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(19)

(54) SILICON STEEL AND PROCESSING THEREFOR

(71) We, ALLEGHENY LUDLUM INDUSTRIES, INC., a Corporation organized under the laws of the Commonwealth of Pennsylvania, United States of America, of Two Oliver Plaza, Pittsburgh, Pennsylvania 15222, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to grain-oriented silicon steel and the manufacture thereof, and to a hot rolled band of silicon steel. Unless otherwise stated, percentages are by weight and the Patents referred to are United States ones.

Electromagnetic silicon steels, as with most items of commerce, command a price commensurate with their quality. Coils of steel from a particular heat are graded and sold according to grade. Coils with a particular core loss generally receive a lower grade than do coils with a lower core loss, all other factors being the same; and as a result thereof, command a lower selling price.

A number of recent patents (3,873,381; 3,905,842; 3,905,843 and 3,957,546) disclose that the quality of electromagnetic silicon steel can be improved by adding controlled amounts of boron to the melt. Steels having permeabilities of at least 1870 (G/O_e) at 10 oersteds and core losses of no more than 0.7 watts per pound at 17 kilogauss, have been achieved with said additions. However, the processes described therein leave room for improvement.

Meaningful additions of copper to the type of steel melts described in Patent Nos. 3,873,381, 3,905,842, 3,905,843 and 3,957,546 is not known from the prior art. None of the four cited patents attribute any benefit to copper despite the fact that three of them specify copper contents in their examples; and, moreover, none of them disclose copper additions as high as the minimum specified hereinbelow. Likewise, Patent Nos. 3,855,018, 3,855,019, 3,855,020, 3,855,021, 3,925,115, 3,929,522 and 3,873,380 fail to render the present invention evident. Although these patents disclose copper additions, they refer to dissimilar boron-free and/or aluminum-bearing steels. Moreover, none of the above patents disclose a process of improving the magnetic quality of steel such that at least 25% of the coils of a particular single stage cold rolled heat have a permeability of at least 1870 (G/O_e) at 10 oersteds and a core loss of no more than 0.7 watts per pound at 17 kilogauss.

It is an object of the present invention to provide an improvement in the manufacture of grain-oriented silicon steel.

The present invention provides a process for producing electromagnetic silicon steel having a cube-on-edge orientation, which process includes the steps of: preparing a melt of silicon steel containing, by weight, from 0.02 to 0.06% carbon, from 0.0006 to 0.008% boron up to 0.01% nitrogen, no more than 0.008% aluminum, from 2.5 to 4% silicon and 0.3 to 1% copper; casting said steel; hot rolling said steel to an intermediate thickness of from 0.05 to 0.12 inch; cold rolling said steel to a thickness no greater than 0.02 inch without an intermediate anneal between cold rolling passes; preparing several coils from said steel; decarburizing said steel; and final texture annealing said steel.

The process of the present invention makes it possible to improve the magnetic quality of individual coils of electromagnetic silicon steel: a heat of silicon steel can be processed so that at least 25%, and sometimes more than 50% of the coils have a permeability of at least 1870 (G/O_e) at 10 oersteds and a core loss of no more than 0.7 watts per pound at 17 kilogauss, at both ends; it will be appreciated that this improvement is achieved through controlled amounts of boron and copper.

The process is preferably effected with a melt which consists of, by weight, 0.02 to 0.06% carbon, 0.015 to 0.15% manganese, 0.01 to 0.05% of sulfur or selenium, 0.0006 to 0.008% boron, up to 0.01% nitrogen, 2.5 to 4% silicon, 0.3 to 1% copper, up to 0.008% aluminum, balance iron and unavoidable impurities. The boron present is preferably at least 0.0008%. The preferred amount of copper is at least 0.5%.

When the process of the invention is effected with a melt containing at least 0.0008% boron, there can generally be produced steel coils wherein at least 50% of said coils have a permeability of at least 1870 (G/O_e) at 10 oersteds and a core loss of no more than 0.7 watts per pound at 17 kilogauss, at both ends.

Specific processing as to the conventional steps can be in accordance with that specified in the patents cited hereinabove. Moreover, the term casting is intended to include continuous casting processes. A hot rolled band heat treatment is also includable within the scope of the present invention.

The present invention also provides a hot rolled band of silicon steel having a thickness of from 0.05 to 0.12 inch and consisting of, by weight, 0.02 to 0.06% carbon, 0.015 to 0.15% manganese, 0.01 to 0.05% sulfur or selenium, 0.0006 to 0.008% boron, up to 0.01% nitrogen, 2.5 to 4% silicon, 0.3 to 1% copper, up to 0.008% aluminum, balance iron and unavoidable impurities.

It is to be understood that both sulfur and selenium may be present in the melt or band, providing their combined amount falls within the limits stipulated above.

Although it is not definitely known why copper is beneficial, it is hypothesized that copper forms sulfide particles which act as an inhibitor; thereby improving magnetic properties through an advantageous effect on secondary recrystallization and grain growth. In addition, it is hypothesized that copper decreases the sensitivity of the alloy to hot working temperatures, and thereby increases the uniformity of the magnetic quality between individual coils and coil ends.

The hot rolled band of silicon steel of the present invention is suitable for processing into cube-on-edge oriented silicon steel having a permeability of at least 1870 (G/O_e) at 10 oersteds and a core loss of no more than 0.7 watts per pound at 17 kilogauss.

The following examples are illustrative of several aspects of the invention.

Three heats (Heats A, B and C) were melted and processed into coils of silicon steel having a cube-on-edge orientation. The chemistry of the heats appears hereinbelow in Table I.

TABLE I

Composition (wt. %)

Heat	C	Mn	S	B	N	Si	Cu	Al	Fe
A	0.029	0.040	0.020	0.0013	0.0048	3.13	0.27	0.003	Bal.
B	0.033	0.040	0.021	0.0014	0.0046	3.14	0.38	0.003	Bal.
C	0.031	0.041	0.020	0.0013	0.0046	3.13	0.50	0.004	Bal.

From Table I it is evident that the only significant variation in the chemistry of the heats is in their copper content. Heat A has a copper content of 0.27% whereas the copper contents of Heats B and C are respectively 0.38 and 0.5%.

Processing for the heats involved soaking at an elevated temperature for several hours, hot rolling to a nominal gage of 0.08 inch, coil preparation, hot roll band annealing at a temperature of approximately 1740°F, cold rolling to final gage, decarburizing at a temperature of approximately 1475°F, and final texture annealing at a maximum temperature of 2150°F in hydrogen.

Coils from Heats A, B and C were measured for gage and tested for permeability and core loss. The results of the tests appear hereinbelow in Table II.

TABLE II

Heat	Cu(%)	Coil No.	Gage (mils)	Core Loss (WPP at 17KB)	Permeability (at 10 O_e)
A	0.27	1 In	12.6	0.706	1918
		Out	9.5	0.645	1941
		2 In	11.8	0.732	1901
		Out	12.3	0.712	1922
		3 In	11.8	0.764	1865
		Out*			
		4 In	10.7	0.657	1896
		Out	11.4	0.703	1913
		5 In	11.6	0.678	1920
		Out	10.8	0.674	1901
		6 In	12.2	0.698	1903
		Out	11.3	0.704	1897
		7 In	12.1	0.766	1881
		Out	11.2	0.705	1892
B	0.38	1 In	11.5	0.685	1915
		Out	11.5	0.658	1914
		2 In	11.0	0.667	1904
		Out	11.3	0.715	1880
		3 In*	—	—	—
		Out	10.5	0.663	1901
		4 In	11.6	0.698	1890
		Out	11.1	0.674	1912
		5 In	12.0	0.748	1878
		Out*	—	—	—
		6 In	11.6	0.709	1886
		Out	11.2	0.667	1910
		8 In	11.4	0.667	1910
		Out	10.7	0.680	1890
C	0.50	1 In	11.7	0.684	1910
		Out	11.1	0.657	1911
		2 In	11.3	0.685	1910
		Out	10.8	0.655	1920
		3 In	11.2	0.687	1904
		Out	11.1	0.665	1925
		4 In	12.4	0.715	1891
		Out	12.2	0.696	1910
		5 In	11.6	0.679	1912
		Out	11.2	0.678	1916
		6 In	11.6	0.701	1903
		Out	10.3	0.698	1872
		7 In	11.5	0.684	1894
		Out	10.9	0.668	1913
		8 In	11.2	0.679	1909
		Out	10.5	0.644	1922

*Heavy Gage

From Table II it is clear that only one of the coils from Heat A had at both ends a permeability of at least 1870 (G/O_e) at 10 oersteds and a core loss of no more than 0.7 watts per pound at 17 kilogauss. Significantly, Heat A has a copper content of 0.27%; a level below the minimum of the present invention. On the other hand, three coils from Heat B and six coils from Heat C had magnetic properties exceeding those specified. Significantly, Heats B and C have copper contents within the subject invention; respectively 0.38 and 0.5%. Moreover, more than 50% of the coils from Heat C exceeded the specified properties. Such data indicates that copper contents in excess of 0.5% should be most beneficial.

It will be apparent to those skilled in the art that the novel principles of the invention disclosed herein in connection with specific examples thereof will suggest various other modifications and applications of the same. It is accordingly desired

that in construing the breadth of the appended claims they shall not be limited to the specific examples of the invention described herein.

WHAT WE CLAIM IS:—

1. A process for producing electromagnetic silicon steel having a cube-on-edge orientation, which process includes the steps of: preparing a melt of silicon steel containing by weight, from 0.02 to 0.06% carbon, from 0.0006 to 0.008% boron, up to 0.01% nitrogen, no more than 0.008% aluminum, from 2.5 to 4% silicon and 0.3 to 1% copper; casting said steel; hot rolling said steel to an intermediate thickness of from 0.05 to 0.12 inch; cold rolling said steel to a thickness no greater than 0.02 inch without an intermediate anneal between cold rolling passes; preparing several coils from said steel; decarburizing said steel; and final texture annealing said steel.

2. A process according to Claim 1, wherein said melt consists of, by weight, 0.02 to 0.06% carbon, 0.015 to 0.15% manganese, 0.01 to 0.05% sulfur or selenium, 0.0006 to 0.008% boron, up to 0.01% nitrogen, 2.5 to 4% silicon, 0.3 to 1% copper, up to 0.008% aluminum, balance iron and unavoidable impurities.

3. A process according to Claim 1 or 2, wherein said melt contains at least 0.0008% boron.

4. A process according to Claim 1, 2 or 3, wherein the amount of copper is at least 0.5%.

5. A process for producing cube-on-edge oriented electromagnetic silicon steel substantially as herein described with reference to Heat B or C.

6. Steel whenever produced by the process claimed in any one of the preceding claims.

7. A hot rolled band of silicon steel having a thickness of from 0.05 to 0.12 inch and consisting of, by weight, 0.02 to 0.06% carbon, 0.015 to 0.15% manganese, 0.01 to 0.05% sulfur or selenium, 0.0006 to 0.008% boron, up to 0.01% nitrogen, 2.5 to 4% silicon, 0.3 to 1% copper, up to 0.008% aluminum, balance iron and unavoidable impurities.

8. A hot rolled band according to Claim 7, having at least 0.0008% boron.

9. A hot rolled band according to Claim 7 or 8, wherein the amount of copper is at least 0.5%.

10. A hot rolled band of silicon steel substantially as herein described with reference to Heat B or C.

11. Cube-on-edge oriented electromagnetic steel made from the hot rolled band claimed in Claim 10.

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