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PROCESS OF HEAT TREATING MAGNETIC MATERIAL

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Fig. 1.

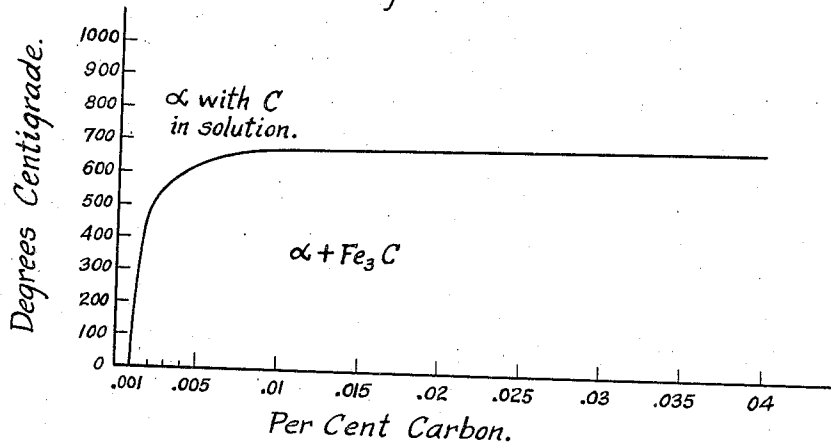
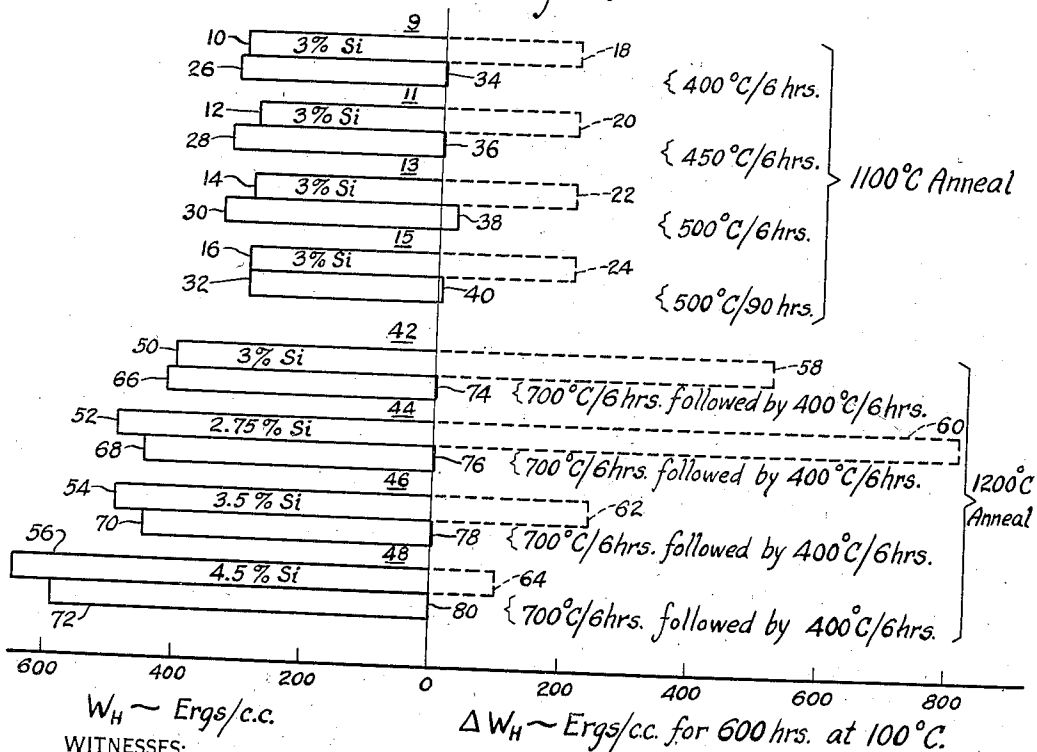


Fig. 2.



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PROCESS OF HEAT TREATING MAGNETIC MATERIAL

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3 Claims. (Cl. 148—21.5)

This invention relates to a process for heat treating magnetic material and particularly silicon iron alloys.

Many heat treatments are known for improving the magnetic properties of silicon iron alloys. The improvements are usually obtained by substantially lowering the content of the carbon impurity which is normally present in the alloy. These heat treatments, however, are not successful for completely removing the carbon impurity but function to reduce the carbon content to about .005% by weight or somewhat higher.

When the silicon iron alloy containing the carbon impurity is employed in the industry, it is often subjected to operating temperatures of between 50° C. and 100° C. or higher. Under these conditions it is found that the alloy so ages because of the precipitation of the carbon impurity at the operating temperature that the magnetic properties are greatly impaired.

An object of this invention is to provide a heat treatment for silicon iron alloys whereby the effect of ageing of the alloy is substantially avoided.

A more specific object of this invention is to provide a heat treatment for causing a precipitation of the carbon in silicon iron alloys without the introduction of ageing strains in the alloy.

This invention will be better understood by reference to the following description when taken in conjunction with the accompanying drawing, in which:

Figure 1 is a representation of the equilibrium diagram of carbon in a silicon iron alloy,

Fig. 2 is an arbitrary chart illustrating the hysteresis losses in silicon iron alloys which have been subjected to an annealing heat treatment to lower the carbon impurity content, the increase in the hysteresis losses for the same alloy when subjected to ageing, the hysteresis losses encountered in the same alloy when heat treated in accordance with the teachings of this invention and the increase of the hysteresis losses in the same alloy when aged.

The expression "ageing treatment" as employed in this application is intended to mean the treatment whereby normally annealed alloys are subjected to a heating which would normally cause a precipitation of carbon from solution and introduce strains in the alloy. In the specific examples given, an ageing treatment at 100° C. is employed in order to obtain an accelerated precipitation of the carbon. The strains which are set up in a silicon alloy cooled from a high temperature to atmospheric in an ageing treatment

cause an increase in the hysteresis losses when employed in electrical apparatus and an impairment of its magnetic properties. This increase in losses is generally known as "ageing" or the "effect of ageing".

In accordance with the teachings of this invention, silicon iron alloys containing up to 4.75% silicon may be subjected to a suitable heat treatment which does not cause an introduction of strains such as are ordinarily caused by the ageing treatments heretofore employed.

Through experiments, it was found that the carbon content present in the alloys as an impurity precipitates as fine particles which are dispersed throughout the alloy. These precipitations introduce strains in the alloy which materially decrease its magnetic properties. This phenomenon is generally known as ageing by those skilled in the art.

In practice it is desired to so reduce the carbon content to a minimum that the maximum magnetic characteristics may be developed. A reduction of the carbon content to about .005% by weight may be effected by heating the alloy at a temperature of between 1000° C. and 1300° C. in a reducing atmosphere. This heat treatment substantially lowers the carbon impurity content and releases the strains normally set up in the alloy during the working of it. Modifications of the annealing heat treatment such as control of the moisture content, and the flow of the reducing gas, may be employed in effecting the reduction of the carbon impurity content.

An examination of the equilibrium diagram for carbon as shown in Fig. 1 of the drawing reveals that with a carbon content of about .005% by weight in the alloy it is impossible to maintain the carbon in solid solution at temperatures lower than about 620° C. With a carbon content of about .005% by weight the equilibrium diagram further reveals that at an operating temperature of 100° C. the carbon content in excess of the solid solubility content at the operating temperature, or about .004% by weight, will precipitate and introduce strains in the alloy. The resulting strains greatly increase the hysteresis losses of the alloy and impairs its use as magnetic material.

In order to avoid the effect of ageing caused by the precipitation of the carbon in the alloy, namely, the setting up of strains in the material which cause an increase in the hysteresis losses, the silicon iron alloys which have been annealed to reduce the carbon content to a minimum may be subjected to a further heat treatment at a

temperature of between 300° C. and 600° C. for a period of time of from two to one hundred hours. Through experiments, it is found that this heat treatment produces an alloy which is substantially free from the effect of ageing.

As a possible explanation of this phenomenon it is believed that the heating of the alloy at a temperature of between 300° and 600° C. for a time of from 2 to 100 hours causes a precipitation of the carbon in excess of the solid solubility content at the heating temperature in such a manner that strains are not set up in the alloy. Where the lower heating temperature is employed, a longer period of the heat treatment is necessary to obtain a complete precipitation of the carbon content in excess of the solid solubility content at the heating temperature. With the higher heating temperature the desired precipitation is effected in the shorter period of time.

Through experiments, it was found that heating the annealed alloy at a temperature of between 400° C. and 500° C. in hydrogen for a period of time of about 6 hours is quite effective in causing the precipitation of the carbon impurity without introducing strains, although a longer period of heating may be necessary. When the alloys have been subjected to this heat treatment and then subjected to an ageing temperature of 100° C., the increase in the hysteresis losses caused by the ageing treatment is so slight as to be practically negligible. In this connection reference may be had to Fig. 2 of the drawing.

In the figure, the representations 10, 12, 14 and 16 to the left of the ordinate are a measure of the hysteresis losses encountered in silicon iron alloy samples 9, 11, 13 and 15 which have a 3% silicon content and which have been subjected to the annealing treatment for reducing the carbon impurities. The representations 18, 20, 22 and 24 shown in dotted lines to the right of the ordinate are a measure of the increase in the hysteresis losses of the annealed samples 9, 11, 13 and 15, respectively, when subjected to an ageing temperature of 100° C. for 600 hours. The increase in the losses for the different samples when aged are more clearly shown in the following table in which it is seen that the total losses of the alloys are of such a value as to impair the magnetic characteristics of the alloys.

Hysteresis loss in ergs/cc./cycle for B=10,000 gauss

Sample	As annealed at 1100° C.	Increase when aged at 100° C.	Total loss after ageing
9.....	300	210	510
11.....	280	210	490
13.....	290	210	500
15.....	295	210	505

When the samples 9, 11, 13 and 15 are subjected to the heat treatment of between 400° C. and 500° C. for a period of 6 hours, the initial hysteresis losses encountered as shown in the drawing by the representations 26, 28, 30 and 32 are comparable to the initial hysteresis losses found in the annealed samples, as indicated by the representations 10, 12, 14 and 16, respectively. The samples 9, 11 and 13 were subjected to a heating temperature of 400° C., 450° C., 500° C. respectively, in hydrogen, for a period of 6 hours. The sample 15 is subjected to a heating temperature of 500° C. in hydrogen for a period of 90 hours.

In order to illustrate the effect of the heat treatment in avoiding the introduction of ageing strains in the alloy and consequently avoiding an increase in the hysteresis losses, the heat treated samples 9, 11, 13 and 15 may be subjected to an ageing treatment at 100° C. for 600 hours. The increase in the hysteresis losses of the alloys, when aged, are shown by the representations 34, 36, 38 and 40 for the samples 9, 11, 13 and 15, respectively. This improvement may be better understood by reference to the following table in which the increase in the hysteresis losses is clearly set forth.

Hysteresis loss in ergs/cc./cycle for B=10,000 gauss

Sample	As annealed at 1100° C. and heated at—	Increase when aged at 100° C.	Total loss after ageing
9.....	315 (400° C/6 hrs.)	3	318
11.....	330 (450° C/6 hrs.)	3	333
13.....	340 (500° C/6 hrs.)	25	365
15.....	295 (500° C/90 hrs.)	5	300

An examination of the total hysteresis losses after ageing at 100° C. for the samples 9, 11, 13 and 15 treated by the process hereinbefore described when compared with the total losses found in the annealed and aged alloys, clearly shows the improvement effected by the process of this invention.

After the carbon impurity content is lowered to a minimum value, it is often desired to shear the alloy into a desirable shape for use in the industry. The shearing of the alloy introduces strains which affect the magnetic characteristics of the alloy. In order to release the shearing strains, the annealed alloy may be heated at a temperature of between 600° C. and 800° C. in a neutral or reducing atmosphere for a period of time of about 6 hours. The annealed alloy which has been freed from shearing strains may then be subjected to a heating temperature of from 400° C. to 500° C. in hydrogen for a period of time of from 2 to 100 hours to cause the precipitation of the carbon impurity in excess of the solid solubility content at the heating temperature without introducing strains caused by the precipitation, as explained hereinbefore.

In Fig. 2 of the drawing, representation has been made of the results obtained by subjecting samples which have been annealed at 1200° C. to the further heat treatment comprising heating at 700° C. in hydrogen for 6 hours followed by a separate heating at a temperature of 400° C. in hydrogen for a period of 6 hours. In the figure, 50, 52, 54 and 56 are representations of the hysteresis losses encountered in samples 42, 44, 46 and 48, respectively, after the annealing treatment.

When these samples are subjected to ageing at 100° C. for a period of 600 hours, the hysteresis losses increase as indicated by the representations 58, 60, 62 and 64, respectively, shown in dotted lines to the right of the ordinate. After the samples 42, 44, 46 and 48 are sheared to the desired size and then subjected to the further heat treatment at a temperature of 700° C. followed by a separate heat treatment at 400° C., as described, the initial hysteresis losses in the heat treated samples, as indicated by the representations 66, 68, 70 and 72, respectively, are found to be comparable to the initial hysteresis losses of the annealed alloy.

When subjected to the ageing treatment, it is

found that the increase in the hysteresis losses of the heat treated alloys because of ageing, as indicated by the representations 74, 76, 78 and 80, are negligible. These results are more clearly set forth in the following table in which it is seen that the total hysteresis losses of the alloys treated in accordance with this invention and then subjected to an ageing treatment are materially lower than the total hysteresis losses found when the annealed material is subjected to the ageing treatment.

Hysteresis loss in ergs/cc./cycle for B=10,000 gauss

Sample	As annealed at 1200° C.	Increase when aged at 100° C.	Total loss when aged
42.....	410	530	940
44.....	490	820	1310
46.....	490	240	730
48.....	650	100	750

Sample	As annealed at 1200° C. and heated at 700° C. followed by 400° C.	Increase when aged at 100° C.	Total loss when aged
42.....	415	3	418
44.....	450	3	453
46.....	450	3	453
48.....	580	0	580

A modification of this heat treatment is to subject the alloy to a continuous heat treatment after it has been sheared. This may be accomplished by heating the sheared and annealed alloy at a temperature of between 700° C. and 800° C. in hydrogen for a period of about 6 hours and then lowering the temperature to between 400° C. and 500° C. and heating it at that temperature for a period of about 6 hours.

A specific heat treatment embodying this modification which has been found desirable, is to anneal the alloy at a temperature of between 1000° C. and 1300° C. in a reducing atmosphere to lower the impurity content, shear the annealed alloy to the desired size and then to heat the sheared alloy at a temperature of about 700° C. in hydrogen for a period of 6 hours to release the shearing strains at the ends of which time the temperature is lowered to 450° C. and held at that temperature for a period of 6 hours to cause the desired precipitation of carbon substantially without strains after which the alloy is cooled to room temperature. It is found that this heat treatment effectively removes the shearing strains and substantially avoids the effect of ageing.

A study of photomicrographs of the alloys which are subjected to the heat treatments hereinbefore described reveals that the ageing strains which may be found in the alloys subjected to the ageing heat treatment after the annealing thereof are not present in the alloys treated in accordance with the process of this invention. An analysis of the alloys treated proves that the carbon content has not been substantially reduced by the heat treatment hereinbefore described, and a possible explanation of the improvement in the conditioning of the alloy is that a precipitation of the carbon impurity content is effected by this heat treatment without the retention of strains. Since, according to this explanation, only a small portion of the carbon

content remains in solid solution in the alloy after subjecting it to the heating temperature, it is evident that upon subjecting the alloy to the ageing treatment there will be obtained only a negligible precipitation of the carbon remaining in solid solution in the alloy. Since the ageing is negligible, it is evident that the magnetic characteristics of the alloy will not be substantially impaired.

Although this invention has been described with reference to a particular process, it is evident that other and various modifications thereof are possible. It is, therefore, not to be restricted except insofar as is necessitated by the prior art and the scope of the appended claims.

We claim as our invention:

1. In the process of heat treating silicon iron alloys which have been heat treated to release working strains and lower the carbon impurity content in excess of the solid solubility content of carbon in the alloy at a temperature of 300° C., in combination, heating the alloy in a reducing atmosphere to a temperature ranging from 400° C. to 500° C. for a period of time of from 6 to 100 hours to stabilize the magnetic characteristics of the alloy without effecting a substantial increase in the hysteresis loss of the alloy whereby the alloy may be subjected to a testing temperature of 100° C. for a period of time of 600 hours without effecting an increase in the magnetic ageing of the alloy.

2. In the process of heat treating silicon iron alloys having as an impurity a carbon content in excess of the solid solubility content of carbon in the alloy at a temperature of 300° C., in combination, subjecting the alloy to a temperature ranging from 1000° C. to 1300° C. in a reducing atmosphere to remove a part of the carbon impurity, shearing the annealed alloy into sheets, subjecting the sheared alloy sheets to a temperature ranging from 600° C. to 800° C. in a hydrogen atmosphere to release the shearing strains, cooling the alloy sheets, and subjecting the alloy sheets which are freed from shearing strains to a temperature ranging from 400° C. to 500° C. for a period of time of from 2 to 100 hours to stabilize the magnetic characteristics of the alloy without effecting a substantial increase in its hysteresis loss whereby the alloy may be subjected to a testing temperature of 100° C. for a period of time of 600 hours without effecting an increase in the magnetic ageing of the alloy.

3. In the process of heat treating silicon iron alloys having as an impurity a carbon content in excess of the solid solubility content of carbon in the alloy at a temperature of 300° C., in combination, subjecting the alloy to a heating temperature of between 1000° C. and 1300° C. to anneal it, shearing the annealed alloy into sheets, heating the sheared alloy sheets at a temperature of between 600° C. and 800° C. to release the shearing strains, reducing the heating temperature to a temperature of between 400° C. and 500° C., and heating the alloy sheets at that temperature for a period of time of from 2 to 100 hours to stabilize the magnetic characteristics of the alloy without effecting a substantial increase in the hysteresis losses whereby the alloy may be subjected to a testing temperature of 100° C. for a period of time of 600 hours without effecting an increase in the magnetic ageing of the alloy.

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