

1

3,239,332

ELECTRIC ALLOY STEEL CONTAINING VANADIUM AND COPPER

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1 Claim. (Cl. 75-125)

This invention relates to sheet steel for use in magnetic cores of electrical apparatus and relates to steel manufacturing methods. The invention particularly concerns the production of silicon steel having a high degree of preferred orientation and highly directional magnetic properties.

Grain oriented silicon steel in sheet form is widely used in the electrical manufacturing industry in large tonnage. Desirable magnetic properties with a grain orientation of approximately 80% have been achieved by alternate heating and cold rolling of suitable hot rolled strip. Suitable procedures are described in the original Goss Patent No. 1,965,559.

Numerous efforts have been made to effect further improvement in grain orientation and to reproduce such results reliably; and 90% grain orientation has long been a goal in the industry.

The sheet materials to which my invention is related are usually referred to in the art as "electrical" silicon steel or, more properly, grain oriented silicon-steel, composed primarily of iron alloyed with silicon and containing relatively minor amounts of impurities such as sulfur, manganese, phosphorous and very low carbon content.

It has been found from experience in the production of commercial grain oriented silicon steel that while all the grains are oriented in the (110) [001] direction, some deviation from the ideal exists. This deviation may be as much as 10 degrees from the ideal. This reduces the apparent orientation, and makes it appear that the grains are only 80% oriented. In testing many specimens by means of the torsion magnetometer, it was found that the apparent orientation varies from 78% to 82% in the best grain oriented silicon steel produced at the present time.

An object of the invention is to cause a high percentage of the grains comprising the material to have their crystal space lattices arranged in a substantially identical relationship to the plane of the sheet and to the direction of rolling. More specifically, in the finished strip the grains are oriented with the (110) [001] direction coinciding with the rolling direction.

An object of the invention is to obtain increased permeability at flux densities of 15,000 gauss or more. Furthermore, it is an object to achieve more nearly perfect crystal structure and grain boundaries and orientation exceeding 85%, as well as grain size control. Moreover, it is an object to accomplish reduction in watt loss and hysteresis at over 15,000 gauss.

The unit cells or body-centered unit cubes comprising these materials each have a high degree of magnetic anisotropy with respect to the crystallographic planes and directions of the unit cube, and hence, each grain or crystal comprising a plurality of such unit cells exhibits a similar anisotropy. More particularly, crystals of the silicon-iron alloys to which this invention is directed are known to have their direction of easiest magnetization parallel to the unit cube edges, that is, the (110) [001] orientation. It is therefore desirable to find processing procedures and chemical compositions which enhance this desired texture.

I have succeeded in achieving a grain orientation of 90%, that is, of the (110) [001] texture, by introducing into the alloy an additive consisting of vanadium alone,

2

or in combination with other suitable elements. The use of such additives has also made less critical than heretofore the processing procedures employed in order to obtain the desired preferred grain orientation, has reduced the cost of manufacture and increased the yield of acceptable magnetic sheet steel.

It was found that by adding small amounts of certain elements to clean 3% silicon steels, the orientation could be improved; that is, the grains could be more perfectly aligned in the direction of rolling. For example, by adding between .005 and .02% vanadium one increased the orientation so that 90% orientation was measured. It was found that by increasing the orientation from 80% to 90%, a marked improvement resulted in the permeability at a flux density of 15,000 gauss and over. Since flux density is measured in gauss, which is in the c.g.s. electromagnetic system, permeability is also in the c.g.s. system, and is a ratio. It is the ratio between the numerical values of flux density in gauss and magnetic field intensity in Gilberts per centimeter, the c.g.s. unit. The ratio is also the ratio of permeability of a sample to that of air.

The material to which this invention relates is silicon steel having a silicon content in general of about 2.8% to 3.4% and preferably in the range of about 3.0% to 3.3%. A typical preferred range and a typical specific analysis for such a steel is as given in the following table.

TABLE I.

	Percent by Weight of Ingot Used in Grain Oriented Strip Steels	
	Average Range	Specific
Silicon.....	3.00-3.30	3.15
Carbon.....	.020-.030	.025
Manganese.....	.035-.10	.050
Sulfur.....	.015-.025	.015
Phosphorous.....	.005-.020	.008
Aluminum.....	.01 max.	<.005
Copper.....	.050-.15	.080
Nickel.....	.030-.15	.050
Tin.....	.005-.020	.010
Chromium.....	.01-.03	.02

A silicon steel may be employed having silicon content up to 3.3% and satisfactory results are obtained by employing a silicon content of approximately 3.00%. In accordance with one example, an additive was employed consisting of approximately .02% vanadium which had been introduced into the melt during ladling prior to the pouring of the ingot in the form of ferro vanadium. In other examples, as little as .008% vanadium was employed. As much as .05% vanadium may be employed, but for economic reasons the vanadium content is preferably limited and favorable results have been obtained with the minimum content of vanadium. The vanadium content may be reduced as the steel is made cleaner, and when combined with other elements as copper, phosphorous and nitrogen.

Where the additive is vanadium, it remains in the finished material. On the other hand, where the additive is nitrogen, it must be removed during the high temperature anneal to values under 0.003%. Small amounts of various nitrogen compounds can greatly reduce the desired magnetic properties, that is, reduce the permeability and increase the watt losses.

Grain oriented silicon steel strip including the principles of this invention may be produced by following this procedure:

(1) Heat ingot which has been poured from a clean melt containing the vanadium additive as described above for a minimum of five hours at a temperature over

2250° F. To remove scabs and to make structure homogeneous and reduce micro segregation may require flash heating to 2450° F. for a short time.

(2) Roll on blooming mill to produce slab having a thickness of 5 to 8 inches and finish at a temperature above 2,000° F., care being exercised to avoid development of laminations and the like.

(2a) Condition surface of slab if required.

(3) Re-heat slab to over 2275° F. and hold to homogenize and reduce slab to a thickness of $\frac{3}{4}$ to $1\frac{1}{2}$ inches. Such reduction is at a fast rate and preferably accomplished in 3 passes on a single stand reversing mill, so that temperature drop is slight.

(4) The partially reduced slab then enters the six stand finishing mill and is rapidly reduced to strip with a thickness of 0.070 to 0.090 inch and at a speed to insure a temperature not more than 1700° F. at front and back end of strip.

(5) Open anneal the hot strip at 1600° F. to 1700° F. followed by a descale operation.

(6) Cold roll the annealed strip to an intermediate gauge thickness of 0.022 to 0.026.

(7) Open anneal the cold rolled strip at a temperature between 1600° F. and 1850° F. in a controlled atmosphere of low dew point.

(8) Cold roll to final thickness usually in the range 0.012 to 0.014.

(9) Open anneal cold rolled strip in decarburizing atmosphere to reduce carbon below 0.005% in a wet reducing gas at a temperature substantially between 1450° F. and 1500° F. Time required is usually 2 to 4 minutes. The strip is then considered semi-processed.

(10) Coat with inorganic material which acts as a spacer material during high temperature anneal and provides an insulating film. The spacer material permits free flow of dry hydrogen during the high temperature anneal. The hydrogen removes the sulfur to under 0.005%.

(11) This anneal is usually performed at 2050° F. to 2150° F.

Although vanadium alone may be employed as an additive in silicon steel to achieve the improved grain orientation, I have found that other additives in addition to vanadium impart desirable results and reduce costs by permitting partial replacement of the vanadium content. In one example, both vanadium and copper were employed as additives. With a copper content in the finished steel between .1 and .25%, less vanadium could be employed and satisfactory results were obtained with as little as .008% vanadium in combination with the copper in a clean steel.

In another example, nitrogen was introduced as well as vanadium. The nitrogen in the ingot ranged from 0.010 to 0.02. This nitrogen must be removed during the final high temperature anneal in dry hydrogen. However, in the early stages of processing and in combination with 0.008 to 0.02% vanadium, it substantially increases orientation to as high as 90% or more.

In still another example, phosphorous was introduced together with the vanadium with phosphorus content maintained between .02 and .04% and vanadium between .008 and .02% with satisfactory results being accomplished with as little as .008% vanadium.

In each melt vanadium is included as one of the constituents of the additive. However, additional constituents may also be employed to advantage. For example, in addition to vanadium there may be both copper and nitrogen, or both copper and phosphorous, or both nitrogen and phosphorous, or copper, phosphorous and nitrogen. The percentages of the additional constituents being within the ranges set forth above.

It is important that any additive added must not generate oxides, nitrides, and so forth, which are finely dispersed in the melt. Such finely divided oxide particles will precipitate into the grain boundary and impair the magnetic properties. It will be noted that the additives

chosen herein are added in very small amounts in order to avoid such deleterious effects. Furthermore, any oxides which can precipitate into grain boundary affect the perfection of (110) [001] texture, and so must be avoided by using suitable deoxidation practices. The cleaner the steel the easier it is to orient the grains by means of suitable additives which tend to perfect the desirable (110) [001] texture.

It is now well established that in a properly processed oriented strip the (110) [001] direction is aligned in the rolling direction for all the grains, but this alignment is not perfect. Torque measurements indicate that in present day material about 80% of the grains are oriented due to the scatter in orientation. However, when the additives vanadium and nitrogen are added to a clean heat, in the sense defined here, even in extremely small amounts, increased perfection in orientation is experienced. A texture which is oriented 90% can be achieved in this way. A clean heat may be defined as one in which the deoxidation products are not finely dispersed. Since it is well known that finely dispersed oxides in excess can adversely affect the magnetic properties, every effort is made to hold the oxides which may be colloidal or finely dispersed under 0.005%. This requires perfection of a suitable deoxidation practice well known in the art.

The additives vanadium and nitrogen singly or in combination with the elements such as copper and phosphorous can therefore only be effective when the heat is substantially free of finely dispersed oxides and so forth. A reliable measure of a clean steel is the initial permeability. Steels having an initial permeability of 1300 or more are usually considered very clean. The best results are obtained with initial permeabilities of 1300 or more. However, I have achieved orientation of 85% or more with steels having initial permeabilities in the range between 1300 or 1350 and 1450. This is an essential requirement, otherwise the additives such as vanadium and nitrogen will not function in the manner described herein.

I have herein shown and particularly described certain embodiments of my invention and certain methods of operation embraced therein for the purpose of explaining its principle of operation and showing its application, but it will be obvious to those skilled in the art that many modifications and variations are possible and I aim, therefore, to cover all such modifications and variations as fall within the scope of my invention, which is defined in the appended claims.

What is claimed is:

Magnetic steel consisting essentially of between 2.8% and 3.3% silicon, between 0.008% and 0.05% vanadium, between 0.1 and 0.25% copper and the balance iron.

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