United States Patent [19]

Fieldler

[11] **3,793,092**

[45] **Feb. 19, 1974**

[54] **FINE-GRAINED, COMPLETELY DECRYSTALLIZED, ANNEALED COBALT-IRON-VANADIUM ARTICLES AND METHOD**

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[22] Filed: **Nov. 10, 1972**

[21] Appl. No.: **305,588**

Related U.S. Application Data

[63] Continuation of Ser. No. 847, Jan. 5, 1970, abandoned.

[52] **U.S. Cl.** **148/31.55,** 148/120, 148/121

[51] **Int. Cl.** **C04b 35/00**

[58] **Field of Search** ..... 148/31.55, 120, 121, 122; 75/123 K, 170, 134

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[57] **ABSTRACT**

Sheet or strip articles composed of an alloy nominally composed of about 49 percent cobalt, 49 percent iron and 2 per cent vanadium are disclosed which have a 0.2 per cent yield strength of about 70,000 p.s.i. or greater and a magnetic induction of about 20,000 gausses or greater at 13 oersteds and 22,400 gausses or greater at 85 oersteds are disclosed.

2 Claims, No Drawings

FINE-GRAINED, COMPLETELY DECRYSTALLIZED, ANNEALED COBALT-IRON-VANADIUM ARTICLES AND METHOD

This is a continuation of copending application Ser. No. 847 filed Jan. 5, 1970 and now abandoned, assigned to the assignee hereof.

This invention relates to magnetically soft alloys and more particularly to the treatment of an alloy of cobalt, iron and vanadium to produce optimum magnetic and mechanical properties therein.

A commercially obtainable magnetically soft alloy of cobalt, iron and vanadium, known as Vanadium Permendur, is commonly used in sheet or strip form for laminations for rotating electrical equipment such as electrical generators or motors, particularly where weight is important. This material has a nominal composition of about 49 weight percent cobalt, 49 weight percent iron and 2 weight percent vanadium, with small amounts of various impurities such as sulfur, carbon, oxygen and nitrogen. This material has both high magnetic saturation and zero magnetocrystalline anisotropy. While mechanical strength has not been of concern in the past, stresses produced by centrifugal force in newer, high speed generators, for example, may exceed the yield strength of conventional commercial material. Vanadium Permendur is conventionally sold as cold-rolled sheet or strip material, from which the purchaser may punch laminates, after which the punched laminates are batch annealed to produce recrystallization and develop the desired magnetic properties in the laminates. In the cold-rolled or incompletely recrystallized state, the mechanical properties are high but the magnetic properties are low. After recrystallization, the mechanical properties are significantly lower but the magnetic properties are higher. It would be desirable if such materials could be made with both high mechanical and magnetic properties and such is a principal object of this invention.

Briefly stated, and in accordance with one aspect of the invention, it has been found that Vanadium Permendur may be treated so that the product has a controlled, small grain size, substantially no gamma phase (an undesirable non-magnetic phase which may be present in conventionally produced material), which improved product has a high yield stress and high magnetic properties. More specifically, the material of the invention has a yield strength of about 70,000 p.s.i. or higher at 0.2 per cent strain, and a magnetic induction of not less than about 20,000 gausses at 13 oersteds and 22,400 gausses at 85 oersteds.

In order to more clearly point out and describe the invention, the following examples of mechanical and magnetic properties achieved by the practice of the present invention upon Vanadium Permendur are compared to those properties conventionally exhibited by this material. For this purpose, four commercial compositions were employed.

TABLE I

	Compositions (per cent by weight)						
Heat No.	V	Co	Fe	S	C	O	N
1	2.0	49.2	48.7	0.003	0.006	—	—
2	2.0	49.1	48.7	—	0.002	0.0036	0.0003
3	1.9	48.8	49.1	—	0.004	—	—
4	1.9	49.2	48.7	—	0.008	—	—

These materials were obtained from the manufacturer as cold-rolled strip about 0.015 inch thick. Tensile test samples and magnetic test samples of these materials were given the conventional, so-called "batch" heat treatments in the following manner. Samples were placed between thin alumina plates one-eighth inch or one-fourth inch thick, sealed with foil in a metal retort through which dry hydrogen was circulated and heated in a hydrogen furnace which had been determined to be within 1°C of the desired temperature. After a predetermined time, the specimens were cooled in the furnace at 50°C per hour to 400°C and the retort removed from the furnace and allowed to come to room temperature before opening. The 0.2 per cent strain yield strengths of these materials were then determined at a strain rate of 0.025 per minute, and the magnetic measurements were made on one-fourth inch high stacks of ring samples 1 ¼ inches I.D. and 1 ¾ inches O.D. or 1 7/8 inches I.D. and 2 ½ O.D. cut from the specimens. The following exemplary data is given for Heat No. 2 heat treated for times at temperature of 0.5 hour and 2.0 hours and are fairly typical of such materials.

TABLE II

	Heat No. 2 Annealed 0.5 Hour Temperature, °C.			
	704°	707°	709°	719°
0.2% Y.S. (p.s.i.)	109,520	91,070	72,080	57,990
	98,140	96,050	64,400	55,590
B at 13 oe.	8,500	10,625	12,725	—
B at 85 oe.	21,575	21,775	22,650	—

TABLE III

	Heat No. 2 Annealed 2.0 Hours Temperature, °C.			
0.2% Y.S.	72,490	59,719	54,770	46,540
	79,720	60,010	55,320	46,710
B at 13 oe.	13,925	19,050	20,325	22,120
B at 85 oe.	22,000	22,625	22,875	23,125

The above yield strengths are all longitudinal, i.e. the stress axis is parallel to the rolling direction.

In all these, it will be seen that when the yield strength of the material is acceptably high, the magnetic inductance is not acceptably high, and when the magnetic properties are acceptable, the yield strength is too low. Upon metallographic examination of these materials, it became evident that the better magnetic properties were exhibited by those samples which had been completely recrystallized at higher temperatures and for the longer times at temperature. In those samples annealed, for example, at temperatures above

702°C for 2.0 hours, the completeness of recrystallization and grain growth lead to a sharp drop in yield strength. An undesirable non-magnetic phase present as a precipitate was found to be prevalent in samples annealed for 2.0 hours at 695° and 702°C, visible in the sample annealed at 710°C and essentially absent from the sample annealed at 750°C. In the samples annealed at the higher temperatures which produced essentially a single phase, the average grain size was large, for example, about A.S.T.M. 9 or less, or stated in terms of grain size intercept length as about 12.5 microns or greater.

It was found that the desired combination of mechanical and magnetic properties in these materials could be achieved by treating the cold rolled material to produce a small recrystallized grain size by heating a short time to minimize grain growth and at a relatively high temperature to promote the nucleation of many rather than a few recrystallized grains, and at the same time, produce a structure free of the non-magnetic gamma phase. This may be demonstrated by the following data obtained from the same materials set forth in Table I and treated in accordance with the following heat treating cycles.

TABLE IV

Cycle	Minutes within 10°C of Max. Temp.	Total Time (min.)
A	3.5	24
B	2	14
C	1	7

The following representative data for materials so heat treated on a traveling mesh belt through a metal retort which at one end was encased in a furnace and at the other by a water cooled jacket.

TABLE V

Heat No. 2, Cycle A
Maximum Temperature, °C

	723°	735°	737°	742°	760°
0.2% Y.S. (p.s.i.)	89,820	69,920	71,580	69,740	61,160
	85,370	69,920	76,570	72,500	58,520
B at 13 oe.	—	20,150	18,600	20,000	20,950
B at 85 oe.	—	22,600	20,800	23,150	23,420

Heat No. 2, Cycle B
Maximum Temperature, °C

	745°	748°	759°	760°	780°
0.2% Y.S. (p.s.i.)	82,720	79,380	72,780	70,950	62,660
	80,910	78,300	73,370	70,410	63,700
B at 13 oe.	17,200	19,750	20,300	20,450	20,800
B at 85 oe.	22,750	22,450	22,650	22,625	22,725

Heat No. 3, Cycle B
Maximum Temperature, °C

	748°	751°	760°
0.2% Y.S. (p.s.i.)	78,650	70,500	66,990
	77,500	71,600	67,750
B at 13 oe.	20,075	20,450	—
B at 85 oe.	22,500	22,725	—

Heat No. 4, Cycle B
Maximum Temperature, °C

	748°	751°	760°
0.2% Y.S. (p.s.i.)	77,440	68,700	65,590
	78,940	70,580	66,440
B at 13 oe.	19,750	20,225	20,500
B at 85 oe.	22,475	22,625	22,700

Heat No. 1, Cycle B
Maximum Temperature, °C

	744°	760°
0.2% Y.S. (p.s.i.)	81,200	75,950
	84,943	75,030
B at 13 oe.	19,125	20,650
B at 85 oe.	22,700	23,200

TABLE VI

Tensile and Magnetic Properties, Cycle C.
Heat No. 2
Maximum Temperature, °C

	765°	770°	790°
0.2% Y.S. (p.s.i.)	74,050	72,790	69,210
	72,610	74,010	68,560
B at 13 oe.	20,075	20,300	20,300
B at 85 oe.	22,575	22,600	22,500

TABLE VII

Heat Treatment, Cycle C.
Maximum Temperatures, 765°C.

	Heat No. 1	Heat No. 3	Heat No. 4
0.2% Y.S. (p.s.i.)	79,450	72,330	71,540
	78,430	71,950	71,650
B at 13 oe.	20,175	20,275	20,000
B at 85 oe.	23,000	22,575	22,750

Microscopic examination of the several structures produced by the foregoing heat treatments revealed that while "batch" type heat treatments are not suitable for producing Vanadium Permendur strip or sheet material with the desired combination of high mechanical and magnetic properties, such materials having the desired combination of high mechanical and magnetic properties must be heat treated at a high enough temperature to promote the nucleation of many rather than few recrystallized grains and to produce no gamma phase, but for a time which is short enough to permit complete recrystallization but to minimize grain growth. Based upon observation, such desirable recrystallized materials should have an average grain size of less than about 8 microns, or, stated of ASTM grain size numbers, about 10.5 or greater. Such heat treatment may be readily achieved by a continuous strip anneal, by passing formed sheet or strip parts through a furnace on a belt or the like, or by using a salt bath, for example. When these materials are used as motor or generator laminations, they are conventionally punched or stamped from sheet or strip material having a thickness range of from about 4 mils to 25 mils, so such expedients as previously referred to are readily adapted to either the sheet or strip before or after the forming operation.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. As an article of manufacture, a fully recrystallized body formed from a wrought sheet or strip consisting essentially of an alloy of about 49 percent cobalt, 49 percent iron and 2 percent vanadium, said body having a yield strength at 0.2 percent strain of about 70,000 psi or greater, a magnetic induction of at least about 20,000 gauss in a field of 13 oersteds and at least about 22,400 gauss in a field of 85 oersteds, said body having an average grain size of about 8 microns or less and being characterized by the absence of the non-magnetic gamma phase, said body having a completely recrystallized grain structure.

2. A method of processing an alloy consisting essentially of 49 percent iron, 49 percent cobalt and 2 percent vanadium, to develop an improved combination of magnetic properties and strength which comprises continuously annealing said alloy at a temperature from about 1367°F to 1418°F for a time sufficient to produce an average grain size of about 8 microns or less and a completely recrystallized grain structure and cooling to produce an annealed product which is characterized by the absence of the non-magnetic gamma phase and having a magnetic induction of at least 20,000 gauss in a field of 13 oersteds and at least about 22,400 gauss in a field of 85 oersteds and a yield strength of at least 70,000 psi.

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