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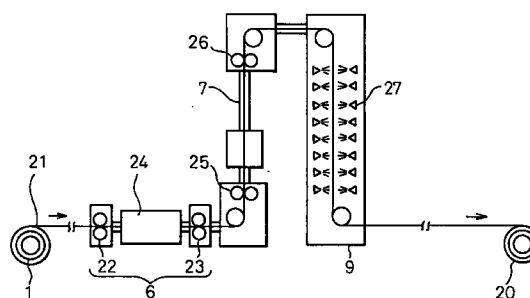
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(54) **METHOD OF CONTINUOUS ANNEALING OF COLD ROLLED STEEL PLATE AND EQUIPMENT THEREFOR**

(57) Cold rolled steel plate is continuously annealed by means of a continuous annealing equipment which comprises heating means provided in a heating zone and a soaking zone to make use of Joule heat, and cooling means provided in a cooling zone to make use of gas-liquid. Further, provided is a heating device which rapidly provides auxiliary temperature-rise at any portion of the soaking zone in a short period of time to perform heating control so as to set a value of annealing parameter (AP) to -33 or more whereby workability and BH property are improved to continuously anneal steel plates in a compact manner by rapid heating and cooling which are favorably controlled.

Fig.2



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Description

TECHNICAL FIELD

5 The present invention relates to a process for continuous annealing a cold-rolled steel sheet and an installation, and particularly to a continuous annealing process and an installation for producing a cold rolled steel sheet which may improve the workability of a cold rolled steel sheet, produce a highly functional steel sheet by imparting baking hardenability (BH) and improve the productivity.

10 BACKGROUND ART

An annealing technique at a high temperature in a continuous annealing apparatus has been known as a fundamental technique for improving the workability, such as deep drawability and bulging, of a cold rolled steel sheet.

15 The main reason is that a cold rolled steel strip or sheet has a fibrous structure, and exhibits poor workability. For the purpose of improving the workability, the steel sheet is, therefore, required to be annealed so that the steel sheet is recovered and recrystallization and grain growth take place. Continuous annealing is particularly excellent, when compared with coil annealing, in that a continuously conveyed steel sheet can be uniformly processed to have a uniform quality, and that the steel can be processed in fewer days due to the shortened processing time.

20 Generally, an installation for continuous annealing a steel sheet generally has, from the entrance side, a heating zone, a soaking zone, a first cooling zone, an overaging zone and a second cooling zone. The steel sheet is conveyed through hearth rolls provided in each of the zones to be continuously annealed. The fundamental point of such a technique is in the thermal hysteresis to which the steel sheet is subjected during annealing. The fundamental heat pattern is as described below. A cold rolled steel sheet is heated to temperature of at least the recrystallization temperature, maintained for a predetermined time, then cooled to a predetermined temperature, optionally overaged in a predetermined temperature range for a predetermined time, and secondarily cooled. A heat pattern corresponding to quality 25 conditions such as a steel sheet for deep drawing or high tensile strength steel sheet is adopted. A suitable heating method and a suitable cooling method are required to be selected so that such a heat pattern can be realized. In particular, to impart baking hardenability to an extra low carbon steel containing Ti and/or Nb, a method has been well known which comprises annealing the steel at high temperature so that part of TiC and NbC are redissolved and solute 30 carbon remains. In such a case, a cold rolled steel strip is uncoiled and introduced into a continuous annealing installation to be recrystallization annealed. The annealing pattern fundamentally consists of heating, soaking and cooling. To improve the workability and impart the baking hardenability, the heating and soaking temperature is made high.

Nonoxidation heating of a direct flame type, radiation tube heating, indirect electric heating, and the like are generally employed as heating methods in the heating zone and the soaking zone. In any of the methods, heat is generated 35 using an exothermic body other than the steel, and the heat is transferred to the steel sheet. As a result, there arise problems in that the heat efficiency becomes unavoidably low compared with that in the case where the steel sheet itself generates heat and rapid heating cannot be conducted due to the insufficient heating ability, that the furnace capacity in the heating zone becomes large, for example, the refractory material becomes thick, due to the inevitably high atmosphere temperature, and that as a result the temperature control becomes difficult and that alteration of the 40 annealing conditions takes much time. To solve the problems, a direct resistance heating and/or an induction heating are developed such a way of a heat is generated using an exothermic body such as hearth roll or steel sheet. Japanese Patent Publication No. 60-26817 (Japanese Unexamined Patent Publication No. 56-116830) and Japanese Patent Publication No. 60-26818 (Japanese Unexamined Patent Publication No. 56-116831) disclose a method comprising heating a steel sheet by direct resistance heating through rolls whereby the steel sheet itself becomes an exothermic body and 45 has a high temperature. Similarly, Japanese Patent Application No. 4-60923 discloses an installation of a heating apparatus by direct resistance heating among hearth rolls within an atmospheric heating furnace. Japanese Unexamined Patent Publication No. 1-142032 and No. 1-187789 disclose a process wherein a closed circuit is formed by providing conductor rolls in the front and the back of a metal strip production line which passes through a ring-form transformer and connecting both conductor rolls with a conductive member so that the metal strip, the conductor rolls and the conductive member form a closed circuit, an induction current is generated in the closed circuit as a secondary coil by 50 applying an alternate current from an external power source to the ring-form transformer, and the metal strip is heated by Joule heat generated thereby.

Furthermore, Japanese Unexamined Patent Publication No. 2-166234 discloses a process for continuously annealing a steel sheet which comprises classifying the steel temperature into a low temperature region from 600 to 700°C 55 and a high temperature region from 800 to 900°C, carrying out reduction heating the steel with a direct flame in the low temperature region and induction heating the steel in the high temperature region while induction heating is controlled by measuring the temperature of the steel sheet coming out of the low temperature region and conducting controlled heating in the high temperature region so that the steel has a desired temperature.

Furthermore, Japanese Unexamined Patent Publication No. 61-204319 discloses a process, for continuously

annealing a cold rolled steel sheet wherein a Ti-containing cold rolled steel sheet is produced by continuous annealing, which comprises rapidly heating the steel in the soaking zone of a continuous annealing line to a temperature higher by 200 to 300°C than the soaking temperature and then quenching the steel. However, the objective steel is limited to a Ti-containing steel, and the rapid heating is restricted to induction heating in the soaking zone. Moreover, the patent publication merely describes that the temperature increase is from 200 to 300°C, and discloses neither detailed conditions of the input energy such as heating rate, holding time and cooling rate nor the object of imparting baking hardenability.

As described above, when a cold rolled steel sheet is annealed at high temperature to improve the workability and impart baking hardenability thereto, the steel sheet thus treated suffers deterioration such as heat buckling and sheet breakage and deterioration of surface quality caused by surface defects, etc. Moreover, there are problems such as an increase in the energy cost and a decrease in the productivity due to the necessity of altering the annealing temperature in accordance with the production of steel sheets of different species and grades. On the other hand, in the heating methods in the patent publications as described above, the electric heating is completely separated from a conventional annealing furnace and combined with a conventional continuous annealing furnace. As a result, there arise problems that the heating temperature range becomes wide and the electric energy cost becomes high, and that the installation cost becomes high due to the separate use of the two heating procedures.

On the other hand, gas jet cooling, roll contact cooling, gas-liquid cooling, etc. are generally employed in the cooling zone. Among these cooling methods, gas jet cooling is nonoxidizing, can conduct uniform cooling, and has a cooling capacity sufficient for cooling a steel sheet having a thickness of up to 0.4 mm. However, gas jet cooling has an insufficient capacity when a steel sheet has a thickness exceeding 0.4 mm. Although roll contact cooling has a high cooling capacity when compared with gas jet cooling, it has a limitation when a higher cooling capacity is required, in addition to the problem of uniform cooling. In contrast to the cooling methods mentioned above, as disclosed in Japanese Patent Publication No. 61-10020, and the like, gas-liquid cooling is a cooling method extremely excellent in capacity, in uniformity and in controllability of cooling, though the steel sheet is lightly oxidized on the surface thereby.

Japanese Patent Publication No. 59-577 discloses a process for continuous annealing a cold rolled steel sheet in a short period of time which process utilizes the advantage of gas-liquid cooling and comprises direct flame heating by directly injecting a high temperature gas against the steel sheet and gas-liquid cooling in combination. However, the heating rate in the high temperature portion is only 50°C/sec at the highest in direct flame heating. The process also has a problem in the follow-up action in the heating temperature and heating rate at the time of changing annealing conditions, and it cannot be concluded that the process fully utilizes the advantage of gas-liquid cooling.

As described above, in the heating method in the patent publications, there is no description about the continuous annealing process comprises a heating step utilizing the Joule heat generated by current applied to steel sheet, combined with a cooling step with a gas-liquid mixture for achieving a rapid heating and cooling in a short period of time.

SUMMARY OF THE INVENTION

In recent years, there has been an increase in the requirements for continuously annealing various kinds of steel sheets in small amounts. Accordingly, the main object of the present invention is to provide a continuous annealing process which avoids a large scale continuous annealing installation and which at the same time is capable of immediately corresponding to a wide range of annealing conditions, namely well controllable continuous annealing process, and an installation therefor.

The another object of the present invention provides a continuous annealing installation in which there is set an optimum annealing parameter for supplementarily heating rapidly in a short period of time, in any stage in heating and soaking, which makes it possible to easily conduct high temperature annealing for imparting formability and bake-hardenable and freely schedule a sheet through the production line and which can extremely shorten the annealing time and the annealing line.

The heating steps defined in the present invention include both heating steps and soaking steps.

The aspects of a continuous annealing process according to the present invention are as described below ① - ⑥.

① A process for continuous annealing a steel sheet comprising a heating step including soaking and a cooling step, said process comprising a step of heating by the Joule heat in said heating step, and a step of cooling with a gas-liquid mixture in said cooling step.

② The process for continuous annealing a steel sheet according to ①, wherein the heating step comprising heating by Joule heat is carried out by means of direct resistance heating.

③ The process for continuous annealing a steel sheet according to ①, wherein the steel strip is heated to 500 to 900°C at a heating rate of 40 - 1000°C/sec in the step of direct resistance heating maintained for 5 - 300 sec, and cooled at a rate of 10 to 300°C/sec in the step of cooling with a gas-liquid mixture.

④ The process for continuous annealing a steel sheet according to ①, wherein the steel sheet is heated from at least 600°C to 700 to 900°C at a heating rate of at least 40°C/sec in the step of direct resistance heating.

⑤ The process for continuous annealing a steel sheet according to ①, wherein the steel sheet is heated to 400°C in the step of direct resistance heating, and then heated to 700 to 900°C in another step of heating in a nonoxidizing or reducing atmosphere.

⑥ The process for continuous annealing a steel sheet according to ①, wherein a heating the steel strip rapidly in a short period of time in an optional portion of said soaking zone which heats the steel strip at a predetermined temperature, so that heating is controlled and an annealing parameter (AP) becomes at least -33.

In addition, a continuous annealing installation according to the present invention are as described below ⑦ - ⑫.

⑦ A continuous annealing installation for a cold rolled steel strip comprising, in series, a heating zone, a soaking zone, and a cooling zone from the entrance side of the steel strip, said continuous annealing installation comprises a means of heating with Joule heat in the entire heating zone including the soaking zone, and a means of cooling with gas-liquid mixture in the cooling zone.

⑧ The continuous annealing installation for a cold-rolled steel sheet according to ⑦, wherein said means of heating with Joule heat in the entire heating zone comprises said means of heating by direct resistance

⑨ The continuous annealing installation for a cold-rolled steel sheet according to ⑦, wherein a heating means provided for heating the steel strip rapidly in a short period of time in an optional portion of said soaking zone which heats the steel strip at a predetermined temperature, so that heating is controlled and an annealing parameter (AP) becomes at least -33.

⑩ The continuous annealing installation for a cold-rolled steel sheet according to ⑦, wherein said means of heating by direct resistance is means of heating the steel sheet by passing an alternate current through a ring form transformer through which the steel sheet is passed to generate an induction current therein and heat the sheet.

⑪ The continuous annealing installation for a cold-rolled a steel sheet according to ⑦ - ⑩, wherein said installation comprising, in series, a heating zone, a soaking zone, a first cooling zone, an overaging zone and a second cooling zone.

⑫ The continuous annealing installation for a cold-rolled steel sheet according to ⑥ and ⑨, wherein the heating means for heating the steel strip rapidly in a short period of time in an optional portion of said soaking zone comprises direct resistance heating means or induction heating means.

The present invention employs a method of direct resistance heating wherein a current is passed through a steel sheet itself, and the steel sheet is heated by the Joule heat of the steel sheet itself. Although, direct resistance heating and induction heating are mainly used in the heating process utilizing the Joule heat, direct resistance heating is mainly explained in the present invention. Since the steel sheet itself becomes an exothermic body in direct resistance heating, the atmospheric temperature is not required to be raised, and the heating efficiency is good. Moreover, in direct resistance heating, the heating capacity can be easily controlled by adjusting the magnitude of the current, and ultrarapid heating to temperature as high as 700 to 900°C at a heating rate of at least 1,000°C/sec becomes possible when a current of at least 40 A/mm is passed.

The annealing parameter (AP) which is characteristic in the present invention is a nondimensional parameter related to a diffused distance of Fe atoms diffused by the input heat energy, namely a distance of grain boundary migration. When the AP is larger, the effects of annealing become more significant. Accordingly, the softening annealing is significant in releasing the strain (by annealing) introduced by cold rolling and imparting formability to the steel sheet. The formability has been found to be expressed as a parameter AP which can be represented by the formula

$$AP = \ln\left\{\left(\frac{1}{T(t)}\right)\exp\left(-\frac{Q}{RT(t)}\right)dt\right\}$$

wherein Q is an activation energy (60 kcal/mol) for self diffusion of Fe, R is a gas constant, and T is an absolute temperature.

Next, in the present invention, a heated steel sheet is cooled by blowing two fluids consisting of water and furnace gas, which contains nitrogen gas as a main component, against the surface thereof. The cooling system exhibits a uniform and extremely high cooling rate, and has an advantage that the cooling capacity and the cooling end temperature can be controlled by adjusting the ratio of the gas to water and the absolute amount of water. For example, a steel sheet having a thickness of 0.7 mm can be cooled in a cooling rate range of 50 to 200°C/sec, and the end temperature of the steel sheet can be controlled within an accuracy of $\pm 10^\circ\text{C}$ in a sheet temperature range of 250 to 550°C. In cooling with a gas-liquid mixture, the steel sheet and steam react to form a thin oxide film on the surface thereof. Since the oxide film has a thickness of the order of several micrometers, the film can be readily removed by simple pickling.

Direct resistance heating and cooling with a gas-liquid mixture have advantages as mentioned above, and each exhibit sufficient effects. Direct resistance heating and cooling with a gas-liquid mixture are conducted in combination in the present invention, and the specific effects described below can be obtained.

(1) The continuous annealing installation can be made smaller.

In the system of direct resistance heating and cooling with a gas-liquid mixture, the length of the steel sheet in the heating zone within the furnace becomes 1/8 of the length thereof in the conventional system of radiant tube heating and gas jet cooling, and similarly the length thereof in the first cooling zone becomes 1/4. Accordingly, the installation can be made significantly smaller. Moreover, when the heating rate is as slow as from 10 to 20°C/sec, solute carbon dissolved from cementite retards the growth of recrystallization grains in the heating step. Soaking, therefore, must be conducted for at least 20 sec. In contrast to the slow heating, when rapid heating is conducted at a rate exceeding the redissolution rate of carbon from cementite, not only can recrystallization be finished in a short soaking time, but also a small amount of carbon dissolved in the process of heating and soaking can be precipitated by overaging for a short period of time after rapid cooling. As a result, a steel material excellent in workability can be obtained by a heat cycle for a short period of time. As described above, direct resistance heating and cooling with a gas-liquid mixture in combination leads to shortening not only the heating zone and the cooling zone but also the soaking zone and the overaging zone. Consequently, an extremely small continuous annealing installation can be realized at a low installation cost.

(2) The controllability of a steel sheet temperature is improved, and any of the heat patterns can be freely realized.

Direct resistance heating is originally a heating method extremely excellent in heat controllability. In the case of heating a steel sheet from room temperature to at least the recrystallization temperature and in the case of partially heating the steel sheet from about 600°C to the soaking temperature, the heating rate and the heating temperature can be freely and accurately controlled by only controlling predetermined current values. However, even when the heat controllability in heating alone is good, the heating cannot cope with all the required heat patterns in the entire continuous annealing. Only by heating, in combination with cooling, with good heat controllability can a freely selected heat pattern be realized with good accuracy. Since cooling with a gas-liquid mixture makes the control of a cooling rate and an end temperature easy as described above, direct resistance heating and cooling with a gas-liquid mixture in combination can realize a freely selected annealing heat pattern, and can cope with demand for the production of various kinds of steel strips in small amounts.

(3) The production capacity is improved.

Since direct resistance heating and cooling with a gas-liquid mixture are both extremely excellent methods in heat controllability and heat response, the methods can immediately cope with the change of conditions such as a size of a steel sheet to be passed and an annealing temperature. For example, in a continuous annealing installation of the type of radiant tube heating and gas jet cooling, when the sheet thickness or annealing temperature is altered, a coil for adjustment is required to be passed at a normal or reduced speed at the cost of the production capacity until predetermined annealing conditions are obtained. However, direct resistance heating and cooling with a gas-liquid mixture in combination solves the problem of lowering the productivity and can improve the production capacity. Moreover, since the installation can be made in a small scale, an inappropriate passing caused by hearth rolls is decreased, and passing a steel sheet through the production line at high speed becomes possible. Accordingly, a further improvement in productivity can be expected.

(4) The quality of a steel sheet is improved.

A steel sheet can be heated and cooled rapidly or heated to a high temperature and cooled rapidly by direct resistance heating and cooling with a gas-liquid mixture in combination. Accordingly, the following results can be obtained: a short heat cycle period for a steel sheet for working as described in (1) can be realized; the baking hardenability (BH) is improved; grain refining of a high tensile strength steel sheet is achieved; and the enlargeability is improved.

As described above, direct resistance heating and cooling with a gas-liquid mixture in combination produces effects exceeding the sum of those of the heating and those of the cooling. Moreover, since the installation becomes small in scale, the control of the atmosphere within the furnace becomes easy. For example, in cooling with a gas-liquid mixture, steam generated in the cooling zone can be easily prevented from entering the heating zone and the soaking zone for the reasons described below. Since the volume of the heating zone and that of the soaking zone can be made small, the control of the ambient atmosphere pressures in the zones becomes easy, and, therefore, the pressure difference between the soaking zone and the cooling zone can be stably ensured. As a result, heating and cooling in combination as mentioned above is effective in controlling the oxide film on the steel sheet and preventing the deterioration of refractory materials in the heating and soaking zones.

A typical heat pattern in the continuous annealing process including direct resistance heating and cooling with a gas-liquid mixture is as follows: a steel sheet is heated to 700 to 900°C in the direct resistance heating step, maintained for at least 5 sec, and cooled at a rate of 10 to 300°C/sec in the cooling step with a gas-liquid mixture. For example, a soaking temperature of 700 to 900°C for a mild steel sheet for working is necessary for recrystallization of the rolled structure and grain growth. Moreover, when direct resistance heating is used as means of heating, the steel sheet can be heated at a rate exceeding the rate of carbon dissolution from cementite. Consequently, a decrease in the recrystallization rate caused by solute carbon can be prevented, and soaking the steel sheet for a short period of about 5 sec can impart excellent workability thereto. The upper limit of the rate of cooling with a gas-liquid mixture is defined to be

300°C/sec for reasons as described below. Although the amounts of alloying elements added for the purpose of improving the non-aging properties, the strength, etc. can usually be decreased with an increase in the cooling rate, the effects are saturated at a cooling rate of 300°C/sec. In addition, poor shapes of the steel sheet tend to be formed due to cooling when the cooling rate exceeds 300°C/sec. On the other hand, the lower limit of the cooling rate is defined to be 10°C/sec because the resultant excessive cooling time makes the installation long and large, and because the oxide film thickness on the steel sheet increases. A cooling rate in a range of 50 to 200°C/sec is usually desirable in order to stably maintain the injection state during cooling with a gas-liquid mixture.

When direct resistance heating is adopted in part of the heating zone, for the purpose of preventing redissolution of carbon into ferrite from cementite as mentioned above and imparting excellent workability, there is required a heating rate of at least 40°C/sec which rate exceeds the dissolution rate of carbon from cementite at temperature from 600°C from which the dissolution limit concentration of carbon in ferrite becomes high. The heat pattern as mentioned above can be realized by providing means of direct resistance heating in the latter stage of the existing heating zone, heating the steel sheet to 600°C in the existing heating zone and then rapidly heating the sheet to 700 to 900°C by current application. What is important at this time is to rapidly heat the sheet from at least 600°C. The direct resistance heating may be in the latter stage of the heating zone, namely either in part of the heating zone or part of the soaking zone.

When direct resistance heating is adopted in part of the heating zone, the heating may also be provided in the former stage of the heating zone. Although there is no effect on the material properties in this case, effects of improving the productivity can be expected because the alteration of the size of the passed steel sheet and annealing conditions can be immediately coped with by utilizing the advantage of the direct resistance heating which exhibits a good heat response. Although similar effects can be expected in the case where means of direct resistance heating is provided in the latter stage of the heating zone, the use of means of direct resistance heating in a region where the steel sheet temperature is low has advantages as described below. A low cost installation may be employed which is not required to have high temperature durability and, in addition, means of heating may also be provided in the front of the heating zone separately from the existing furnace installation. Accordingly, the reformation of the existing furnace becomes unnecessary, and the installation may be prepared at further lower cost.

The present invention will be illustrated in detail by making reference to drawings.

Fig. 1 is a whole view showing a continuous annealing installation which includes a coiler 1, a shear 2 on the entrance side, a welder 3, a cleaner 4, a looper 5 on the entrance side 5 and a heating zone 6 containing a direct resistance heating apparatus. A soaking zone 7 and a slow cooling zone 8 are provided with a heating apparatus such as an electric heater and a cooling apparatus such as gas jet. The slow cooling zone 8 may not be provided in some cases. A first cooling zone 9 herein is equipped with a gas-liquid cooling apparatus, and, therefore, a drying zone 10 is provided. There are provided subsequently to the drying zone 10 an overaging zone 11, a second cooling zone 12, a cooling bath 13 and a post-treatment bath 14. The post-treatment bath 14 usually includes four baths in total, namely a pickling bath, a first washing bath, an electrolytic bath and a second washing bath. There are provided, subsequent to the post-treatment bath 14, a dryer 15, a looper 16 on the exit side, a skin pass roll 17, an inspection and finishing operation section 18, a shear 19 on the exit side and a coiler 20.

Fig. 2 is a view showing an embodiment of a heating zone, a soaking zone and a first cooling zone of a continuous annealing installation according to the present invention. A steel sheet 21 coiled via a cold rolling step is continuously conveyed, and charged into a heating zone 6. In the heating zone 6, a direct resistance heating apparatus is arranged which generates an induction current in the steel sheet 21 by the use of a ring-form transformer 24. An electric current is passed in the steel sheet 21 through conductor rolls 22, 23 connected to a conductive member, whereby the steel sheet 21 is heated with Joule heat. The rapidly heated steel sheet 21 is successively maintained in the soaking zone 7. In the present embodiment, conductor rolls 25, 26 are also arranged in the soaking zone 7, and the steel sheet is maintained by heating through current application. In the present embodiment, the heating zone 6 is a horizontal furnace, and the soaking zone 7 is a vertical furnace. The horizontal furnace and the vertical furnace may be selected in accordance with the installation capacity. That is, when the installation is a highly productive one, a vertical installation becomes essential because the production line length would otherwise become large. However, when the installation is a less productive one, the operation becomes easy in the horizontal one. Next, the steel sheet 21 is introduced into a first cooling zone 9 where the sheet is rapidly cooled by a gas-liquid cooling apparatus 27. Then, the steel sheet 21 is optionally reheated and overaged, and an oxide film formed thereon is removed.

Fig. 3 is a schematic view of a horizontal current-application heating apparatus. Conductor rolls 22, 23 are arranged on the lower surface of a steel sheet 21 to be heated, and pressure rolls 28, 29 are arranged on the upper surface thereof in opposition to the conductor rolls 22, 23. The pressure rolls 28, 29 have pressurizing means consisting, for example, of respective cylinders 30, 31 and the pressure rolls 28, 29 and the opposing conductor rolls 22, 23 hold the steel sheet 21. Moreover, a ring-form transformer 24 is arranged between the conductor roll 22 on the low temperature side and the conductor roll 23 on the high temperature side and around the outer periphery of the steel sheet 21. The conductor rolls 22, 23 are connected with a conductive member 32 such as copper which has an electric resistance far lower than that of the steel sheet 21, and a closed circuit is formed by the steel sheet 21, the conductor rolls 22, 23 and the conductive member 32. An alternating current is applied to the ring-form transformer 24 from an outer power source

33, and an induction current is generated in the closed circuit as a secondary coil, whereby the steel sheet 21 is heated by Joule heat generated through the induction current. The heating rate and the heating temperature can be controlled by an alternate current the magnitude of which is calculated under the conditions of the specific resistance, the sheet thickness, the sheet width, the sheet speed, and the like of the material to be heated. There are transformer type direct resistance heating systems and directly external current applying systems in the direct-resistance heating systems. Since a current of large magnitude can be passed through the steel sheet efficiently, the former system is desirable.

Fig. 4 is a schematic diagram of the cooling zone. A plurality of gas-liquid cooling chambers 34 are arranged along a downpass 36 in the first cooling zone 9, and each of the chambers 34 is provided with a deflector on the directly down-side. Since the steel sheet 21 is symmetrically cooled on the front and the back surfaces and nonuniform cooling caused by dripping water in the high temperature portion of the steel sheet 21 is prevented, the vertical downpass is most effective in the first cooling zone. As shown in Fig. 5, a plurality of gas-liquid mixing nozzle units 37 each consisting of a gas-liquid jet nozzle header 39 and a liquid jet nozzle header 38 are vertically arranged along the sheet pass direction on both sides of the steel sheet 21. The gas-liquid mixing nozzle unit 37 mixes a gas and a liquid directly before the jet to stably maintain the atomized state. The cooling rate of the gas-liquid mixture is controlled by a liquid amount density which is represented by the amount of water per minute per m^2 and which is achieved by adjusting a liquid flow rate control valve 41 provided in a liquid tube 40 leading to the liquid jet nozzle header 38. The end temperature is controlled by the number of the nozzle units which is determined by turning the liquid flow rate control valve 41 on or off.

Fig. 6 shows one embodiment of a continuous annealing installation in which a direct resistance heating apparatus 6' is provided in the front of a heating zone 6 having a radiant tube, and an annealing heat cycle, as shown in Fig. 6(A) and Fig. 6(B) respectively. Since the direct resistance heating apparatus 6' is provided, the alteration of an annealing temperature and a size of a passing steel sheet can be readily coped with by controlling the current of the direct resistance heating apparatus alone. Accordingly, schedule-free annealing becomes possible, and the productivity can be improved.

Fig. 7 shows one embodiment of a continuous annealing apparatus in which a direct resistance heating apparatus 6' is provided between a soaking zone 7 and a first cooling zone 9, and an annealing heat cycle as shown in Fig. 7(A) and Fig. 7(B) respectively. As a result of providing the direct resistance heating apparatus 6' between the soaking zone 7 and the gas-liquid cooling apparatus, not only the alteration of an annealing temperature and a size of a passing sheet can be more readily coped with than in the case where the direct resistance heating apparatus 6' is provided in the front of the heating zone 6, but also the improvement of a new quality such as the improvement of workability and the impartment of baking hardenability becomes possible because the steel sheet can be heated to high temperature exceeding the heating capacity of the existing radiant tube.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view showing one embodiment of a continuous annealing installation of the present invention.

Fig. 2 is a whole view showing a continuous annealing installation.

Fig. 3 is a detail view showing a direct resistance heating apparatus.

Fig. 4 is a schematic view showing a gas-liquid cooling apparatus.

Fig. 5 is a detail view showing a gas-liquid cooling apparatus.

Fig. 6(A) is a view showing one embodiment of a continuous annealing installation of the present invention and Fig. 6(B) shows one embodiment of a continuous annealing heat cycle.

Fig. 7(A) is a view showing one embodiment of a continuous annealing installation of the present invention and Fig. 7(B) shows an annealing heat cycle employed in the examples.

Fig. 8(A), Fig. 8(B) and Fig. 8(C) are graphs showing relationship between the annealing parameter (AP) according to the present invention and an r-value, an EI-value, or YP and TS.

THE MOST PREFERRED EMBODIMENT

The most preferred embodiment according to the present invention will be explained by the following examples.

EXAMPLES

Example 1

Three kinds of steel sheets 0.7 mm thick, namely (1) a low carbon Al-killed steel sheet (steel sheet for working), (2) a Ti-SULC steel sheet (steel sheet for working) and (3) a high tensile strength steel sheet, were annealed by radiant tube heating (RT heating) and gas jet cooling (GJC) in comparative examples, and by direct resistance heating and cooling with a gas-liquid mixture in examples, and the results were compared. The installation in the examples could be easily realized by partly modifying the installation in comparative examples. The results thus obtained are shown in

Table 1.

Table 1

Steel sheet	Heating/ cooling system	Type of steel	Annealing conditions					
			Heating rate (°C/sec)	Soaking temp. (°C)	Heating time (sec)	Cooling rate (°C/sec)	Overaging time (sec)	Annealing time (sec)
5	(C.Ex.) RT heat- ing/GJC	Low C Al- killed	15	750	60	40	180	302
	(Ex.) Direct resistance heating /gas- liquid cooling		300	750	10	200	90	110
10	(C.Ex.) RT heat- ing/GJC	Ti- SULC	15	830	30	40	-	103
	(Ex.) RT, Direct resistance heating /gas- liquid cooling		15	heating at 700°C soaking for 30 sec rapid heating to 860°C		200	-	100
15	(C.Ex.) RT heat- ing/GJC	Si:1.0 Mn:1.5 C :0.1	15	770	<1	40	-	-
	(Ex.) Direct resistance heating /gas- liquid cooling		300	770	<1	200	-	-

Table 1 (continued)

Steel sheet	Heating/ cooling system	Type of steel	Material properties					
			Strength (N/mm ²)	Elongation (%)	r-Value (-)	n-Value (-)	BH (N/mm ²)	Enlarge- ability (-)
10	(C.Ex.) RT heat- ing/GJC	Low C	-	45	-	0.20	-	-
	(1) ----- (Ex.)	Al- killed	-----	-----	-----	-----	-----	-----
15	Direct resistance heating /gas- liquid cooling		-	50	-	0.25	-	-
20	(C.Ex.) RT heat- ing/GJC		-	-	2.0	-	0	-
	(2) ----- (Ex.)	Ti- SULC	-----	-----	-----	-----	-----	-----
25	RT, Direct resistance heating /gas- liquid cooling		-	-	2.0	-	40	-
30	(C.Ex.) RT heat- ing/GJC	Si:1.0 Mn:1.5 C :0.1	690	-	-	-	-	1.2
	(3) ----- (Ex.)	Si:1.0 Mn:1.0 C :0.1	-----	-----	-----	-----	-----	-----
35	Direct resistance heating /gas- liquid cooling		690	-	-	-	-	1.6

Note: (1): a steel sheet for working

(2): a steel sheet for working

(3): a high tensile strength steel sheet

In annealing the low carbon Al-killed steel sheet, not only a short period heat cycle, in the examples, namely an annealing time as short as 1/3 of that in comparative examples, could be realized, but also the elongation and the n-value were improved. It is estimated that the results are obtained because dissolution of C was inhibited by annealing through rapid heating and rapid cooling and because precipitation of C dissolved in a small amount was accelerated.

In annealing the Ti-/SULC steel sheet in the example, the steel sheet was subjected to an annealing heat cycle of instantly heating to a high temperature of 860°C by the direct resistance heating apparatus and subsequent rapidly cooling. As a result, baking hardenability could be imparted while an r-value as high as in the comparative example where the RT heating and the GJC systems were employed was maintained. The annealing cycle utilized a phenomenon that C is dissolved even when the steel sheet is treated at high temperature for only a moment.

Furthermore, in annealing the high tensile strength steel sheet, even when the alloying content of Mn was decreased from 1.5% to 1.0% in the example, the same strength could be manifested by annealing through rapid heating and rapid cooling, and the enlargeability was improved. Reasons for the manifestation and the improvement are as

described below. The rapid heating inhibits dissolution of C, and quenching the steel sheet from the austenite dual phase region having a high C content effects grain refining.

Example 2

During annealing a steel sheet 0.7 mm thick under the conditions of a heating temperature of 750°C and a cooling end temperature of 400°C, the heating temperature was changed from 750°C to 800°C, and the time necessary for reaching the predetermined annealing conditions was compared among (1) RT heating/GJC system, (2) RT heating/gas-liquid cooling system, (3) direct resistance heating/GJC system and (4) direct resistance heating/gas-liquid cooling system. In addition, since the time necessary for reaching the cooling end temperature depended on the heating temperature, cooling was adjusted after the heating temperature reached the predetermined temperature, and a time for reaching the predetermined cooling end temperature was defined to be the time necessary for reaching the cooling end temperature. The results thus obtained are shown in Table 2.

Table 2

Heating/cooling system	Time necessary for reaching heating temp. (sec)	Time necessary for reaching cooling end temp. (sec)	Time necessary for reaching annealing temp. (sec)
(1) RT heating/GJC	1320	120	1320
(2) RT heating/gas-liquid cooling	1320	10	1320
(3) Direct resistance heating/GJC	5	120	120
(4) Direct resistance heating/gas-liquid cooling	5	20	10

It is seen from Table 2 that RT heating exhibited an extremely poor heat response, than GJC exhibited a poor heat response, and that direct resistance heating and cooling with a gas-liquid mixture exhibited a very good heat response. Since the time for reaching a predetermined annealing heat cycle is determined by the system which exhibits a poorer heat response, it is best to select a combination of a heating technique exhibiting a good heat response and a cooling technique exhibiting a good heat response, namely a combination of direct resistance heating and cooling with a gas-liquid mixture for the purpose of immediately responding to the alteration of the annealing conditions.

Example 3

The cold rolled Ti-/SULC steel sheet shown in Table 1, (2) was subjected to the following heat cycle as shown in Fig. 7(B): a (heating rate): 10°C/sec, b: 700°C × 40 sec, c: 100°C/sec, and d: cooled to 675°C at a rate of 5°C/sec and air cooled. The steel strip was then skin pass rolled to have a reduction of 0.8%, and used as a sample. As to the installation in such a case, the sample was supplementarily heated rapidly in a short period of time in an optional portion in the soaking zone, for example, in the final portion thereof by a direct resistance heating apparatus or an induction heating apparatus.

Fig. 7(B) is a graph showing one example of a heat pattern practiced in the present invention. As shown in Fig. 2, the mark "a" designates a stage where an as cold rolled steel strip is uncoiled and heated in a continuous annealing furnace. The heating pattern includes heating at a rate of 1 to 200°C/sec and a target temperature of 500 to 900°C. The mark "b" designates a soaking stage, and the soaking temperature and the holding time are from 500 to 900°C and from 0 to 300 sec, respectively. The mark "c" designates a rapid temperature increase in a short period of time by direct resistance heating, or the like, the temperature increase being characteristic of the present invention. The heating rate is from 50 to 1,000°C/sec, and the steel strip is heated to 750 to 910°C. The mark "d" designates an immediate cooling stage after rapid heating in a short period of time. The mark "e" designates a stage in the case where the installation has an overaging zone, and the steel strip having been rapidly heated and immediately cooled is held at an overaging temperature of 250 to 450°C and then cooled to room temperature.

Fig. 8 are graphs showing relationships between AP and r, EI, or YP and TS, and showing in Fig. 8(A), Fig 8(B) and Fig. 8(C) respectively.

It can be seen from Fig. 3 that the average r-value which is an index of deep drawability and the elongation EI (%) which is an index of bulging, the yield strength YP and the tensile strength TS can be made at least the desired value for a deep drawing steel sheet by controlling heating so that the annealing parameter (AP) becomes at least -33. That

is, when AP becomes at least -33, the values mentioned above become as follows: average r-value: at least 1.5, EI (%): at least 42%, YP: at least 180 N/mm², and TS: at least 320 N/mm². The results thus obtained are not limited to the Ti-containing extra low carbon steel shown in Table 1, but similar results are obtained when there are used a Nb-containing extra low carbon steel sheet, a Ti-Nb composite containing added extra low carbon steel sheet and a low carbon Al-killed steel sheet. It has been confirmed that steel sheets having the same AP value exhibit the same tensile characteristics regardless of the annealing heat cycle.

The partial heating in this case can be practiced in a range of 0.5 to 15 sec by providing direct resistance heating or induction heating between passes in the soaking zone. In addition, a direct resistance heating apparatus or an induction heating apparatus is employed in the present invention for reasons as described below. Examples of the heating system for a cold rolled steel sheet within a continuous annealing furnace are a nonoxidation heating system of direct flame type, a radiation tube heating system, and the like. Since each of these systems is a heating system by heat transfer, the heating ability per unit time is not very high. Heating for a long time is required to ensure a necessary total heat amount, and the heating zone necessarily becomes long. In contrast to the systems mentioned above, in the present invention a steel strip is heated in direct resistance heating while the steel strip is being passed along conductor rolls provided on the entrance and the exit sides. An electric current is applied to the rolls which guide the steel strip, a conductive material, and an electric current is passed through the steel strip placed between the rolls, whereby the steel strip itself is heated rapidly in a short period of time due to its electric resistance.

Furthermore, a current is applied in induction heating from a high frequency power source to a heating coil winding around a steel strip, and an induction current is allowed to pass therethrough by a magnetic field formed by the heating coil, whereby the steel strip can be heated rapidly by Joule loss. The steel strip is supplementarily heated by a direct resistance heating apparatus or induction heating apparatus. The annealing parameter (AP) can be thus easily controlled, and at the same time the deteriorated portion of the top end of the steel strip in the longitudinal direction is also partially heated to be compensated, whereby uniform properties thereof in the longitudinal direction may be obtained.

INDUSTRIAL AVAILABILITY

The continuous annealing process including direct resistance heating and cooling with a gas-liquid mixture and the installation according to the present invention produces effects in that the installation can be made extremely small that the controllability of a steel sheet temperature is improved, that a freely selected heat pattern can be realized, that the production capacity is improved and that the quality is improved. Furthermore, there can be obtained a steel strip which can be passed through rolls without heat buckling and sheet breakage and which has good surface quality and no surface defects by the use of the installation according to the present invention, and the productivity of the steel is improved and the cost is reduced by freely scheduling in the steel sheet production line. In addition, the present invention achieves industrially extremely excellent effects of producing a cold rolled steel sheet excellent in workability and baking hardenability by controlling the AP value to be at least -33.

Claims

1. A process for continuous annealing a steel sheet comprising a heating step including soaking and a cooling step, said process comprising a step of heating by the Joule heat in said heating step, and a step of cooling with a gas-liquid mixture in said cooling step.
2. The process for continuous annealing a steel sheet according to claim 1, wherein the heating step comprising heating by the Joule heat is carried out by means of direct resistance heating.
3. The process for continuous annealing a steel sheet according to claim 1, wherein the steel strip is heated to 500 to 900°C at a heating rate of 40 - 1000°C/sec in the step of direct resistance heating maintained for 5 - 300 sec, and cooled at a rate of 10 to 300°C/sec in the step of cooling with a gas-liquid mixture.
4. The process for continuous annealing a steel sheet according to claim 1, wherein the steel sheet is heated from at least 600°C to 700 to 900°C at a heating rate of at least 40°C/sec in the step of direct resistance heating.
5. The process for continuous annealing a steel sheet according to claim 1, wherein the steel sheet is heated to 400°C in the step of direct resistance heating, and then heated to 700 to 900°C in another step of heating in a nonoxidizing or reducing atmosphere.
6. The process for continuous annealing a steel sheet according to claim 1, wherein the steel is heated strip rapidly in a short period of time in an optional portion of said soaking zone which heats the steel strip at a predetermined temperature, so that heating is controlled and an annealing parameter (AP) becomes at least -33.

- 5
7. The continuous annealing installation for a cold rolled steel strip comprising, in series, a heating zone, a soaking zone, and a cooling zone from the entrance side of the steel strip, said continuous annealing installation comprises a heating means for Joule heating in the entire heating zone including the soaking zone, and a means of cooling with gas-liquid mixture in the cooling zone.
- 10
8. The continuous annealing installation for a cold-rolled steel sheet according to claim 7, wherein said heating means for Joule heating in the entire heating zone comprises said means of heating by direct resistance.
- 15
9. The continuous annealing installation for a cold-rolled steel sheet according to claim 7, wherein a heating means provided for heating the steel strip rapidly in a short period of time in an optional portion of said soaking zone heats the steel strip to a predetermined temperature, so that heating is controlled and an annealing parameter (AP) becomes at least -33.
- 20
10. The continuous annealing installation for a cold-rolled steel sheet according to claim 7, wherein said means of heating by direct resistance is means for heating the steel sheet by passing an alternate current through a ring form transformer through which the steel sheet is passed to generate an induction current therein and heat the sheet.
- 25
11. The continuous annealing installation for a cold-rolled steel sheet according to claims 7 - 10, wherein said installation comprises, in series, a heating zone, a soaking zone, a first cooling zone, an overaging zone and a second cooling zone.
- 30
12. The continuous annealing installation for a cold-rolled steel sheet according to claims 6 and 9, wherein the heating means for heating the steel strip rapidly in a short period of time in an optional portion of said soaking zone comprises direct resistance heating means or induction heating means.
- 35
- 40
- 45
- 50
- 55

Fig.1

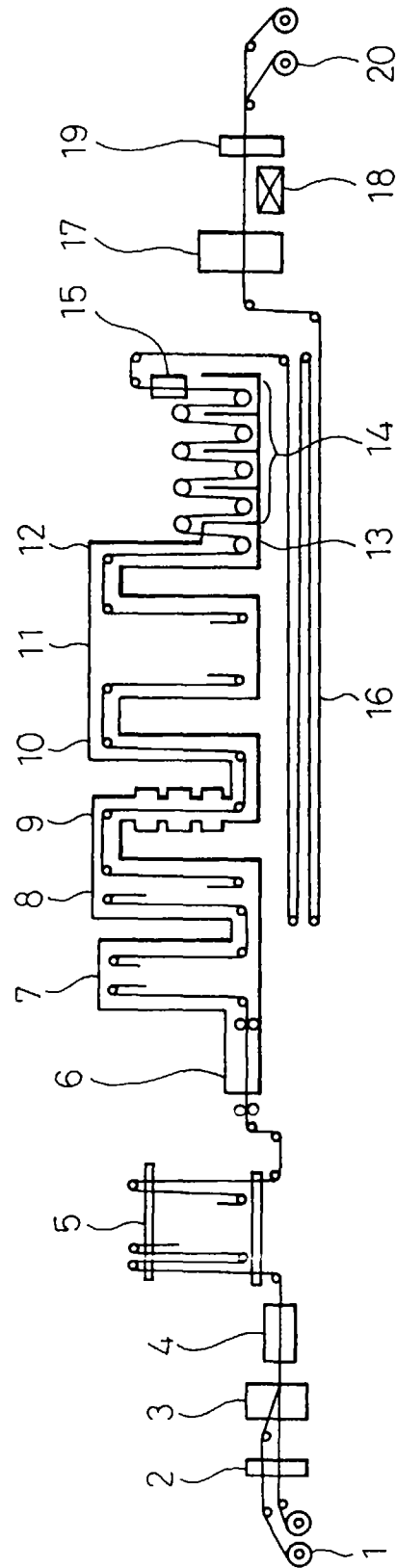


Fig.2

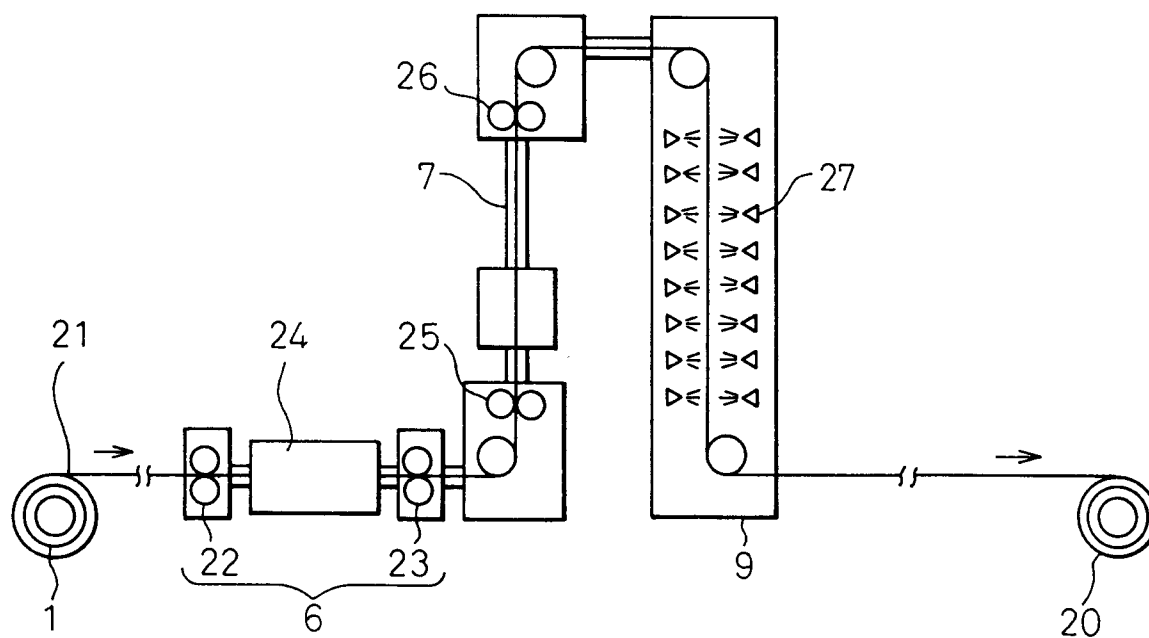


Fig.3

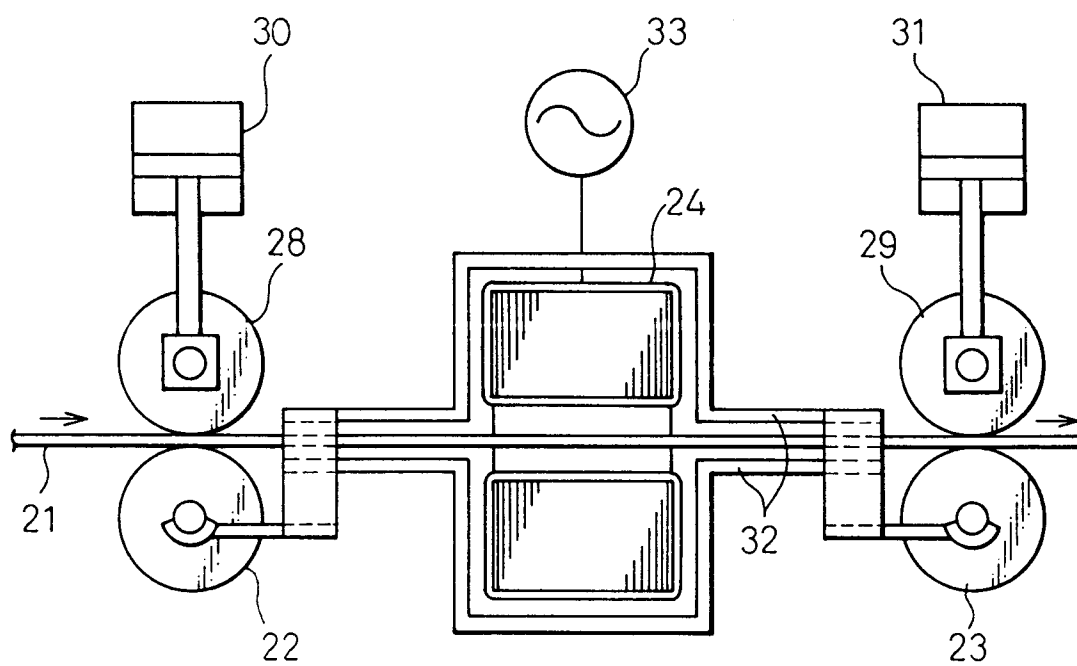


Fig.4

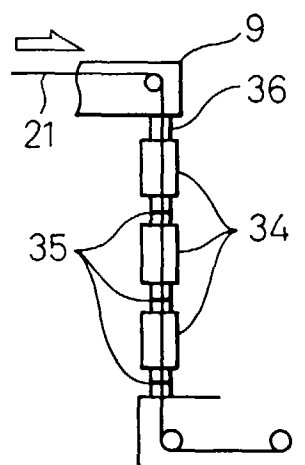


Fig.5

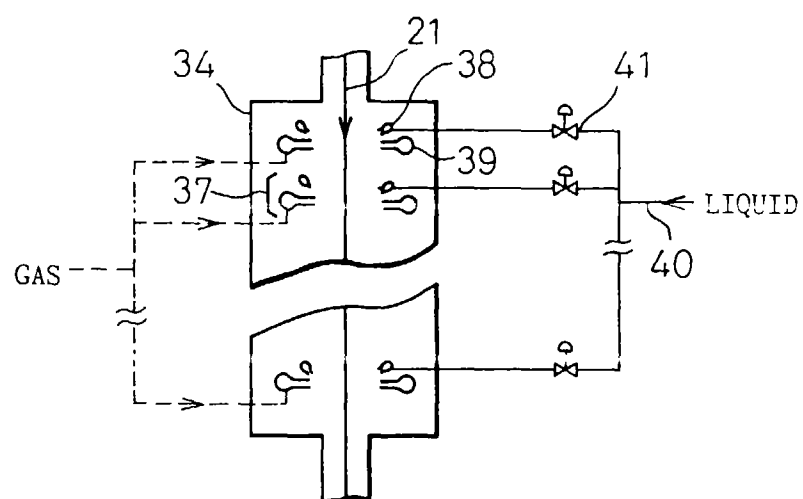


Fig.6(A)

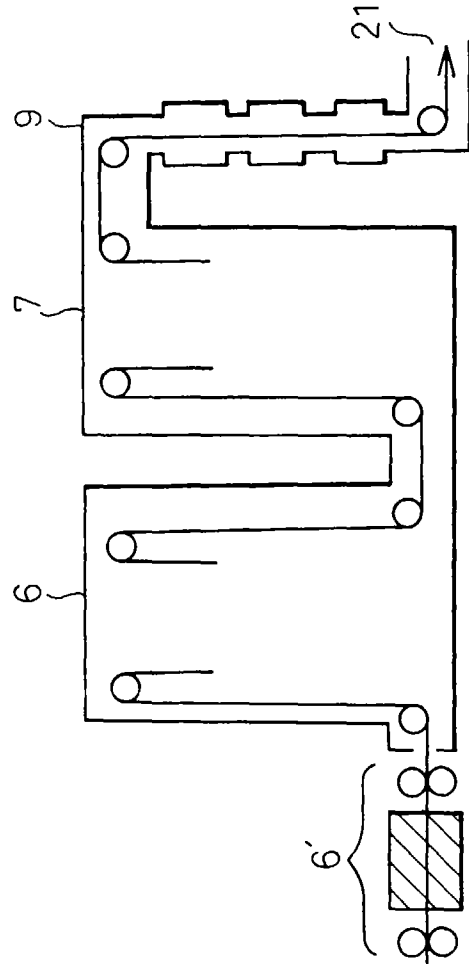


Fig.6(B)

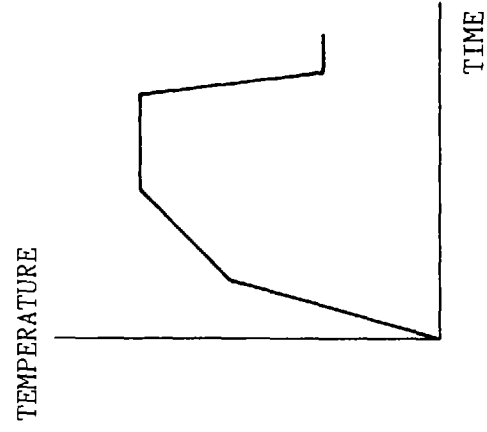


Fig.7(B)

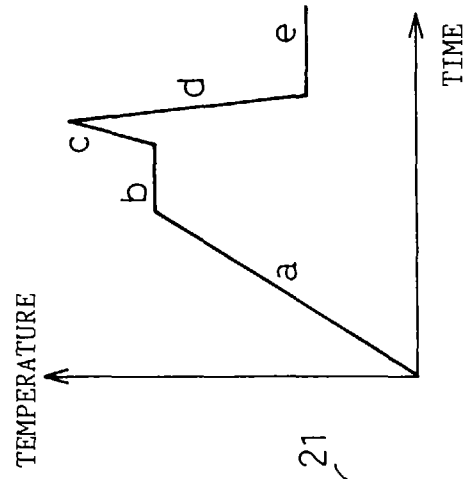


Fig.7(A)

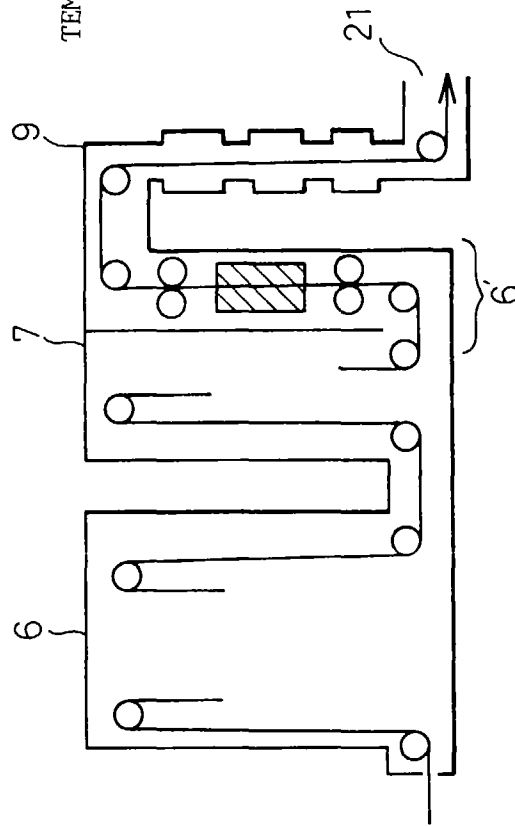


Fig.8(A)

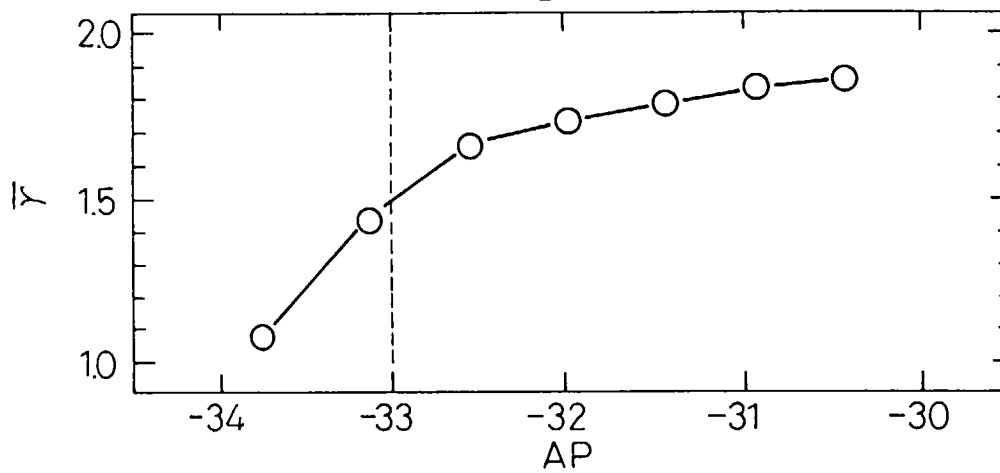


Fig.8(B)

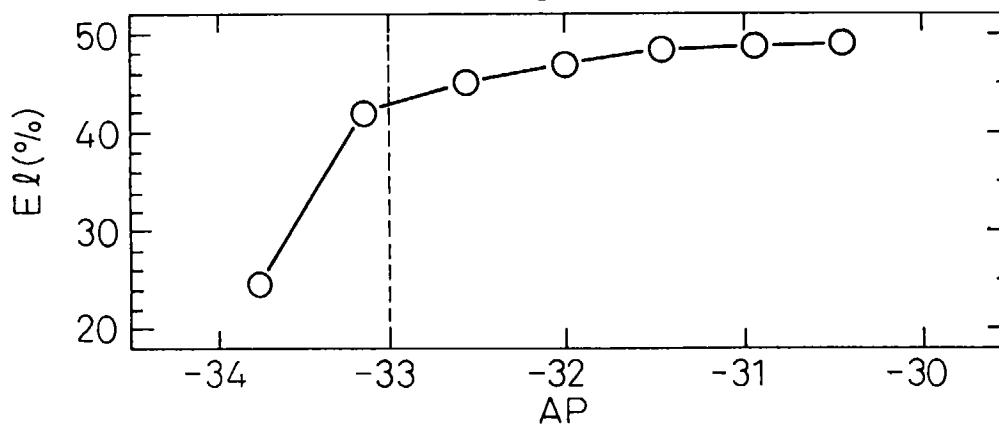
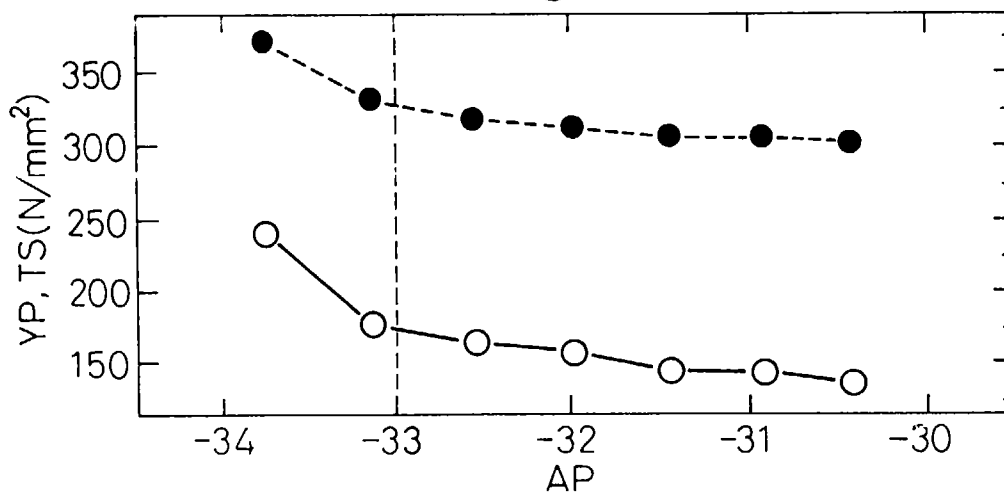


Fig.8(C)



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP95/02111

A. CLASSIFICATION OF SUBJECT MATTER		
Int. Cl ⁶ C21D9/56		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
Int. Cl ⁶ C21D9/56, C21D9/573, C21D9/60, C21D9/62		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Jitsuyo Shinan Koho 1926 - 1995		
Kokai Jitsuyo Shinan Koho 1971 - 1995		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 7-90391, A (Nippon Steel Corp.), April 4, 1995 (04. 04. 95), Lines 2 to 5, column 1	1-5, 7-8, 10-11
Y	Lines 9 to 12, column 1 (Family: none)	10-11
Y	JP, 57-16133, A (Nippon Steel Corp.), January 27, 1982 (27. 01. 82), Lines 6 to 9, lower left column, page 1 (Family: none)	1-5, 7-8, 10-11
Y	JP, 59-577, B2 (Nippon Steel Corp.), January 7, 1984 (07. 01. 84), Lines 20 to 26, column 1 (Family: none)	3 - 4
Y	JP, 2-166234, A (Sumitomo Metal Industries, Ltd.), June 26, 1990 (26. 06. 90), Lines 5 to 10, lower left column, page 1, lines 1 to 4, lower left column, page 2 (Family: none)	5
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search November 7, 1995 (07. 11. 95)		Date of mailing of the international search report November 28, 1995 (28. 11. 95)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.		Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP95/02111

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 56-156778, A (Nippon Steel Corp.), December 3, 1981 (03. 12. 81), Lines 17 to 20, lower left column, page 1 & ZA, A, 8103250	7-8, 10-11
A	JP, 57-94524, A (NKK Corp.), June 12, 1982 (12. 06. 82), Line 19, upper left column to line 4, upper right column, page 2 (Family: none)	6, 9, 12

Form PCT/ISA/210 (continuation of second sheet) (July 1992)