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JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2014, 21(12): 1065-1072

Growth Rate, Microstructure and Phase Composition of Oxide Scales for Three Typical Steels in Simulated Continuous Casting Process

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Abstract: Growth rate, microstructure and phase composition of scale layer formed during oxidation in 56% H_2O-9% O_2-N_2 and following continuous cooling in ambient air were experimentally investigated by means of optical microscopy, scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS) and X-ray diffraction (XRD) for 45, 20CrMnTi and TTS443M steels respectively, to examine the effects of strand surface temperature and steel composition on the scale formation in simulated continuous casting process. The growth rates were found to be approximately parabolic and the calculated activation energy of TTS443M steel is much higher than those of the two other steels. For 45 and 20CrMnTi steels, the scale layers were looser and a distinct gap formed at the scale-substrate interface at higher strand surface temperature. The dominant phases within the scale were iron oxides except for $FeO \cdot Cr_2O_3$ phase simultaneously existing in the oxide scale of 20CrMnTi steel. On the other hand, the scale layer formed on TTS443M steel was compact and tightly attached to the steel surface. At both lower and higher strand surface temperature, iron oxide was main phase in external layer of the scale, while chromia was dominant in inner layer with an appreciable Cr enrichment.

Key words: oxide scale; growth rate; microstructure; phase composition; continuous casting

Scale formation on the slab surface as a result of steel oxidation below the mold is a significant disturbance factor during continuous casting process. First of all, the yield loss of iron is considerable due to scale formation and descaling in continuous casting and the derived loss of iron mass is about 0.7 to 7 kg/m^2, which is particularly pronounced in the thin slab casting for the larger specific surface[1]. Secondly, the surface quality is frequently impaired, such as scale pits, scale adherence and surface hot shortness caused by subscale enrichment of residual elements[2-4]. Additionally, lower thermal conductivity of scale layer is assumed to change the heat transfer between strand surface and environment within secondary cooling and air cooling zones, which increases the difficulty of accurate determination of secondary cooling intensity and surface temperature of the slab[5-8].

In the previous studies, more investigations on the scale formation and descaling during reheating and hot rolling of hot rolled steel products have been carried out, including the effects of heating and rolling temperature on the thickness and microstructure of scale layer, the effects of heating time, furnace atmosphere, cooling mode, and steel composition on the scale formation[9-15], and thus more effective measures and technology have been adopted to control the scale of hot rolled steel. On the other hand, very less research work regarding the scale formation in continuous casting was done and systematic investigations are lacking. Hardly any specific efforts and countermeasures are taken as yet.

In continuous casting, oxide scale is formed at higher temperature in moist air within secondary cooling zone and consecutively at lower temperature in ambient air within air cooling zone. Besides the effects of different atmospheric conditions in the areas of secondary cooling and strand discharge respec-

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Foundation Item: Item Sponsored by National Natural Science Foundation of China (51174052, 51174049, 51374062, 51374057); Fundamental Research Funds for the Central Universities of China (110402009)

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tively, the scale formation is assumed to mainly depend on variations in strand surface temperature and the corresponding holding time. Accordingly, scale growth and its microstructure at different strand surface temperatures are important issues to reveal a clear feature of oxide scale formed in continuous casting, and furthermore, scale composition is also desired to improve awareness of the interrelationship between scale formation and heat transfer in secondary cooling and air cooling zones[16-20].

In the present work, growth rate, microstructure and phase composition of the oxide scale formed during oxidation with moist air and following continuous cooling in ambient air, i. e. , under the condition of simulated continuous casting process, were investigated experimentally for three typical steels, attempting to examine the effects of strand surface temperature and steel composition on the scale formation in continuous casting.

1 Experimental

Three typical steels with the chemical compositions listed in Table 1, i. e. , 45 carbon steel, 20CrMnTi gear steel, and TTS443M ferritic stainless steel, were used to study the scale formation in simulated continuous casting process. 45 and 20CrMnTi steels were selected to compare the difference of microstructure and phase composition of oxide scale between unalloyed and low-alloyed steels, while TTS443M was selected to reveal the influence of Cr content on the growth rate and phase composition of scale layer. The wide surface of slab cast were firstly cut into pieces in rectangular shape with the dimensions of 10 mm×10 mm×5 mm, and the original surface oxide scale formed during casting process was removed using SiC abrasion paper and cleaned ultrasonically in ethanol. In order to evaluate the effects of different strand surface temperatures in secondary cooling zone on scale formation, the oxidation experiment was designed to be composed of initial oxidation in moist air for specific temperature and time, and following continuous cooling in ambient air. The initial oxidation in moist air was carried out inside a horizontal tube furnace. The specimen was firstly put into a crucible boat which was placed in the thermal stability zone of the tube furnace, and then was oxidized at the desired temperature for a certain time under the gas condition of 56% H_2O-9% O_2-N_2. Subsequently, the sample was rapidly taken out of the furnace and continuously cooled in ambient air. The flow rates of O_2 and N_2 were both controlled by the mass flow controller while H_2O vapor was generated by bubbling O_2-N_2 gas mixtures through a distilled water bath maintained at 85 ℃. The experiment conditions are shown in Table 2. Three initial oxidation temperatures representing different strand surface temperatures are typified by 1200, 1100 and 1000 ℃ respectively, and the holding time was chosen to obtain a certain thickness of scale layer to ensure a higher quality of microstructure illustration.

Table 1 Chemical composition of steels used in the experiment mass%

Steel	C	Si	Mn	P	S	Ni	Cr	Ti	Al	Cu
45	0.45	0.22	0.57	0.018	0.008	0.04	0.08	0.003	0.012	0.02
20CrMnTi	0.18	0.26	0.88	0.014	0.005	0.04	1.12	0.040	0.015	0.10
TTS443M	0.0075	0.39	0.07	0.012	0.001	0.11	20.61	0.220	0.026	—

Table 2 Experimental condition for scale formation

Oxidation step	Temperature/℃	Atmosphere	Time/s
Initial oxidation	1000—1200	56%H_2O-9%O_2-N_2	900—3600
Consecutively continuous cooling	Room temperature	Ambient air	—

The growth kinetics of the scales formed under different oxidation conditions were established by measuring the thickness of scale layer versus time by using the optical microscopy. The microstructure and composition of scale layer were examined by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) along the cross section of scale layer. In some cases, X-ray powder diffraction (XRD) analysis was used to confirm the phase identification in oxide scale suggested by the EDS analysis.

2 Results and Discussion

2.1 Growth rate of oxide scale

Figs. 1, 2 and 3 illustrate the growth rates of oxide