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PROCESS OF PRODUCING HIGH PERMEABILITY SILICON STEEL

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My invention is addressed to the problem of securing the highest possible straight-grain permeability in silicon steels, coupled with low core and hysteresis losses. It has been shown that in the silicon steels having the highest high induction permeability measured parallel to the rolling direction heretofore produced, (which steels have relatively very low permeabilities in other directions), the crystals have a high degree of preferred orientation of a type known as twin derivative. This means that so-called [100] directions of substantially all crystals are parallel to each other and (110) planes are parallel to a face of the sheet as indicated by the diffraction of X-rays. The terminology is that of Miller's indices.

Such an orientation of the crystals will give the highest straight-grain permeabilities produced, or so far as is known producible, in any given chemistry of the silicon steel.

In Patent 2,158,065, Cole and Davidson teach a process for producing such orientations. They have pointed out that when hot-rolled silicon steels have been annealed, and then are cold worked with reductions of between 40 to 85%, the common cold rolling orientation of the crystals produced thereby may be altered by incipient twinning on (112) planes if the temperature of the cold rolling is carefully controlled. An intermediate anneal causes the twinning to increase or grow, so that after the intermediate anneal the crystals may be preferentially oriented in two of the four possible (112) plane twin positions, i. e., those having two mutually perpendicular [110] directions so oriented that one of them is parallel to the sheet surface and perpendicular to the rolling direction, while the other makes an angle of 19°28' with a perpendicular to the sheet surface. A second cold rolling with reductions of between 40 and 65% is next practiced, followed by a final anneal, as a result of which the twin derivative type of orientation referred to above is produced.

It will be observed that the process of necessity involves at least two cold rollings with large reductions, and at least two annealings following the cold rollings respectively. Hitherto it has not been possible to attain the same product by a process involving a single stage of cold rolling followed by a single anneal. The results of single stage processes have given no significant increases of permeability, or if carried on under optimum conditions have given only the same result as that attained after the first cold rolling and intermediate anneal of the Cole and Davidson process referred to above,—namely a twinned crystal orientation. A material having a high degree of twinned orientation will have a higher straight-grain permeability than a product characterized by cold rolling orientation merely; it is useful for many purposes, but its straight-grain permeability is by no means as high as the permeability of a material in which the preferred orientation is of the twin-derivative type. It is also not as highly directional.

It will be clear that if the permeabilities which are attained in the straight-grain or rolling direction in materials of twin-derivative orientation could be secured with a single stage of cold rolling and a single final anneal, substantial savings could be made. I have discovered that this may be done with the coincidence of certain steps and conditions, and this attainment constitutes the primary object of my invention. In other words it is my object to secure a silicon steel having a twin-derivative orientation and a straight-grain permeability characteristic thereof, by a process involving no more than one cold rolling stage and no more than one necessary heat treatment thereafter. It is also my object to produce a material of such character and so made, which material will have in addition a low core loss.

These and other objects of my invention which will be set forth hereinafter or will be apparent to one skilled in the art upon reading these specifications, I accomplish by that certain process of which I shall now set forth an exemplary embodiment.

My process is applicable to silicon steels containing from 1% or less of silicon to 4% and somewhat higher, and thus embraces the range of "low silicon steels" (up to about 3%) and the range of "intermediate silicon steels" (from about 3% up to about 4 or 4.5%). The steel should also contain the usual amount of manganese. I prefer between around 0.10% to around 0.15%. In any case the manganese should not be too low to give the desired rollability and physical qualities nor so high as to impair the magnetic properties. The remainder of the silicon steel will have the usual compositions for silicon steels for all of the uses in the low and intermediate grades excepting for the carbon content. The permissible carbon content of the starting material depends upon the silicon content, on whether the final anneal is to be an open anneal or a box anneal, whether the material is to be used in an application where low core loss is demanded, and whether any of the processing steps is to ac-

complish an effective amount of decarburization, the manner of dependency of which will now be described.

If the final anneal is to be a short open anneal, it is essential that the ultimate carbon content should be low, preferably not exceeding 0.02%, in order that the twin-derivative orientation can develop very rapidly without the restraining action of larger amounts of carbon. This is true without regard for the silicon content of the material.

If the final anneal is to be a box anneal, such a strict limitation on the carbon content is not necessary since a longer time is available for the development of the desired orientation. Materials containing from about 2% upwards of silicon are somewhat more sluggish, however, and for best results these materials should not contain carbon to exceed around 0.03%.

Although these instructions will be sufficient as a guide to the permissible carbon content which will permit the development of the desired type of preferred crystal orientation and the accompanying high high-induction straight-grain permeability, the principle should also be followed that wherever the material is to be used in an application demanding low core loss, the final carbon content should be as low as possible.

When a low carbon content is indicated for the final material it is equally effective to start with material of the approximate carbon content desired, or to start with a somewhat higher carbon content and introduce decarburizing steps into the process. While not wishing to be limited to it, I prefer to decarburize during the box anneal preceding the cold reduction in a manner to be described later. The carbon can also be reduced after the material has been cold rolled to gage, by suitable decarburizing procedures.

The silicon steel ingots having the composition ranges above indicated are hot rolled in the usual way and the hot rolling is finished at the usual temperatures. The manner in which the hot rolling is carried on, the number of passes, and whether or not there are intermediate reheatings, as well as the finishing temperatures, do not constitute limitations on the invention. I prefer for economic reasons to finish the hot rolling in one part, i. e. without reheating. Consonant with the usual practice I finish hot rolling steels containing 2 to 4% silicon at around 1400 degrees F. and lower silicon steels at around 1500 degrees F. The finish temperature should, of course, be high enough to avoid brittleness.

I hot roll the material to a thickness 3 to 6 times the desired final gauge. While my process is adapted to the production of both light and heavy gauge silicon steel, it will be understood (since the process involves but a single stage of cold rolling, and since the amount of cold rolling is limited as hereinafter set forth) the desired finished gauge will determine the amount of hot work necessary. As between light and heavy gauges a convenient line of demarkation may be drawn at around a finished gauge of 0.018 inch. In making heavy gage material I hot roll the silicon steel to around 0.11 inch, and carry the piece down by cold rolling the rest of the way. This is readily accomplished on any usual mill installation and my process will effect a correspondingly great saving under such circumstances. Where I desire to produce a steel having a light finished gauge such as 0.014 inch by way of example, I hot roll down to 0.05 inch.

After hot rolling, I prefer to box anneal the material at temperatures of about 1200 to 1700 degrees F. This step is not absolutely necessary to the process of producing twin-derivative orientation, but I have found it useful in producing uniformly successful results. In some cases open anneals preferably at high temperatures up to around 2100 degrees F. may give satisfactory results, and where the finishing temperature off the hot mill is sufficiently high this anneal may be dispensed with altogether. I prefer, however, to employ a box anneal as a means of preparing the material for the subsequent steps of the proces in a way that gives commercially consistent results.

If the material is to be decarburized, I also prefer to utilize this box anneal as a decarburizing step. Decarburization is effected by box annealing the unpickled material in the presence of its mill scale formed during the hot rolling operations, at about 1300 to 1500 degrees F. For best results I prefer between 1350 and 1400 degrees F. During such annealing there is an interaction between the oxygen in the mill scale and the carbon in the steel which, without any qualification of furnace atmosphere, will carry the carbon down to low levels at proper temperatures, the extent of the decarburization depending on the time of treatment. I ordinarily anneal for from 2 to 10 hours at temperature, followed by a slow cooling. By the use of my decarburizing treatment I can secure carbon contents of 0.01% and under.

The amount of cold rolling is important. I have indicated that I hot roll to from three to six times the final desired gauge. This leaves for the cold rolling stage reductions of from about 66⅔% to about 83⅓%. These limits can be departed from and useful results obtained; but at or about the limits set forth I find that the attainment of the desired orientation and the consequent high permeability in the rolling direction begins to fall off appreciably, and more rapidly the greater the departure therefrom. Within the limits set forth, the desired orientation can be obtained throughout the silicon ranges which I have given; but it is convenient to vary the cold rolling within the range in accordance with the silicon content of the material. Thus the higher part of the range is appropriate for the lower silicon contents and vice versa.

The manner in which the cold rolling is done is not a limitation upon my invention. No substantial difference that I have been able to detect arises from variations in the number of passes through the mill or mills, or the manner in which the total necessary reduction is divided up between the several passes. As a consequence, in cold rolling the silicon steel I prefer to take as great a reduction per pass as is practicable and consonant with good operation of the particular mill installation. Also, contrary to assumptions based upon the state of the art, I have found that the specific temperature of cold rolling, with silicon steels within the composition ranges given, where the carbon content is proper and where the preceding steps of the process have been correctly carried out is not a limitation upon the securing of the desired type of orientation; and I can permit my temperatures to rise without disadvantage. A rise in temperature and the retention of a varying high temperature naturally occurs where strip material is being heavily worked and immediately coiled. I do not have to employ precautions to cool the

sheets or strips. I have successfully secured the desired crystal orientation in intermediate silicon steels which I have rolled at temperatures up to 900 degrees F.

Following the cold rolling I practice a heat treatment at temperatures higher than those heretofore used following a single stage of cold rolling. The heat treatment may be a box or open anneal depending upon the qualities desired in the final product. It may be stated generally that better magnetic qualities appear to result from a box anneal. The annealing temperatures likewise are dependent upon the silicon content or the magnetic quality desired. If I am working with a material containing 1% silicon the box annealing temperature may be as low as 1300 degrees F. whereas with 3% silicon and higher the annealing temperature may be of the order of 2000 to 2100 degrees F. The annealing is carried on for conventional lengths of time, say from two to twelve hours at temperature; but this is variable. Where an open anneal is preferred excellent results are secured with continuous heat treatments of the order say of two minutes or longer (which will depend upon the furnace) at temperatures preferably at least 100 degrees higher than the temperatures given for the box annealing. The twin-derivative orientation of the crystals appears to develop and is carried to completion during this final annealing.

The discovery that an open annealing following a single cold rolling stage can be depended upon to give a twin-derivative type of orientation effects a further economy attendant upon my process. An open annealing for two minutes at 2100 degrees F. for 3% silicon steel will give the proper orientation when the carbon is under .015%. This also is true of the higher silicon contents. With respect to the lower silicon contents, the carbon may be higher. With 1% silicon steel or any other silicon steel which has an A_3 point, the final anneal should be carried on at temperatures below this point.

Wherever I have referred to an open anneal, I mean the carrying of single or spaced multiple strips or single sheets of material through an elongated heating chamber. This is in distinction to a so-called box anneal in which a tightly wound coil or a large stack of sheets is heated to and cooled from the annealing temperature.

My process is applicable to the treatment of silicon steel in either sheet or strip form. Where a problem of removing coil set is involved in handling strip steel, or where for any other purpose a reannealing is desired, such reannealing may be practiced without destruction of the twin-derivative type of orientation providing the temperature of such reanneal does not exceed the allowable maximum temperature for the annealing following the cold rolling.

Modifications may be made in my invention without departing from the spirit thereof.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A process of securing a twin-derivative orientation in silicon steel and involving a single cold rolling stage, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge 3 to 6 times the desired final gauge, cold rolling the said steel to gauge and finally heat treating the said steel at temperatures between substantially 1300 and substantially 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results.

2. A process of securing a twin-derivative orientation in silicon steel and involving a single cold rolling stage, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge 3 to 6 times the desired final gauge, annealing the said steel at temperatures from 1200 to 2100 degrees F., thereafter cold rolling the said steel to gauge and finally heat treating the said steel at temperatures between substantially 1300 and substantially 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin derivative orientation of the crystals results.

3. A process of securing a twin-derivative orientation in silicon steel and involving a single cold rolling stage, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge 3 to 6 times the desired final gauge, box annealing the said steel at temperatures from 1200 to 1700 degrees F., thereafter cold rolling the said steel to gauge and finally heat treating the said steel at temperatures between substantially 1300 and substantially 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results.

4. A process of securing a twin-derivative orientation in silicon steel and involving a single cold rolling stage, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge 3 to 6 times the desired final gauge, then box annealing the steel in the presence of its mill scale at a temperature substantially from 1300 to 1500 degrees F., whereby to decarburize the said steel and reduce its carbon content to a maximum of 0.03%, then cold rolling the steel to gauge and finally heat treating the steel at temperatures substantially from 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results.

5. A process as set forth in claim 4 in which the steel is decarburized to a maximum carbon content of 0.015 per cent.

6. A process as set forth in claim 4 in which the final heat treatment is a box anneal.

7. A process as set forth in claim 4 in which the steel is decarburized to a maximum carbon content of 0.015 per cent and in which said final heat treatment is an open anneal for a minimum of substantially 2 minutes at temperature.

8. A process of producing silicon steel having a high permeability in the straight-grain direction with a single part cold rolling, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge of substantially 0.11 inch, box annealing the material at substantially 1200 to 1700 degrees F., then cold rolling the material to substantially 0.018 to 0.040 inch, finally heat treating the material at temperatures substantially between 1300 and 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results.

9. A process of producing silicon steel having a high permeability in the straight-grain direction with a single part cold rolling, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge of

substantially 0.11 inch, then box annealing the steel in the presence of its mill scale at a temperature substantially from 1300 to 1500 degrees F., whereby to decarburize the said steel, then cold rolling the material to substantially 0.018 to 0.040 inch, finally heat treating the material at temperatures substantially between 1300 and 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results, the material as finished having a carbon content not in excess of 0.03 per cent.

10. A process of producing silicon steel having high permeability in the straight-grain direction with a single part cold rolling, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge of substantially 0.11 inch, then box annealing the steel in the presence of its mill scale at a temperature substantially from 1300 to 1500 degrees F., whereby to decarburize the said steel, then cold rolling the material to substantially 0.018 to 0.040 inch, finally heat treating the material at temperatures substantially between 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results, the material as finished having a carbon content not in excess of 0.03 per cent, the said final heat treatment being a box anneal.

11. A process of producing silicon steel having high permeability in the straight-grain direction with a single part cold rolling, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon and substantially from 0.10 to 0.15 per cent manganese to a gauge of substantially 0.11 inch, box annealing the material in the presence of its mill scale at temperatures substantially between 1350 and 1400 degrees F., whereby to decarburize said steel, then cold rolling the material to substantially 0.018 to 0.040 inch, finally heat treating the material at temperatures substantially between 1300 and 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results, the material as finished having a carbon content not in excess of 0.03 per cent, the said final heat treatment being a box anneal.

12. A process of producing silicon steel having high permeability in the straight-grain direction with a single part cold rolling, which process comprises hot rolling silicon steel containing substantially from 1 to 4% silicon to a gauge of substantially 0.11 inch, then box annealing the steel in the presence of its mill scale at temperatures substantially between 1300 and 1500 degrees F., whereby to decarburize the said steel, then cold rolling the material to substantially 0.018 to 0.040 inch, finally heat treating the material at temperatures substantially between 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results, the material as finished having a carbon content not in excess of 0.02 per cent, said final heat treatment being an open anneal having a minimum duration of substantially 2 minutes.

13. A process of producing high permeability silicon steel with one stage of cold rolling, which process comprises hot rolling steel containing substantially from 1 to 4% silicon to substantially 0.11 inch, then box annealing the said steel at substantially 1300 to 1500 degrees F. in the presence of its mill scale whereby to decarburize it, then cold rolling the said steel to substantially 0.018 to 0.040 inch and finally heat treating the said steel at temperatures of substantially 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin derivative orientation of the crystals results, the said steel as finished having a maximum carbon content of substantially 0.015 per cent.

14. A process of producing high permeability silicon steel with a single cold rolling stage which comprises hot rolling silicon steel containing substantially 1 to 4% silicon to a gauge of substantially 0.05 inch, box annealing the said steel at temperatures of substantially 1200 to 1700 degrees F., then cold rolling the said steel to substantially 0.013 to 0.017 inch, and finally heat treating the said steel at temperatures substantially from 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results.

15. A process of producing high permeability silicon steel with a single cold rolling stage which comprises hot rolling silicon steel containing substantially 1 to 4% silicon to a gauge of substantially 0.05 inch, box annealing the said steel in the presence of its mill scale to temperatures substantially between 1300 and 1500 degrees F., whereby to decarburize the said steel, then cold rolling the said steel to 0.013 to 0.017 inch, and finally heat treating the said steel at a temperature substantially from 1300 to 2200 degrees F., said temperature varying directly with the said silicon content, and being of such duration that a twin-derivative orientation of the crystals results, the said steel as finished containing carbon not in excess of 0.03 per cent.

16. A process as set forth in claim 15 in which the final heat treatment is a box anneal.

17. A process as set forth in claim 15 in which the final heat treatment is an open anneal having a minimum duration of substantially 2 minutes, the finished steel containing carbon not in excess of 0.02 per cent.

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