

# PATENT SPECIFICATION (11) 1 589 820

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- (21) Application No. 39670/77 (22) Filed 23 Sep. 1977  
 (31) Convention Application No. 51/114454 (32) Filed 24 Sep. 1976 in  
 (33) Japan (JP)  
 (44) Complete Specification Published 20 May 1981  
 (51) INT. CL.<sup>3</sup> B05D 1/06 5/00  
                     C03C 5/00  
 (52) Index at Acceptance  
         B2E 1101 1205 1214 1323 409S 415T  
             417T 418T 419T BDA  
         C1M 494 VQ  
         C7E 8



## (54) A METHOD FOR COATING HOT ROLLED STEEL STRIP WITH A SCALE-CONVERTING AGENT

(71) We, NIPPON STEEL CORPORATION, a Japanese Company, of No. 6-3, 2-chome, Ote-machi Chiyoda-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

5 This invention relates to a method for coating hot rolled steel strip with a scale-converting agent, which enables the nature of scale adhering to the hot rolled steel strip to be controlled. It particularly concerns methods for applying a scale-converting agent to hot rolled steel strip running at high speeds and at high temperatures during a continuous hot rolling step. Such strip is hereinafter referred to as "running steel strip and it should be understood that the invention extends also to the similar treatment of hot rolled steel sheet, and references herein to steel strip including sheet. 10

The most typical production method of the hot rolled steel strip is as follows. A steel slab is charged into a continuous heating furnace where the slab is heated to a pre-determined temperature, and then passes through a vertical scale breaker, and a rough rolling mill 15 where the slab is rolled into a steel bar of 20 to 40 mm thickness. The thick primary scale produced while the slab is heated in the heating furnace is removed by a vertical scale breaker and a descaling spray during the rough rolling step. Then the steel bar passes through a crop shear, a finishing scale breaker, and a finishing rolling mill whereby the steel bar is finished to a controlled thickness and shaped at a predetermined finishing temperature. 20

Further, the steel strip thus obtained is cooled to a predetermined coiling temperature by a cooling device while the strip is running on a run-out table, and coiled on a down-coiler.

25 The temperature control in the hot strip rolling, including control of the heating temperature, the rough rolling temperature, and the finishing rolling temperature is very important for both the strip quality and the rolling operation. The temperatures for these various rolling steps have naturally a certain feasible range depending on the design of the rolling mills. 25

From these temperature ranges are selected appropriate temperatures for specific steel grades to be rolled taking account of the desired final metallurgical requirements.

30 The heating temperature is selected by taking into consideration the fall in temperature of the material before it is subjected to the finishing rolling step, the removability of the primary scale and the fusion sticking of the slabs, etc. In the rough rolling step, efforts are made so as to minimize the heat loss, and the steel strip is charged to the finishing rolling mill. The finishing temperature at the exit side is adjusted by the rolling mill speed and the coiling temperature is adjusted by the amount of cooling water on the run-out table. 35

40 The most important temperature factors from the aspect of the product quality in the hot rolling of a carbon steel are the finishing temperature at the exit side (finishing rolling temperature) and the coiling temperature. Since the structure of the carbon steel after the hot rolling depends on the final rolling temperature and the conditions of the subsequent cooling step, an appropriate final rolling temperature and coiling temperature should be 40

selected depending on the final applications of the product. For example, for applications where severe workability such as deep-drawing is required, a higher finishing rolling temperature and a higher coiling temperature should be selected; For applications such as automobile frames, where strength is most important a lower coiling temperature should be selected. Further for improving impact property and yield ratio, the finishing temperature should be just above  $A_{r3}$  transformation point of the steel, and in case of a low-carbon Al-killed steel when used as hot rolled material, a higher coiling temperature is selected in order to precipitate AlN, and when cold rolled subsequently and considerably low coiling temperature is selected so as to prevent precipitation of AlN during the coiling step.

The hot rolled steel strip thus obtained is covered with a secondary scale produced after the bar has passed through the finishing scale breaker. The Physical properties and the amount of the secondary scale vary depending on the steel grades and the hot rolling conditions, but the scale is generally composed mainly of iron oxides, such as wustite ( $FeO$ ), magnetite ( $Fe_3O_4$ ) and hematite ( $Fe_2O_3$ ), and the amount of scale ranges from 30 to 100 g/m<sup>2</sup>.

Then, some of the hot rolled strip coils with the secondary scale adhering thereto or after removal of the secondary scale are shipped to users as a hot rolled steel strip, others are passed to a cold rolling step to obtain cold rolled products, such as a cold-finished hoop and a black plate sheet for tinplate.

Before cold rolling, the hot rolled coil, it is necessary to descale the coil, usually by a chemical descaling method in  $HCl$ ,  $H_2SO_4$  or  $H_3PO_4$ . The descaling is partially done by a mechanical method such as shot blasting and buff-rolling.

The scale removed by the pickling and mechanical descaling, leads to loss of material. Therefore, in order to obtain a higher metal yield, and thereby lower the cost for the descaling it is naturally desirable to minimize the amount of the scale formed on the surface of the hot rolled steel strip.

Regarding the nature of the scale, it is desirable that the scale is easily and simply removed by chemical or mechanical means.

When the hot rolled coil is shipped without removing the secondary scale, similar descaling is done by users if necessary.

On the other hand, for applications such as drum cans, building materials, for example, light-weight section steels and automobile frames, where the hot rolled steel strip is used as it stands, the requirements are different to the above-mentioned applications, and it is required that the secondary scale firmly adheres to the base metal and does not peel off mechanically even when subjected to severe forming operations.

Thus, it is very important from the aspect of technology to control the nature or properties of the secondary scale on the surface of a hot rolled steel strip according to the requirements of the final applications.

However, on the basis of the level of conventional technology it has been extremely difficult to control the nature of the secondary scale while maintaining the metallurgical properties of the steel strip.

To illustrate the difficulties, the relation between the rolling temperature and the properties of the secondary scale will be discussed. The amount of the secondary scale to be formed depends on the coiling temperature and the scale composition depends on the cooling rate after the completion of the rolling. When the finishing rolling temperature and the coiling temperature are raised in order to obtain the required workability, not only does the oxidation of the strip surface progress and the amount of the scale increase, but also the wustite completes its transformation while the steel coil is cooled slowly so that the scale composition is mainly composed of magnetite and hematite. The time required by the pickling is shorter as the scale amount is less and the proportion of hematite decreases and the proportion of wustite increases. In case of the mechanical descaling, the scale is more easily removed as the proportion of wustite increases. Therefore, it has been almost impossible to obtain a hot rolled steel strip having a secondary scale favourable for the descaling when the finishing rolling and the coiling are done at higher temperature.

On the other hand, in order to maintain adequate adhesion to the base metal of the secondary scale during the mechanical workings, it is desirable to maximise the transformation of the wustite to form a secondary scale mainly composed of magnetite and hematite. From the aspect of reducing the amount of the secondary scale, a low-temperature finishing rolling and a low-temperature coiling are desired, but there are certain limitations in this direction from the aspect of the product quality. When the coiling is done at a low temperature, the transformation of the wustite is hindered so that the resultant scale is composed mainly of wustite. Therefore, it has been difficult to obtain a steel strip having a favourable secondary scale while maintaining the required product qualities even in the case of applications where the firm adhesion of the secondary scale is required.

As described above, in the production of a hot rolled steel strip, it is required that the hot rolling is done in such a way as to produce the required metallurgical properties required for the steel strip. It has been very difficult to control the nature of the secondary scale formed on the hot rolled steel strip while performing the hot rolling in the above manner.

The only method for obtaining a hot rolled steel strip having a secondary scale of desired nature which is considered to be possible is to apply a scale-converting agent on the steel surface, from which a primary scale has been removed during the hot rolling step, to convert the nature of the secondary scale on the surface of the hot rolled steel strip after the coiling step irrespective of the rolling operation. The present invention has been developed from this technical possibility.

Regarding the possibility of controlling the scale, BARLOW *et al* suggested in "Journal of the Iron and Steel Institute", pp. 45-50, Jan. 1967 that it would be possible to inhibit the transformation of the wustite if lime could be dissolved in solid solution into the wustite, and ROLLS *et al* suggested in "Corrosion Science" 14, pp.431-441, 1974 that it would be possible to inhibit the oxidation of the steel surface at high temperatures by covering the steel surface with calcium metaborate and di-sodium tetraborate.

However, the conclusions of both BARLOW *et al* and ROLLS *et al* have been made from the laboratory test results using small-size test pieces, and cannot be applied to a commercial process for production of hot rolled steel strip. There are many and various technical difficulties to be overcome to achieve successful control of the secondary scale by applying a scale converting agent on the steel strip in a commercial production line of hot rolled steel strip where a slab is extracted from a heating furnace at temperatures not lower than 1100°C and is rolled at a finishing rolling temperature at a temperature not lower than 750°C and the steel strip thus obtained runs at a maximum speed of 1600 mpm and is coiled at a temperature not lower than 450°C.

The greatest difficulty is encountered when one tries to apply the scale-converting agent on the surface of the steel strip running at a high speed and at a high temperature without adverse effects on the rolling conditions determined by the metallurgical requirements of the steel to be obtained.

BARLOW *et al* and ROLLS *et al* suggested use of a slurry in which a scale-converting agent is dispersed. However, if a high-temperature steel strip is immersed in such a slurry, this causes direct cooling of the steel strip.

Therefore, this suggestion is largely limited both from the metallurgical aspect and the capital aspect.

Also according to the results of experiments conducted by the present inventors in a commercial hot strip mill, it was difficult to spray such a slurry on the high-temperature strip surface, because the dispersion media boiled immediately upon contact with the high-temperature strip surface and the strip surface was covered with a vapour film so that the scale-converting agent does not deposit thereon and NO scale-conversion effect was achieved.

Further, in order to eliminate the boiling phenomenon, the present inventors made trials for coating the strip surface with the scale-converting agent by blowing an air stream in which scale-converting agent in the form of powder is dispersed, on the strip surface, but the result was unsuccessful. A rising air stream exists around the high-temperature steel strip due to the convection, and in addition to this rising air stream, a horizontal air stream is formed as the steel strip moves at a high speed. As a result, the powder particles of the scale-converting agents are entrained in the rising air stream and are dispersed before reaching the strip surface. If relatively large powder particles are blown at higher speed, they can reach the strip surface, but they are repelled and mostly dispersed by the elastic collision with the surface. Therefore, most scale-converting agents cannot satisfactorily be applied on the strip surface by this method, with only a very limited number of scale-converting agents capable of being applied to the strip surface and then only where there is a very slow speed of the strip movement with a coating efficiency of 1 to 10% (amount adhering on the surface/amount blown x 100). Even in this case, if the strip moves at a high speed, no scale-converting agent adheres to the strip surface and thus no scale-converting effect can be achieved. Thus, the above method is limited in the selection of suitable scale-converting agents and also considerably limited in the coating equipment and the rolling operation which can be used.

The present invention seeks to provide a process in which the scale-converting agent is applied to the surface of a high-temperature steel strip which has been hot rolled or is being hot rolled so that the physical and chemical properties of the scale to be formed on the steel strip can be controlled, having regard to the subsequent treatment and application of the steel. It is obviously desirable that any such process is highly efficient even when used with high-temperature steel strip running at a high speed in the hot rolling step. A coating efficiency of 90% or higher is preferable when treating the surface of a steel strip running at

a high speed so that the scale-converting agent applied to the strip surface can be utilised for coating the steel strip surface without any substantial waste.

It is also desirable to provide a compact coating apparatus for use in such a process, suitable for arrangement in the hot rolling line of a steel strip. As indicated hereinafter the apparatus used in the invention may occupy a relatively small space, and might conveniently be installed in very limited space between the finishing rolling stands.

In one aspect the invention provides a method for coating hot rolled steel strip with a scale-converting agent, in which a particulate scale-converting agent is applied to the surface of a running steel strip as hereinbefore defined either following hot rolling or during hot rolling after the removal of primary scale, the particles of the scale-converting agent being melted at least over their surface immediately prior to contacting the strip surface. In a preferred embodiment the particles are blown towards and into contact with the strip surface by a carrier gas, and most preferably the carrier gas used to project the particles is combustible or contains combustible material. Then by using a burner as described hereinafter the particles are projected at the strip at the same time as being heated.

The scale-converting agent particles are preferably preheated uniformly before being further heated so as to melt at least the surface thereof.

The particulate scale-converting agent may be in the form of a solid powder or granules, and preferably the agent has a melting point lower than the temperature of the steel strip to which the scale-converting agent is applied. Preferred scale-converting agents include metal halides, borates and phosphates of alkali metals and alkaline-earth metals, as well as other inorganic compounds such as boric acid, boric anhydride and polyphosphates. The agent may comprise one of these compounds or a mixture of two or more such compounds. The scale-converting agent may be in the form of a glass powder containing one or more of phosphate glass and borate glass.

Alternatively, the scale-converting agent may be in the form of particles of a higher-melting-point substance coated with a lower melting point scale-converting compound. Examples of suitable higher-melting-point substances which may be used as the core in such composite particles include sodium aluminate, lime and magnesia. A preferred form of this type of scale-converting agent comprises a powder consisting of one or more of sodium aluminate, lime and magnesia, with at least some of the powder particles being coated with one or more compounds selected from the group consisting of metal halides, borates and phosphates of alkali metals and alkaline-earth metals, boric anhydride, boric acid, polyphosphates, phosphate glasses and borate glasses.

In a preferred aspect this invention provides a method for coating hot-rolled steel strip with a scale-converting agent, in which method the particles of the scale-converting agent are pre-heated and fluidized by passing therethrough a gas at super atmospheric pressure and above ambient temperature, an adjustable amount of the pre-heated scale-converting agent is then mixed with one or more combustible gases, the mixture thus obtained is blown to the surface of a hot rolled steel strip and the particles of the scale-converting agent are heated so as to melt the particles at least over their surface immediately prior to contacting the strip surface.

The particles of scale-converting agent may be stored in a vessel and discharged from a vessel through a transfer pipe at a predetermined rate by maintaining a constant pressure difference between the pressure in the vessel and the pressure in the transfer pipe.

The invention will be described in more detail by reference to the accompanying drawings, in which:-

*Figure 1* is a schematic flow-sheet of a production line for hot rolled steel strip;

*Figure 2* is a graph showing the temperature ranges of the material at various steps in the production of a hot steel strip;

*Figure 3* shows schematically an arrangement of coating apparatus for performing the method, of the invention;

*Figure 4* shows an example of a burner which may be used in performing the method of the invention;

*Figure 5* is a graph showing the principle of the differential pressure transfer of the scale-converting agent in the apparatus shown in *Figure 3*;

*Figure 6* is a graph showing the relation between the coating efficiency and the running speed of the steel strip in comparison with the conventional methods;

*Figure 7* is a graph showing the relation between the coating efficiency and ambient temperature; and

*Figure 8* shows the apparatus used to obtain the experimental results of *Figure 7*.

This invention is based on the appreciation by the present inventors that when the scale-converting agent in the solid powder form is applied to the surface of the steel strip at high temperatures, if at least the surface of the powder particles of the scale-converting agent is in a molten state, and thus "wet", just before they collide against the strip surface,

they coat the strip surface without being repelled thereby and without a vapour film forming as it does with application of slurries due to the boiling of the dispersion agent.

It also allows coating to be effected using substances having a very high melting point, since it is possible to coat the strip surface with the high melting point substance covered with a scale-converting agent having a lower melting-point or a low softening point.

According to the results of experiments conducted by the inventors, 90% or higher coating efficiency may be achieved even at a strip running speed of 1000 mpm or higher if at least the surface of the particles of scale-converting agent is melted just before they collide against the strip surface.

Whilst it may be considered possible to improve coating efficiency by completely melting the scale-converting agent using large amounts of heat, it has been established, and confirmed experimentally, that there is no advantage in complete melting as compared with melting of the surface only. Moreover, in case of the complete melting of the agent, not only economical disadvantages may be found, but also troubles such as clogging of the transferring pipe may result if the scale-converting agent is melted in a melting tank and transferred by means of pipe lines.

On the other hand, when only the surface of the scale-converting agent (whether in the form of a powder or granules) is melted, not only advantages in heat economy may be achieved, but also the troubles such as the clogging of the transferring pipe can be lessened or avoided because the particulate agent can be transferred through the pipe line easily by air pressure and the melting of the surface can be performed by a burner at the time of blowing the agent onto the surface of the steel strip.

Referring to Figure 3 which shows a coating apparatus for performing the method of the present invention, air at super-atmospheric pressure is introduced into a heat-exchanger tank 1 utilising heated waste furnace gas. A part of the air heated to a desired temperature passes through a combustion air supply pipe 2 and is mixed with CO gas supplied through a fuel gas supply pipe 2', and the mixture gas is supplied to the burner 3 for combustion.

Meanwhile, another part of the air passes through the air supply pipe 4 and is introduced to the fluidized bed 5 for heating the scale-converting agent stored in the tank. The remainder of the air passes through a transfer air supply pipe 6 and is introduced into a scale-converting agent delivery pipe 7 for transferring the scale converting agent.

All equipment after the heat-exchanging tank is sealed with heat-insulating materials for preventing heat loss.

Scale-converting agent 5' stored in the fluidized bed 5 is converted into a fluidized state by the heated air supplied through a flow adjusting plate 8 from an air supply pipe 4, and at the same time is preheated preferably to a temperature which does not cause fusion adhesion among the powders or granules of the scale-converting agent. The preheated scale-converting agent passes through the delivery pipe 7 to a mixer 9. The amount of the heated air introduced to the fluidized bed 5 is adjusted so as to obtain an appropriate fluidized state of the scale-converting agent, while the amount of the air supplied to the delivery pipe 7 is adjusted so as to obtain a flow rate of 10 m/sec. or higher.

The scale-converting agent supplied to the mixer 9 is mixed therein with the combustion air and the fuel gas and is supplied to the burner 3. Thus the scale-converting agent passes through the burning flame during which passage the surface of the scale-converting agent is melted and is applied to the surface of the hot steel strip 11.

The orifice of the burner has preferably a rectangular cross section so as to apply the scale-converting agent uniformly across the width of the strip surface.

In order to attain uniform coating of scale-converting agent on the strip surface, a rectangular cross section of the burner orifice is preferable, but burners having orifices of other cross sections may be used. Figure 4 shows one example of a burner having orifices of circular cross section, which can give a uniform coating across the width of the steel strip. Referring to Figure 4, there is provided a delivery pipe 12 for the scale-converting agent, through which the scale-converting agent is transferred by air pressure to a burner 13 and blown onto the strip surface through a plurality of jet nozzles 14 provided on the side face of the burner 13.

A transfer pipe 15 is provided for transferring the combustion gas or a mixture of the combustion gas and air, through which pipe the combustion gas or the mixture gas is supplied to the burner 13, and a gas jet nozzle 16, is provided near the jet opening 14 for the scale-converting agent and communicates with pipe 15, from which the combustion gas or the mixture gas is jetted and burnt.

The gas stream jetted from each gas jet nozzle 16 intersects the powder stream of the scale-converting agent blown from the jet nozzle 14 with a predetermined angle  $\alpha$ , so that the powder particles blown from the nozzle 14 are heated by the flame of the combustion gas or the mixture gas blown from the gas jet nozzle 16 at a predetermined distance from the top end of the burner and at least the surfaces of the particles are melted thereby before

they collide against the strip surface. In this way a satisfactory adherence of the particles on the strip surface is achieved.

In order to maintain a the amount of the scale-converting agent discharged from the fluidized bed 5 continuous and constant, the delivery pipe 7 is connected to the fluidized bed 5 through a valve 10 and the pressure  $P_A$  in the fluid tank is maintained all the time above the pressure  $P_B$  in the delivery pipe. In this way the scale-converting agent powder is discharged continuously and consistently from the fluidized bed 5. Also by controlling the pressure  $P_A$  in the fluid tank 5 and the pressure  $P_B$  in the discharging pipe, it is possible to control the discharge rate from the fluidized bed 5 as desired. The principle of the control is illustrated in Figure 5. Adjustment of the pressures  $P_A$  and  $P_B$  is performed by adjustment of the valve 10 and the air pressure supplied to the fluidized bed 5 and the delivery pipe 7.

In this way according to the present invention almost all of the powder particles of the scale-converting agent blown from the jet nozzles adhere on the high-temperature steel strip running at a high speed either during or after the hot rolling with a high coating or adherence efficiency of 90% or higher as defined by the following formula.

$$\text{Coating efficiency} = \frac{\text{Amount of scale-converting agent adhering on strip surface } \text{g/m}^2}{\text{Blowing rate of scale-converting agent } \text{g/m}^2} \times 100$$

Such a high coating efficiency as above has never been achieved by any of the conventional methods, as clearly understood from the results of experiments shown in Figure 6, which shows the relation between the coating efficiency and the running speed of the steel strip when low-melting-point borate glass powder particles are blown at a rate of 1 g/m<sup>2</sup> on a running steel strip at 700°C. As clearly shown, a coating efficiency of 90% or higher can be achieved in the present invention over a wide range from the low-speed zone to the high-speed zone, irrespective of the running speed of the steel strip. Whereas in the case when the glass powder is used, in the form of a water-slurry no adherence thereof on the strip surface is achieved, because the adherence is hindered by the vapour film produced on the strip surface by the steam. Also in the case where the glass powder is unheated and blown on the strip surface, a coating efficiency of not higher than 10% can be obtained in the low running zone. As the running speed of the strip increases the coating efficiency lowers sharply, and at a running speed of 100 mpm or higher, no adherence can be obtained, because the glass powder particles blown on the strip surface are repelled by the strip surface when they collide therewith and are dispersed all around. Also, as the running speed of the strip increases, the proportion of the particles which are entangled by the air stream and do not collide with the strip surface increases sharply.

Thus, according to the method of the present invention in which at least the surfaces of the particles of the scale-converting agent are melted immediately prior to contacting the strip surface, a high coating adherence efficiency can be achieved and remarkable scale-converting effect can be achieved with the scale-converting agent when applied to the surface of a running steel strip (as defined herein).

The application of the scale-converting agent to the strip surface may be at any desired stage after the vertical scale breaker in the hot rolling process as shown in Figure 1, for example between the rough rolling mill stand A, just after the rough rolling mill stand B, just before the finishing rolling mill stand C, between the finishing rolling mill stand D, just after the finishing mill stand E, and just before the coiler F.

Regarding selection of the scale-converting agent, the agent should have satisfactory scale-converting properties, and desirably an agent having no adverse effect on the rolling operation is employed, of course taking into consideration the position or stage at which that agent is applied.

The present inventors have conducted studies on the basic properties of the scale-converting agent which can satisfy the above requirements, and optimum results have been obtained when the scale-converting agent melts at a temperature lower than that of the steel strip at the position or stage at which the scale-converting agent is applied thereto, so that the melted agent can spread over the strip surface. Referring to Figure 1 and Figure 2, to satisfy this criterion the scale-converting agent would have to melt and spread at a temperature not higher than 1000°C if it is applied at the stage A or B, at a temperature not higher than 900°C if it is applied at the stage C, at a temperature not higher than 750°C if applied at the stage D or E, and at a temperature not higher than 450°C if applied at the stage F.

Thus, as the scale-converting agent used in the present invention, the following substances may be selected.

1) Metal halides, including alkali metal chlorides, such as NaCl and KCl, alkaline-earth

metal chlorides of alkali metals, such as  $\text{CaCl}_2$ , and transition metal chlorides, such as  $\text{FeCl}_2$ ,  $\text{MnCl}_2$  and  $\text{ZnCl}_2$ . These chlorides can reduce the amount of secondary scale formation and render the secondary scale readily removable mechanically.

2) Phosphates such as orthophosphates, poly-phosphates, and meta-phosphates of alkali metals and alkaline earth metals. These phosphates can reduce the amount of secondary scale formation and improve the adhesion of the secondary scale to the base metal.

3) Boric acid, boric anhydride and borates such as the borates of alkali metals and alkaline earth metals. These substances can reduce the amount of the secondary scale formation, and inhibit the hematite formation thus improving the acid solubility of the scale.

4) Low-melting-point glasses, such as glasses composed mainly of  $\text{B}_2\text{O}_3$  and/or  $\text{P}_2\text{O}_5$  as network-former. These glasses can reduce the amount of secondary scale formation, and can produce a scale which is easily removable mechanically or soluble chemically, depending on the amount of these glasses to be applied.

The scale-converting agents described above can adhere to the surface of steel strip if in the form of particles that are melted at least over their surfaces before they collide against the strip surface, and then are completely melted by the heat contained in the steel strip and spread thereon to react with the oxide layer on the strip surface and convert the scale nature.

According to the experiments conducted by the present inventors on the adherence of the scale-converting agent on the strip surface, so far as at least the surfaces of the powder particles of the scale-converting agent are in the melted state, all of the particles colliding against the strip surface adhere by fusion thereto, and then if the temperature of the steel strip is higher than the melting point of the scale-converting agent, the particles are melted and spread over the strip surface. Figure 7 shows the coating efficiency obtained by experiments using the apparatus shown in Figure 8 when  $\text{B}_2\text{O}_3$  is applied to the surfaces of steel sheet test pieces at room temperature and  $700^\circ\text{C}$ , both running at 800 mpm.

In Figure 8, a is  $\text{B}_2\text{O}_3$  powder contained in a container, b is a vibrator, c is a furnace core, d is a muffle furnace, e is a steel sheet test piece. The  $\text{B}_2\text{O}_3$  powder a in the container is discharged little by little by the vibration of the vibrator b, falls down into the furnace core c while being heated by the muffle furnace d, and falls onto the surface of the test piece e moving at 800 mpm. The temperature within the furnace core c is maintained at a predetermined temperature by the muffle furnace d, but the powder passing through the furnace core c is not heated to this predetermined temperature.

Two series of experiments were carried out to determine the proportion of  $\text{B}_2\text{O}_3$  powder adhering to a moving test piece in relation to a number of predetermined furnace temperatures. In the first series of experiments the temperature of the moving test pieces was  $700^\circ\text{C}$ , whilst in the second series of experiments the temperature of the moving test pieces was room temperature. The results of the tests are shown in Figure 7.

At furnace temperatures below the melting point of  $\text{B}_2\text{O}_3$  (approximately  $450^\circ\text{C}$ ), in the case where the temperature of the test pieces was  $700^\circ\text{C}$ , the powder particles tended to melt and, on falling to the steel surface, the powder tended to fuse and spread on the steel sheet surface. On the other hand, in the case where the temperature of the test pieces was room temperature the powder fell on to the surface in the form of dust and did not adhere finely to the surface.

As the furnace temperature increases higher than the melting point of  $\text{B}_2\text{O}_3$ , the proportion adhering to the steel sheet surface increases sharply. At a furnace temperature of  $500^\circ\text{C}$ ,  $\text{B}_2\text{O}_3$  powder particles deposited on the test piece of  $700^\circ\text{C}$  are also fused and spread thereon, while on the test piece of the room temperature, the particles adhere to the steel sheet surface still maintaining their original shapes. This means the surfaces of the  $\text{B}_2\text{O}_3$  powder particles are in the softened state only when they collide against the steel surface. In this case the adherence is not so firm. In case of a furnace temperature at  $600^\circ\text{C}$ , it is observed that the outer portions of the particles adhering to the room temperature test piece are fused and spread on the steel sheet surface. This means the surfaces of the  $\text{B}_2\text{O}_3$  particles are in the melted state when they collide with the steel sheet surface. Only when the furnace temperature increases higher than  $700^\circ\text{C}$ , is complete fusion and spreading of the  $\text{B}_2\text{O}_3$  particles on the room temperature test piece observed.

As can be clearly understood from the results of the above experiments, when the scale-converting agent is applied to a high-temperature steel strip running at high speed in the continuous hot rolling process, if the scale-converting agent is one which melts and spreads on the strip surface at a temperature lower than the temperature of the steel strip to which the scale-converting agent is blown, and at least the surfaces of the powder particles of the scale-converting agent are melted just before the blowing to the strip surface, a high coating efficiency can be achieved.

Therefore the present invention is very advantageous in that the scale conversion can be

performed with high efficiency without causing any trouble in the rolling operation.

As for the means for melting at least the surface of the powder and granular scale-converting agent according to the present invention, there are various methods available therefore, but it is important to melt the surface of the agent with maximum efficiency of heat energy.

According to the present invention, the above requirement can be satisfied by preheating the scale-converting agent to a temperature at which no fusion adhesion is caused among the powders or granules by means of a heat exchanger of fluid layer type or air flow type, for example, then melting the surface of the agent during the step of blowing the agent to the steel strip by means of direct firing for example.

The particle size of the scale-converting agent is also important from the aspect of heat exchange. When the amount of the scale-converting agent to be blown is constant, the surface area of the particles increases as the particle size decreases. Therefore, the heat input per unit weight of the scale-converting agent required for melting at least only the surfaces of the particles is smaller for a smaller particle size. Also, the time required for the particles to melt and spread on the strip surface after their deposition thereon is shorter for a smaller particle size.

According to the results of experiments conducted by the present inventors in a commercial continuous hot rolling line, the particle size of the scale converting agent should be 500 $\mu$  or smaller, more preferably 200  $\mu$  or smaller. With particle sizes above 500  $\mu$ , not only are increased difficulties in the handling of the powder and increased heat input requirement caused, but also in some cases the strip surface is damaged.

Further the present inventors have studied the possibility of applying high-melting-point scale-converting agents to the strip surface for the scale conversion in the present invention, and have found that high-melting-point substances, such as CaO, MgO, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> or sodium aluminate can be easily applied to the strip surface if they are covered with the low-melting-point substances mentioned hereinbefore, and the scale-converting effect inherent in these high-melting-point substances is readily obtained. Although these substances by themselves can be caused to adhere to the strip surface by melting them completely before they collide against the strip surface, they solidify immediately after they deposit on the strip surface, and when rolled in between the rolling rolls they are forced into the strip surface to cause surface damages. According to the present invention, these high-melting-point substances can be applied to the strip surface without the above problems.

When the high-melting-point scale-converting agents are used in the present invention, it is desirable that the particle size of such scale-converting agents is not larger than 5  $\mu$ , more preferably not larger than 1  $\mu$ . In case of CaO and MgO, not only the oxides, but also hydroxides and carbonates may be used. These high-melting-point scale-converting agents are covered with the low-melting-point agents, such as B<sub>2</sub>O<sub>3</sub>, or they are dispersed in the low-melting-point scale-converting agents, and are applied to the strip surface in a particle size of 500  $\mu$  or smaller, more preferably 200  $\mu$  or smaller. When the high-melting-point scale-converting agent covered by or dispersed in the low-melting-point scale-converting agent is applied to the steel strip running at a high speed, the low-melting-point substance covering the high-melting-point substance is first melted and spread over the strip surface, causing the high-melting-point substance to fuse together, so that the desired scale-converting effect can be attained.

The following Examples are now given, though only by way of illustration, to illustrate certain preferred aspects of the invention.



*Example 1.*

A burner as illustrated in Figure 3 is arranged with its nozzle top directed to the rear face of the rolling roll of a finishing rolling stand, and the treatment is performed under the conditions set below.

5	Temperature of Heating Air	150°C	5
	Amount of Air supplied through air supply pipe 4	50 l/min.---(1)	
	Amount of Air supplied through air transfer pipe 6	100 l/min.---(2)	
	Amount of Air supplied through combustion air supply pipe 2	800 l/min.	
10	The amount of the air consumption for the combustion as a whole is: 50 l/min. of 1) + 100 l/min. of 2) + 800 l/min. = 950 l/min.		
15	Fuel Gas	CO gas	
	Amount of Fuel Gas	270 l/min.	15
	Height of Burner Nozzle		
	for strip surface	800 mm	
20	for strip back surface	200 mm	20
	Pressure at Pressure Meter (A)	$P_A = 1 \text{ kg/cm}^2$	
	Pressure at Pressure Meter (B)	$P_B = 0.5 \text{ kg/cm}^2$	
	Amount of Scale Converting Agent	25 g/min.	
25	Blown to the Strip		
	Production Line: Continuous Hot Rolled Strip Production Line		
30	Strip Width	700 mm	30
	Finishing Temperature	860°C	
	Coiling Temperature	580°C	
	Line Speed	600 mpm	
35	Scale Converting Agent		
	Particle Size; 200 - 300 $\mu$ in diameter		35
	Composition: (1) $B_2O_3$		
	(2) CaO coated with $B_2O_3$		
40	The CaO coated with $B_2O_3$ is prepared by suspending CaO powder into molten $B_2O_3$ , cooling the suspension and dividing into a desired particle size.		

The results obtained from the above experiments are shown in Table 1.

TABLE 1

45	Scale Converting Agent	Melting Point	Coating Efficiency	Time Required for Descaling (10% HCl - 70°C)	45
50	(1)	~ 450°C	~ 95%	12 sec.	50
	(2)	450°C at Surface 2500°C at Centre	~ 93%	10 sec.	

(The steel strip without the coating according to the present invention required 25 seconds for the descaling.)

*Example 2.*

20 parts by weight of  $Na_2O.B_2O_3$ , and 80 parts by weight of  $Na_2O.P_2O_5$  are mixed and melted, and MgO powder of 0.1  $\mu$  particle diameter was added thereto at 700°C, and cooled rapidly to obtain a glass mass dispersed with MgO powder. The glass mass was divided into particles of 100  $\mu$  or smaller.

The powder particles thus obtained were applied to the surface of the steel strip entering the finishing rolling mill stand in a continuous hot strip rolling line to give a final coating amount of 3g/m<sup>2</sup> of the bar surface. The coating machine as shown in Figure 3 was used except for the burner. The burner as shown in Figure 4 was used. The preheating

temperature in the fluidized bed was 300°C, and the heat input at the time of blowing the powder to the strip surface was 300 Kcal per 1 kg of the powder so that the surfaces of the powder particles were melted just before the particles collided with the bar surface.

- 5 The temperature of the bar at the entrance of the finishing rolling mill train was 1050°C, the temperature of the strip at the exit of the finishing rolling mill train was 900°C, and the coiling temperature was 750°C. The rolling speed of the first finishing rolling stand was 180 mpm, and the rolling speed of the last finishing rolling stand was 900 mpm. The coil obtained was cooled to 100°C and the properties of the secondary scale on the surface of the coil were investigated. Two comparison tests were also performed, in the first of which there was no heat input at the time of blowing the powder on to the strip, and in the second of which there was no coating applied to the strip. The results of the above three experiments, experiments 1, 2 and 3 respectively are shown in Table 2.
- 10

TABLE 2

	Coating Efficiency	Amount of Scale	Scale Composition		Acid Solubility 90°C 10% HCl	Remark
			Wustite	Hematite		
Experiment 1	94.8%	20.3g/m <sup>2</sup>	30.2%	0.1%	80 sec.	
Experiment 2	1.1%	95 g/m <sup>2</sup>	0	8.5%	68 sec.	No heat input
Experiment 3	-	97 g/m <sup>2</sup>	0	9.0%	75 sec.	No coating

*Example 3.*

0.8g/m<sup>2</sup> of FeCl<sub>2</sub> powder was applied according to the present invention to the surface of a steel strip at 860°C at the exit of the last finishing rolling stand in a continuous hot strip rolling line, and the strip was coiled at 580°C. The secondary scale formed on the strip thus obtained had numberless fine crackings, and could be very easily removed and a lustrous metal surface was exposed.

*Example 4.*

3g/m<sup>2</sup> of Na<sub>2</sub>O.P<sub>2</sub>O<sub>5</sub> was applied according to the present invention to the surface of a steel strip between the third finishing rolling stand and the fourth finishing stand in the continuous hot rolling line, and the rolling was finished at 890°C and the strip was coiled at 630°C.

The amount of the scale on the steel strip thus obtained was 35g/m<sup>2</sup>, and the scale had very strong adhesion, and did not peel off by 60°C bending.

As described hereinbefore, in the present invention the coating efficiency of the scale-converting agent is very high, and thus it is possible to perform the coating with a compact equipment and the heat consumption required can be saved greatly with great advantages for converting the scale of hot rolled steel strip.

**WHAT WE CLAIM IS:-**

1. A method for coating hot rolled steel strip with a scale-converting agent, in which a particulate scale-converting agent is applied to the surface of a running steel strip (as hereinbefore) defined either following hot rolling or during hot rolling after the removal of primary scale, the particles of the scale-converting agent being melted at least over their surface immediately prior to contacting the strip surface.

2. A method as claimed in claim 1, in which the particles are blown towards and into contact with the strip surface by a carrier gas.

3. A method as claimed in claim 2, in which the carrier gas is combustible or contains combustible material.

4. A method as claimed in any of the preceding claims, in which the scale-converting agent particles are preheated uniformly before being further heated so as to melt at least the surface thereof.

5. A method as claimed in any of the preceding claims, in which the scale-converting agent has a melting point lower than the temperature of the steel strip to which the scale-converting agent is applied.

6. A method as claimed in any of the preceding claims, in which the scale-converting agent is one or more compounds selected from metal halides, alkali metal and alkaline-earth metal borates and phosphates, boric acid, boric anhydride and polyphosphates.

7. A method as claimed in any of claims 1 to 5, in which the scale-converting agent is a glass powder containing one or more of phosphate glass and borate glass.

8. A method as claimed in either of claims 6 and 7, in which the particle size of the scale-converting agent is not greater than 500μ.

9. A method as claimed in claim 8, in which the particle size is not greater than 200μ.

10. A method as claimed in any of claims 1 to 5, in which the scale-converting agent is in the form of particles of a higher-melting substance selected from sodium aluminate, lime and magnesia coated with one or more scale-converting compounds having a melting point lower than the temperature of the steel strip being coated.

11. A method as claimed in claim 10, in which the higher melting point substance is coated with one or more compounds selected from metal halides, alkali metal and alkaline-earth metal, borates and phosphates, boric anhydride, boric acid, polyphosphates, phosphate glasses and borate glasses.

12. A method as claimed in claim 10 or claim 11, in which the particle size of the higher-melting point substance is not greater than 5μ.

13. A method as claimed in claim 12, in which the particle size is not greater than 1μ.

14. A method as claimed in claim 1, and substantially as described herein with reference to any one of the Examples.

15. A method as claimed in claim 1, and substantially as described herein and illustrated in the accompanying drawings.

16. A method as claimed in claim 1, in which the particles of the scale-converting agent are pre-heated and fluidized by passing therethrough a gas at super atmospheric pressure and above ambient temperature, an adjustable amount of the preheated scale-converting agent is then mixed with one or more combustible gases, the mixture thus obtained is blown to the surface of a hot rolled steel strip and the particles of the scale-converting agent are heated so as to melt the particles at least over their surface immediately prior to contacting the strip surface.

17. A method as claimed in Claim 1, in which the particles of the scale-converting agent are stored in a vessel and are discharged from the vessel at a predetermined rate through a transfer pipe by maintaining a constant pressure difference between the pressure in the vessel and the pressure in the transfer pipe.

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FIG. 1

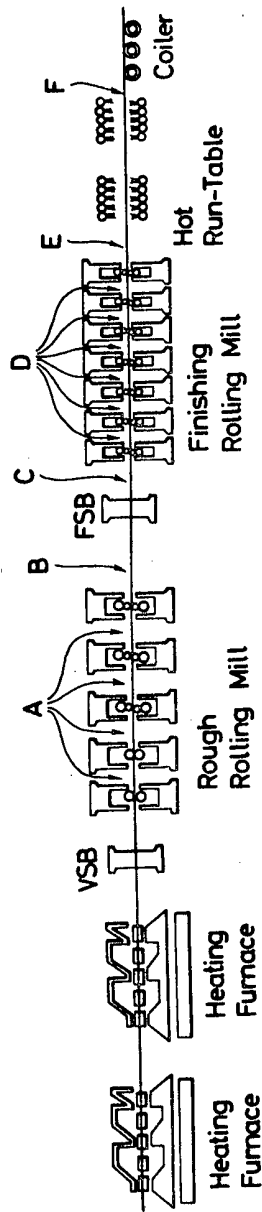


FIG. 6

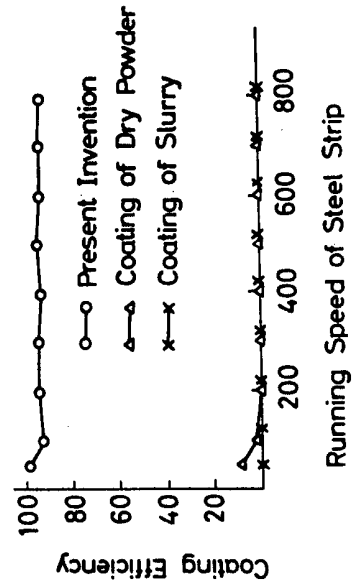
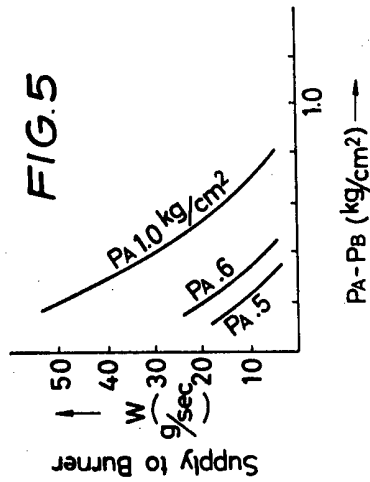


FIG. 5



**FIG. 2**

Temp. at Various Stages in Hot  
Strip Rolling Mill

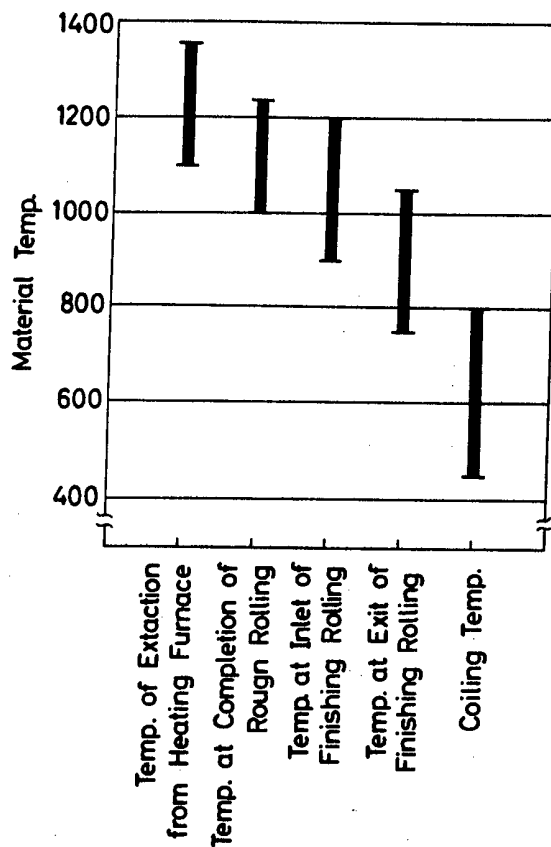


FIG. 3

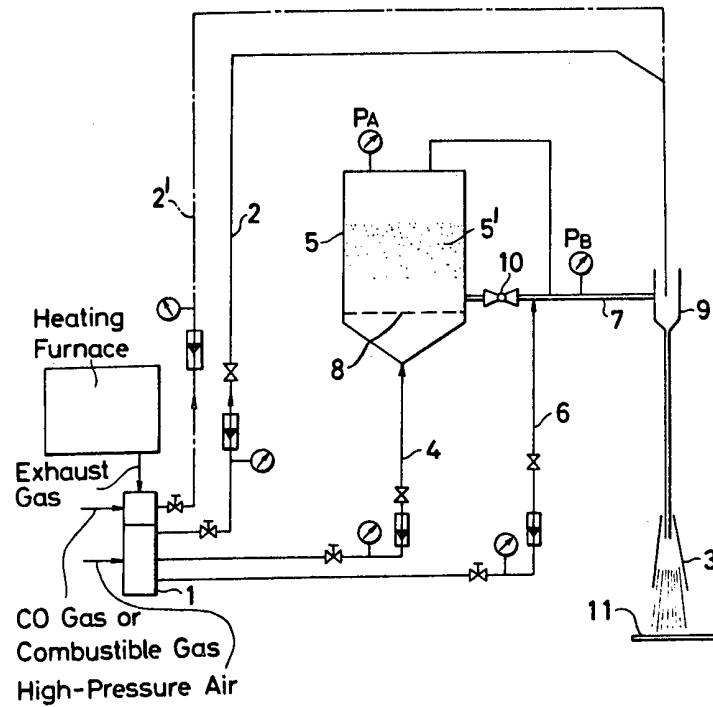


FIG. 4

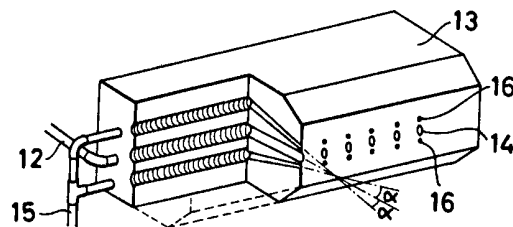


FIG. 7

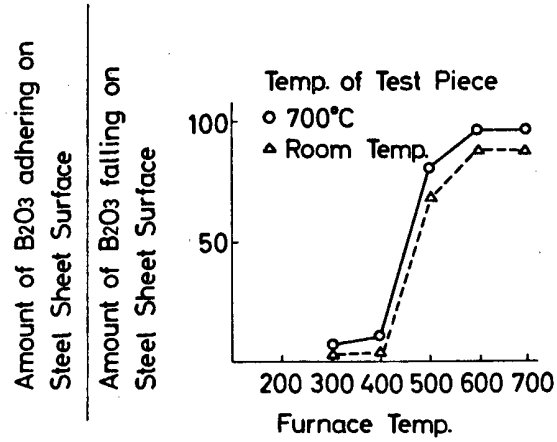


FIG. 8

