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2,990,277

HIGH INITIAL PERMEABILITY MAGNETIC ALLOY

Carl B. Post, Wyomissing, and Warren S. Eberly, Temple, Pa., assignors to The Carpenter Steel Company, Reading, Pa., a corporation of New Jersey
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This invention relates to a magnetic alloy and more particularly to such a composition characterized by extremely high initial permeability for very low magnetizing forces with relatively low hysteresis loss.

A composition which has long been known and used is set forth in U.S. Patent No. 1,768,443 and is commercially available as an alloy containing about 0.05% carbon, 0.50% manganese, 0.15% silicon, 79.0% nickel, 4.50% molybdenum and the balance iron. The alloy is normally melted in an electric (arc or induction) melting furnace and processed into strip ranging from about 0.001 to 0.020 inch in thickness. Laminations and parts are formed from the strip as by blanking or deep drawing followed by an annealing treatment at about 2050° F. for a period of about four hours in an oxygen free atmosphere of dry hydrogen, followed by cooling at rates determined by the nature of the product, its intended use and the properties required.

Experience has shown that such compositions are difficult to melt and process so as to provide commercially desirable uniformity in its magnetic properties. A commercial standard of minimum initial permeability (μ) of 20,000 has been established although, even when great care is used in the selection and processing of the materials used, the initial permeability may and often does vary from one heat to another to a wide degree.

This standard of merit represents a substantial compromise because higher initial permeability is much desired. Here and elsewhere throughout the present application, by permeability it is intended to refer to the standard value represented by the ratio of the flux density measured in gauss, produced in the composition to the magnetizing force in oersteds producing this flux density. The initial permeability values set forth herein were obtained with a flux density of 40 gauss induced by a 60 cycle per second current, but it is to be understood that use of the present composition is not limited thereto because other flux densities and direct or alternating current may be used.

More recently it has been found that initial permeabilities of about 50,000 may be obtained by melting an alloy containing somewhat more molybdenum (up to about 5%), in vacuum and then annealing the strip material at a temperature of about 2400° F. Unfortunately, this improved result is not as readily attainable by this method as is desired. Furthermore, it involves a substantial increase in costs because furnaces designed for operation at temperatures of around 2400° F. are not only more costly but also have a relatively short life. There is also a greater probability of the strips or laminations sticking together or becoming distorted when treated at such a high temperature thereby increasing the amount of scrap or wastage.

The present invention is mainly concerned with the provision of a composition capable of demonstrating extremely high initial permeability when fabricated into parts and processed commercially in the field. Unexpectedly high initial permeability is obtained even when a part made from the present composition is processed and then annealed at, for example, 2050° F. Higher annealing temperatures may be utilized when even higher initial permeabilities are desired. However, as will be more fully pointed out hereinafter the results achieved when

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the annealing treatment is carried out at the lower temperatures, which are more practical from the commercial standpoint, compare favorably with the results hitherto obtainable when such a high annealing temperature as 2400° F. had been utilized.

In order to achieve the foregoing as well as other advantageous properties, it is necessary to prepare a composition in which the following alloying elements are present within narrow ranges as indicated:

	Percent
Nickel	75-85
Molybdenum	3.0-5.0
Vanadium	0.04-0.95

and in which the balance is substantially iron as will be more fully pointed out hereinbelow. The magnetic properties are sensitive to the presence of impurities and are detrimentally affected thereby. Care is exercised to keep impurities to a minimum by selection of high quality commercial grades of the raw materials utilized. While care is to be exercised to avoid the presence of undesired impurities customary commercial practices result in various elements being present in quantities which may vary from a few thousandths of a percent to a few hundredths of a percent. For example, phosphorous and sulphur each were present in the alloys listed in Table I, hereinbelow, in amounts less than 0.01%. Chromium was present in amounts less than 0.05%. Furthermore, various elements not necessary to the achievement of the desired magnetic properties may be included which do not adversely affect the magnetic properties to an undesirable extent but which are beneficial as, for example, in connection with the melting or working of the alloy. It is, therefore, intended to include by the expression "balance substantially iron" such elements as, for example, silicon and manganese, which do not objectionably affect the desired magnetic properties but are beneficial for other purposes.

The effect of the various constituent elements of the composition is not fully understood at the present time. However, as is known, nickel-iron-molybdenum alloys provide optimum magnetic properties when the nickel ranges in amount from about 75% to 85% of the composition. The highest initial permeability and maximum permeability are obtainable when the nickel content is close to 80%, that is, ranging from about 79% to about 80.5%. Carbon is believed to adversely affect the desired magnetic properties and for this reason is limited in this composition to not more than 0.10% and preferably is limited to not more than 0.04%. Silicon and manganese are included for the purpose of maintaining fluidity in the melt and to improve the hot workability of the composition. For this purpose, up to about 1% manganese and 1% silicon is helpful. Molybdenum in amounts ranging from about 3% to 5% improves the resistivity of the composition, increases initial permeability, and simplifies the heat treatment necessary to obtain high initial permeability. However, in amounts more than 5% it appears that molybdenum may detrimentally affect the magnetic properties of the composition to an undesirable extent. Best results are achieved with the molybdenum content ranging from about 3.75% to about 4.5%.

Vanadium is effective to provide the outstandingly high initial permeability in this composition although the mechanism by which this is accomplished is not fully understood at this time. It has been found that when present in amounts of from 1% or more, vanadium is not effective to provide the desired improvement in initial permeability. Tests conducted have shown that vanadium in such large quantities as 1% or more has no apparent beneficial effect and the measured initial permeabilities are substantially the same as those obtained when vanadium

is present in only residual amounts, about 0.01% or less. Vanadium in amounts ranging from 0.04% up to 0.95% is effective in this composition to provide initial permeabilities, the mean value of which is consistently higher by a significant amount than the mean value obtainable when vanadium is present in only residual amounts or when more than about 1.0% vanadium is present. The mean value of the initial permeabilities obtained is referred to here and elsewhere in this application because of the sensitivity of such magnetic compositions to minor variations in processing with the result that the value of the initial permeability of specimens may vary from one annealing treatment to another. Also some further dispersion in the value attained may result from variations in the amount of impurities present in the composition. Thus, while the value 26,000 is usually considered as the mean initial permeability for commercially prepared compositions hitherto available having an analysis such as that of said patent, the actual dispersion usually ranges from just above 20,000 to just above 30,000. By using vacuum melting techniques even higher results may be obtained but not consistently enough to be considered practical for commercial purposes. Because of this dispersion in the attainable values it was found necessary to establish initial and maximum permeability standards which would permit equipment manufacturers to attain consistently no less than established minimum performance characteristics. In connection with said prior art composition, with an annealing treatment of 2050° F., it was necessary to establish a standard minimum initial permeability of 20,000 even though in some instances an initial permeability of as much as 30,000 or more is obtained. As will be pointed out more fully hereinafter, a minimum improvement of about 5,000 is achieved in the initial permeability with vanadium present in amounts ranging from about 0.04% to about 0.95%.

Preferably a vanadium content of from about 0.25% to about 0.75% is included in this composition in order to consistently achieve an improvement in initial permeability of about 10,000. The maximum attainable initial permeabilities are achieved with a vanadium content close to 0.5% or ranging from about 0.45% to about 0.6%. At this level of vanadium initial permeabilities of 50,000 or more are consistently achieved providing an improvement of about 30,000 in the minimum initial permeability attainable.

It is to be understood that the foregoing permeability values refer to products formed from the composition and annealed at the low temperature of 2050° F. Results obtained indicate that even better values of initial permeability are achieved when a higher annealing temperature of from about 2200° F. to 2300° F. is used and to obtain such optimum values it is not necessary to resort to the higher annealing temperature of 2400° F. Also it should be noted for purposes of comparison that here and elsewhere in the present application the strip thickness of the material as tested was 0.008 inch.

In preparing the composition a charge is made up of ingot iron, electrolytic iron, plate nickel and metallic molybdenum which is melted in a crucible in the desired proportions. To this melt, metallic silicon, ferrovanadium (FeV) and electrolytic manganese are added in proper proportions. The melting, refining and teeming of the metal are all carried out in a vacuum furnace. The thus formed ingots are stripped from the molds and allowed to cool in air. The ingots are then reheated to about 2300° F. and hot worked into a slab. The slab is reheated and by hot working and hot rolling is formed into strip usually .25 inch to about .20 inch in thickness. This strip is cleaned to remove the milled scale and is then cold rolled to the final thickness which for most purposes is .014 inch or less. Alloys were prepared, in keeping with the foregoing, having analyses as set forth in Table I below:

Table I

Ex. No.	C	Mn	Si	Ni	Mo	V	Initial Permeability B ₄₀ Gauss
1	.087	.67	.16	79.86	4.47	.25	55,000
2	.004	.70	.10	79.72	4.29	.26	39,800
3	.004	.66	.21	79.75	3.90	.26	38,800
4	.010	.67	.26	80.22	4.25	.35	53,500
5	.020	.53	.03	79.87	4.28	.60	70,050
6	.010	.53	.18	80.01	4.17	.56	69,000
7	.010	.55	.04	80.05	4.32	.50	66,000
8	.022	.53	.18	80.04	4.09	.56	58,050
9	.030	.53	.20	80.83	4.42	.58	57,500
10	.020	.52	.17	79.84	4.00	.54	56,050
11	.026	.53	.17	79.76	4.15	.52	55,500
12	.030	.61	.24	79.36	4.00	.51	48,000
13	.020	.53	.17	79.71	4.09	.48	47,500
14	.020	.54	.17	79.67	4.09	.51	46,400
15	.005	.67	.16	80.18	4.10	.76	60,700
16	.002	.67	.15	80.20	4.90	.75	47,500
17	.005	.68	.16	80.10	4.39	.76	42,500

Rings having an outside diameter of 1½ inches and an inside diameter of 1 inch were formed from 0.008 inch strip by blanking. A stack of 30 such rings weighing about 30 grams was formed of each example and was annealed in a dry hydrogen atmosphere having a dew point of -40° or less. This annealing treatment was carried out at 2050° F. for about 4 hours. Then each specimen was cooled through the Curie point at a rate of 200° to 250° F. per hour. This cooling was accomplished in the dry hydrogen atmosphere. A specimen of each of the examples in Table I was thus prepared and after being demagnetized was subjected to an increasing 60 cycle per second magnetizing force until a flux density of 40 gauss was obtained. The energizing current producing this flux density was measured and the initial permeabilities indicated in Table I were calculated.

For purposes of comparison, examples were prepared having analyses as indicated in Table II but with only 0.01% or less vanadium in the case of Examples 18 and 19, as indicated by the R in the vanadium column or more than 1% as in the case of Examples 20 and 21.

Table II

Ex. No.	C	Mn	Si	Ni	Mo	V	Initial Permeability B ₄₀ Gauss
18	.022	.62	.02	79.43	4.33	R	21,050
19	.021	.53	.02	79.74	4.19	R	30,500
20	.032	.65	.21	79.76	4.65	1.11	17,400
21	.063	.60	.19	80.14	4.14	1.12	25,800

Test specimens of Examples 18-21 were prepared and tested in the same manner as indicated in connection with Examples 1-17. On comparing the values given in Table II under initial permeability with those indicated in Table I, it is seen that unexpectedly high values of initial permeability are obtained with the present composition. Furthermore, Examples 5-13 indicate that even though the relatively low annealing temperature of 2050° F. is utilized, the present composition provides results which compare well with those obtained with compositions hitherto available even when the latter are annealed at the more favorable annealing temperature of 2400° F.

For purposes of further comparison alloys were prepared having the analyses indicated in Table III:

Table III

Ex. No.	C	Mn	Si	Ni	Mo	V	Initial Permeability	D.C. Coercive H _c at 1 Oersted
22	.020	.67	.23	80.22	4.27	.51	84,800	.0044
23	.028	.26	.02	79.78	4.65	R	61,000	.0054

Test specimens were prepared from each of Examples 22

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and 23 and the fabrication and treatment of each of these test specimens was the same as indicated in connection with the specimens prepared from examples of Table I except that in connection with Examples 22 and 23 the annealing treatment was carried out at 2400° F. A low hysteresis loss is indicated by the low D.C. coercive force (H_c) as tested under a 1 oersted magnetic force ($H=1$) as shown in Table II. The initial permeability of 84,800 obtained from the specimen having the composition of Example 22 compares favorably with the initial permeability of 61,000 obtained from the specimen of Example 23. The low D.C. coercive force (H_c) as obtained with the analysis of Example 22 also compares well with that obtained from the prior art composition represented by Example 23.

As brought out hereinabove, such magnetic alloys are sensitive to the method of treatment utilized. It is, therefore, to be understood that the values and results stated herein are necessarily subject to wide variations depending upon the treatment utilized. This is particularly the case if the cooling rate of about 200° to about 250° F. set forth herein is departed from.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. A magnetic alloy, consisting essentially of about 75% to about 85% nickel, about 3% to about 5% molybdenum, about 0.04% to about 0.95% vanadium, and the balance essentially iron.

2. A magnetic alloy, consisting essentially of about 75% to about 85% nickel, about 3% to about 5% molybdenum, about 0.04% to about 0.95% vanadium, up to about 0.10% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

3. A magnetic alloy, consisting essentially of about 75% to about 85% nickel, about 3% to about 5% molyb-

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denum, about 0.04% to about 0.75% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

4. A magnetic alloy, consisting essentially of about 75% to about 85% nickel, about 3% to about 5% molybdenum, about 0.25% to about 0.75% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

5. A magnetic alloy, consisting essentially of about 79% to about 80.5% nickel, about 3.75% to about 4.5% molybdenum, about 0.04% to about 0.95% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

6. A magnetic alloy, consisting essentially of about 79% to about 80.5% nickel, about 3.75% to about 4.5% molybdenum, about 0.04% to about 0.75% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

7. A magnetic alloy, consisting essentially of about 79% to about 80.5% nickel, about 3.75% to about 4.5% molybdenum, about 0.25% to about 0.75% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

8. A magnetic alloy, consisting essentially of about 75% to about 85% nickel, about 3% to about 5% molybdenum, about 0.45% to about 0.6% vanadium, and the balance essentially iron.

9. A magnetic alloy, consisting essentially of about 79% to about 80.5% nickel, about 3.75% to about 4.5% molybdenum, about 0.45% to about 0.6% vanadium, up to about 0.1% carbon, up to about 1% manganese, up to about 1% silicon, and the balance essentially iron.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Carl B. Post et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 8, for "II" read -- III --.

Signed and sealed this 23rd day of January 1962.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

DAVID L. LADD

Commissioner of Patents