Study on Red-Scale of Low-Carbon Wire Rod Surface

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Abstract

It is easy to generate "red scale" on the surface of low-carbon wire rods(e.g. low-carbon cold heading steel SWRCH22A) after hot rolling and laying. This paper research the mechanism of "red scale" generation by adjusting the technological parameters such as heating temperature、control rolling and cooling parameters,etc. The degree of red scale is reduced by setting low heating temperature、less on-line cooling water and higher cooling rate .

Keywords

Wire rod; iron oxide scale; red scale; low-carbon wire rod; controlled rolling and cooling.

1. Introduction

During steel hot rollingl, the scale is reformed on the surface of steel which is gray or steel-gray colored.Usually the scale was composed of FeO, Fe2O3, Fe3O4 in different proportions. So it is in wire rod production. However, under certain conditions, the oxide scale was red which is usually called red scale on the surface of wire rods[1,2].Especially for low-carbon steel, the problem is particularly prominent.

Red scale not only affects the image of wire rods, but it is particularly detrimental to subsequent operations, especially for drawing process.The surface red scale is not conducive to the effect of pickling and phosphating in drawing process, and increased breaking appearance and abrasion during drawing process.It also have the varying degree influence to the fatigue property of steel wire. Then again ,for low-carbon cold heading steel, as uncleanness after pickling and phosphating lead to stick the mold and so on. At present, there are a little research on red scale in domestic industry [3-6].

Now, the layout of the high-speed wire rod line is similar. This paper analyses the influencing factors that have lead to red scale appears by using the technology in practice.The process layout as follows: reheating (160 billet) — rough mill (120mm) — shear — middle mill — shear — pre-finishing rolling — water box — finishing mill — water box — reducing and sizing mill — water box— laying — air-cooling conveyor — vertical collecting system.

2. Red scale mechanism analysis of Low-carbon wire rod surface

2.1 Analysis of influencing factors

Low-carbon cold heading wire rod (e.g. SWRCH22A), low-carbon wire rod for drawing (e.g. SAE1008) or less alloy welding wire (e.g. ER70S-G) and other require slow cooling technology are extremely vulnerable to red scale. The mechanism is more complex, involving high temperature oxidation corrosion and high temperature electrochemical corrosion and other fields[7,8,9].By case study, the main influencing factors of this issue are heating process, on-line rolling temperature and cooling rate after rolling, etc., especially when the heating temperature of billet is high enough, and in order to satisfy the temperature requirement of rolling technology , large amounts of water are used to cool the rolling pieces on line, it lead to form great temperature gradient of products across the board, the red scale defects is more significant. Therefore, in the early stage, by increasing the rolling temperature, reducing the amount of water in the tank to control the red scale. But large amounts of Widmanstatten structure were found after heating and spinning in high temperature, then affect the deformation performance of cold heading.The solution to this problem: Firstly, to reduce the heating temperature as far as possible and both ensure heating and rolling process. Secondly, open the hood insulation cover to reduce the surface temperature of the rolled piece(ie, reducing the rolling temperature gradients). Thirdly, under satisfying the technology characteristic, reduce the red scale by increasing the cooling rate.

2.2 Process practice

According to the actual surface of low-carbon wire rod, we set grades of the red scale, that is A\B\C\D. Grade A stands for no red scale, Grade B stands for slightly rust which can be erased, Grade C represents moderate rust, Grade D represents severe red scale, and the color is black. Compareing red scale samples by XRD, the Grade and the compositions in weight percent are presented in table 1.

Table 1 Compositions of different grades red scale

Red scale rade	Fe2O3,%	Fe3O4,%	FeO,%
A	7.7	5.2	87.1
B	9.2	4.8	85.9
C	12.2	8.7	79.1
D	13.3	12.4	74.3

As can be seen from the table 1, no rust or slight rust, that is, A, B grade. The proportion of FeO in iron sheet is more than 85%, with the increase of red scale state, the proportion of FeO reduce, and Fe2O3 and Fe3O4 increase, especially in the D grade, iron sheet appears reddish black.

As an example of low-carbon cold heading steel, this paper study the influence of red scale through setting different technical parameters,separately from the heating process, control rolling and cooling and other aspects to illustrate the differents of the red scale on wire rod surface. SWRCH22A conventional production parameters are shown in Table 2 .

Table 2 Control rolling and cooling parameters for Ø6.5mm SWRCH22A

Steel rade	Diameter /mm	Heating zone	Finishing temperature	Diameter-reducing temperature	Laying temperature	Finished rolling speed	Cooling state	Red scale grade
SWRCH22A	Ø6.5	1100℃	930℃	920℃	910℃	105m/s	Slow cooling	D

A. Heating

Taking cold heading steel SWRCH22A as an example, testing at different heating temperatures, and the parameters in Table 3.

Table 3 Comparison of red scale levels on surface of Ø6.5mm SWRCH22A wire rods at different heating temperatures

Steel grade	Diameter/mm	Process	Heating zone/℃	Red scale grade	Comment
SWRCH22A	Ø6.5	1	1100	D	Conventional process
		2	1070	C	Cooling
		3	1030	B	Cooling

As can be seen from table 1, with the heating temperature decreases, 22A surface red scale significantly reduced from grade D to B. By combining actual process, after cooling and with constant rolling temperature, the amount of cooling water reduction by 40%, the total temperature gradient of wire rod slow.

B. Rolling temperature

From Table 4, by reducing the rolling temperature at each process point, the amount of cooling water under constant, the temperature gradient of the wire rod increases, the red scale level changes from B to D. It is worth mentioning that, although the red scale level is low at high rolling temperature but it's easy to form a coarse Widmanstatten structure in low-carbon steel, then affect the cold deformation capacity. And Widmannstatten structure as shown in Figure 1.

Table 4 Comparison of red scale levels under different conditions

Steel grade	Diameter /mm	Process	Finishing temperature/℃	Diameter -reducing temperature/℃	Laying temperature /℃	Red scale grade	Comment
SWRCH22A	Ø6.5	4	950	940	940	B	
		5	920	900	900	C	Conventional process
		6	890	850	840	D	

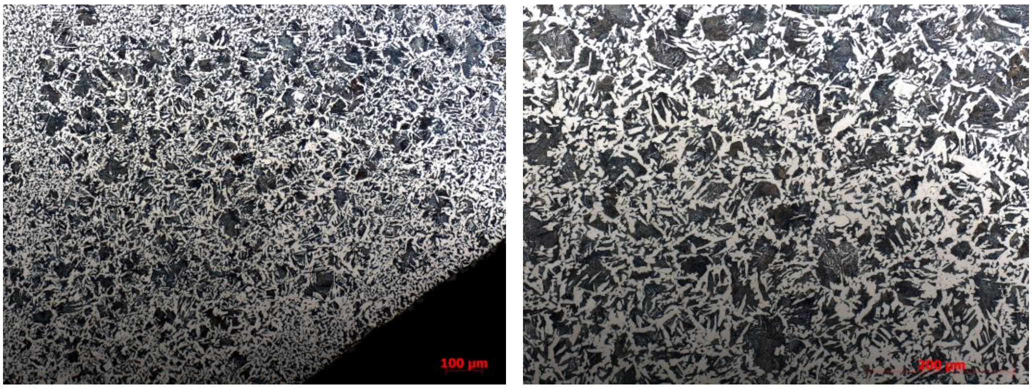

Fig.1 Widmanstatten structure micrograph of Low-carbon steel

C. Controlled cooling technology

Table 5 shows that the cooling process also contribute to the red scale. Under typical process, after air-cooled, the red scale level is B, but under conventional cooling case in slow the red scale is serious. While the speed of fan reach to limits, the air-cooled speed of Ø6.5mm wire rod can reach to 18°C/s, and in conventional condition, the air-cooled speed can reach to 5.5°C/s. If add insulating cover, the speed at 1.5°C/s. Thus the higher cooling speed , the lower red scale grade.

Table 5 Comparison of red scale on the surface of Ø6.5mm SWRCH22A wire rod under different controlled cooling conditions

Steel grade	Diameter/mm	Process	Cooling process	Diameter -reducing temperature/℃	Cooling rate, ℃/s	Red scale grade	Comment
SWRCH22A	Ø6.5	7	Air-cooled	900	18	B	
		8	Air-cool		5.5	C	
		9	Slow cooling		＜1.5	D	Conventional process

3. Theoretical analysis

The metal oxidation process is the heterogeneous reaction between gas and solid phases. The growth of the iron oxide scale thicken gradually, and the process involves high-temperature corrosion and electrochemical fields. Generally, the formation of the iron oxide layer has two phases: the phase of initial forming and the phase of thickening gradually. In the oxidizing environment, the growth rate of the primary film is extremely high, and form a very thin oxide film(FeO, about 20~25 Å thickness) rapidly. With growth and thicken, the oxidation rate is controlled by the stable diffusion of Fe and O atoms in the oxide film, this process conforms to Wagner's theory[10]. The specific process is: ①O_2 is close to the surface of the oxide film and adsorbed; ②The adsorbed O_2 decomposes to O atoms [O(ad)]; ③[O(ad)] gets electrons (e^-) from oxide film then changes into chemisorption [O^{2-}(chem)] and continues to diffuse; ④Finally, [O^{2-} (chem)] enters the crystal lattice and forms FeO with Fe^{2+}.

$$\frac{1}{2}\mathrm{O}_2(g) \to \frac{1}{2}\mathrm{O}_2(ad) \to \mathrm{O}(ad) \to \mathrm{O}^{2-}(chem) \to FeO \qquad (1)$$

Where: ‘g’ is gas state; ‘ad’ is absorbed state; ‘chem’ is chemical state.

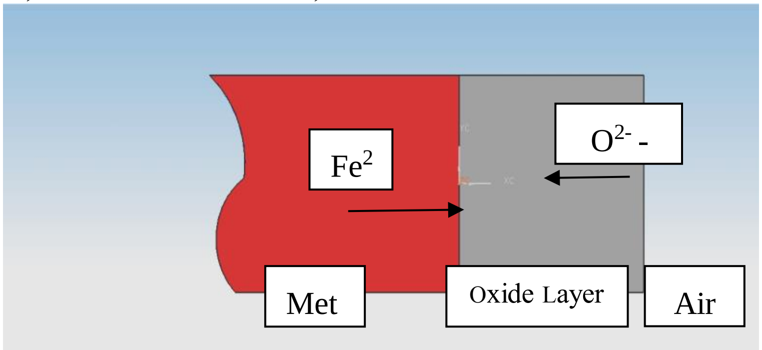

Fig.2 The process of metal oxydation

Therefore, two important processes are the diffusion of Fe^{2+} into FeO, and the dissolution of O_2 and other corrosive media into FeO. In addition, the dissolved amount of O is influenced by the thickness of FeO, the thickness of FeO is affected by the diffusion of Fe^{2+}, and the diffusion of Fe^{2+} is affected by the temperature.

Through the above mentioned process parameters, we can see that the size of the blank increases, and for meet the hourly output meanwhile, the total furnace time of the billet is limited. In order to compensate for the lack of heating, a method of increasing the heating temperature is usually adopted. Therefore, FeO rapidly grows again after descaling the billet, due to the higher overall billet temperature, the heat will continuously spread from the heart to the surface, cause heat accumulation on the surface of the billet, which can lead to the surface in a high temperature for a relatively long time. At high temperatures, the ionization and adsorption rates of O_2 and H_2O are in high performance, and the amount of them dissolved in iron oxide, the red scale phenomenon is serious. To this, the influence of seasonal factors is more obvious. In winter ,the heat of billet exchange quickly on the surface in a high temperature section, heat accumulate less, and the increase capacity of surface temperature is limited. That is, the heat is dissipated into the space instead of being used to generate the iron oxide skin.

In addition, the billet temperature is higher, in order to ensure the requirements of the rolling temperature, the amount of on-line cooling water is large. H_2O is in direct contact with the red steel, and similar to O_2 adsorption in FeO, H_2O adsorption is in the form of OH^-, and OH^- react with Fe^{2+} to form $Fe(OH)_2$, then further decomposed into Fe_2O_3. In addition, the formation of red scale takes also a certain amount of time, diffusion of Fe^{2+}, adsorption of O_2 on the oxide film surface, dissolution, inward diffusion, and further oxidation of FeO, etc., each part requires a certain time to produce.

$$\mathrm{H_2O}(l) \to \mathrm{H}^+(ad) + OH^-(ad) \to FeO \qquad (2)$$

Where:*l* is liquid.

The formation of red scale need some time, temperature, and environmental factors. In addition, the quality of online cooling water also can’t be ignored. The water contains a variety of ions, which can enhance the conductivity and accelerate the adsorption and dissolution of H_2O in oxidation process. Therefore, the conductivity of online cooling water should be reduced efficiently.

4. Conclusion

This paper analyzes and studies the formation of red scale on the surface of low-carbon steel wire rod after rolling. The main results are as follows:

(1)Reduce the billet heating temperature, can reduce the levels of red scale;

(2)Lowering the rolling temperature and increasing the amount of on-line cooling water can increase the levels of red scale;

(3)Improving the cooling rate of wire rod after spinning can reduce red scale levels;

(4)Under the different conditions of rolling and cooling, a large amount of oxidation factors O- and OH- are dissolved in the scales, then formed the red scale easily.

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