METHOD OF PRODUCING LOW CARBON ELECTRICAL SHEET STEEL

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This invention relates in general to a method of manufacturing silicon steel sheet for use in electrical apparatus and in particular to a method of effecting improvements in the magnetic characteristics of low silicon electrical sheet steel, that is, steel sheet having a silicon content of .50%—2.00% by weight.

In an effort to improve the efficiency of the many types of electrical apparatus in use today, it is customary to use a core material in the form of thin sheets or strip characterized by high permeability and low core loss value. It is well known that the addition of silicon to steel to form an iron-silicon alloy enhances the magnetic characteristics of the steel sheet. It is also well known that carbides, nitrides and non-metallic inclusions adversely affect the magnetic characteristics of the iron-silicon alloys. For this reason the elements such as carbon, manganese, phosphorus, sulfur, nitrogen, etc. are kept as low as possible when producing electrical steels. The aforementioned iron-silicon alloy steel strip is characterized by excellent magnetic properties, principally low core losses, but also low hysteresis losses, high specific resistance and high magnetic permeability. All of these characteristics are important, but the criterion for a good electrical steel sheet as designed by the industry—AISI Standards—is the core loss value per pound exhibited by the steel during use. The core loss property of a steel sheet is directly related to grain-coarsening and grain-orientation of the steel. Grain-orientation is important in the iron-silicon alloy steel sheet because the directionality of the grains directly affects the magnetic characteristics of the steel sheet. Grains which have their axes disposed in a specific direction preferably in the rolling direction and not randomly oriented in space and which display a cube-on-edge or cube-on-face orientation offer the least resistance to magnetization and as a result the sheet has a low core loss per pound value. Grain-coarsening is important because the finer the grain size the more grain boundaries are available in the steel to impede the flow of magnetic flux resulting in high hysteresis loss thus increasing the core loss per pound value of the steel. The fewer the grain boundaries the better are the magnetic characteristics. As the silicon content of the steel is increased, the susceptibility of the steel to grain coarsening and grain orientation upon rolling and annealing is increased. The core loss value per pound of steel is thereby decreased, thus enhancing this characteristic of the steel. Therefore, to improve the magnetic characteristics of the electrical steel sheet, it is customary to increase the silicon content. However, increasing the silicon content increases the difficulties in rolling and heat treating the steel.

In the conventional method of processing silicon electrical steel, the steel is subjected to a series of rolling steps and heat treatment steps to produce the strip of the required gauge. The steel is hot rolled to an intermediate gauge strip and is then decarburized at temperatures of 1650° F. and above in a controlled atmosphere which is usually a nitrogen, hydrogen, or nitrogen-hydrogen mixture. After decarburization, the steel strip is allowed to cool, and is then annealed to prepare the steel for further processing. The steel is then reduced to strip of the desired final gauge by several cold rolling and annealing operations in which the steel acquires a coarse grain structure, and preferred grain cube-on-face or cube-on-edge orientation and grain-orientation in the direction of rolling. The temperatures used in annealing the steels are usually 1500° F. and higher. The process may or may not include a final aging step as the silicon content of the steel is increased, the susceptibility of the steel to brittleness upon working is increased. It is, therefore, necessary to limit the amount of reduction per pass, and to limit the total amount of reduction per rolling. It is also necessary to heat treat (anneal) the steel at higher temperatures in order to soften the steel for further reduction. Higher starting temperatures and higher finishing temperatures are required in hot rolling high silicon steels. These prior art processes are complicated and costly. They do not produce a uniform quality final product. Nor do they effect a great improvement in the core loss value of the steel unless the silicon content of the steel is above 2.50%.

It is therefore the primary object of this invention to produce a low silicon steel sheet having magnetic characteristics, i.e. lower core loss per pound, equal to, or better than, those of sheets of intermediate or high silicon steel. By an intermediate silicon steel, I mean a steel which has a silicon content of 2.00% up to 3.50% by weight, and by a high silicon steel I mean a steel which has a silicon content of 3.50% up to about 7.00% by weight.

It is another object of this invention to produce a low silicon steel sheet having magnetic characteristics which are equal to, or better than, those of an AISI standard grain-orientation steel sheet having an intermediate or high silicon content.

It is another object of this invention to produce a low silicon steel sheet which will have a fine-grained structure but will have magnetic characteristics equal to, or better than, those of the conventional AISI standard coarse-grained intermediate or high silicon content steel sheet. It is another object of this invention to produce a silicon steel which can be rolled to its final thickness in one cold rolling operation from the decarburized and annealed hot rolled steel strip.

It is another object of this invention to provide a silicon steel sheet which can be annealed at lower temperatures than heretofore have been used to produce a sheet having magnetic characteristics equal to, or better than, those of intermediate or high silicon steel sheets.

It is another object of this invention to produce a low silicon steel sheet by a solid state dual temperature, dual atmosphere, decarburization and annealing treatment, said sheet having magnetic characteristics equal to, or better than, those of the intermediate or high silicon steel sheets. Broadly, the invention comprises producing, in accordance with any well-known steel mill practice, an ingot of low silicon steel which is hot rolled into strip of intermediate thickness. The hot rolled strip is then coined. The coined hot strip is then pickled. It is then decarburized in a controlled atmosphere at well-known decarburizing temperatures. The temperature of the strip is then raised from the decarburizing temperature to an annealing temperature. The strip is annealed in a controlled atmosphere. After annealing, the strip is cold rolled in any suitable mill to the required gauge. The strip is then coined and again annealed in a controlled atmosphere furnace. The annealed strip is then cooled to an aging treatment temperature and held within said range for a suitable time, and then cooled to room temperature. After cold rolling and before the last mentioned anneal, the steel sheet exhibits good stamping characteristics, and can be supplied to the industry as a semi-processed electrical steel sheet to be processed into
a finished product. The magnetic characteristics, particularly core losses, are equal to, or better than, those exhibited by an electrical steel sheet having an intermediate high silicon content. By my process, I produce a low silicon steel sheet having its grain structure oriented in the plane of rolling but not necessarily oriented in relation to the edges of the sheet. The (110) and (100) planes of the individual grains are oriented in the rolling plane but the (001) or cube edge of the grains may be randomly oriented with the rolling direction.

In a preferred form of the invention, an ingot of steel is prepared, by any of the conventionally known steel mill practices, said steel consisting essentially of the following range of elements, by weight:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.01–0.25</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.01–0.50</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.30–2.00</td>
</tr>
</tbody>
</table>

Balance iron and incidental elements and impurities.

By incidental elements are meant those elements, for example, vanadium, nickel, molybdenum, copper, present in amounts which will not materially affect the novel properties of the steels of the invention. By impurities is meant phosphorus, sulphur, and nitrogen, which impurities should be kept below 0.025%, 0.025% and 0.005% respectively. The steel is hot-rolled to a strip having a thickness of approximately 0.070 inch to about 0.085 inch. The hot rolled strip is coiled on a conventional coiler. The hot rolled sheet strip is then picked up to remove scale which may be formed during the hot rolling operations. After pickling, the coil is washed and dried, and is then prepared for decarburization by the well-known open-coil method. The open coil is then subjected to a dual temperature, dual atmosphere, decarburization-annealing cycle. The coil is decarburized by placing it in a batch type furnace. A controlled atmosphere containing, for example, wet hydrogen is established in the furnace. The furnace temperature is raised to from about 1300°F to 1350°F and the strip is held within this range of temperatures until the carbon content of the steel has been reduced to a content not greater than 0.01%. The furnace atmosphere of wet hydrogen is then purged, and a controlled atmosphere of dry hydrogen is established in the furnace. Without permitting the strip to cool after decarburization, the furnace temperature is raised to a furnace decarburization temperature to from about 1650°F to about 1850°F, and the strip is annealed within this temperature range in the said dry hydrogen atmosphere for example for 5 hours. After the strip is annealed, it is cooled to room temperature, preferably by spraying the covering bell with cold water. The steel may be cooled in air if desired, after its temperature has fallen to about 950°F or below.

The decarburized and annealed strip is now ductile enough to be cold rolled to its final gauge, e.g. 0.025 inch to 0.012 inch. The cold rolling deforms and breaks up the moderately coarse grains which result from the annealing operation and elongates them in the direction of rolling.

The strip is then coiled and subjected to an annealing operation at from about 1350°F to about 1850°F in a batch-type furnace. The atmosphere in the furnace is preferably dry hydrogen, although the environment can be a vacuum or neutral gases. After annealing the strip, for example, for 24 hours, the furnace temperature is lowered at not more than 50°F per hour to about 1000°F. The strip is then aged at from 900°F to 1100°F for at least 2 hours in a protective environment, again preferably dry hydrogen, although a vacuum of neutral gases may be used. The strip is then quenched in room temperature. The last mentioned aging treatment induces precipitation of nitrides. Precipitation at the aging temperatures, 900°F to 1100°F, induces insignificant residual stresses which will cause no increase in the core loss of the electrical steel sheet.

Low silicon electrical steel sheet produced by the foregoing method has a substantially fine-grained structure. The strip (110) and (100) planes of the individual grains are oriented in the rolling plane but the (001) or cube edge of the grains may be randomly oriented with the rolling direction. As a result the core loss values of Epstein strips cut transversely to the rolling direction are equivalent to the core loss values of Epstein strips cut along the rolling direction. It is therefore evident that the silicon steel sheet produced by this method is suitable for use in rotary apparatus. Epstein samples taken from a 24 gauge sheet produced as above described, when tested in the direction of rolling at 60 cycles and 10 kilogausses, showed a maximum core loss value of 1.10 watts per pound and when tested at 60 cycles and 15 kilogausses showed a maximum core loss value of 2.25 watts per pound. The standard AISI grades of low silicon steel sheet having varying silicon contents between 0.50% and 2.00% show a core loss value of 1.30 watts per pound when tested at 60 cycles and 10 kilogausses and a core loss value of 3.04 watts per pound when tested at 60 cycles and 15 kilogausses.

As a specific example of the invention, a steel ingot was produced having the following compositions by weight:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>1.62</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.09</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.06</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.006</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.004</td>
</tr>
<tr>
<td>Copper</td>
<td>0.02</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.005</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.01</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.06</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Balance substantially iron.

This ingot was hot rolled to a strip 0.085 inch thick, pickled, washed and dried. The strip was then coiled, using spacers to separate the laps, and placed in a batch-type furnace. The steel was decarburized by heating the strip to 1300°F for 24 hours using a 100% wet hydrogen atmosphere having a dew point of 70°F. After 24 hours and while the coil remained in the furnace to prevent cooling thereof, the furnace was purged of moist hydrogen and was supplied with an inert atmosphere of 100% dry hydrogen. The temperature of the coil was raised to 1650°F and held at this temperature for 10 hours. The steel was then cooled to room temperature by spraying water onto the covering bell of the furnace. A chemical analysis of the strip to determine carbon and nitrogen showed them to be 0.003% and 0.001% respectively. The other elements were substantially unaffected. The annealed strip was then cold rolled to a thickness of 0.025 inch in a cold rolling operation to its final thickness of 0.025 inch. The coil was then annealed at 1350°F for 48 hours in an atmosphere of 100% dry hydrogen. The coil was furnace cooled 50°F per hour to 1000°F and held at this temperature for 2 hours. After 2 hours the coil was furnace cooled to room temperature. Macroscopic examination of specimens of sheets of this final annealed steel showed the steel to have a fine-grained structure. Laugrams were made on individual secondary grains and the sheet was found to have a grain structure oriented in the plane of rolling but not oriented in the rolling direction. Epstein samples were taken from the sheet. Epstein samples revealed the steel to have a core loss value of 1.02 watts per pound and, when tested at 60 cycles and 15 kilogausses, had a core loss value of 1.20 watts per pound. This more than meets the minimum core loss requirements for stress relieved M-27 grade silicon steel sheet according to August 1961 AISI specifications of 1.17 watts per pound when tested at 60 cycles and 10 kilogausses and 2.74 watts per pound when tested at 60 cycles and 15 kilogausses.
The excellent core loss values of the silicon steel sheet processed by my method, 1.02 watts per pound when tested at 60 cycles and 10 kilogausses and 2.25 watts per pound when tested at 60 cycles and 15 kilogausses, compare favorably with the AISI standard stress-relief-annealed M-22 grade which has maximum core losses of 1.00 watt per pound when tested at 60 cycles and 10 kilogausses and 2.35 watts per pound when tested at 60 cycles and 15 kilogausses. The standard AISI M-22 grade is a silicon steel having a silicon content of 2.70% to 3.50%, having a coarse-grained structure and being grain-oriented. As has been pointed out above, the manufacture of this steel presents difficulties in melting, rolling and heat treating.

All references herein to the composition of this steel are by weight.

I claim:

1. A method of manufacturing a silicon electrical steel sheet comprising:

(a) hot rolling an ingot consisting essentially, by weight, of 0.50% to 2.00% silicon, 0.01% to 0.25% carbon, balance iron, to an intermediate gauge of from about 0.070 inch to about 0.085 inch;

(b) decarburizing the hot rolled sheet in a furnace in a temperature range of from about 1300° F. to about 1350° F. for at least 24 hours in a controlled atmosphere of wet 100% hydrogen, purging the furnace of said wet 100% hydrogen atmosphere, substituting therefor an atmosphere of dry 100% hydrogen, annealing the decarburized sheet in the temperature range of from about 1650° F. to about 1850° F. without cooling the sheet, holding the decarburized sheet in the temperature range of from about 1650° F. to about 1850° F., for at least 24 hours, and cooling the sheet to room temperature;

(c) cold rolling the decarburized and annealed sheet to the required final gauge in one cold rolling operation;

(d) annealing the cold rolled sheet at a temperature of from about 1350° F. up to about 1850° F. for at least 24 hours in a batch-type furnace in a controlled atmosphere of dry 100% hydrogen, furnace cooling the sheet at 50° F./hr. to a temperature of from about 900° F. to about 1100° F. and holding the sheet at this temperature for at least 2 hours in a controlled atmosphere of dry 100% hydrogen.

2. A method of manufacturing a semi-processed silicon electrical steel sheet comprising:

(a) hot rolling a solidified ingot consisting, by weight, essentially of silicon 0.5% to 2.00%, carbon 0.01% to 0.25%, the balance iron, to a gauge of from about 0.070 inch to about 0.085 inch,

(b) decarburizing the hot rolled sheet in a batch furnace in a temperature range of from about 1300° F. to about 1350° F. for at least 24 hours in a controlled atmosphere of wet 100% hydrogen,

(c) raising the furnace temperature to from about 1650° F. to 1850° F., purging the furnace of the said wet 100% hydrogen atmosphere, substituting therefor an atmosphere of dry 100% hydrogen, annealing the decarburized sheet in the temperature range of from about 1650° F. to about 1850° F. for at least 24 hours, cooling the sheet to room temperature, and

(d) cold rolling the decarburized and annealed sheet to the required gauge within the range of 0.025 inch to 0.012 inch.

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