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MAGNETIC SHEETS OF LOW ALUMINUM-IRON ALLOYS

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This invention relates to magnetic aluminum-iron alloy materials that exhibit both a high magnetic saturation and a large amount of double orientation, and therefore a high permeability.

It is an object of the present invention to provide aluminum-iron alloys, and shapes thereof, that are characterized by a high amount of cube-on-face grain orientation and a high magnetic saturation.

It is a further object of the present invention to provide a magnetic aluminum-iron alloy according to the foregoing object in which no deleterious alpha-gamma transformation occurs during or subsequent to heat treatment of the alloy.

These objects are attained in accordance with my discoveries in aluminum-iron alloys with low aluminum content. Sheets of alloys are prepared for use in magnetic applications by a rolling and annealing schedule which, in conjunction with the particular compositions involved, characterize the resulting products with a high magnetic saturation and a large amount of double orientation, and thus a high permeability. Consequently, outstanding magnetic materials can be prepared in accordance with my discoveries that have particular utility for such applications as in rotating machinery, because maximum flux level can be experienced without incurring disproportionate copper losses in these magnetic materials. It is also apparent that these materials are further desirable as an aid to minimizing the copper required in a winding in a rotating device since the material has a high permeability.

The materials used in practicing the present invention are aluminum-iron alloys in which the aluminum content is minimized but yet is sufficient to suppress the alpha-gamma transformation evidenced in substantially pure iron upon heat treatment. To secure the highest saturation value, the aluminum content should be kept as small as possible. However, sufficient aluminum must be present to suppress the alpha-gamma transformation and permit retention of the orientation characteristics obtained in the rolling-annealing schedule hereinafter described. Accordingly, the aluminum content should be in an amount sufficient to suppress the alpha-gamma transformation in the resulting alloy but not more than a maximum of about 1.5 percent by weight. While on a theoretical basis it can be said that the amount of aluminum should be minimized so that the highest saturation can be obtained, for practical considerations of commercial practice slightly more than a minimum amount is generally used. Hence the practical minimum is on the order of one percent by weight of aluminum.

Alloys for use in practicing my invention can readily be prepared in accordance with conventional techniques. A satisfactory procedure involves melting electrolytic iron of a purity of at least about 99 percent and then adding commercially pure aluminum of a purity of at least about 99.9 percent to the melt. The melt may be prepared in a vacuum furnace under a partial pressure, e.g. on the order of about one-half atmosphere, of helium or other protective gas. The melt normally is poured under the protective atmosphere to minimize aluminum loss. I have found it convenient to pour at the melting pressure. The solidified alloy then is hot rolled, i.e. at a temperature on the order of 800° to 1000° C. or more, to prepare a plate of the alloy for subsequent rolling and annealing in accordance with the invention. Generally the ingot is hot rolled to a plate of a thickness on the order of about 0.40 to 0.75 inch, for this has been found to be a convenient starting point for the subsequent cold rolling operations.

The plate of aluminum-iron prepared as just described is then cold rolled to the final thickness, i.e. to a thickness on the order of 2 to 30 mils or more. As pointed out above, the resulting products are of particular use in rotating machinery. For this reason, the thicker gauges of about 20 to 30 mils are preferred. Aluminum-iron with about 1 to 1.5 percent of aluminum is ductile and may be cold rolled at room temperature. If desired, warm rolling, i.e. at a temperature up to about 650° C., can be used. When the final thickness is obtained, the sheet is annealed.

To obtain the most desirable characteristics in the final product, a particular annealing schedule is followed. In accordance with my discoveries this involves subjecting the alloy sheet to a temperature of about 650° to 800° C. in dry hydrogen or other protective gas for about ½ to 2 hours or more. The strip suitably is then furnace cooled, or cooled in a cooling chamber, to a temperature below about 400° C. to about room temperature. Thereafter the cooled material is placed in a furnace at a temperature of about 950° to 1250° C. in an atmosphere of dry hydrogen or other protective gas, and the sheet is annealed at this temperature for at least about one hour and generally for about 2 to 4 hours. Products with good characteristics may also be obtained with a single annealing step. In this latter procedure, just the high temperature, or final, anneal is used. Similarly where a double annealing schedule is used, good properties can be developed even upon omitting the cooling step between the anneals.

In the foregoing manner, strips, sheets and other shapes of the alloys described are produced having a high degree of cube-on-face, or double, orientation. Generally the products are characterized by at least 50% of the grains having cube-on-face orientation. It is evident, therefore, that the materials produced will be characterized, magnetically, with properties more nearly approaching those of single crystals than commercial magnetic materials used for these general purposes.

The invention will be described further in conjunction with the following example. It should be understood that the details are given by way of illustration and are not to be construed as limiting on the invention.

Electrolytic flake iron of a purity of 99.9% was placed in a magnesia crucible in a vacuum furnace provided with a resistance winding. The furnace was evacuated and then repressured to about one-half atmosphere with helium. The iron was then melted. Commercially pure aluminum (purity 99.99%) was added to the melt from within the furnace. When the melt was deemed to be uniform, it was poured into a ingot mold within the furnace and then permitted to solidify.

When the ingot had cooled, it was reheated to about 950° C. and then hot rolled to a thickness of 0.50 inch. The resulting plate was permitted to cool to room temperature whereupon it was cold rolled at about room temperature to a sheet of a thickness of 0.025 inch.

The sheet thereby obtained was placed in an annealing furnace containing an atmosphere of dry hydrogen and maintained there at a temperature of 700° C. for about one hour. At the end of this period the sheet was placed in a cooling chamber and permitted to cool to about room temperature. Then the sheet was placed in a furnace containing an atmosphere of dry hydrogen at 1200° C. and held for two hours. At the end of this time it was air cooled.

Strips of material produced as just described were sub-

jected to routine D.-C. testing procedures to determine the magnetic properties. The data obtained are as follows:

TABLE I

Iron alloy	Alloy element	μmax.	H_c	B_1*	B_{10}*	B_{100}*	Br_{10}*	H(B=10)	B_s
Si—Fe	2.65% Si	8,600	.58	8.0	14.5	17.4	7.9	3.2	20.4
Si—Fe	1.30% Si	6,800	.85	5.3	13.8	17.3	8.7	2.11	21.1
Si—Fe	.70% Si	6,000	.94	4.5	14.0	17.5	8.2	2.52	21.2
Si—Fe	.25% Si	2,000	2.0	1	14.0	17.9	8.5	4.0	21.4
Al—Fe	1% Al	14,000	.31	12.0	16.7	19.0		0.70	21.2

[1] In kilogausses, averaged in the rolling and transverse directions in the sheet.

Each of the silicon-iron alloys tested in Table I was a commercial product and the data tabularized are the published data on these materials. The aluminum-iron was prepared in accordance with this invention. From these data, it will be noted that in the first two silicon-irons the saturation induction is high but the maximum permeability is only a moderate value. It is believed that those alloys were not subject to alpha-gamma transformation. In the alloy containing 0.25 silicon it will be noted that a very high saturation induction was obtained. However, in that case the maximum permeability was seriously degraded, probably due to the occurrence of transformation. The aluminum-iron, on the other hand, evidenced a saturation induction on the order of the best of the silicon-irons and had a maximum permeability far superior to any of the other alloys. While this is the most outstanding characteristic developed in the materials, it may be noted from the remaining data that significant improvement was obtained in each of the properties tested for which values are given in Table I. About 60% of the grains were double oriented.

A series of tests were conducted on sheets of two commercial silicon-irons and an alloy prepared in accordance with this invention to determine comparative loss data. The results obtained are as follows:

TABLE II

60 Cycle Loss Data for 1% Al—Fe vs. Other Materials at Indicated Kilogausses

Material	Core losses (watts/#), p_c			Exciting volt-amperes, p_a			A.-C. permeability, μ		
	10/kg.	15/kg.	17/kg.	10/kg.	15/kg.	17/kg.	10/kg.	15/kg.	17/kg.
1.1% Al—Fe	1.16	2.80	3.90	1.47	3.73	8.35	6,850	5,790	1,800
0.25% Si—Fe	2.5	5.4	7.5	11.1	19.4	55.5		1,820	670
2.65% Si—Fe	1.2	2.8	3.3	18.0	45.0	90.0		2,150	

From these data in Table II it can be concluded that the advantages of increased maximum permeability, both A.-C. and D.-C., and the high magnetic saturation induction that characterize products obtained in accordance with my invention are not secured at a sacrifice in other properties such, for example, as core losses. The aluminum-iron shows a core loss comparable to or improved over that for the silicon-irons. Moreover the exciting volt amperes for these magnetic products is vastly improved over that of silicon-irons.

From the foregoing disclosure and data, it is evident that my invention provides magnetic materials with properties that make them highly useful for a wide variety of magnetic applications.

In accordance with the provisions of the patent statute, the principle of the invention has been explained and there is described what is considered to represent its best embodiment. However, it is to be understood that the invention may be practiced otherwise than as specifically described.

I claim as my invention:

1. A method of producing magnetic sheet characterized by a high maximum permeability, a high magnetic saturation induction and at least 50 percent of its grains having a cube-on-face orientation which comprises cold rolling without any intermediate annealing a hot-rolled aluminum-iron alloy plate of a thickness of about 0.40 to 0.75 inch, which alloy consists essentially of aluminum in an amount sufficient to prevent alpha-gamma transformation, the aluminum being present in an amount of from about 1 percent but not in excess of about 1.5 weight percent and the remainder iron, to a sheet of a thickness of 2 to 30 mils, annealing the resulting sheet in a protective atmosphere at a temperature of about 650° to 800° C., and then further annealing the sheet in a protective atmosphere at a temperature of about 950° to 1250° C.

2. A method in accordance with claim 1 in which said alloy is slowly cooled to about room temperature between said annealing steps.

3. A method in accordance with claim 1 in which said alloy is cold rolled to a thickness of about 20 to 30 mils.

4. A method in accordance with claim 2 in which said first annealing step is extended for about 1 to 2 hours and said second annealing step is extended for at least 1½ hours.

5. A method of producing magnetic materials characterized by high maximum permeability, a high magnetic saturation induction and at least 50 percent of the grains having cube-on-face orientation which comprises cold rolling without any intermediate annealing a hot-rolled aluminum-iron alloy plate of a thickness of about 0.4 to 0.75 inch, which alloy consists essentially of aluminum in an amount of from about 1 to 1.5 weight percent and the remainder iron, to a thickness of about 20 to 30 mils, annealing the resulting sheet in dry hydrogen at a temperature of about 650° to 800° C. for ½ to 2 hours, slowly cooling the annealed sheet, and then further annealing the sheet in an atmosphere of dry hydrogen at a temperature of about 1150° to 1250° C. for about 1 to 4 hours.

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