

The influence of slab surface temperature on the descalability of fayalite in a hot strip mill

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Abstract. Silicon is a cost-effective alloying element added to low carbon steel for improved strength, while maintaining ductility and formability. During hot rolling Si-alloyed steel forms uneven patches of red oxide scale over the surface. These patches are difficult to remove by industrial pickling processes. The influence of slab surface temperature on the descalability of fayalite was investigated. When hydraulic descaling is executed at a slab surface temperature higher than the melting point of fayalite (1177°C), the liquid fayalite is washed away. The red oxide scale coverage of the surface was decreased significantly.

1 Introduction

The addition of alloying elements to low carbon steel is executed in order to manufacture steel that is more durable, lighter and stronger. Alloying elements with favourable hardenability properties for enhanced tensile properties are selected, with attention to the effect of the element on important metallurgical and mechanical properties, like, machinability, formability and toughness. In industry, silicon (Si) is added to low carbon steel due to its strength improvement capabilities with the added advantage of being cost effective. The strengthening mechanism of Si is solid solution hardening, and by adding Si, the formability and ductility is maintained [1]. Si-alloyed steels are used in pipelines, for core material of motors and transformers, and for automotive components [2].

During the hot rolling of Si-alloyed steel, an uneven scale layer, namely red oxide scale, is formed that is hard to remove during pickling processes in industry [3]. The aesthetical properties of the product are detrimentally influenced by the uneven red oxide scale blemishes, since the material cannot be used as exposed parts and components. The surface appearance of hot rolled Si-alloyed steel with red oxide scale stripes and patches is shown in Figure 1.

The purpose of this project is to investigate the influence of slab surface temperature during the primary descaling step on the descalability of fayalite in the hot rolling process.

The hypothesis is that when descaling is executed at a slab surface temperature higher than the melting point of fayalite (1177°C), the liquid fayalite is washed away by the high pressure water sprays. The fayalite %-coverage of the steel surface will be decreased to levels as low as 0%.

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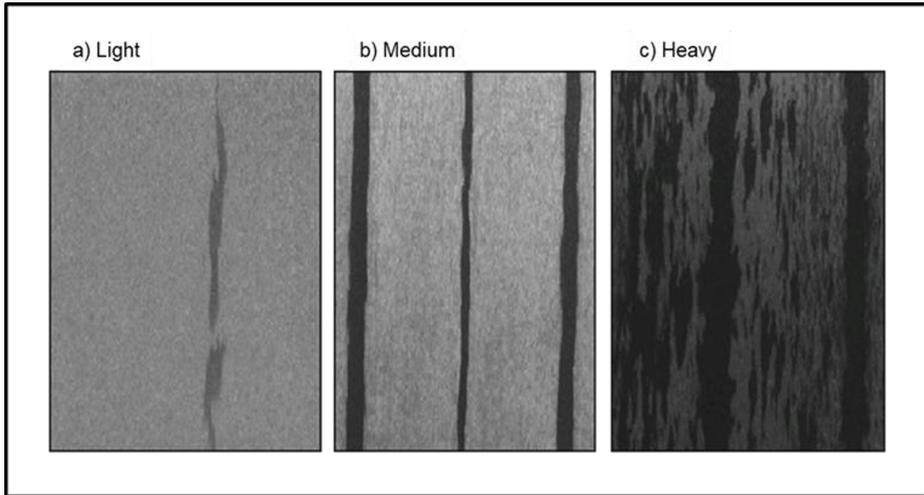


Fig. 1. Uneven red oxide scale on the Si-alloyed steel surface (magnification 1:5). [4]

2 Formation mechanism: red oxide scale

During the hot rolling process, steel slabs are reheated and rolled into coils at temperatures between 800-1250°C [3]. While reheating low carbon steel slabs, oxidation reactions that are exothermic in nature, take place between the oxygen in the atmosphere (both air and furnace) and the Fe in steel. When iron reacts with oxygen, scale or iron oxides form on the surface.

The scale consists of isothermal layers, namely wüstite (FeO), magnetite (Fe_3O_4) and hematite (Fe_2O_3) [5, 6], with wüstite being higher in iron than the other layers, and hematite being the most oxygen rich of the three layers. Figure 2 illustrates the isothermal scale layers that form when low carbon steel is processed at temperatures ranging from 1100-1200°C.

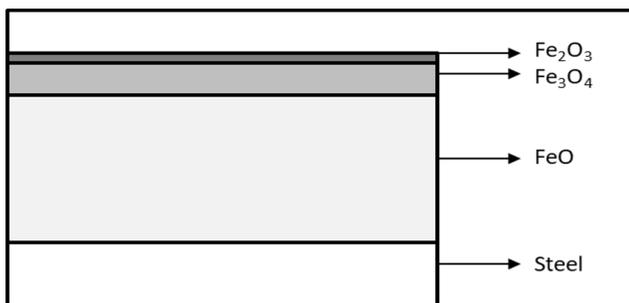


Fig. 2. Isothermal scale layers that form on low carbon steel during hot rolling: 1100-1200°C.

During the reheating phase of hot rolling Si-alloyed steel, an additional scale layer grows between the steel substrate and iron oxide layers. This irregular fayalite layer (Fe_2SiO_4) forms due to the higher O_2 affinity of Si compared to Fe.

The melting point of fayalite is 1177°C. Above this temperature, a fast diffusion rate of Fe-ions through the fayalite layer (liquid) is observed, resulting in an increased rate of scale growth [7]. Below this temperature, fayalite solidifies and acts as a diffusion barrier between iron and oxygen, resulting in a decreased rate of scale growth [8].

Fayalite solidifies by growing dendritic arms along the grain boundaries of the steel substrate and in the FeO scale layer. The dendritic arms are anchoring the fayalite, making it hard to remove during high pressure water descaling processes typically found in a hot strip mill.

After the primary descaling process, FeO, entrapped by the fayalite anchors, is exposed to oxygen in air and oxidizes to magnetite, Fe₃O₄. Fe₃O₄ reacts with oxygen and oxidize to hematite, Fe₂O₃. The deformation of the scale layer in the finishing mill results in the fracturing of the hematite, making it a powdery substance. Powdered hematite is red in colour, which gives the name to the scale: Red oxide scale.

A schematic diagram of red oxide scale formation is illustrated in Figure 3[9].

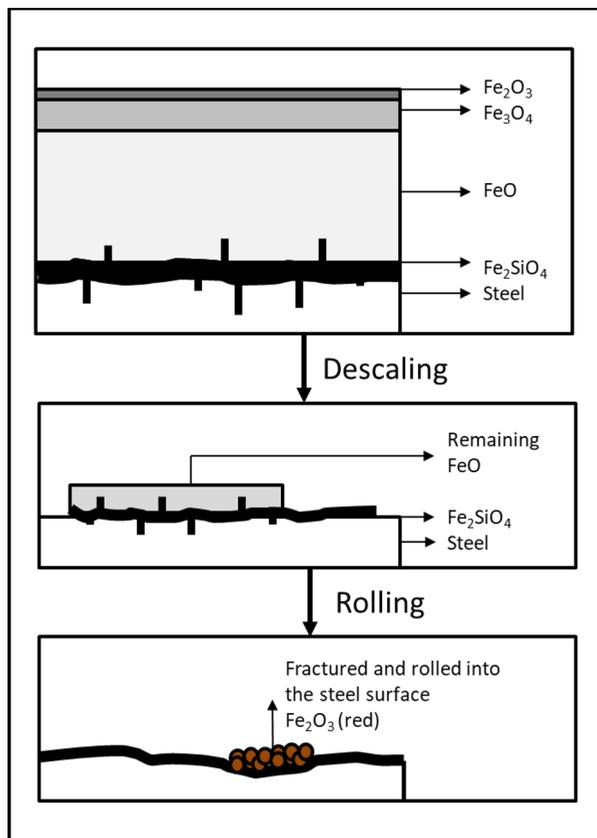


Fig. 3. Red oxide scale formation during hot rolling of Si-alloyed steel.

3 The formation of the irregular red oxide scale pattern

Red oxide scale manifests in irregular patterns or blemishes intermittently or continuously over the surface area of Si-alloyed steel. These patterns resemble long streaks, or tiger stripes. The quest for understanding this irregular pattern phenomenon started by studying the reheat temperatures, the slab surface temperature after primary descaling and the nozzle spray pattern of the primary descaler.

The aimed reheat temperature of a Si-alloyed steel slab is between 1200-1230°C. The aimed roughing mill exit temperature of the transfer bar after the roughing passes is

1080°C. That implies that the temperature before the first roughing mill pass must ideally be in the region of 1190°C, which is above the melting point of fayalite (1177°C).

Ideally, primary hydraulic descaling occurs while fayalite is still liquid. The bonds between the liquid fayalite and the steel are weak, making this layer highly descalable by hydraulic descaling. If it is assumed that under ideal conditions the surface temperature of the slab is homogenous and above 1177°C, no red oxide scale should be present.

However, in industry red oxide scale still occurs on the Si-alloyed coil surface, although primary descaling was executed at temperatures higher than the melting point of fayalite.

In Figure 4 a thermal graph of a 1200mm wide slab after primary descaling is shown. Colder stripes in between hot bands occur over the width of the slab. There is a strong correlation between the thermal graph and the red oxide scale pattern.

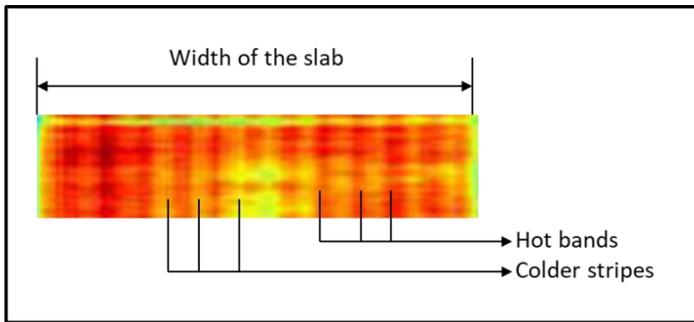


Fig. 4. A typical thermal graph of a 1200mm wide slab after primary hydraulic descaling [10].

The spray pattern of the nozzles of a primary descaler can be seen in Figure 5.

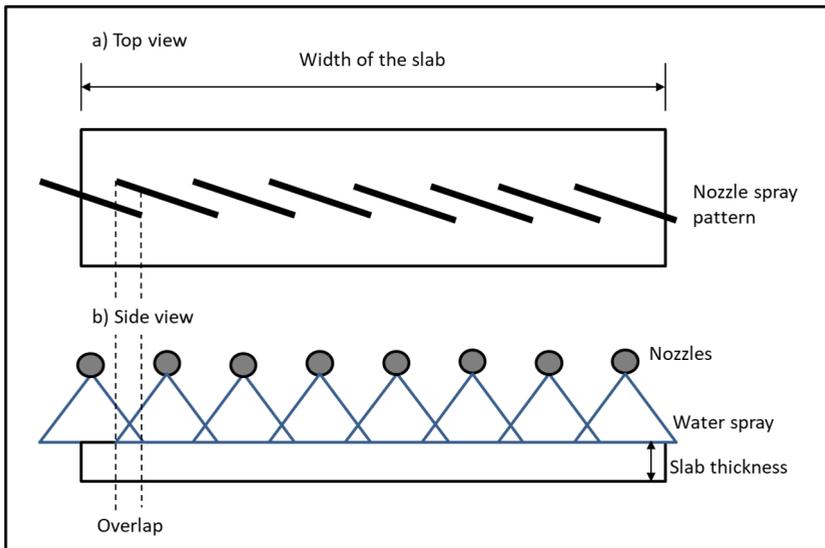


Fig. 5. Spray pattern of the nozzles of a primary descaler [11].

The purpose of the nozzle setup in a descaler is to ensure full width descaling without any gaps in between the nozzle spray patterns. This is established by deliberate overlap of the spray patterns. The steel surface areas where the spray overlap occurs are exposed to a higher volume of water, which causes localized cooling.

Since the melting point of fayalite (1177°C) and the expected roughing mill entry temperature (1190°C) are in close proximity, the following can be concluded from the observations:

- In the surface areas where no overlap of nozzle spray pattern occurs, the surface temperature is above the melting temperature of fayalite. Therefore, upon descaling, fayalite is still in liquid form and easily descaled. In those areas, no red oxide scale can be observed on the final hot rolled surface.
- In the surface areas where the nozzle spray pattern overlaps, the surface temperature falls below the melting temperature of fayalite. Upon descaling, fayalite is solidified. The strong dendritic anchors are difficult to descale, hence, red oxide scale is encountered on those areas on the final hot rolled surface.
- The irregular streaks or tiger stipe pattern of red oxide scale can be attributed to the localized cooling pattern of the nozzle sprays of the primary descaler in the hot rolling process.

The apparent question is “In Industry: Can the reheat temperature be increased to such temperatures that the slab surface temperature is uniformly higher than the melting point of fayalite in the primary descaling step?”

4 Methodology and results

Industrial Trial: Slabs with varying reheat furnace drop out temperatures were descaled in the main descaler and went through the normal processing route of the hot strip mill at ArcelorMittal, South Africa, Vanderbijlpark. The descaling pressure was above 140bar.

Using the Parsytec system, an automatic surface inspection system, situated at the exit side of the finishing mill, the surface of these coils was inspected and the percentage coverage with red oxide scale was determined.

Figure 6 is an image of the coil surface when slabs were descaled at a surface temperature below 1177°C. The fayalite solidified before hydraulic descaling, trapping the iron oxide in it. Therefore red oxide scale was observed on the coil surface.

Figure 7 is an image of the coil surface when slabs were descaled at a surface temperature above 1177°C. The image shows that little to no red oxide scale could be seen. Descaling was done when fayalite was still in the liquid phase and the hydraulic pressure washed it away. No subsequent red oxide scale was formed.

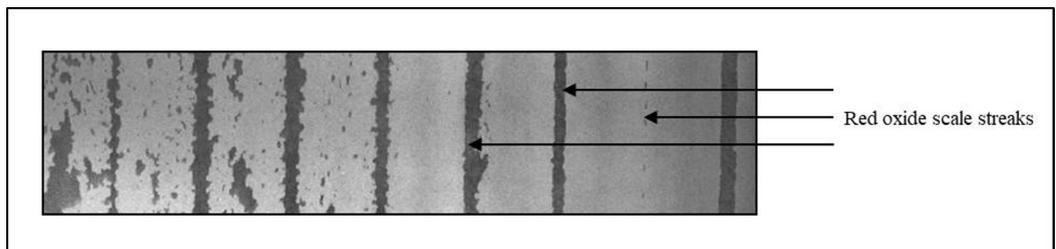


Fig. 6. Red oxide scale coverage when slab surface temperature was < 1177°C (magnification 1:4).

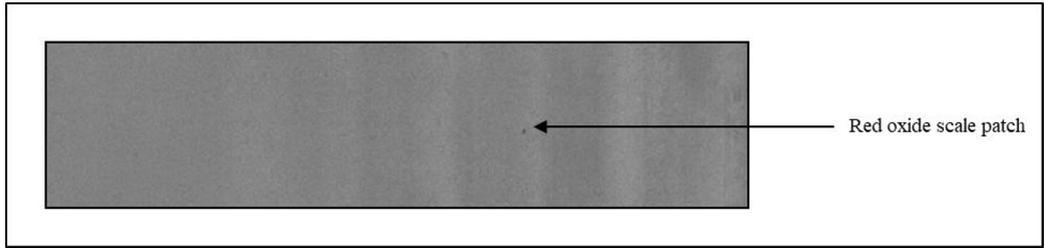


Fig. 7. Red oxide scale coverage when slab surface temperature was $> 1200^{\circ}\text{C}$ (magnification 1:4).

Table 1 contains the data obtained during the industrial trial. The width of the material was 1950mm and the thickness of the final coil varied between 10 and 12mm.

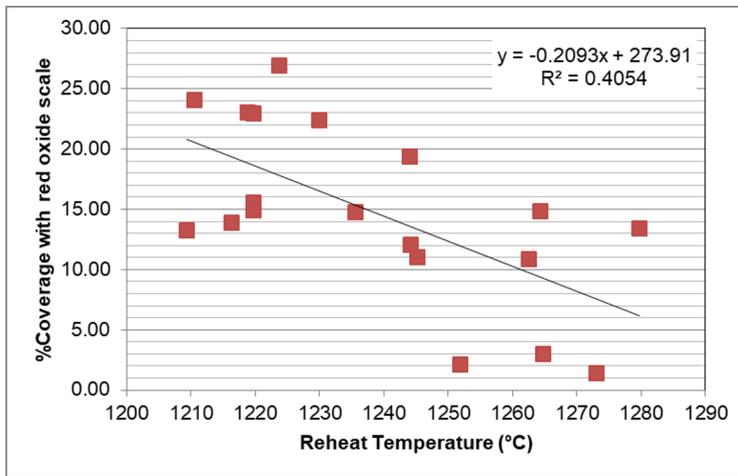
Table 1. Data obtained during the industrial trial.

Coil Number	Reheat Temperature ($^{\circ}\text{C}$)	RM Exit Temperature ($^{\circ}\text{C}$)	%Coverage (total)	%Coverage front end (50m)
1	1229.96	1082.84	73.14	22.39
2	1219.68	1080.21	38.74	15.59
3	1245.18	1116.65	30.64	10.99
4	1210.62	1078.3	63.37	24.05
5	1209.42	1080.55	54.78	13.24
6	1216.34	1072.98	58.84	13.88
7	1251.84	1123.7	46.00	2.14
8	1218.88	1081.12	61.79	23.07
9	1219.78	1076.09	49.79	22.92
10	1264.76	1131.5	48.69	2.97
11	1223.76	1082.91	86.86	26.95
12	1219.76	1091.53	55.84	14.96
13	1264.35	1126.18	82.54	14.80
14	1235.63	1090.78	57.98	14.74
15	1244.23	1099.83	64.23	12.10
16	1273.14	1143.66	47.74	1.39
17	1262.64	1090.51	34.54	10.86
18	1244	1091.44	55.74	19.41
19	1279.7	1126.45	70.59	13.44

When looking at the red oxide scale %-coverage for the full length of the coil, no correlation could be seen. But when only the first 50m of the coil was inspected, a clearer dependency could be observed. This is because the slab starts to cool down immediately after being extracted from the furnace, over the whole length. Therefore, the front end of the slab will be at a higher temperature when descaled, compared to the tail end of the slab.

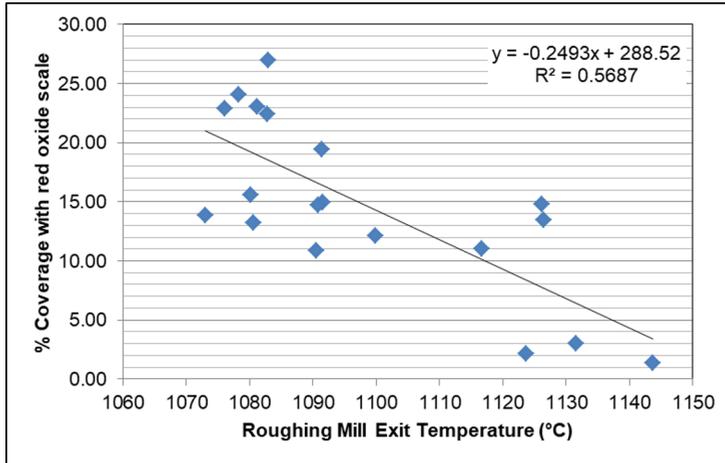
Although it might be true that the front end was descaled at a temperature $> 1177^{\circ}\text{C}$, the tail end might have been colder and the fayalite solidified by the time of descaling. Hence it was decided to only look at %-coverage of the first 50m.

Graph 1 shows the relationship between reheat temperature and %-coverage of the front end with red oxide scale. From the graph, it can be seen that the relationship is poor with the R^2 value (0.40). Although this would not have been a meaningful relationship if theoretical or laboratory results were analysed, when analysing industrial data collected in a non-ideal environment, the relationship is deemed strong.



Graph 1. Red oxide scale %-coverage as a function of reheat temperature.

Graph 2 shows the relationship between the roughing mill exit temperature and %-coverage of the front end with red oxide scale. The dependency of %-coverage on the roughing mill exit temperature is 0.57, which is relatively strong when considering industrial results.



Graph 2. Red oxide scale %-coverage as a function of roughing mill exit temperature.

Although %-coverage with red oxide scale shows a relatively strong dependency on roughing mill exit temperature and reheat temperature, there are other factors to consider. Literature suggests that %-coverage with red oxide scale has also a strong dependency on chemistry combined with the slab surface temperature [9]. The next step will be to investigate the influence of chemistry on the %-coverage over the whole length of the coil, using advanced statistics and data processing techniques.

5 Conclusion

Industrial trials were executed where the slab surface temperature at descaling in the primary descaler was varied between 1150 and 1260°C, even on the surface areas where the nozzle spray patterns overlap, and the following conclusions can be made:

- The red oxide %-coverage was found to be more dependent on the roughing mill exit temperature than the slab reheat temperature.
- When descaling was executed at a slab surface temperature higher than the melting point of fayalite (1177°C), the liquid fayalite was washed away by the high hydraulic water pressure and that reduced the fayalite %-coverage to levels as low as 0%.

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