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MANUFACTURE OF MAGNETIC ALLOYS

Filed Oct. 21, 1931

Fig. 1.

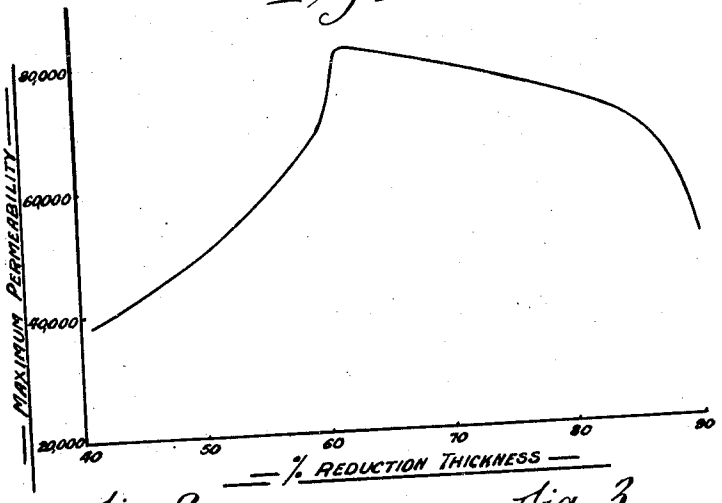


Fig. 2.



Fig. 3.

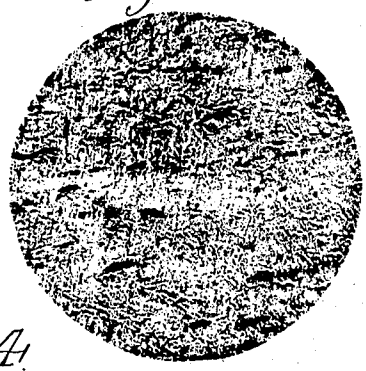
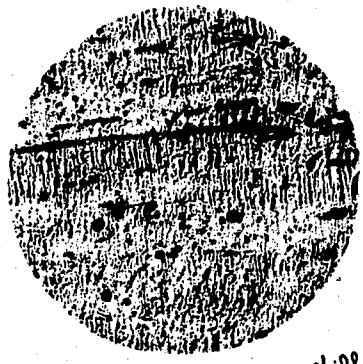


Fig. 4.



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UNITED STATES PATENT OFFICE

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MANUFACTURE OF MAGNETIC ALLOYS

Application filed October 21, 1931, Serial No. 570,252, and in Great Britain October 31, 1930.

This invention relates to the manufacture of magnetic materials and alloys and more particularly to a method for increasing high magnetic permeability therein.

Variations in the magnetic properties of certain ferro-magnetic metals and alloys, especially at low magnetizing fields, have never been thoroughly explored or controlled, although subjected to much examination in later years. Differences in chemical composition, the presence or absence of impurities and dissolved gases, variations in heat treatment, grain size, and internal strains have all been considered as contributory causes. We have found, however, that while these various factors have their effect upon magnetic properties, an important factor which materially influences the magnetic properties of the alloy, is the crystallomorphic orientation of the crystals of which the alloy is built up.

It is a known fact that in the case of a single crystal of iron, the magnetic permeability in a direction at right angles to a cube-face rises more steeply with increasing magnetizing field than in a direction at right angles to a face of the rhombic dodecahedron, where, however, the permeability rises more steeply than in a direction at right angles to an octahedron face. On the other hand, in the case of a single crystal of nickel, the magnetic permeability in the direction at right angles to an octahedron face rises more steeply than in the direction at right angles to a cube face, with the direction at right angles to a facet of the rhombic dodecahedron occupying an intermediate position.

We have found that ferromagnetic material in the form of strip upon which a mean amount of cold-work has been carried out possesses, after standard heat treatment, a higher permeability than a strip of the same material worked either more or less and subjected to the same heat-treatment. We have also found that this increased permeability can indeed be developed in the strip which has been subjected to the greater amount of work if the latter is subjected to a very much longer heat treatment than is that upon which the proper amount of cold work has been carried out, whereas the lightly work strip, such a strip that has received hot-rolling but little or no cold rolling, will never fully respond to heat treatment.

Our investigations have revealed that these phenomena are due to the presence or absence in the ferromagnetic material of a particular form of crystallization. It seems that high magnetic permeability is associated with a definite crystal orientation, which is most readily induced in the material by subjecting the latter to the proper amount of cold-work before the heat-treatment to develop the magnetic properties. While the amount of cold work necessary varies with the constituents of the alloy and with the ultimate thickness of the strip, in general the desired crystal orientation is produced when the material has been cold worked to a point where the crystal outline is substantially completely obliterated without, however, rendering the material amorphous, the cold working being arrested when the crystallographic axes are inclined to the plane of rolling so that after recrystallization the octahedral face coincides with the rolled surface of the alloy. If the material has been cold worked to an excessive degree there is obtained after heat treatment a more or less unstable crystal orientation which, however, passes into the more stable form if the heat treatment is greatly prolonged.

The object of this invention, therefore, is so to precondition a piece of ferromagnetic material, which is composed not of a single crystal but of innumerable minute crystals, that upon subjecting it to heat treatment to develop magnetic permeability it will crystallize wholly or predominantly in the form in which the highest magnetic properties are manifested.

In accordance with the present invention, therefore, the amount of cold working of a magnetic material is controlled with the object of obtaining, after a final heat treatment an increased or higher magnetic permeability.

In one method of carrying out the invention the ferromagnetic material in strip or sheet form is reduced by the ordinary known methods, such as by hot rolling followed by

cold rolling with the necessary intermediate anneals to a size such that the subsequent reduction in the cold necessary to bring the alloy to its finished size will not produce an overworked or underworked condition in the alloy but will leave the alloy in the proper condition for the development after heat treatment, of the highest magnetic permeability.

In practice the metal or alloy is melted by known methods with the usual precautions to obtain purity and constancy of composition. The metal is cast as an ingot in chilled moulds and reduced by hot rolling at a temperature of about 1000–1100° C. to a thickness between three and four times that of the finished strip required. The hot rolled strip is then reduced, without further annealing, by cold rolling to the finished size, the amount of cold rolling being sufficient to develop on recrystallization the crystal form in which the metal or alloy exhibits its optimum magnetic properties.

It will be appreciated that the amount of cold working to which an alloy may safely be subjected, varies with the constituents of the alloy, and is dependent upon the ultimate size or thickness required which also controls the amount of reduction that can be effected at each passage of the material through the rolling mills.

The invention is illustrated in the accompanying drawing in which Figure 1 is a diagram illustrating the variation in maximum permeability of a typical nickel iron alloy, which is obtained after the necessary heat treatment by controlling the amount of cold rolling prior to heat treatment. Figures 2, 3 and 4 are photo micrographic views (magnification x 150) of polished sections of an alloy showing the same respectively in underworked, mean worked in accordance with the invention, and over worked conditions respectively. Referring to Figure 1, the y-co-ordinates denote permeability and the x-co-ordinates the percentage of final reduction in thickness of the alloy by cold rolling, this being the ratio that the thickness of the finished strip bears to the thickness of the strip following the last anneal. It will be noted that there is a peak value at about a 62% final reduction, but that high permeability values are obtainable between about 58–85% reduction.

In some cases therefore, when a very thin finished size is required, it may be more economical to carry out two stages of cold rolling; for instance, in the production of .005″ strip, the ingot should be hot rolled to .06″, cold rolled to .018–.02″, then annealed to resoften the material, and finally reduced by further cold rolling to the thickness required.

After the amount of cold working which is required in accordance with this invention, the alloy is subjected to the usual heat treatment for developing magnetic permeability.

Referring now to Figures 2–4, three samples were prepared from a nickel iron alloy of high nickel content containing small proportions of copper and other elements, by reducing specimens of the alloy, by the usual methods of hot rolling and cold rolling with the necessary intermediate anneals, as described above, and then subjecting the specimens to the different final reductions in the cold, stated in the table below. The micrographs were taken after the final cold work but before heat treatment.

Micrograph	Extent of cold work	Remarks	After heat treatment	
			μ_o	μ_{max}
Figure 2	40%	Under-worked—crystal grains still apparent.	15,000	30,000
Figure 3	66%	Worked in accordance with the invention—grains broken up but no striations as in overworked sample.	16,000	43,000
Figure 4	85%	Overworked—striated appearance due to overwork.	12,000	25,000

The values of the initial and maximum permeability given in the above table were obtained after heat treatment of the cold worked specimens in the usual manner; the permeability values of the cold worked alloy prior to heat treatment are very low in all three cases.

The values of the final reduction in the cold, stated in the above table, apply for the particular alloy used, but vary of course with the composition of the alloy; the structures illustrated in the micrographs are, however, typical for all the magnetic metals and alloys in question.

By way of example it may be mentioned that it has been found necessary to cold work the alloys described and claimed in the U. S. Patent No. 1,656,959, Smith and Garnett, of January 24, 1928, in order to develop in them after heat treatment high magnetic permeability. Careful investigation has shown, however, that these alloys must be cold worked to a definite extent, within not very critical limits, in order to develop after heat treatment the highest magnetic permeability and it has been found that for the production of .005″ strip, the thicknesses given in the preceding paragraph are suitable limits for the different stages of reduction. The effect of heat treating this alloy strip preferably at about 1150° after it has received the correct amount of cold work is to develop an octahedral structure in the direction of rolling which in these alloys is accompanied by a very high magnetic permeability. If the cold working has been insufficient, a cubic structure is developed, while another type of structure is developed after excessive cold work.

When the alloy has been subjected to ex-

cessive cold work the material may be annealed for a period and/or at a temperature which is dependent upon the crystal formation required to give high magnetic permeability.

By making small additions of other elements such as silicon, to the pure alloy, it is possible to render a form of crystallization, which the pure alloy assumes with difficulty, more easily attainable. The addition of such elements has the effect of causing the alloy or metal to favour the form of crystallization desirable for high permeability, thereby making it much easier to control the crystallization by the preliminary cold work.

Example 1.—An alloy containing:

	Per cent
Iron	16.8
Chromium	1.6
Manganese	0.7
Copper	5.0
Silicon	0.02

and nickel the remainder, after reduction by the optimum process described and annealing gives values for μ_{max} varying between 70,000 and 120,000.

Example 2.—An alloy containing:

	Per cent
Iron	16.8
Chromium	1.6
Manganese	0.6
Copper	5.0
Silicon	0.20

and the remainder nickel, gives, when subjected to the optimum treatment, a value of $\mu_{max}=100{,}000$ within $\pm 10\%$.

Example 3.—An alloy having the composition:

	Per cent
Ni	76.51
Fe	16.65
Cu	4.90
Cr	1.36
Mn	0.40
Si	0.18

was reduced to strip 0.015 inch in thickness in the way described above, the final reduction by cold rolling being about 60%. The strip was then sheared to a width of ¾ inch wound into a spiral of 3 inches internal diameter and 4.9 inches outside diameter, heat treated in a neutral atmosphere at 1120° C. for 30 minutes, and cooled in the annealing box withdrawn from the furnace.

The permeability of this sample at H=0.005 gauss was found to be 23,000. The same alloy when treated in the normal manner by the best methods available prior to this invention will develop an initial permeability of 7000 which is of the order of that of the example alloys of Patent No. 1,656,959 referred to above, with which the present example alloy bears a close resemblance.

While, as a criterion of most alloys treated in accordance with the present invention, it may be said that the initial permeability developed as a result of the mechanical working and heat treating is appreciably greater than that of iron (μ about 250) as in the case of the nickel iron alloys having a high nickel content as described above, this may not be the case with all magnetic materials to which the invention may be usefully applied.

Thus for many applications the specific resistance of the material is the leading factor. Generally speaking extremely high specific resistance can only be obtained by sacrificing initial permeability, and in such cases it may well be that the initial permeability before or even after heat treatment in accordance with the invention is less than that of iron, but as a result of treatment in accordance with the invention the permeability will be improved.

It will be appreciated that this invention enables the preferred grain orientation to be developed in magnetic materials by graduating the amount of work upon the metal during reduction by cold rolling, and finally heat treating the rolled strip.

The method of this invention for developing magnetic permeability in ferro-magnetic materials by obtaining a preferred orientation of the grains by means of controlled cold work is to be distinguished from the well known method of obtaining an increased grain size by "critical deformation", which method involves critically cold working the metal one or more times, and which has been proposed for the treatment of iron and more particularly its silicon alloys in order to develop their electrical properties for making transformer laminations.

What we claim is:—

1. A method of increasing magnetic permeability in ferro-magnetic alloys, which comprises reducing the alloy by hot rolling to a thickness about three to four times the finished size, annealing, reducing by cold rolling to the finished size, and finally heat treating to develop the permeability.

2. A method of increasing magnetic permeability in nickel iron alloys which comprises reducing the alloy by hot rolling to a thickness about three to four times the finished size, annealing, reducing, by cold rolling to the finished size, and finally heat treating at 1150° to develop permeability.

3. A method of increasing magnetic permeability in a ferromagnetic material, which comprises subjecting the material to a predetermined amount of cold working, such as by rolling, in order to reduce the material to the finished size, and which working is sufficient to obliterate substantially completely the crystal outline without render-

ing the material amorphous, and finally heat treating the material to develop permeability.

4. A method of increasing magnetic permeability in a ferromagnetic material, which comprises subjecting the material to a predetermined amount of cold working, such as by rolling, in order to reduce the material to the finished size, the working being continued until the crystal outline is substantially completely obliterated and arrested at the stage of crystal orientation when the crystallographic axes are inclined to the plane of rolling and finally heat treating the material to develop permeability.

5. A method of increasing magnetic permeability in a nickel iron alloy which comprises subjecting the alloy to a predetermined amount of cold working, such as by rolling in order to reduce the alloy to the finished size the working being continued until the crystal outline is substantially completely obliterated and the crystallographic axes of the grains have been orientated so that after recrystallization the octahedral face coincides with the rolled surface of the alloy, and finally heat treating the alloy to cause recrystallization and develop permeability.

6. A method of increasing magnetic permeability in ferromagnetic alloys, which comprises reducing the alloy by hot rolling to a thickness about three to four times the finished size, annealing, reducing by cold rolling to the finished size to obliterate substantially completely the crystal outline without rendering the material amorphous, and finally heat treating to develop the permeability.

In testimony that we claim the foregoing as our invention we have signed our names this ninth day of October, 1931.

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