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열연사상 압연시 스케일 결함발생에 미치는 산화피막 두께의 영향

민 경 준*
포항제철소 열연부
포항종합제철주식회사

The Effect of Oxide Layer Thickness to the Scale Defects Generation during Hot finish Rolling

K.Z. Min
Hot Rolling Dept. Pohang works
POSCO

Abstract

Scale defects generated on the strip surface in a tandem finishing mill line are collected from the strip trapped among the production mills by freezing the growing scale on the strip by the melt glass coating and shutting down the line simultaneously. The samples observed of its cross sectional figure showed the process of scale defect formation where the defects are formed at the base metal surface by thicker oxidized scale during each rolling passes. The properties of the oxidized layer growth both at rolling and inter-rolling are detected down sized rolling test simulating carefully the rolling condition of the production line. The thicknesses of the oxidized layer at each rolling pass are simulated numerically. The critical scale thickness to avoid the defect formation is determined through the expression of mutual relation between oxidized layer thickness and the lanks of the strip quality for the scale defects. The scale growth simulation is also used to design the adequate cooling device called Interstand Cooler which is expected to restrain the growth of scale less than the critical thickness and also to keep the bulk temperature tuning the water flow rate and cooling time appropriately. Two units of Inerstand Cooler are designed and settled among the first three stands in the production line. The number of scale defect is counted from the recoiled strip and the results showed distinct decrease of the defects comparing to the conventionally rolled products.

Key words : Scale defect, Interstand descaling , oxide layer

1.Introduction

The scale defect is one of the well-known and persistent problems in a hot strip rolling precess [1]-[4]. This problem is being paid more attention along with the raise of end user's request for strip surface quality. The mechanism of the defect generation has not yet been cleared enough and many hot strip makers are only trying to decrease the chance to spread the trouble generally according to their private experience. The general conditions where the scale defect tend to increase are known to be the higher strip temperature and the lower threading speed especially at the entrance section of finish mills. From these experiences, it is supposed that the scale defect has a relation to the growth of the oxidized layer of the strip before rolling. However it is not allowed both to lower the strip temperature than ever from the metallurgical restriction for the rolling and also to increase the threading speed form the restriction of the strip head steering stability until trapped into the coiler. Although, from the consideration of oxidizing condition, cooling only the surface layer of the strip could be effective both for the prevention of the growth of oxidized layer and the prevention of cooling the strip bulk temperature. However, in order to realize the cooling device, we have to know many conditions such as for instance what passes the scale defects are formed at, how much is the critical thickness of the oxidized layer and consequently what are the practical specifications of the cooling device.

The procedure of this study is divided in three steps and shown in Table 1. At the first step, the process of the scale defect formation is detected through a production line test by collecting the defect samples. At the second step, the critical condition to avoid the defect formation is detected through the down sized rolling test and the regulation of the relations between calculated oxidized layer thickness and the quality ranks of the strip concerning for the scale defects collected from of the products. At the third step, the strip cooling device called Inter Stand Cooler (here after ISC) are designed through the scale growth calculation and settled among the first three finishing mills in a production line. The devices are examined their performance for decreasing the scale defects comparing to the conventional products ISC are not applied.

Table 1 Main step of this study

Step	Aim	Method
1 Observation	Analysis of the scale defect formation process	Using a productin line (1) Stop the strip during rolling and cover the strip surface with melt glass among the mills simultaneously (2) Collect the glass covered samples (3) Observe the scale defects at each rolling pass
2 Simulation	Determination of critical conditions	Using a down sixed experimental mill and furnace (1) Reproduce the defects (2) Measure the growth speed of oxidized layer Using computer simultion and scale defects samples (3) Plot the calculated oxidized layer thickness and the ranks of the scale defects (4) Extract the critical thickness of oxidized layer
3 Substaniation	Substaniation of the perfomance of the strip cooling device (ISC)	Using computer simulation (1) Design the optimized strip cooling device Using a production line (2) Evaluate the ranks of scale defects of the products on which ISC are applied

2.Observations of scale defect

2.1 Sampling method of scale defects

In order to observe the forming process of the scale defects, the samples have to be collected from each rolling pass of a production line. The glass coating method is used to freeze its oxidized layer growing on the defects not to allow any transformation of the defects. SiO_2 powder glass is selected as the coating material through the melting and blowing test against a heated plate. The grade with no rare earth metal is selected to avoid deoxidizing the oxidized layer. The temperature level of the melt glass just before the blow is decided to be about 850℃ considering to avoid the peeling of the oxidized layer by thermal shock and also considering the fluidity on the strip to avoid the damage to the work roll. The powder glass is heated and blown from air pressured pots. The internal structure of the pot is shown in Fig1. The powder glass is fed from one of the top mouth, stored in the 65A chamber and heated by 1kW wire heater with thermo-couples around it. Melt glass of about 200cc per one blow is used to cover almost 0.01 m^2 of the strip except for scattered area. The whole system of the glass blowing equipment is shown in Fig 2. Air pressure is fed to the another top mouth. The air pipe is connected to the compressor through the electromagnetic valve. This pot is hung on the strip pass line among the finishing mills. When an air valve switch is put on, air pressure is fed in the pot and the melt glass is blow out from the bottom mouth on the strip. The mill line is shut down simultaneously by turning on the emergency switch connected to the air valve switch. The line position where the glass pots are settled are shown at the upper side in Fig 3. Most of the pots are settled at the upstream side of the mill line according to the experience where scale defects are detected. No.1 pots are used to detect the oxidized layer thickness just after the FSB i.e. water jet descaler. No.6 pots are used to detect the thickness of the oxidized layer and the final shape of the scale defect.

2.2 Shape of the scale defect

The cross sectional view of the samples collected from the tested strip are shown at the lower side in Fig3. The upper pictures raw shows the samples from which no scale defects are observed. The temperature of this sample at the delivery section of rougher mills is 1000℃, and the threading speed at the entrance section of the finisher mills (F1) is 0.5m/s. The lower pictures raw shows the samples collected from the strip from which many scale defects are observed. The temperature at the dilivery section of rougher mill is 1080℃, and the threading speed at the entrance side of the F1 is 0.25m/s. The quality of the strip material is the low carbon steel. Three areas are distinguished in each picture. The bottom white area in each picture is the base metal. The middle narrow area is the oxidized layer. The upper dark area is the glass solidified on the strip. The mean thickness of the oxidized layer at 670mm after the FSB is measured to be 2.4 μm from the upper sample with no scale defect. The oxidized layer thickness with scale defects is 7.0 μm at the same position which is evidently thicker than the sample with no scale defects. The oxidized layer are shown to grow thicker to the F3 stand at each mill delivery section in spite of the rolling reduction on both cases.

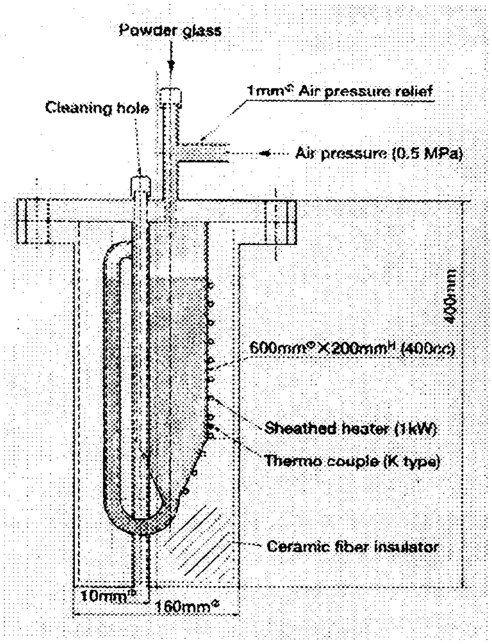


Fig1. Melt glass blowing pot

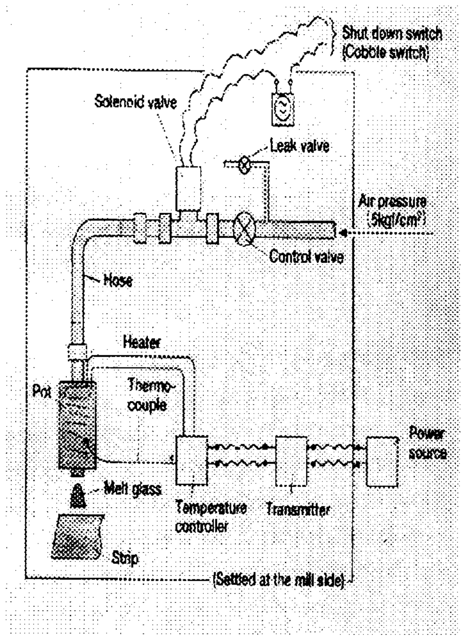


Fig2. Systematic view of glass coating equipment

The samples in the lower pictures raw shows evident increase of roughness especially at the F2 and F3 delivery sections. A cross sectional view of the scale defect is shown at the delivery section of F7 in the lower pictures raw. A distinctive dent of the base metal is observed. From these pictures, the defect seems to be formed from the increased roughness at F2 or F3 and remained in spite of the reduction of its bulk thickness through the later rolling

3. Simulation

3.1 Experimental equipment

The thickness of the oxidized layer at some rolling passes seem to have relation with the scale defects. However, the number of the samples collected by glass coating method are not enough to determine the critical thickness for the scale defects. On the other hand, many scale defects can be observed at the recoiling section under various rolling conditions. Therefore the critical thickness of the oxidized layer and the influential rolling pass for the scale defect is determined from the simulation of oxidized layer growth for these defect observed products. In order to simulate the growth of oxidized layer, the growth speed in the air and the reduction rate at the rolling have to be cleared. These are measured using the down sized experimental mill and furnace. The shematic view of the equipment is shown in Fig 4. The test plate heated in the furnace is pulled out by wire at constant speed, passed under the descaler, rolled for certain passes and coated with glass. The water jet is blown from 100mm height with 75 ° angle by descaling nozzle with 1500MPa pressure. The test plate of 12mm initial thickness and the work roll of almost 200mm diameter are chosen as the representative scale of the experimental conditions. The barrel axial length of 300mm is divided into steps of diameter to realize the continuous three rolling passes without changing the roll gap. The furnace is also used to measure the growth speed oxidized layer the air at the certain constant furnace temperature. Low carbon steel which have the same quality of material with the samples collected from the production line is used as the test piece. The samples are collected at each test process from the delivery side of the descaler to that of the third pass of rolling.

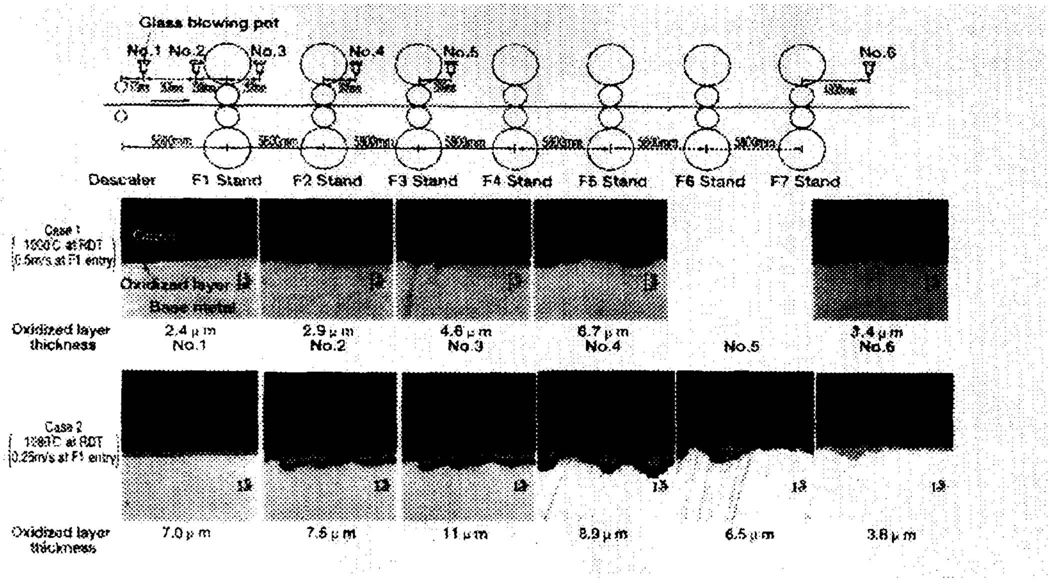


Fig. 3 Glass coated positions and cross sectional view of collected samples

3.2 Experimental results

The growth speed of the oxidized layer for the certain temperature range are expressed as scale growth rate constant K in Fig 5. Lower K value compared to the high purity steel are shown. The cross sectional figure of this down sized rolling test sample collected from the delivery side of the third pass is shown in Fig 6. The similar increase of the base metal surface roughness is observed compared to the lower picture in Fig 3. The reduction rate between the base metal and the oxidized layer are compared in Fig 7. These reduction rates are shown as the accumulated value of plural passes. The initial thickness of the oxidized layer is distinguished in four levels. The reduction rates of the oxidized layer are shown to be almost same with those of the base metal regardless of the initial oxidized layer thickness.

3.3 Numerical simulation

The thickness profile at each section in the finishing rolling process from which the oxidized layer samples are collected is calculated numerically. The calculation model is made using the following representative assumptions.

(1) The growth of the oxidized layer thickness in the atmosphere is subject to one dimensional diffusion equation.

(2) The scale growth rate constant K depends only on the surface temperature of the base metal and can be expressed as the power series function of the temperature regardless of its reduction history.

(3) The thickness of the oxidized layer in a rolling bite is reduced with the same rate of the base metal.

(4) The descaler FSB peel the oxidized layer completely.

The calculation of the strip temperature is conducted in order to give the surface temperature to the oxidization layer growth calculation. Twenty-one calculation points are prepared in the strip half thickness to take its distribution into account. Experimental heat flux is given at the descaling section. Deformation heat and friction heat are given at each rolling pass conducting the rolling load calculation based on the Karman's theory. The contact heat flux is calculated using the oxidized layer thickness as the substantial heat resistance. The oxidized layer thickness is applied from its growth calculation. The strip temperatures measured at two positions by radiation thermometers are utilized for the simulation. The temperature at the delivery side of the rougher mills is used as the initial strip temperature of the simulation

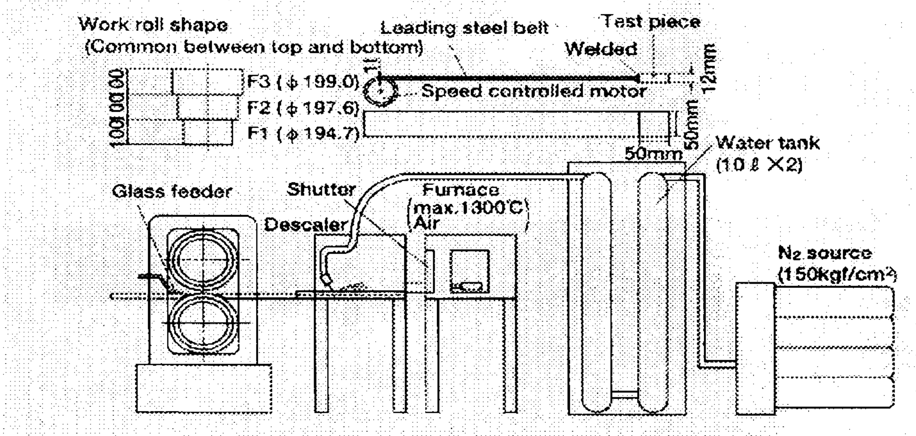


Fig 4. Down sized rolling test equipment

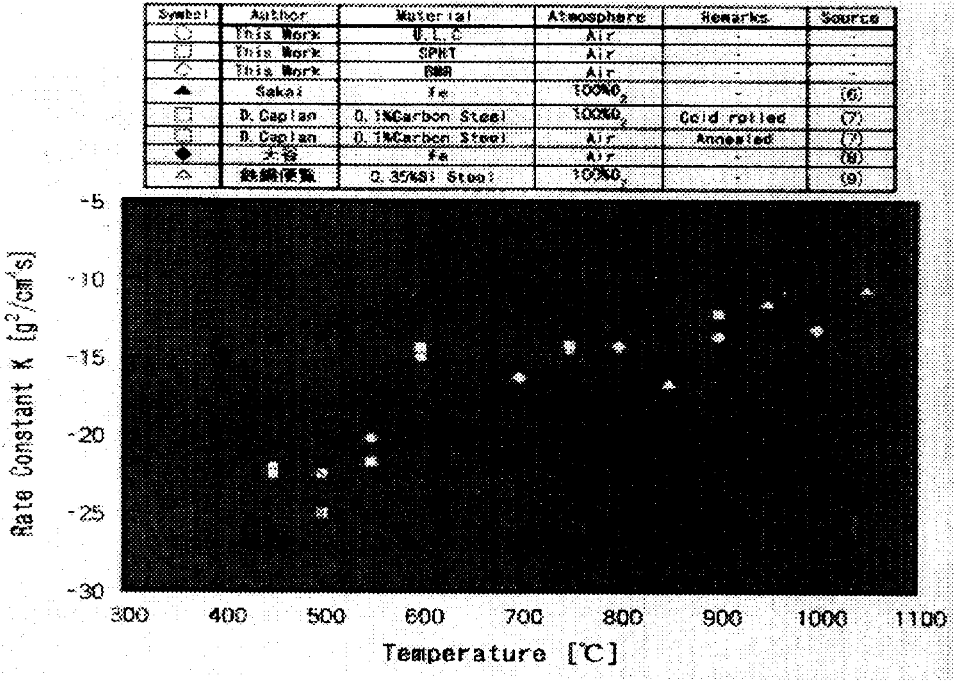
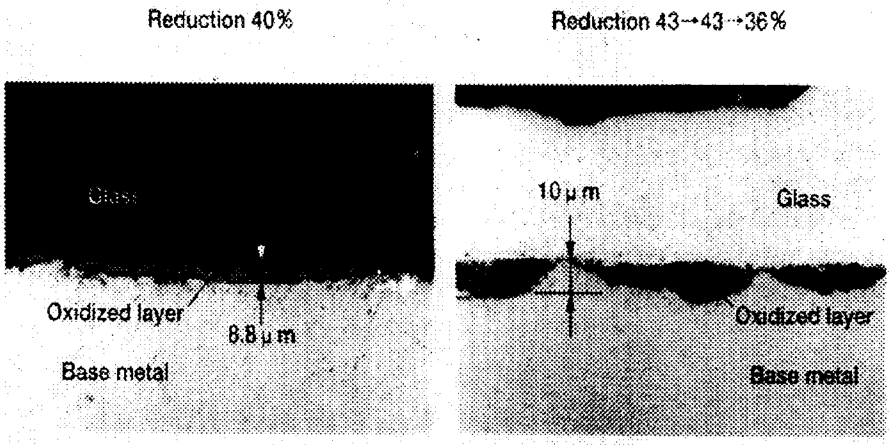


Fig 5. Scale growth rate constant K



Just after the first pass

Just after the third pass

Fig 6. Surface roughness of down sized rolling test samples

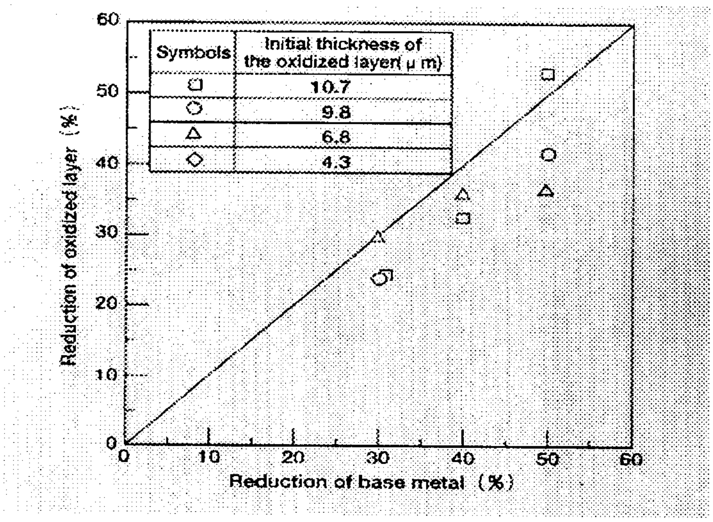


Fig 7. Comparison of reduction between base metal and oxidized layer

The temperature at the delivery side of the finisher mills is used to adjust thermal emissivity of the strip. An example of the simulation results is shown in Fig 8. The upper three curves show the strip temperature corresponding to the thickness center, mean and the surface respectively. The tail level of the curve is adjusted to the measured one by using emissivity of 0.6. This emissivity is verified to be adaptable for other cases successfully. The plots show the oxidized layer thickness collected from the production line and the thickness is in the range almost from 3 to 8 μ m. The simulation result is shown as the lower curve. It corresponds roughly to the measured plots, and the curve shows its peak at the entry side from F1 to F3. The relation between the reduction rate, the oxidized layer thickness and the levels of the scale defect are shown in Fig 9. to Fig 11. Fig 9 is for F1, Fig 10 for F3 and Fig 11 for F7. The reduction rates are collected from the logging record of production controller. The oxidized layer thickness is calculated from the numerical simulation. The ranks of the scale defects are evaluated by an inspector at the recoiling section. The revels are devided into six ranks and the higher rank means having more scale defects. The allowable level is settled less than the 3'rd degree in this standard. The scale defect levels at F1 and F7 don't show clear dependency on both oxidized layer thickness and reduction rate. However the scale defect levels at F3 seems to show the dependency on the both parameters to some extent. Especially, concerning for the oxidized layer thickness, the border line can be drawn at 5 μ m regardless of the reduction rate. This means the oxidized layer less than 5 μ m at the entrance of F3 is expected to make no scale defect at a certain probability for any reduction rate.

4. The effect of strip surface cooling

4.1 Design of the cooling device (ISC)

According to the result of Fig 10, the strip cooling device to restrain the oxidized layer thickness less than the limit is designed through the oxidized layer growth simulation. The cooling conditions for the temperature simulation are given from Mitsuzuka's experimental equation for spay cooling [5]. The profiles of the oxidized layer thickness and the strip temperature are shown in Fig 12. ISC are supposed to be used between F1, F2 and F3.

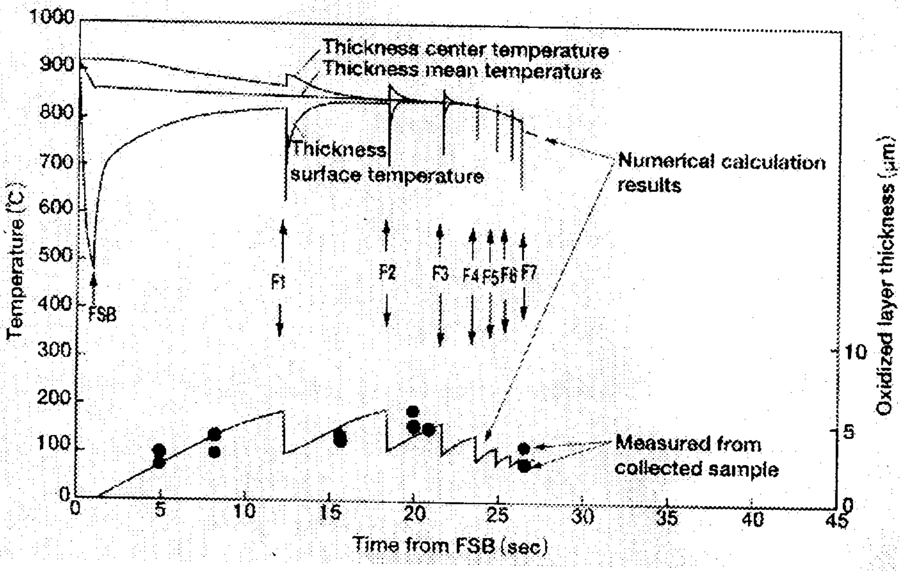


Fig 8. Profiles of temperature and oxidized layer thickness of the strip with no scale defects

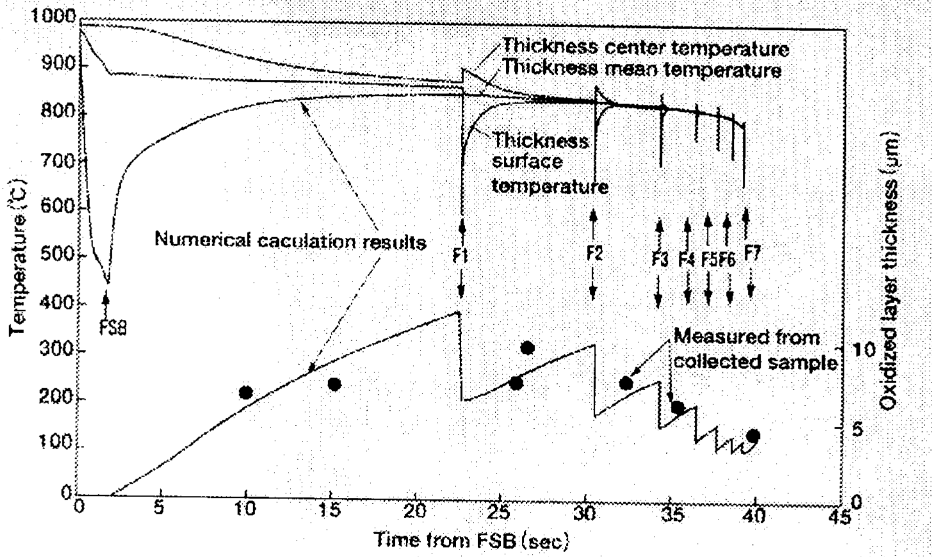


Fig 9. Profiles of temperature and oxidized layer thickness of the strip with no scale defects

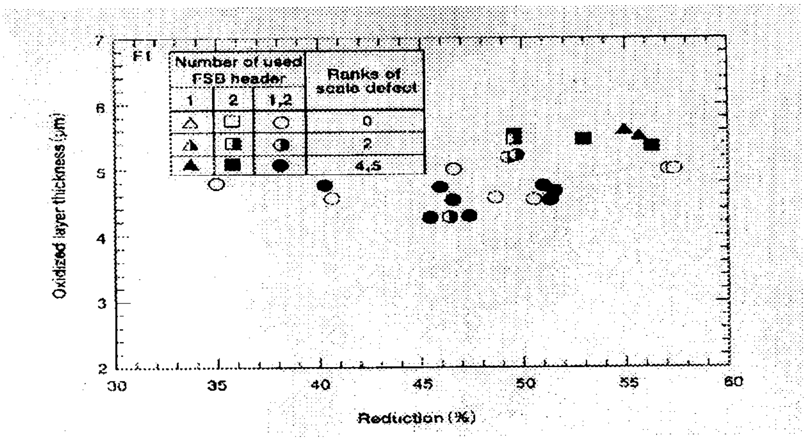


Fig 10. Ranks of scale defects at each reduction and oxidized layer thickness (F1 entry side)

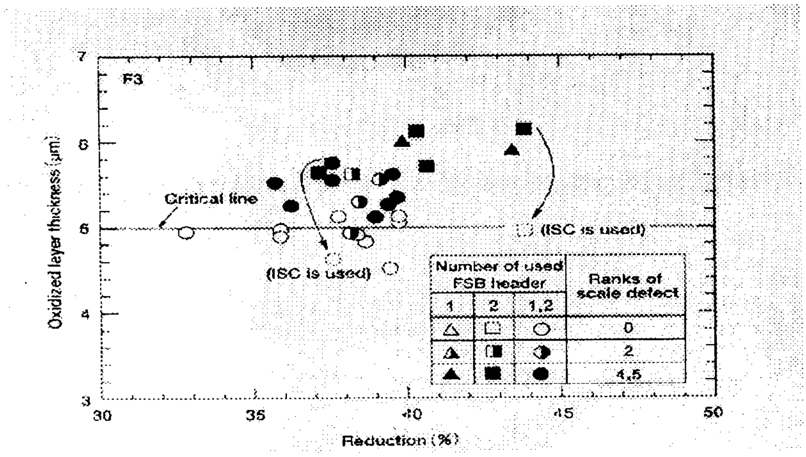


Fig 11. Ranks of scale defects at each reduction and oxidized layer thickness (F3 entry side)

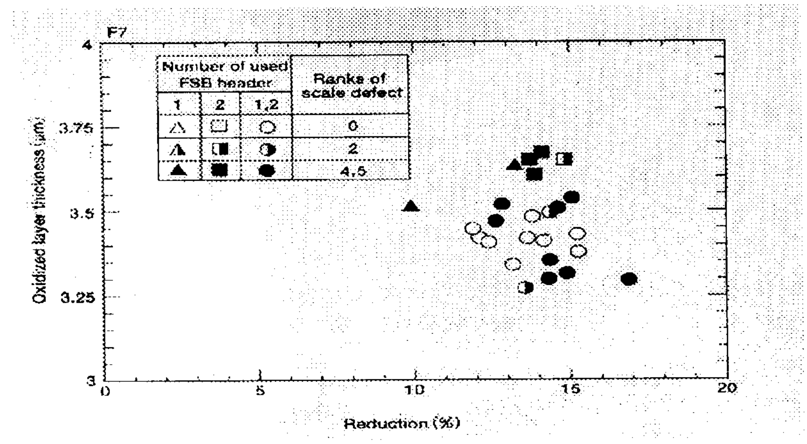


Fig 12. Ranks of scale defects at each reduction and oxidized layer thickness (F7 entry side)

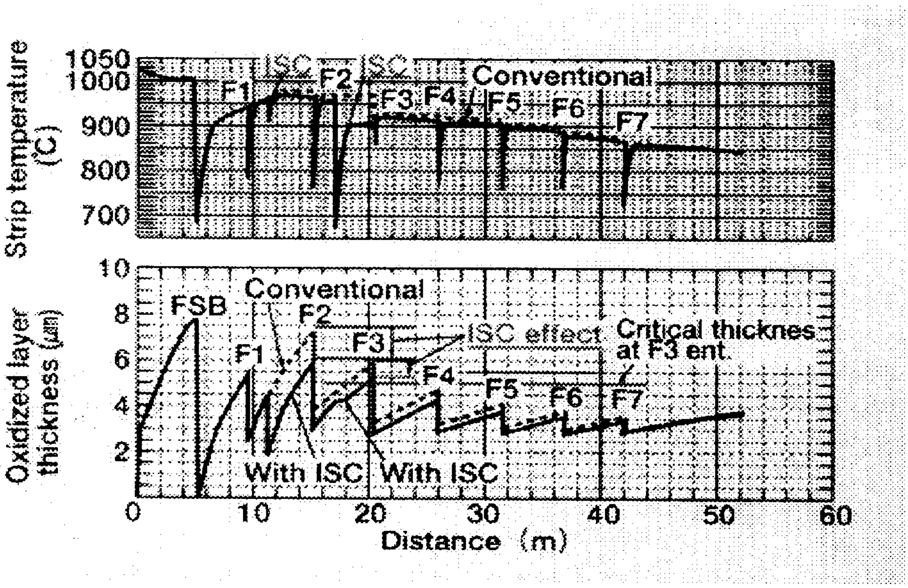


Fig 13. Profiles of strip temperature and oxidized layer thickness

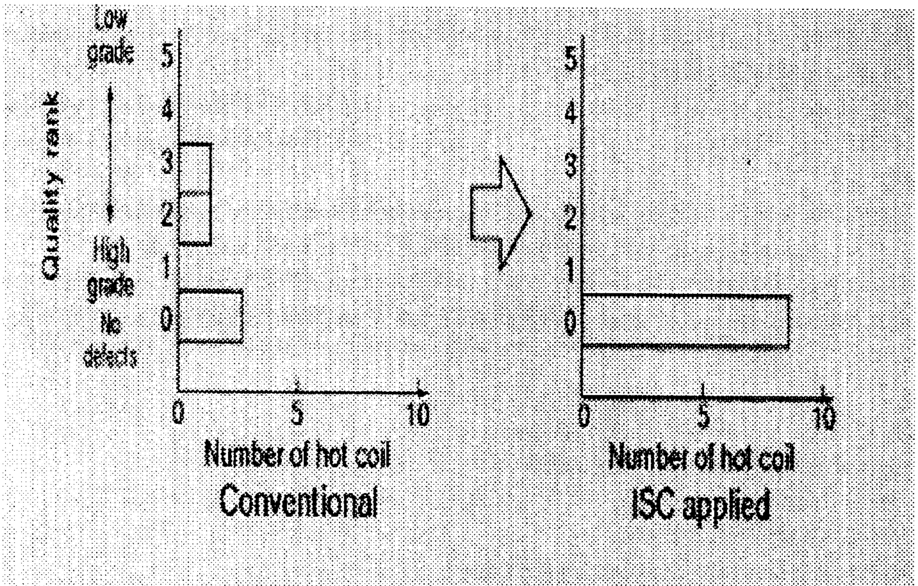


Fig 14. Improvement of scale defect rank by ISC

The upper curves show the profiles of the strip surface temperature. The lower one shows the cases using ISC. The gap of these curves becomes negligibly small at the final rolling pass. The profiles of the oxidized layer thickness are shown as lower curves. The lower one shows the case with ISC. The thickness at the entrance of F 3 is just below 5 μ m and it means the scale defects will not be formed in this case.

4.2 Test in the production line

The cooling conditions used in this simulation are realized in a production line by settling the water spray nozzle and its headers additionally between F1, F2 and F3 respectively considering the space between their strip guides both upper and down side of the pass line. The flat type nozzle tips are arranged in strip width direction over wrapping their impact area slightly. The high pressured water is fed to the ISC between F1 and F2 conducting a pipe line from that for FSB. The spraying angles are directed to the up stream slightly considering to avoid the invasion of scales to the downstream rolling

The verification test is conducted fixing the strip material on the low carbon steel. The change of the product's quality concerning for the scale defect rank are shown in Fig 13. All the products to which ISC are applied are evaluated as 0 rank which means no scale defects is found on their surface.

5. Conclusions

The scale defects prevention device is developed through three investigative steps of observation, simulation and substantiation. The following results are led from each step.

(1) The samples are collected from the strip trapped among the finishing mill of a production line coating its surface with melt glass.

(2) From the observation of the sample, the scale defects is supposed to be formed at mainly F2 or F3 from increased roughness of the base metal when initial oxidized layer is thicker and the defect remains through the later rolling in spite of the reduction of its bulk thickness.

(3) The property of the oxidized layer growth are detected from the test palte and found that the reduction rates of the oxidized layer are shown to be almost same with those of the base metal regardless of the initial oxidized layer thickness.

(4) The critical thickness of the oxidized layer to avoid the scale defect is predicted to be 5 μ m at the entrance of F3 for a low carbon steel through the analysis of the scale defects and the numerical analysis.

(5) The strip surface cooling device ISC is designed and settled at between F1, F2 and F3 respectively in the production line. The tested low carbon strip showed no scale defects on their surface at the recoiling section.

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