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METHOD OF PRODUCING DEEP DRAWING STEEL

John Neil Laidman, Baltimore, Md., and Edward H. Mayer and Frederick B. Schunk, Bethlehem, Pa., assignors, by mesne assignments, to Bethlehem Steel Corporation, a corporation of Delaware

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This application is a continuation-in-part of the copending application of John N. Laidman et al., Serial No. 43,323, filed July 18, 1960, now abandoned, and assigned to the assignee of the present invention.

This invention relates broadly to a method of producing steel strip having excellent deep-drawing properties. More specifically, it relates to the production of steel strip having excellent deep-drawing properties by a method which includes a continuous annealing operation. Still more specifically, it relates to the production of steel strip having excellent deep-drawing properties and having a coating thereon by a method which includes a continuous annealing operation, and it relates also to the coated product resulting from the process.

Ordinary rimmed, capped, semi-killed or killed steel strip intended for deep-drawing purposes is generally reduced to final gauge by a cold rolling operation. This cold reduction alters the structure of the steel, causing the steel stip to be relatively hard and unformable, and rendering it unsuitable for deep drawing. The steel must, therefore, be annealed or normalized after cold rolling to increase its ductility and softness.

Several heat treatments have heretofore been devised for increasing the softness and ductility of the strip, the most successful of which we believe to be box or batch annealing, in so far as the properties which result therefrom affect the final quality of the product for deep-drawing purposes. Box or batch annealing, however, necessitates a long period of time to achieve the intended result, usually several days at the least. The carbides present in ordinary steel strip provide points for nucleation, causing the grains which form during recrystallization to be relatively small, and these carbides also act as barriers to grain growth, so that long periods of time are required for box annealing to allow sufficient grain growth to obtain grains of the proper size for deep-drawing quality strip. Furthermore, cooling rates from high temperatures are necessarily very slow, so that carbon in solution at annealing temperatures can precipitate and coalesce to form relatively harmless spheroidal carbides. If this carbon is not permitted to precipitate and coalesce it will precipitate later since at room temperature the steel will contain a supersaturated solution of carbon in ferrite.

Therefore, it has been impossible to obtain properties equal to those obtained by batch annealing by a short-time continuous anneal of ordinary rimmed, capped, semi-killed or killed steel. Continuously annealed steel sheet or strip made by prior art processes is harder and has higher tensile strength and poorer ductility than its batch annealed counterpart because of the relatively fine grains formed during the anneal, the size and distribution of the carbides formed, and also because of the carbon which is retained by the ferrite. These drawbacks have placed known continuous annealing processes at a distinct disadvantage; consequently, steel sheets which must be subsequently subjected to severe deep drawing operations have been produced by batch annealing, due to the softer and more ductile product obtained by the latter process.

Because of the disadvantages of continuous annealing as discussed above, it has heretofore been impossible

to produce a soft, ductile, deep-drawing quality zinc-, tin-, or aluminum-coated steel sheet by continuous annealing-continuous coating processes. Thus, to produce deep-drawing quality galvanized strip, prior practices have generally comprised cleaning the cold-rolled strip, box annealing it at slow heating and cooling rates for a period of hours or days at around 1300° F., and then skin rolling continuously pickling, fluxing, drying and continuously coating the strip. The skin rolling step is necessary to harden the strip slightly to avoid the danger of strip "cross breaks" during subsequent continuous operations. The steps of pickling, fluxing, and drying are necessary in the prior art practices to prepare the previously box annealed strip before entrance into the galvanizing pot, to promote adhesion of the coating. The temperature of the steel strip is kept as low as possible during all the stages of processing following the box anneal to insure a relatively ductile, deep-drawing quality final product. The temperature of the steel is, however, raised in the coating operation since the steel generally approaches the temperature of the molten bath during coating, and carbon, which is present in the steel as relatively harmless spheroidal carbides because of the long, slow box anneal, goes back into solution and precipitates on cooling, thereby increasing the hardness and decreasing the ductility of the steel.

It has furthermore been impossible to produce by any known methods a deep-drawing quality aluminum coated steel strip because such strip has heretofore contained more than .01% carbon. A brittle alloy of aluminum and iron grows rapidly at the interface of the ferrous base metal and the aluminum coating during and after coating until the temperature of the steel is below about 1050° F. It is therefore necessary to coat the steel in as short a time as possible and to rapidly cool the coated steel immediately after coating to below the temperature at which alloy growth occurs. An unsatisfactory solidification of the coating and an unduly heavy alloy layer will occur if these practices are not observed. The carbon present in ordinary undecarburized steel, most of which has gone back into solution because of the high temperature of the molten aluminum, does not have time to precipitate and coalesce to form harmless particles in a process of this type employing fast cooling. Our new aluminum coated sheet steel, however, by virtue of an extremely low carbon content, can be cooled as rapidly as necessary to control the alloy layer growth with no increase in hardness.

It is an object of the present invention to provide a method of producing a continuously annealed steel strip which possesses ductility and softness comparable to that of a box annealed steel strip or sheet and which is formed from ordinary rimmed, capped, semi-killed or killed steel.

It is a further object of the invention to provide a method whereby steel strip formed from ordinary rimmed, capped, semi-killed or killed steel can be continuously coated with molten metal, for example zinc, tin, or aluminum immediately following or in line with a continuous annealing operation, the properties of the coated strip being excellent for subsequent deep drawing.

It is a further object of the invention to provide an aluminum coated steel strip which has excellent ductility and a high degree of softness.

It is a still further object of the invention to produce an aluminum coated steel strip which is excellent for deep-drawing and which has an aluminum-iron alloy interface which is much thinner than that exhibited by aluminum coated steel strip heretofore produced.

These and other objects of the invention will be apparent to those skilled in the art from the following de-

scription, and the scope of the invention will be indicated in the appended claims.

The process of the invention broadly comprises rolling a slab of ordinary rimmed, capped, semi-killed or killed steel to a strip of intermediate gauge, decarburizing the steel strip, cold reducing the strip directly to final gauge, and continuously annealing the strip. The annealed strip may then be coated.

More specifically the process of the invention compries rolling a slab of such steel to a strip of intermediate gauge by a method which avoids the presence of "critical strain" (hereinafter defined) in such strip, decarburizing the strip to a carbon content of .01% max., thereafter cold reducing the decarburized strip to final gauge to reduce its thickness by at least 15%, and continuously annealing the strip below the lower critical temperature to produce in the strip a grain size of 100 to 200 grains per square inch at 100 magnifications. The strip may then be coated.

Still more specifically, the invention comprises dipping steel strip produced as aforesaid into a bath of molten aluminum for a period of time long enough to produce an aluminum coating thereon, and immediately and rapidly cooling the coated strip.

In practicing our invention, we start with slabs of ordinary rimmed, capped, semi-killed, or killed steel of the following analyses, for example:

Carbon, percent maximum	0.30
Manganese, percent	0.20–1.7
Phosphorus, percent maximum	0.040
Sulfur, percent maximum	0.040
Silicon, percent maximum	0.04

Balance essentially iron.

There is no clear limit to the amount of carbon which may be present in the steel slabs. Because of the economics of the process, however, we prefer to limit the carbon content to that of ordinary low to medium carbon steels, i.e., about .30% max. The upper limit of the manganese is based on the percentage above which the drawability of the steel decreases rapidly. Again, due to the economics of the process, we prefer to keep the manganese below 0.50%.

The silicon content is kept low to insure good drawability. Although any impurities present may tend to make the steel harder and less ductile, the presence of substantial amounts of silicon is especially detrimental to steels which are to be subjected to deep drawing. The phorsphorus and sulfur contents are normal for deep-drawing quality steels. Other elements, in amounts which do not substantially affect the deep-drawing quality of the finished product, may be present.

A slab of steel having an analysis within the above ranges is reduced in rolling mills to a strip of intermediate thickness. This rolling operation may be carried out either entirely in the hot mill, or by a combination of hot and cold rolling operations. This step of the process must be carefully controlled so that the steel does not contain an amount of strain within the "critical strain" range. "Critical strain" may be defined as an amount of strain which causes objectionably large grains to grow upon recrystallization during a subsequent anneal. This critical strain, which lies within a range equivalent to that imparted to the steels of this invention by cold reduction of from about 3% to about 7% (i.e., 3% to 7% cold work), may be avoided by controlling the rolling operations and any intermediate practice prior to the decarburizing anneal so that as the steel enters the annealing furnace, it is either essentially free from strain, i.e. contains less than 3% cold work, or has been strained substantially beyond the critical range, i.e., contains more than 7% cold work, e.g., 15 to 20%. A steel strip with less than the critical amount of strain will not recrystallize during the decarburizing anneal, and will therefore not develop massive grains. A steel strip which has been processed so as to have more than the critical amount of strain, e.g., 10% cold work, will recrystallize during the anneal but will develop relatively fine grains rather than the objectionable massive grains. A steel strip which has been critically strained prior to the decarburizing anneal or in the cold rolling step preceding the continuous anneal will upon continuous annealing develop a grain size too coarse to permit the steel to be deep drawn.

The degree to which our steel is strained beyond the critical strain range preceding the decarburizing anneal is not strictly limited, so long as it is such as will result in a final product having a grain size of 100 to 200 grains per square inch at one hundred magnifications. Thus, a reduction of approximately 15% will give a grain size which is not optimum for good deep drawing properties. However, this may be corrected in the final steps of the process in which the final cold reduction will be whatever is required to produce a steel having, after being continuously annealed, a grain size of 100 to 200 grains per square inch. In any event, the steel must not contain 3 to 7% cold work following either the reduction to intermediate gauge or the reduction to final gauge.

We have developed several methods of producing intermediate gauge steel strip which is free of critical strain. In two of these methods the steel is strained during rolling substantially beyond the critical strain range, while in the other two the steel is treated in such a manner that it is substantially free of any strain whatsoever. To produce an intermediate gauge strip which is strained substantially beyond the critical strain range, the steel may be reduced to the intermediate gauge desired either entirely in the hot mill or by a combination of hot and cold rolling operations. Should the steel be reduced to intermediate gauge entirely in the hot mill, the amount of reduction in the last stand of the hot rolling mill and the hot mill finishing and cooling temperatures are carefully controlled so that the hot-rolled steel is strained beyond the "critical strain" range. That is, the steel is reduced by at least 7%, e.g., from 9% to 14%, in the last stand of the hot mill. The temperature of the steel during this final reduction, i.e. the finishing temperature, must be such that the steel consists essentially of ferrite. For low carbon steels, this temperature lies below about 1500° F., e.g., 1450° F. The strip is then cooled fairly rapidly and coiled at a temperature below 1200° F., e.g., 1150° F. to insure that the strained ferrite grains do not recrystallize. By following the above procedures in the hot mill, that is, controlling the percentage reduction and the finishing temperature so that the steel is drastically deformed while it consists essentially of ferrite, and by controlling the coiling temperature and rate of cooling so there is insufficient heat and time for recrystallization, the steel upon cooling to room temperature has the characteristics of steel which has been cold reduced by more than 7%, and the aforementioned objectionable massive grains will not form during the subsequent decarburizing anneal. However, the hot mill practice may be varied somewhat, provided the variation does not result in a decrease in strain sufficient to cause massive grain growth during the subsequent anneal.

Should the steel be reduced to intermediate gauge by a combination of hot and cold rolling operations, the hot mill practice need not be so carefully controlled, provided there is substantial cold work imparted to the steel during either the hot rolling or the cold rolling operations individually, or during the combination of hot and cold rolling operations, to strain the steel beyond the critical strain range. That is, the steel may be hot rolled by ordinary hot mill methods, e.g. finished at about 1600° F. and coiled at about 1100° F., without regard to the percentage of strain introduced in the finishing and coiling steps. The hot-rolled steel is then pickled to remove the hot mill scale from the surface of the strip. Following pickling, the steel is cold reduced to impart to the steel an amount of strain which exceeds the critical

strain range, e.g., 15 to 20%, and preferably from 40 to 50%.

To produce steel strip which prior to decarburization is substantially free of strain, and therefore free of critical strain, the steel is reduced to intermediate gauge entirely in the hot mill. The steel is finished within temperature ranges in which the steel is substantially single phase, i.e., the steel consists essentially either of ferrite or of austenite, but not a mixture of both ferrite and austenite. Should the steel be finished within temperature ranges in which is consists essentially of austenite, the percentage reduction in the last stand is not critical, since the austenite grains recrystallize very quickly to form strain-free uniform grains. For low carbon steels the steel should be finished above about 1600° F. The steel strip should then be coiled above about 1300° F., e.g., 1350° F., and slowly cooled to room temperature at a rate which is insufficient to strain the steel.

Should the steel be finished within temperature ranges in which it consists essentially of ferrite, e.g., at temperatures below 1500° F., the steel is reduced by more than 7%, e.g., from about 9 to 14% in the last stand of the hot mill. The steel is then slowly cooled to about 1350° F., coiled, and slowly cooled to room temperature. The slow cooling from below 1500° F. permits the strained ferrite grains to recrystallize, and the steel upon cooling is therefore substantially strain-free. By following the above procedures in the hot mill the steel upon cooling will be strained not more than 3%, and massive grains will not form during the decarburizing anneal.

The steel which has been rolled to intermediate gauge in such a manner as to avoid critical strain is then decarburized to a carbon content of less than .010%, and preferably to below .003%. There are several methods of decarburizing the steel depending upon the method employed to reduce the steel to said intermediate gauge. If the steel has been reduced entirely in the hot mill, either of the following two methods may be used. One method is to cool the hot-rolled coil, pickle or otherwise remove the mill scale, open wind the coil, using string, wire, or other means to space the laps, place the coil in an annealing furnace and anneal the strip at 1200–1350° F. for several hours in a decarburizing atmosphere. We have found that a moist nitrogen-hydrogen atmosphere, e.g., 10% to 20% hydrogen, water vapor equivalent to a dew point of 35° F. to 85° F., remainder nitrogen, works exceptionally well in attaining the desired low carbon level. Increasing the hydrogen and water vapor content increases the reaction rate, thus decreasing the time required to attain the preferred carbon level of .003% or less, but increasing the hydrogen adds to the cost. Practical temperatures and times are those customarily used for batch anneals, and the atmospheres are inexpensive and easy to make. The temperature of the steel during the decarburizing treatment should be sufficient to completely anneal the steel, but insufficient to cause excessive grain growth therein. Preferably, the temperature should not exceed about 1350° F., and the grain size of the decarburized steel should be about 100–200 grains per square inch at one hundred magnifications.

The decarburizing step may be modified somewhat when the hot rolling has been finished above 1600° F. Since it is economical to utilize the residual heat present in the hot-rolled coil to supply most of the heat required during decarburization, the coil is loosely wound at the hot mill coilers and placed, while still hot, in an annealing furnace containing a decarburizing atmosphere.

Steel which has been reduced to intermediate gauge by a combination of hot and cold rolling operations may be decarburized in substantially the same way as hot-rolled steel which has been cooled prior to decarburization. The cold-rolled steel is open wound, using spacers, placed in an annealing furnace, and annealed in a decarburizing atmosphere in the above-described manner.

After having been decarburized, the steel strip is cold rolled by normal procedures directly to substantially final gauge. By "directly," we mean without intermediate annealing. The cold rolling should be sufficient to reduce the thickness of the strip by at least 15%, and sufficient to produce a steel which after continuous annealing will be of the proper grain size for deep drawing, i.e., from 100 to 200 grains per square inch at 100 magnifications.

As has been heretofore mentioned, the percentage cold reduction to final gauge depends upon the amount of strain imparted to the steel during the prior rolling to intermediate gauge. It has been pointed out that if the steel is strained by an amount equivalent to 3 to 7% cold work during the reduction to intermediate gauge, objectionably large grains will form during the decarburizing anneal and no amount of cold work imparted to the steel during the subsequent reduction to final gauge will result in a deep-drawing quality continuously annealed steel strip. Should the steel be strained by 15 to 20% during the first reduction, it may be necessary to reduce the steel by at least 60% during the final cold reduction, if the continuously annealed product is to have a grain size of 100 to 200 grains per square inch. Should the steel be strained by an amount equivalent to 40% cold work during the first rolling operations, the steel will have a grain size following decarburization such that a final cold reduction of 40% is sufficient to result in a deep-drawing quality continuously annealed steel strip. Should the steel be strain-free following reduction to intermediate gauge, the steel will, upon decarburizing, develop a grain of a size equivalent to that developed by a steel which has been strained by about 40% prior to decarburization. The reduction to final gauge should then be from about 40 to 60%.

The substantial cold reduction to final gauge serves an additional function besides insuring that the steel has a final grain size suitable for deep drawing purposes. The surface of steel strip which has been annealed by either the batch or the open coil decarburization process is such that the steel cannot be coated, e.g., galvanized, without intermediate treatment, such as pickling, if there is to be satisfactory zinc adherence. By virtue of the heavy cold reduction to final gauge in the instant process, satisfactory coating adherence is obtained without the necessity of a pickling operation following decarburization, provided the steel has been pickled following hot rolling to remove the hot mill scale.

The cold reduced strip is then continuously annealed to relieve the strains produced in the cold rolling operation. Our method of continuous annealing broadly comprises passing the decarburized and cold-rolled strip through a conventional continuous annealing furnace containing a protective atmosphere at temperatures within the range of 1050° F. to the lower critical temperature, on heating, of the steel, such critical temperature being, in some cases, as high as 1600° F. A temperature range of 1050° F. to 1480° F. has been found satisfactory. The strip is heated preferably to within the range of 1050° F. to 1350° F. in from about 5 seconds to about 4 minutes, held within this temperature range for about 30 seconds to 8 minutes, and cooled to below about 200° F. as quickly as desired; e.g., in less than 10 minutes, and usually in about three or four minutes. The time required depends upon the gauge of the strip, heavier gauges requiring longer times for heating, holding, and cooling. The speed of the strip is usually from 100 to 400 feet per minute.

The continuously annealed steel strip is extremely soft and ductile and is of deep drawing quality, due to the grain size and the extremely low carbon content of the steel. That is, because of the decarburizing treatment and the amount of strain imparted to the steel during the rolling operations, the continuously annealed steel contains less than .010% carbon and has a grain size of 100 to 200 grains per square inch at 100 magnifications.

The above described process of rolling to intermediate gauge, decarburizing, cold rolling and continuous anneal-

ing is particularly adapted for the treatment of steel strip which is to be immediately continuously coated with molten metal, in which case the coating bath is in line with the continuous annealing furnace. For example, when the strip is to be galvanized in line with the continuous annealing operation, the continuous anneal is substantially the same anneal as outlined above except for a modification of the cooling practice. That is, the steel strip is heated in the same way, held within the same temperature range for similar periods of time, but is cooled only to the approximate temperature of the molten zinc, and is then immediately introduced into the zinc bath. The strip is in the zinc bath for a matter of a few seconds only, and the subsequent cooling may be as rapid as desired because of the extremely low carbon in the steel.

Our method as described provides a way to produce deep-drawing quality aluminum coated sheet, a product which has heretofore been impossible to produce for the reasons previously pointed out. By applying an aluminum coating to a steel consisting of less than .010% carbon, balance essentially iron and having a grain size of 100 to 200 grains per square inch, the problems existing in the prior art have been obviated. More specifically, low to medium carbon steel which has been, for example, reduced to intermediate gauge, decarburized and cold rolled in the manner described, is heated in a continuous annealing furnace containing a protective atmosphere to the temperatures above described and then led directly into a bath of molten aluminum in line with the continuous annealing furnace. There is substantially no cooling of the strip prior to its immersion in the molten aluminum since the temperature of the coating bath is approximately the same as the temperature of the strip in the holding zone of the continuous annealing line, i.e., about 1220° F. The strip, therefore, is fed directly from the holding zone into the bath, where it is held for not over 30 seconds, e.g., for about 15 seconds, and preferably for less than 5 seconds, and then rapidly cooled, to below 1050° F., to prevent the growth of a thick, brittle aluminum-iron alloy layer at the interface of the ferrous base metal and the aluminum coating. Since there are no carbides present in our steel, the rapid cooling will not adversely affect the deep-drawing qualities of the steel.

Example I

As a specific example of our process, we may take a slab of rimmed steel of the following analysis:

	Percent
Carbon	.08
Manganese	.39
Phosphorus	.009
Sulfur	.028
Silicon	<.01

Balance essentially iron, except for normal impurities.

We hot roll the steel to produce a strip of intermediate gauge, reducing the strip by about 12% in the last stand of the hot mill at a temperature of about 1450° to 1500° F., and then slowly cool the strip to a temperature of about 1300° F. and coil it.

The coil is cooled slowly to room temperature. The steel, which is substantially free of strain, is then pickled and is re-coiled with a spacer of steel wire between adjacent laps. The coil is placed on a furnace base providing a coil in which both sides of the strip are exposed. An annealing cover is placed over the coil and the coil is heated to about 1250° F. in a dry nitrogen-hydrogen atmosphere containing about 4% hydrogen, then held in the range 1250–1330° F. for 32 hours in a moist nitrogen-hydrogen atmosphere containing 17½% to 18½% hydrogen, water vapor equivalent to a dew point of 75° F., balance essentially nitrogen. The steel is then slowly cooled to atmospheric temperature in a dry 4% H_2, 96% N_2 atmosphere. An examination of the microstructure of the steel after cooling shows that massive grains did not form during the anneal because of the procedures followed in the hot mill. The grain size of the steel is about 100–200 grains per square inch at 100 magnifications.

The steel then has the following composition:

	Percent
Carbon	.004
Manganese	.39
Phosphorus	.009
Sulfur	.028
Silicon	<.01

Balance essentially iron, except for normal impurities.

The decarburized strip is then cold reduced by 60% in a conventional cold rolling mill.

The cold-rolled strip is then passed through a continuous annealing furnace to remove the strains produced by the cold rolling operation. The continuous annealing may be carried out at a speed of 100 feet per minute. The strip is heated in a non-oxidizing atmosphere to 1280° F. in 20 seconds, held at about this temperature for 30 seconds, and cooled in an atmosphere containing 96% N_2 and 4% H_2 to 200° F. in 5 minutes. The continuously annealed steel strip has a grain size of 100 to 200 grains per square inch at 100 magnifications, and is suitable for deep drawing operations.

Example II

As a second specific example of our process in which the steel is reduced to a substantially strain-free strip of intermediate gauge, we start with a slab of rimmed steel of the composition specified in Example I. The slab is hot rolled, finishing the rolling operation within a temperature range of 1600 to 1650° F., cooled slowly to about 1350° F., and coiled. The steel is then cooled slowly to room temperature and pickled to remove the hot mill scale. The substantially strain-free steel thus produced is re-coiled and decarburized as specified in Example I to a carbon content of .005%. The grain size of the decarburized steel is 100 to 200 grains per square inch at 100 magnifications. The steel strip is cold reduced by 50% directly to final gauge and is then continuously annealed as specified in Example I. The annealed steel is of deep drawing quality and has a grain size of 100 to 200 grains per square inch at 100 magnifications.

Example III

As a specific example of our process in which the steel is strained substantially beyond the critical strain range in the hot mill, we take a slab of rimmed steel of the following analysis:

	Percent
Carbon	.07
Manganese	.34
Phosphorus	.007
Sulfur	.030
Silicon	<.01

Balance essentially iron, except for normal impurities.

We hot roll the steel to produce a strip of intermediate gauge, reducing the strip by about 15% in the last stand of the hot mill within a temperature range of 1400 to 1450° F. The strip is then cooled rapidly to about 1150° F., coiled, and cooled rapidly to room temperature. The steel, which is strained well beyond the critical strain range, is pickled, re-coiled with a spacer of steel wire between adjacent laps, and decarburized by the method specified in Example I. The steel then has the following composition:

	Percent
Carbon	.003
Manganese	.34

	Percent
Phosphorus	.007
Sulfur	.030
Silicon	<.01

Balance essentially iron except for normal impurities.

Since only about 20% cold work was imparted to the steel in the hot mill, the grain size of the decarburized steel strip is somewhat larger than optimum, but the grain size is corrected by cold reducing the steel by 60% directly to final gauge.

Following cold reduction, the steel is continuously annealed as specified in Example I. The final product has a grain size of 100 to 200 grains per square inch at one hundred magnifications, and is excellent for deep drawing operations.

Example IV

As a specific example of our process in which the steel is reduced to intermediate gauge by a combination of hot and cold rolling operations, we take a slab of rimmed steel of the composition specified in Example III and hot roll it, finishing the rolling at about 1600° F. and coiling the steel at about 1100° F. The steel is cooled to about room temperature, pickled, and then cold reduced by about 40 to 50% to within about 40 to 50% of final gauge. It is then re-coiled, using spacers between adjacent laps, and decarburized as specified in Example I. Following decarburization the grain size of the steel is optimum, and the proper final grain size can be obtained by further cold reducing the steel directly to final gauge strip and continuously annealing it. The annealed steel has a grain size of 100 to 200 grains per square inch at 100 magnifications and has excellent drawing properties. If desired, the steel may be immediately coated without an intermediate pickling operation.

Example V

As a specific example of continuous annealing in combination with hot-dip coating we take a slab of rimmed steel of the composition specified in Example I and subject it to the hot rolling, coiling, pickling, decarburizing and cold rolling treatments specified in Example I. We then pass the strip through a continuous annealing furnace containing a protective atmosphere and having a galvanizing pot in line with the furnace. In this operation, we heat the strip to 1280° F. in about 20 seconds, hold it at that temperature for about 30 seconds, cool the strip in about two minutes to a temperature of about 860° F., pass the strip through a bath of molten zinc for about 15 seconds and then cool the coated strip in air to about 150° F. in about 2½ minutes. The coated strip has a grain size of 100 to 200 grains per square inch at 100 magnifications and has excellent deep-drawing properties, since the coating step does not adversely affect the properties of the continuously annealed steel.

Example VI

As a second specific example of continuous annealing in combination with hot-dip coating we take a slab of rimmed steel of the composition specified in Example I and subject it to the hot rolling, coiling, pickling, decarburizing and cold rolling treatments specified in Example II. We then pass the strip through a continuous annealing furnace containing a protective atmosphere and having an aluminizing pot in line with the furnace. In this operation, we heat the strip to 1280° F. in about 20 seconds, hold it at that temperature for about 30 seconds, and immediately immerse it in the molten aluminum bath. The steel is coated in about 15 seconds, rapidly air cooled to below 1050° F., and further cooled to room temperature in about 5 minutes. The rapid cooling from relatively high temperatures has not adversely affected the deep-drawing properties of the steel, and has prevented the formation of an undesirably thick aluminum-iron alloy layer at the interface of the ferrous base metal and the aluminum coating.

Example VII

As a third specific example of continuous annealing in combination with hot-dip coating we take a slab of rimmed steel of the composition specified in Example III and subject it to the hot rolling, coiling, pickling, decarburizing aid cold rolling treatments specified in Example III. The steel is then continuously annealed and galvanized as specified in Example V. The coated strip has a grain size of 100 to 200 grains per square inch at 100 magnifications and has excellent deep-drawing properties.

Example VIII

As a fourth specific example of continuous annealing in combination with hot-dip coating we take a slab of rimmed steel of the composition specified in Example III and subject it to the hot rolling, pickling, cold rolling, decarburizing and cold rolling treatments specified in Example IV. The steel is then continuously annealed and coated with molten aluminum as specified in Example VI. The aluminized steel strip has a grain size of 100 to 200 grains per square inch at 100 magnifications and an extremely thin alloy layer at the interface, and the deep-drawing properties of the coated sheet are excellent.

Example IX

As a specific example of our process as applied to a medium carbon steel we hot roll a slab of rimmed steel of the following analysis:

	Percent
Carbon	.18
Manganese	.37
Phosphorus	.008
Sulfur	.029
Silicon	<.01

Balance essentially iron, except for normal impurities.

The steel is reduced about 10% in the last stand of the hot mill at a finishing temperature of about 1450° F. The hot-rolled strip is then cooled fairly quickly to below about 1200° F. and coiled. The strip is then pickled and decarburized as specified in Example I to a carbon level of about .008%. An examination of the microstructure following decarburization shows no evidence of massive grains, since the steel has been strained beyond the critical strain range in the hot mill while it consisted essentially of ferrite. The steel is next cold rolled to final gauge and continuously annealed as in Example I. The final grain size is such that the steel is suitable for deep drawing in the uncoated condition, or it may be coated as in Examples V through VIII.

The procedures of the invention, as outlined above, serve to produce a steel sheet which has properties similar to those heretofore obtained only by batch annealing. By virtue of its low carbon content, the cold-rolled final gauge material is particularly adapted for continuous annealing in that it can be heated rapidly to an annealing temperature and can be cooled rapidly to room temperature or to any intermediate temperature, e.g., about 860° F. for galvanizing, without resulting in a hard, low ductility product. The softest continuously annealed and continuously galvanized sheet produced commercially at present is between about 50 and 56 Rockwell B hardness, while by the process of this invention continuously annealed and continuously galvanized steel of about 42 Rockwell B hardness can be made. Thus, continuously galvanized steel of our invention has better drawability than that which can be produced by any known practice which involves continuous annealing. Furthermore, our method of continuous galvanizing eliminates several costly steps,

i.e., skin rolling, cleaning, fluxing and drying, which have heretofore been necessary for producing deep-drawing quality, continuously galvanized sheet, since the high temperatures of our continuous annealing operation satisfactorily remove impurities from the surface of the strip, and the heavy cold reduction to final gauge adequately prepares the surface for proper adhesion of the coating. Moreover, since long heating, holding, and cooling cycles are no longer necessary to produce proper grain size and sufficient carbide precipitation in the final gauge strip, the speed of processing strip during the continuous annealing and coating steps of the invention is increased considerably over prior art processes. The only limitations in the strip speed are the heating capacity of the continuous annealing furnace and the coating capacity of the molten metal. Thus the tonnage output of a continuous annealing line or a continuous annealing and coating line is increased considerably.

The continuous annealing method of this invention, per se and in combination with continuous coating methods, is far superior to the best continuous methods now known for producing steel strip, either coated or uncoated, particularly in so far as the deep-drawing properties of the steel are concerned.

Although we have described our invention in considerable detail, we do not wish to be limited to the exact compositions, coatings and methods shown and described, but may use such substitutions, modifications or equivalents thereof as are embraced within the scope of our invention or as pointed out in the claims.

We claim:

1. A method of producing a coated steel strip comprising rolling to intermediate gauge strip, under such conditions that said steel is free of critical strain, a steel consisting essentially of 0.30% max. carbon, 0.20 to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, and coating said steel with molten metal.

2. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20 to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel to be free of critical strain upon cooling, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, and coating said steel with molten metal.

3. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20 to 1.7% manganese, 0.040% max. phosphorous, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be strained beyond the critical strain range, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, and coating said steel with molten metal.

4. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be substantially free of strain, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, and coating said steel with molten metal.

5. A method of producing a coated steel strip comprising straining a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, beyond the critical strain range by reducing said steel to intermediate gauge strip by hot and cold rolling operations, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, and coating said steel with molten metal.

6. A method of producing a coated steel strip comprising rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron to intermediate gauge strip under such conditions that said steel is free of critical strain, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

7. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel to be free of critical strain upon cooling, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

8. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be strained beyond the critical strain range, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

9. A method of producing a coated steel strip com-

prising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be substantially free of strain, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

10. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, pickling said steel, cold reducing said steel beyond the critical strain range and directly to intermediate gauge strip, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

11. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max silicon, balance iron, pickling said steel, cold reducing said steel by at least 15%, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and coating said steel with molten metal.

12. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand within a temperature range in which the steel is substantially all ferrite and coiling said steel at a temperature not higher than 1200° F. to strain the steel beyond the critical strain range, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

13. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand at a temperature not higher than 150° F. and coiling said steel at a temperature not higher than 1200° F. to strain the steel beyond the critical strain range, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

14. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling within a temperature range in which the steel is substantially of a single phase, slowly cooling said steel to a temperature above 1350° F., coiling said steel at said temperature, and slowly cooling said steel to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

15. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling within a temperature range in which the steel is substantially all austenitic, slowly cooling said steel to a temperature above 1350° F., coiling said steel at said temperature, and slowly cooling said steel to produce to intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

16. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling at a temperature not lower than 1600° F., slowly cooling said steel to a temperature above 1350° F., coiling said steel at said temperature, and slowly cooling said steel to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

17. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand of the hot mill within a temperature range in which the steel is substantially all ferritic, slowly cooling said steel to a temperature above 1350° F., coiling said steel at said temperature, and slowly cooling said steel to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

18. A method of producing steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand of the

hot mill at a temperature not higher than 1500° F., slowly cooling said steel to a temperature above 1350° F., coiling said steel at said temperature, and slowly cooling said steel to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing the steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, and continuously annealing said steel below the lower critical temperature.

19. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand within a temperature range in which the steel is substantially all ferrite and coiling said steel at a temperature not higher than 1200° F. to strain the steel beyond the critical strain range, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

20. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand at a temperature not higher than 1500° F. and coiling said steel at a temperature not higher than 1200° F. to strain the steel beyond the critical strain range, decarburizing said steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing the steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

21. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling within a temperature range in which the steel is substantially of a single phase and coiling said steel at a temperature above 1350° F. to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continously coating said steel with molten metal.

22. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling within a temperature range in which the steel is substantially all austenitic and coiling said steel at a temperature above 1350° F. to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

23. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling at a temperature not lower than 1600° F. and coiling said steel at a temperature above 1350° F. to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

24. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand of the hot mill within a temperature range in which the steel is substantially all ferritic and coiling said steel at a temperature above 1350° F. to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

25. A method of producing a coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon. 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, reducing the steel by at least 7% in the last stand of the hot mill at a temperature not higher than 1500° F. and coiling said steel at a temperature above 1350° F. to produce an intermediate gauge strip which upon cooling is substantially free of strain, decarburizing the hot-rolled steel at a temperature not exceeding 1350° F. to a carbon content of less than .010%, cold reducing the steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel within a temperature range of 1050° F. to 1350° F., and immediately continuously coating said steel with molten metal.

26. A method of producing an aluminum coated steel strip comprising rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, to intermediate gauge strip under such conditions that said steel is free of critical strain, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100

magnifications, continuously annealing said steel below the lower critical temperature and immediately continuously coating the steel with molten aluminum.

27. A method of producing an aluminum coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel to be free of critical strain upon cooling, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, immersing said steel into molten aluminum, holding said steel in said aluminum for less than about 30 seconds, and cooling said steel rapidly to less than about 1050° F.

28. A method of producing an aluminum coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be strained beyond the critical strain range, decarburizing said steel to a carbon content of less thna .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, immersing said steel into molten aluminum, holding said steel in said aluminum for less than about 30 seconds, and cooling said steel rapidly to less than about 1050° F.

29. A method of producing an aluminum coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, finishing the hot rolling and coiling within temperature ranges which cause the steel upon cooling to be substantially free of strain, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, immersing said steel into molten aluminum, holding said steel in said aluminum for less than about 30 seconds, and cooling said steel rapidly to less than about 1050° F.

30. A method of producing an aluminum coated steel strip comprising hot rolling a steel consisting essentially of 0.30% max. carbon, 0.20% to 1.7% manganese, 0.040% max. phosphorus, 0.040% max. sulfur, 0.04% max. silicon, balance iron, pickling said steel, cold reducing said steel beyond the critical strain range and to intermediate gauge strip, decarburizing said steel to a carbon content of less than .010% at a temperature insufficient to cause excessive grain growth therein, cold reducing said steel directly to final gauge by an amount, at least equal to 15%, which upon continuous annealing will produce a steel having a grain size of 100 to 200 grains per square inch at 100 magnifications, continuously annealing said steel below the lower critical temperature, immersing said steel into molten aluminum, holding said steel in said aluminum for less than about 30 seconds, and cooling said steel rapidly to less than about 1050° F.

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