner set forth in the foregoing specific example. The hot rolled strip, which was 0.090 inch thick, was pickled and cold reduced to strip 0.0359 inch thick, a reduction of 60%. The strip was then slowly heated, decarburized, soaked, cooled, and skin rolled as in the first specific example. The composition of the steel as determined by analysis of the skin rolled strip was:

C, percent	Mn, percent	P, percent	S, percent	Cu, percent	N, percent	Fe
0.004	0.42	0.034	0.021	0.06	0.005	Balance

The R-value of a sheet of this steel was 1.36.

As a third specific example of our product and the method of making it, an open hearth heat of the following ladle analysis was melted.

C, percent	Mn, percent	P, percent	S, percent	Cu, percent	Fe
0.11	0.39	0.08	0.023	0.05	Balance

The heat was poured into ingot molds and treated in accordance with standard capped steel practice. The steel ingots were processed into hot rolled strip 0.080 inch thick in the same manner as that described in the first specific example. After pickling, the hot rolled strip was cold reduced into strip 0.0299 inch thick, a reduction of 62%. A coil of this material was heated to 1290°

F., the rate of heating being 125°F. per hour through the temperature range 950–1100° F. This steel was decarburized as above set forth and skin rolled. The composition of the steel as determined by analysis of the skin rolled strip was:

C, per-cent	Mn, per-cent	P, per-cent	S, per-cent	Cu, per-cent	N, per-cent	Fe
0.006	0.45	0.09	0.032	0.05	0.0015	Balance

Although the carbon content of this steel was slightly higher than that of our preferred range, .004% maximum, the R-value of a sheet of this steel was 1.31.

The steel sheets of the invention, by reason of a novel combination of composition and crystallographic texture, have properties enabling them to be successfully drawn into intricate shapes. The R-values of the sheets are consistently 1.20 or higher, and the ductility, uniform elongation, and related properties are excellent for all types of drawing operations. In addition, the steel sheets can be rendered substantially non-aging by limiting the nitrogen contents thereof to 0.001% maximum.

The method of manufacturing said sheets results in a particular type of preferred crystallographic orientation which is manifested as exceptionally high R-values. Said method includes a particular series of steps in the treatment of a particular composition of steel. The combination of process and composition results in unkilled steel sheets having excellent deep drawing properties.

Although we have described our invention hereinabove in considerable detail, we do not wish to be limited narrowly to the exact and specific particulars disclosed, but we may also use such substitutes, modifications, or equivalents as are included within the scope and spirit of the invention or pointed out in the appended claims.

We claim:

1. A method of making a sheet of steel comprising hot rolling and unkilled steel consisting essentially of phosphorus 0.03 to 0.09%, balance iron, cold reducing said steel, heating said steel at a maximum rate of 500° F. per hour through the range 950 to 1100° F. and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.010% max.

2. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of phosphorus 0.03 to 0.09%, balance iron, cold reducing said steel by at least 40%, heating said steel at a maximum rate of 500° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.010% max.

3. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15% min., phosphorus 0.03 to 0.09%, balance iron, cold reducing said steel by at least 40%, heating said steel at a maximum rate of 500° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.010% max.

4. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15% min., phosphorus 0.03 to 0.09%, balance iron, cold reducing said steel by at least 40%, heating said steel at a maximum rate of 50 to 200° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.010% max.

5. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15 to 0.60%, phosphorus 0.03 to 0.09%, silicon 0.10% max., balance iron, cold reducing said steel by at least 40%, heating said steel at a maximum rate of 500° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.004% max.

6. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15 to 0.60%, phosphorus 0.03 to 0.09%, silicon 0.10% max., balance iron, cold reducing said steel by at least 40%, heating said steel at a maximum rate of 50 to 200° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.004% max.

7. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15 to 0.60%, phosphorus 0.03 to 0.09%, silicon 0.10% max., balance iron, cold reducing said steel by 55 to 75%, heating said steel at a maximum rate of 500° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.004% max.

8. A method of making a sheet of steel comprising hot rolling an unkilled steel consisting essentially of manganese 0.15 to 0.60%, phosphorus 0.03 to 0.09%, silicon 0.10 max., baalnce iron, cold reducing said steel by 55 to 75%, heating said steel at a maximum rate of 50 to 200° F. per hour through the range 950 to 1100° F., and holding said steel in a decarburizing atmosphere within the temperature range of 1100 to 1400° F. for a time sufficient to both anneal the steel and reduce its carbon content to 0.004% max.

9. A sheet of unkilled steel consisting essentially of carbon 0.010% max., manganese 0.15% min., phosphorus 0.03 to 0.09%, balance iron, said sheet having in its plane a greater than random number of cube-on-corner crystals and a lesser than random number of cube-on-face crystals.

10. A sheet of unkilled steel consisting essentially of carbons 0.004% max., manganese 0.15 to 0.60%, phosphorus 0.03 to 0.09%, silicon 0.10 max., balance iron, said sheet having in its plane a greater than random number of cube-on-corner crystals and a lesser than random number of cube-on-face crystals.

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