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PROCESSING OF METAL

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This invention relates to magnetic material and in particular to the process of producing electrical steel strip from silicon steel.

Many different processes have heretofore been developed for the production of silicon steel in strip form to provide the different grades of silicon steel for electrical apparatus based on specified or anticipated core loss values, such silicon steels having a silicon content of from 0.25% to 3.50% and in some cases as high as 4.5%. One of the well-known processes is that commonly referred to as the Freeland process which consists essentially of hot rolling the steel to a thickness between 0.060 and 0.125 inch, descaling, cold rolling to a predetermined thickness greater than the final gauge, normalizing at a temperature of about 1725° F. in a dry gas atmosphere having a dew point of less than +60° F. to strain relieve the strip, temper rolling to final gauge and then normalizing at a temperature of about 1500° F. in a gas atmosphere having a dew point in excess of +60° F. to effect decarburizing and induce grain growth.

Another well-known process of producing strip from sheets is that disclosed in the Jackson et al. Patent No. 2,582,382 in which hot rolled silicon steel sheets having scale thereon are welded into coil form after which the strip thus formed is normalized in a reducing gas atmosphere at a temperature of 1400° F. to 1725° F. or 1900° F. to 2150° F. to decarburize the steel and reduce the mill scale thereon thus eliminating a pickling step.

The process of the Jackson et al. Patent No. 2,358,788 is also well known and has been used to good advantage in some instances, although such process has a disadvantage. This process utilizes a box annealing heat treatment. However, in the box annealing cycle the mechanism of decarburization is such that the oxygen in the scale combines with the carbon which migrates to the surface of the steel and the scale is partially reduced to pure iron rendering it very difficult to pickle even though the technique of scale breaking is employed. In this process as well as in the process taught by Patent No. 2,582,382 it is necessary to have the scale present on the strip during the normalizing or annealing treatment in order to effect decarburization.

In commercial practice it is desirable to simplify the number of treatments applied in producing electrical steel strip to more efficiently produce such strip while enhancing the magnetic characteristics thereof. It is also highly desirable that the treatments applied be of a continuous nature instead of by the batch processing so that such processing can be integrated in modern steel mill practice and eliminate the necessity of a number of handlings which often inflict damage to the strip.

An object of this invention is to provide a simplified process of producing silicon steel strip having a low carbon content and good magnetic characteristics.

Another object of this invention is to provide a process in which scale-free cold rolled silicon steel strip is continuously heat treated to reduce the carbon content, recrystallize the steel, enhance the grain growth and maintain scale-free surfaces whereby electrical steel strip having good magnetic characteristics is produced.

A more specific object of this invention is to provide, in the process of producing cold rolled silicon steel strip,

for subjecting the strip of final gauge to a controlled progressive heat treatment in a zone controlled furnace having a protective gas atmosphere for successively decreasing the carbon content to below 0.013%, effecting recrystallization and grain growth and maintain a scale-free surface on the strip, the treated strip having enhanced magnetic characteristics.

Other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying claims.

In practicing the present invention, the steel can be melted by ordinary commercial open-hearth or electric furnace practice and preferably has a composition within the range set forth in Table I.

Table I

[Composition (percent by weight)]

Silicon	0.25% to 4.5%.
Manganese	0.10% to 0.40%.
Aluminum	Trace to 0.80%.
Phosphorus	0.05% max.
Sulfur	0.03% max.
Carbon	0.07% max.
Iron	Bal.[1]

[1] Includes usual traces of impurities.

It will be appreciated that with recent developments in the steel-making art it is sometimes possible to produce silicon steel with as low as .015% carbon therein. However, presently used commercial practices yield a product having a carbon content in the range between 0.02% and 0.07%. In all cases the amount of decarburization effected by the use of the process of this invention will be sufficient to decarburize the steel to substantially below 0.013% and preferably below 0.009%.

The ingot having a composition within the range given is first reduced to a strip by hot rolling to an intermediate gauge of between 0.06 and 0.125 inch after which it is subjected to any suitable pickling or descaling treatment to remove the scale therefrom. The descaled strip is then side trimmed, after which it is cold rolled to a final gauge of between 0.014 and 0.031 inch.

In accordance with this invention, the descaled and cold rolled strip of final gauge is then subjected to a controlled heat treatment consisting of a continuous normalizing to effectively and progressively reduce the carbon content of the steel to below 0.013%, effect a recrystallization and grain growth and maintain scale-free surfaces on the strip. Such treatment is applied through the use of a temperature zoned annealing furnace, the construction of which is well known to those skilled in the art, the strip being passed continuously therethrough at a predetermined rate while being suitably supported therein and being admitted at the lower temperature zone of the furnace, the heat treatment being applied in the presence of a protective gas atmosphere having a controlled dew point.

In practicing this invention, the temperature zoned furnace preferably is provided with a plurality of predetermined temperature zones ranging from a temperature of not less than 1400° F. progressively up to a temperature zone of between 1725° F. and 2150° F. and preferably between 1800° F. and 2150° F. with one of the intermediate temperature zones having a temperature preferably in the range of 1525° F. to 1650° F. to effectively introduce a temperature of between about 1400° F. and 1600° F. in the strip as the strip passes therethrough. As illustrative of different progressive temperature zones which have been successfully utilized in practicing this invention reference may be had to Table II.

Table II

[Temperature in the different zones (°F.)]

EXAMPLE 1

# Zone	°F. Temp.	Fractional Part of Furnace	Time in Each Zone (Seconds)		
			.014"	.0185"	.025"
			4.0 Min. (240 Sec.)	5.0 Min. (300 Sec.)	6.0 Min. (360 Sec.)
1	1,525	.06176	14.8	18.5	22.2
2	1,525	.0647	15.5	19.4	23.3
3	1,525	.0588	14.1	17.6	21.2
4	1,525	.09118	21.9	27.4	32.8
5	1,600	.18824	21.2	26.4	31.8
6	1,650	.09118	21.9	27.4	32.8
7	1,800	.09118	21.9	27.4	32.8
8	1,800	.08824	21.2	26.4	31.8
9	1,800	.09118	21.9	27.4	32.8
10	1,800	.09118	21.9	27.4	32.8
11	1,800	.08824	21.2	26.4	31.8
12	1,800	.09412	22.5	28.2	33.9

EXAMPLE 2

1	1,525	.08796	21.1	26.4	31.7
2	1,525	.0648	15.6	19.4	23.3
3	1,525	.1343	32.2	40.3	48.3
4	1,650	.1435	34.4	43.1	51.7
5	1,800	.1435	34.4	43.0	51.7
6	1,800	.1435	34.4	43.1	51.7
7	1,800	.1435	34.4	43.0	51.7
8	1,800	.1389	33.4	41.7	50.0

Example 1 illustrates the distribution of the temperature in a furnace 340 feet long, whereas Example 2 illustrates the temperature distribution in a furnace 216 feet long. The temperature of the different zones can be readily controlled by known methods, and as will be appreciated the different zones can be of different length, depending upon the time it is desired to subject the strip to the different temperatures and treatment to be described, it being understood that the strip is advanced throughout the furnace at a uniform rate. In practice, the cold rolled strip having a thickness in the range between about 0.014 and 0.031 inch is usually passed through the zoned furnace so that the strip is subjected to the various temperatures for various periods of time ranging between 3.5 and 8 minutes, depending upon the thickness. It has been found that regardless of the length of the furnace, optimum results are obtained where the strip is heat treated in the furnace for a total time of between 3.5 and 8 minutes, depending upon the thickness as the thickness increases from .014 to .031 inch, and that regardless of the length of the furnace, it must be provided with a low temperature zone comprising between 38% and 49% of the total length of the furnace.

From Table II it will be appreciated that the low temperature zone portion is of different length from that of the high temperature zone portion in each of the furnaces. In addition, it is also seen that each of the temperature zones within each of the high temperature zone and low temperature zone portions of the furnace may also be of different length. However, it has been found to be necessary to maintain the low temperature zone portion of a sufficient length to extend a distance comprising between 38% and 49% of the total length of the furnace. In Example 1 of Table II it is seen that the low temperature zone comprises about 45.7% of the total length of the furnace, whereas in Example 2, the low temperature zone comprises about 42.3% of the length of the furnace. However, if the length of the low temperature zone of the furnace becomes less than 38%, insufficient decarburization is accomplished, whereas, if the length of the low temperature zone of the furnace is greater than 49% of the total length of the furnace, the strip material is subjected to the high temperature treatment for an insufficient period to effect complete recrystallization and grain growth so that, in either case, the resulting material will possess poor magnetic characteristics. It is at once seen that the length of the furnace is immaterial so long as the requisite temperatures and times are maintained within the respective portions of the furnace. In this same vein, the rate of feed of the strip through the furnace is also immaterial so long as the strip is subject to the requisite temperatures as set forth hereinbefore for a time period of between 3.5 and 8 minutes, depending upon the thickness of the strip and the furnace is provided with a low temperature zone of between 1400° F. and 1650° F., said low temperature zone comprising between 38% and 49% of the total length of the furnace. In the examples set forth in Table II, the rate at which the strip passes through the furnace is between about 0.5 and 2.0 feet per minute per inch of strip thickness.

Of interest also is the fact that the material in its passage through the furnace remains for different times in each of the individual zones of the low and high temperature zones. This, of course, follows since the strip passes through the furnace at a uniform rate and the length of the zones is different. It is sufficient that the steel remain in the low temperature zone of the furnace to induce a temperature in the strip within the range between 1400 and 1600° F. for a time period of between about 1.3 minutes and 3.9 minutes to effectively decarburize the steel, and within the high temperature zone for a period of between 2.2 and 4.1 minutes to complete the process of recrystallization and grain growth. Table II clearly illustrates the time period any segment of a steel strip remains within the respective zone of the furnace. Thus, in Example 2, steel having a thickness of 0.014 inch required 4.0 minutes to travel 216 feet, whereas steel having a thickness of 0.025 inch requires 6.0 minutes in the same furnace. In Example 1, the furnace is 340 feet long, yet the strip having a thickness of 0.014 inch requires 4.0 minutes for its passage therethrough and the strip 0.025 inch in thickness requires 6.0 minutes. It is thus apparent that the process of this invention is independent of the furnace length, but the rate of travel of the strip through the furnace is dependent upon the furnace length. Subjecting the silicon steel strip to the temperatures indicated and for a time period indicated is effective for continuously decarburizing the steel and completing the process of recrystallization and grain growth, and, most important, maintaining the strip in a scale-free condition.

As the strip passes through the zoned furnace it is completely enveloped by protective gas atmosphere having a controlled composition and dew point. Protective gases, such as dissociated ammonia containing 75% hydrogen and 25% nitrogen, forming gas containing 15% hydrogen and 85% nitrogen, cracked natural gas having an air to gas ratio of no less than 5½ to 1 and line hydrogen as well as mixtures of dissociated ammonia and cracked natural gas, forming gas and cracked natural gas and line hydrogen and cracked natural gas have been successfully used in this process so long as the dew point and the hydrogen concentration thereof are controlled as will be next described.

In admitting the gas atmosphere to the furnace the dew point of the gas is preferably maintained at less than +60° F. and usually has a dew point in the neighborhood of +40° F. to +45° F. The gas is supplied at a sufficiently high rate to completely fill the successive zones and to maintain a positive pressure in the different zones of the furnace to prevent any infiltration of atmospheric air therein. In the furnace utilized in the commercial adaptation of this invention a sustained flow of from about 8,000 to about 11,000 cubic feet per hour to the furnace has been found to give satisfactory results. The gas is admitted to the furnace near the end at which the strip emerges, that is, the high tempera-

ture zone of the furnace. The gas usually enters the furnace perpendicular to the direction of travel of the strip and completely fills the furnace, the gas being dissipated at both the entrance and the exit end of the furnace with respect to the strip travel. This gas is ignited and continuously burns throughout the process of the invention.

Normally, the gas as admitted to the high temperature zone of the furnace has a dew point of less than +60° F. and will not react with the silicon steel strip in such zone where the temperature is in excess of 1650° F. to effect the formation of scale thereon with the result that a scale-free surface is maintained on the strip as it emerges from the furnace. It is believed that with the use of dissociated ammonia, forming gas or line hydrogen without the addition of any cracked natural gas thereto or other gas or air to the furnace atmosphere, there is a reaction which takes place which immediately raises the dew point to greater than +60° F. and in some cases to greater than 100° F. at the high temperature zone in the furnace. Normally a gas atmosphere having such a high dew point in the presence of hot steel would react to form iron oxide on the surface of the steel strip. It has been found, however, that with the gases specified hereinbefore, the hydrogen concentration is sufficiently great that a reaction takes place to reduce the iron oxide of the scale thus formed to iron and thereby form water vapor. While the reason for the formation of water vapor to effectively increase the dew point of the gas to greater than +60° F. where the gas is admitted to the furnace is not completely understood, it has been observed that when the gas atmosphere is ignited to burn at each end of the furnace water vapor is formed which somehow diffuses into the ends of the furnace and is carried therethrough. This phenomenon is most readily apparent at the gas exit end of the furnace, that is, the end of the furnace into which the strip enters which is the lower temperature zone of the furnace.

As was stated hereinbefore, while the gas enters perpendicular to the direction of movement of the strip, the gas is forced by the construction of the strip exit end of the furnace to flow countercurrent to the direction of the movement of the strip and only sufficient gas escapes at the strip exit end of the furnace to maintain a positive pressure within the furnace. Where the burning of the gas at the ends of the furnace is sufficient to increase the dew point to greater than +60° F. it has been found that a hydrogen concentration in excess of about 12% hydrogen by volume is necessary to reduce any scale thus formed, thus maintaining a relatively clean surface on the strip. Where an atmosphere of cracked natural gas is utilized as the furnace atmosphere, other reactions take place, to be more fully described hereinafter, in addition to the phenomenon of increasing the dew point through the burning of the gas at the ends of the furnace which also adds to the effective dew point of the furnace atmosphere. In any event, the hydrogen concentration is always maintained at greater than 12% with the result that a relatively clean surface is maintained on the strip as it emerges from the furnace. In some instances, it has been observed that a relatively thin, adherent, hardly detectable film of oxides, as distinguished from readily detectable scale, is present on the surface of the strip which is not detrimental to the ultimate use of the steel but instead enhances the punchability characteristics and provides an insulating medium.

Where cracked natural gas having an air to gas ratio of at least 5.5 to 1 is used as the furnace atmosphere, it has been found that as the gas flows through the zones of the furnace there is a reaction between the hydrogen and the carbon dioxide which is effective for increasing the dew point of the protective gas atmosphere to greater than +60° F. to thereby effectively decarburize the silicon steel and reduce the carbon content substantially in

all cases to a value below 0.009%. While the precise mechanism by which the protective gas atmosphere reacts in the presence of hot steel to form water vapor to thereby increase the dew point has been postulated by different investigators, it is believed that the hydrogen reacts with the carbon dioxide to form water and carbon monoxide. This reaction also takes place where the furnace atmosphere is comprised of mixtures of cracked natural gas and other protective atmospheres such as dissociated ammonia as has been described. As illustrative of the gas compositions and dew points obtained in practicing this invention with a furnace atmosphere of cracked natural gas having an air to gas ratio of at least 5.5 to 1 and a dew point of less than +60° F. as admitted to the furnace, reference may be had to Table III recording data as measured at the various temperatures in different zones of a twelve-zone furnace.

Table III

Zone	Temperature (° F.)	CO_2 (Percent)	CO (Percent)	Dew Point, ° F.
11	1,800	5.8	9.4	51
9	1,725	4.0	12.0	74
6	1,600	3.6	12.2	78
2	1,500	2.6	13.4	80

It is apparent from the foregoing table that with the use of a cracked natural gas atmosphere as the gas flows from the hot end, that is, zone 11, having a temperature of about 1800° F., the gas has a dew point of about 51° F. and a gas composition including among other gases 5.8% carbon dioxide and 9.4% carbon monoxide. As the gas approaches the lower temperature zone of the furnace, that is, the end of the furnace into which the steel strip enters, the temperature being about 1500° F., the gas has an increased dew point of +80° F. and a composition of 2.6% carbon dioxide and 13.4% carbon monoxide. It is thus apparent from the decrease in the percentage of carbon dioxide and the increase in the carbon monoxide with a corresponding increase in dew point of the gas that the reaction has taken place whereby the hydrogen has probably reduced the carbon dioxide to form carbon monoxide and water. The effective increase in the dew point to greater than +60° F. in conjunction with the low temperature of the steel, that is, between 1400° F. and 1600° F., makes it possible for effectively decarburizing the steel. This is true irrespective of the fact that there is an increase in the carbon monoxide concentration, a well-known carburizing agent, as a component of the furnace atmosphere. While the chemistry for the different protective gas atmospheres used may vary somewhat from the chemistry set forth above, all of the protective gas atmospheres used produce the same results, that is, in the highest temperature zone of the furnace if there is any reaction resulting from an increased dew point of greater than +60° F. with the resulting formation of scale on the surface of the strip, such scale is reduced in the presence of the hydrogen-containing gas atmosphere where the hydrogen concentration is greater than 12% by volume with the result that the strip emerges from the furnace having a scale-free condition. With the increase in the dew point and in particular in the lower temperature zone of the furnace, a reaction takes place between the carbon contained in the silicon steel strip and the water vapor carried by the gas to effectively decarburize the silicon steel strip to a carbon content of less than 0.013% and preferably less than 0.009%. This is also found to be true in cases where the gas is burned at the open ends of the furnace and the furnace atmosphere is devoid of cracked natural gas or atmospheric air.

In order to more clearly demonstrate the effectiveness of

the process of this invention reference may be had to Table IV which illustrates the effect of the heat treatment outlined hereinbefore on the carbon content of the strip, it being noted that various gas atmospheres are used.

Table IV

EFFECT ON CARBON

A. Atmosphere: Cracked natural gas 6.5/1 ratio air to gas			
Dew point entry +40° F.			
Dew point exit +80° F.			
Heat No. 5330—			
Percent carbon start	0.026		
Percent carbon finish	0.008	0.005	
Percent carbon finish	0.006	0.006	
Percent carbon finish	0.008	0.006	
Percent carbon finish	0.006	0.006	
Percent carbon finish	0.009	0.006	
Percent carbon finish	0.005	0.007	Ave. 0.0065
B. Atmosphere: Cracked NH_3=(75% H_2+25% N_2)			
Dew point entry −40/−45° F.			
Dew point exit +92° F.			
Heat No. 6892—			
Percent carbon start	0.050		
Percent carbon finish	0.0056		
Percent carbon finish	0.0054		Ave. 0.0055
C. Atmosphere: Forming gas=(15% H_2+85% N_2)			
Dew point entry −40° F.			
Dew point exit +92° F.			
Heat No. 6892—			
Percent carbon start	0.050		
Percent carbon finish	0.008	0.005	
Percent carbon finish	0.007	0.009	Ave. 0.0072.

As can be seen from the data recorded in subsection A of Table IV for heat 5330, heat treatment of coils of silicon steel strip in accordance with the process of this invention is effective for decreasing the carbon content from 0.026% to an average of about 0.0065% for the twelve coils tested when a furnace atmosphere of cracked natural gas having an air to gas ratio of 6.5 to 1 is used. It is to be noted that the dew point has been increased from +40° F. where the gas was introduced into the high temperature zone of the furnace to +80° F. where the gas was discharged from the furnace. Thus from the data recorded in subsection A it is apparent that the process of this invention is highly effective for decarburizing the steel in an atmosphere of cracked natural gas.

Referring now to subsection B of Table IV, it is seen that the process of this invention is also effective for decarburizing the steel when an atmosphere of pure cracked ammonia having a dew point between −40° F. and −45° F. is used as the furnace atmosphere. Thus it is clearly seen that steel from heat 6892 having a carbon content of about 0.050% prior to heat treatment is effectively decarburized to a carbon content of 0.005% after heat treatment, it being noted that the dew point of the gas has risen from about −45° F. to about +92° F. This gas was ignited and burned in the air atmosphere as it escaped from each end of the furnace. Substantially similar results were obtained as recorded in subsection C of Table IV when the steel from the same heat was heat treated by the process of this invention using an atmosphere of pure forming gas, that is, about 15% hydrogen and about 85% nitrogen, the entry dew point being −40° F. and the exit dew point being +92° F. The process, when using forming gas, is effective for decreasing the carbon content from 0.050% to about an average of 0.0072%. Thus it is apparent from the examples given that different protective gas atmospheres having at least 12% hydrogen by volume are effective for substantially decarburizing the steel when the dew point of the gas in the low temperature zone of the furnace is in excess of +60° F.

A heat treatment providing for mere decarburization without an increase in the magnetic characteristics would be of little value where the steel is to be used for electrical purposes. Therefore, in order to show the beneficial effect upon the magnetic characteristics of the heat treatment of the process of this invention, reference may be had to Table V which illustrates the effect of the heat treatment of this invention previously described on the magnetic characteristics of different silicon iron alloy steels.

Table V

MAGNETIC CHARACTERISTICS

Heat No.	Atmosphere	Watts per lb. @ 10,000 B.	
5330	Cracked Natural Gas air/Gas=6.5/1	1.17	1.14
		1.13	1.14
		1.08	1.20
		1.06	1.07
		1.18	1.23
		1.14	1.20
			Ave. 1.15
6892	Forming Gas (H_2—15%; N_2—85%)	1.02	1.05
		1.01	1.02
			Ave. 1.04
	Cracked Ammonia (H_2—75%; N_2—25%).	1.08	1.10
		1.09	1.15
			Ave. 1.09

Each of the coils from the various heats was given the standard Epstein Test in which half of the samples of the steel of the test specimen were cut in the direction of rolling and half of the samples of the steel were cut perpendicular to the direction of rolling, the samples making up the test specimen being in the "as-cut" condition. From the data recorded in Table V it is seen that for heat 5330, a commercial heat having an initial analysis of about 0.025% carbon, about 0.28% manganese, about 0.008% phosphorus, about 0.018% sulfur, about 0.28% aluminum, about 2.9% silicon and the balance iron with incidental impurities, this steel had an average watt loss of 1.15 watts per pound when measured at 10,000 B. It is thus apparent that the process of this invention is effective for producing superior magnetic characteristics in the steel. This is readily substantiated when it is considered that for this grade of steel of this particular gauge the accepted watt loss is 1.30 watts per pound when measured at 10,000 B. When the steel of heat 6892, also a commercial heat of steel having an analysis of about 0.050% carbon, about 0.36% manganese, about 0.010% phosphorus, about 0.025% sulfur, about 0.24% aluminum, about 2.83% silicon and the balance iron with incidental impurities, was heat treated in accordance with the process of this invention using forming gas in one instance and cracked ammonia in the other, the steel had an average watt loss of 1.04 watts per pound for four tests and an average watt loss of 1.09 watts per pound for four tests, respectively. This is well within the limits of experimental error and clearly illustrates the outstanding advantage of the use of the process of this invention. This is especially borne out when it is considered that the currently accepted value for these steels of the same gauge is 1.30 watts per pound when measured at 10,000 B.

As a further illustration of the commercial success and the effectiveness of the process of this invention, a number of coils of M–36 grade silicon steel having an analysis of up to 0.07% carbon, between 0.20% and 0.40% manganese, up to 0.05% phosphorus, up to 0.04% sulfur, between 1.0% and 2.0% silicon, up to 0.40% aluminum and the balance iron with incidental impurities, having a 24 gauge thickness were made and tested using various atmospheres according to the process of this invention. Of the 662 coils tested, 656 coils had a watt loss of less than 1.7 watts per pound, and the average watt loss for the 662 coils was 1.39 watts per pound. The currently acceptable watt loss of 24 gauge steel when measured at 10,000 B. is 1.7 watts per pound. Similar results were also obtained on 26 gauge steel. Of the 1170 coils of 26 gauge steel which were tested, all but 84 coils had a watt loss of less than 1.35 watts per pound, the currently acceptable watt loss for 26 gauge being 1.35 watts per pound measured at 10,000 B. Thus it is apparent that the process is effective for producing silicon steel on a com-

mercial scale, said steel having superior magnetic characteristics.

From the foregoing it is apparent that the process of this invention is effective for producing a superior quality of electrical steel. This is amply demonstrated by the fact that the steel has been effectively decarburized and in the same heat treatment has been subjected to grain growth, all of which are necessary for improved magnetic characteristics. As clearly demonstrated by the data set forth in Table V, the process is effective for producing superior magnetic characteristics through the use of a single cold rolling and a single heat treatment operation. It is to be noted that while it is preferred to utilize a high temperature treatment of 1800° F. to 2150° F., the process of this invention is also especially effective where the high temperature treatment is in the somewhat lower level of 1725° F. to 1900° F. as evidenced by the results given hereinbefore where the high temperature treatment is at 1800° F. The combination of the continuous heat treatment including a high temperature treatment of only 1725° F. to 1900° F. makes it possible to effect economies in the process and equipment used while producing excellent results as described.

This is a continuation-in-part of application Serial Number 640,063, filed February 14, 1957, now abandoned.

I claim:

1. In the method of producing electrical steel strip from silicon steel having a silicon content of between 0.25% and 4.5% and a carbon content of up to 0.07% characterized in that a continuous heat treatment operation utilizing a single atmosphere is effective for decarburizing, recrystallizing, developing a large grain size and improving the magnetic characteristics of the steel, the steps comprising, hot rolling the silicon steel to a strip having a thickness of between 0.060 and 0.125 inch, descaling, cold rolling the descaled hot rolled strip to a final thickness of between 0.014 and 0.031 inch, and normalizing the steel, the normalizing heat treatment being effected by passing the scale-free cold rolled strip through a continuous furnace in a time period ranging between 3.5 and 8 minutes, said furnace having two contiguous temperature zones and a common atmosphere, in which the temperature zones in said furnace progressively increase in temperature from not less than 1400° F. up to a high temperature zone of between 1725° F. and 2150° F. in predetermined increments, the furnace having a low temperature zone of between 1400° F. and 1650° F. and comprising between about 38% to about 49% of the total length of the furnace, admitting a controlled atmosphere of a hydrogen-containing protective gas atmosphere having a dew point of less than +60° F. adjacent the strip exit end of the high temperature zone of the furnace to flow throughout the furnace countercurrent to the direction of movement of the strip therethrough, said atmosphere being common to both the high temperature zone and the low temperature zone of the furnace, the furnace atmosphere having a minimum of 12% hydrogen by volume and reacting at least in the low temperature zone of the furnace to provide a dew point in excess of +60° F. therein, the furnace atmosphere having a dew point in excess of +60° F. cooperating with the carbon of the strip in the low temperature zone of the furnace to effectively decrease the carbon content of the strip in the low temperature zone of the furnace to produce a final strip at the exit end of the furnace having a carbon content of below 0.013%, the hydrogen content of the protective gas atmosphere cooperating with the strip in the high temperature zone of the furnace to maintain a scale-free surface thereon.

2. In the method of producing electrical steel strip from silicon steel having a silicon content of between 0.25% and 4.5% and a carbon content of up to 0.07% characterized in that a continuous heat treatment operation utilizing a single atmosphere is effective for decarburizing, recrystallizing, developing a large grain size and improving the magnetic characteristics of the steel, the steps comprising, hot rolling the silicon steel to a strip having a thickness of between 0.060 and 0.125 inch, descaling, cold rolling the descaled hot rolled strip to a final thickness of between 0.014 and 0.031 inch and normalizing the steel, the normalizing heat treatment being effected by passing the scale-free cold rolled strip through a continuous furnace in a time period ranging between 3.5 and 8 minutes, said furnace having two contiguous temperature zones and a common atmosphere in which the temperature zones in said furnace progressively increase in temperature from not less than 1400° F. up to a high temperature zone of between 1725° F. and 2150° F. in predetermined increments, the furnace having a low temperature zone of between 1400° F. and 1650° F. and comprising between about 38% to about 49% of the total length of the furnace, admitting a controlled protective atmosphere of cracked natural gas having an air to gas ratio of at least 5.5 to 1 and having a dew point of less than +60° F., adjacent the strip exit end of the high temperature zone of the furnace to flow throughout the furnace countercurrent to the direction of movement of the strip therethrough, said atmosphere being common to both the high temperature zone and the low temperature zone of the furnace, the furnace atmosphere having a minimum of 12% hydrogen by volume and reacting at least in the low temperature zone of the furnace to provide a dew point in excess of +60° F. therein, the furnace atmosphere having a dew point in excess of +60° F. cooperating with the carbon of the strip in the low temperature zone of the furnace to effectively decrease the carbon content of the strip in the low temperature zone of the furnace to produce a final treated strip at the exit end of the furnace having a carbon content below 0.013%, the hydrogen content of the protective gas atmosphere cooperating with the strip in the high temperature zone of the furnace to maintain a scale-free surface thereon.

3. In the method of producing electrical steel strip from silicon steel having a silicon content of between 0.25% and 4.5% and a carbon content of up to 0.07% characterized in that a continuous heat treatment operation utilizing a single atmosphere is effective for decarburizing, recrystallizing, developing a large grain size and improving the magnetic characteristics of the steel, the steps comprising, hot rolling the silicon steel to a strip having a thickness of between 0.060 and 0.125 inch, descaling, cold rolling the descaled hot rolled strip to a final thickness of between 0.014 and 0.031 inch and normalizing the steel, the normalizing heat treatment being effected by passing the scale-free cold rolled strip through a continuous furnace having a length within the range between 200 and 350 feet in a time period ranging between 3.5 and 8 minutes and at a rate ranging between 0.5 and 2.0 feet per minute per inch of strip thickness, said furnace having two contiguous temperature zones and a common atmosphere, in which the temperature zones in said furnace progressively increase in temperature from not less than 1400° F. up to a high temperature zone of between 1725° F. and 2150° F. in predetermined increments, the furnace having a low temperature zone of between 1400° F. and 1650° F. and comprising between about 38% to about 49% of the total length of the furnace, admitting a controlled atmosphere of a hydrogen-containing protective gas atmosphere having a dew point of less than +60° F. adjacent the strip exit end of the high temperature zone of the furnace to flow throughout the furnace countercurrent to the direction of movement of the strip therethrough, said atmosphere being common to both the high temperature zone and the low temperature zone of the furnace, the furnace atmosphere having a minimum of 12% hydrogen by volume and reacting at least in the low temperature zone of the furnace to provide a dew point in excess of +60° F. therein, the furnace atmosphere having a dew point in

excess of +60° F. cooperating with the carbon of the strip in the low temperature zone of the furnace to effectively decrease the carbon content of the strip in the low temperature zone of the furnace to produce a final treated strip at the exit end of the furnace having a carbon content of below 0.009%, the hydrogen content of the protective gas atmosphere cooperating with the strip in the high temperature zone of the furnace to maintain a scale-free surface thereon.

4. In the method of producing electrical steel strip from silicon steel having a silicon content of between 0.25% and 4.5% and a carbon content of up to 0.07% characterized in that a continuous heat treatment operation utilizing a single atmosphere is effective for decarburizing, recrystallizing, developing a large grain size and improving the magnetic characteristics of the steel, the steps comprising, hot rolling the silicon steel to a strip having a thickness of between 0.060 and 0.125 inch, descaling, cold rolling the descaled hot rolled strip to a final thickness of between 0.014 and 0.031 inch and normalizing the steel, the normalizing heat treatment being effected by passing the scale-free cold rolled strip through a continuous furnace in a time period ranging between 3.5 and 8 minutes, said furnace having two contiguous temperature zones and a common atmosphere, in which the temperature zones in said furnace progressively increase in temperature from not less than 1400° F. up to a high temperature zone of between 1725° F. and 2150° F. in predetermined increments, the furnace having a low temperature zone of between 1400° F. and 1650° F. and comprising between about 38% to about 49% of the total length of the furnace, admitting a controlled atmosphere of a hydrogen-containing protective gas atmosphere having a dew point of less than +60° F. adjacent the strip exit end of the high temperature zone of the furnace to flow throughout the furnace countercurrent to the direction of movement of the strip therethrough, said atmosphere being common to both the high temperature zone and the low temperature zone of the furnace, the furnace atmosphere being supplied to the furnace at a rate of between 8,000 and 11,000 cubic feet per hour and having a minimum of 12% hydrogen by volume and reacting at least in the low temperature zone of the furnace to provide a dew point in excess of +60° F. therein, the furnace atmosphere having a dew point in excess of +60° F. cooperating with the carbon of the strip in the low temperature zone of the furnace to effectively decrease the carbon content of the strip in the low temperature zone of the furnace to produce a final treated strip at the exit end of the furnace having a carbon content of below 0.009%, the hydrogen content of the protective gas atmosphere cooperating with the strip in the high temperature zone of the furnace to maintain a scale-free surface thereon.

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