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Influence of Protective Coating at High Temperature on Surface Quality of Stainless Steel

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Abstract: A ceramic matrix coating for minimizing steel loss of stainless steel at high temperatures was prepared by handled air-spraying technique, and the influence of coating on surface quality of stainless steel was mainly investigated in laboratory. Experimental results showed that the protective coating reduced the oxidation of stainless steel by more than 91% and minimized high-temperature scaling and also enhanced steel surface quality. The scales of coated specimen were removed completely and the scales of uncoated specimen were partly residual on the surface after cooling process. Mn-rich and Fe-rich zones were found in the oxides. The Cr_2O_3 found in scales came from the underlying stainless steel and formed a Cr-rich layer along the spalled surface.

Key words: protective coating; oxidation loss; surface quality; stainless steel

The oxide film grows inevitably on top of the free surfaces of alloys during the heating operation for hot rolling of stainless steel as well as in other hot working operations, which is usually at temperature above 1 200 ℃ in an oxidizing atmosphere for a few hours. Thick multilayer oxide scales would cause metal loss ranging from 1% to 2% of the crude stainless steel, and negatively impact the surface quality of the downstream products[1-3]. Thus, there is considerable motivation to avoid or slow down as much as possible the high-temperature oxidation process. Inorganic coating attracts lots of attention for protecting metals from oxidation at high temperatures[4-7]. A simple and low-cost spraying technique is an excellent method to manufacture protective coating. The coating should be easily removed after slab reheating process, because any residual coating may affect the steel surface quality seriously.

Some works have been devoted to the removal of oxide scales and the transfer of trace elements on the surface of stainless steel. Genève et al.[8] presented a study of the descaling ability of different steels. The results show that it is possible to qualitatively predict the adhesion capacity of the scale depending on the composition of alloy and on the mechanical and oxidation conditions during the hot rolling stage. Zhou et al.[9] prepared a high temperature MgO protective coating on $20Cr_2Ni_4A$ low alloy steel by slurry spraying technique and investigated the descaling ability of scale. The results show that Si-rich layer, which exists at the interface of scale and substrate, is strongly adhered to the steel, and results in bad descaling ability, is reduced by the coating. Yu et al.[10] simulated the behavior of spherical non-metallic inclusions in type 304 stainless steel strips during multi-pass cold rolling by 3D finite element method and updating geometric method. Unlu et al.[11] introduced the neutron depth profiling (NDP) method to measure nondestructively the concentration versus depth distributions of several isotopes of technological importance in any substrate. However, studies on coating used for slab reheating of stainless

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steel and the influences of protective coating at high temperature on surface quality are very limited.

Based on previous researches in laboratory, Liu et al.[4] prepared a glass coating onto AISI 304 stainless steel by a slurry-spraying technique and discussed its effects on oxidation behavior of this steel at 1250 ℃ in air. In the present study, a ceramic matrix coating for minimizing steel loss of stainless steel at high temperatures was prepared by low-cost and easily handled air-spraying technique, and the influence of coating on surface quality of stainless steel is mainly investigated in laboratory.

1 Experimental

1.1 Coating preparation

Table 1 shows the composition of the ceramic coating used in this study. The coating composition was selected based on the softening point, linear coefficient of thermal expansion (CTE) and reactivity with stainless steel by trial and error. The raw materials came from natural minerals which mainly included silica, bauxite and magnesite, and so on. Mixtures of the required raw material were ball-milled with water for about 12 h, using ZrO_2 balls as milling media, to make thick and sprayable coating slurry. The steel specimens were cut into cuboids of 50 mm×50 mm×5 mm from cold-rolled plates and the surfaces were polished to 300 grit on silicon carbide papers, then cleaned with ethyl alcohol in an ultrasonic bath, and dried. In order to simulate practical conditions in the slab reheating, steel specimens were pre-heated to about 500 ℃ in a muffle furnace, and then the coating slurry was air-sprayed on the hot specimen surfaces to the required thickness (1 mm). The coating can reduce the metal loss dramatically during heating process.

Table 1 Chemical composition of ceramic coating

(mass percent, %)

SiO_2	Al_2O_3	NaO_2	ZnO	B_2O_3	MgO	Fe_2O_3
65—70	10—15	5—10	1—4	1—4	1—4	1—2

Steel loss measurement was performed in a muffle furnace. The specimen mass was recorded before heating and after descaling, and determined by the following equation

$$\delta=\frac{M_1-M_2}{M_1}\times 100\% \quad (1)$$

where, M_1 and M_2 are specimen mass before heating and after descaling; δ is steel loss due to high-temperature scaling. Higher δ means better oxidation resistance.

1.2 Evaluation of surface quality

The descaling ability was evaluated by the area fraction of the remaining oxide scale after compression test at high temperature. The area fraction was calculated by computer aided image analysis. The surface morphologies and structures of coating and cross section of the steel specimens after oxidation were characterized by using scanning electron microscopy (SEM) (JSM-6700F, JEOL, Japan) equipped with an energy dispersive X-ray spectroscopy (EDX) (NORAN, Thermo Fisher, USA) and X-ray diffractometry (XRD) (X′ Pert Pro, Philips, The Netherlands).

2 Results and Discussion

2.1 Oxidation loss

Oxidation loss is the direct parameter of protective effect of the coating and closely connected with the metal yield. Fig. 1 shows the steel loss of bare and coated specimens from 1150 to 1300 ℃ in air.

At 1150 ℃, the oxidation losses of bare specimen after holding for 3, 6 and 9 h are respectively 1.01%, 3.29%, and 7.35% and those of the coated specimen are 0.1%, 0.275%, and 0.31%. The steel loss percentage decreased by 91%, 92%, and 96% respectively according to calculation. At 1200 ℃, the corresponding value was 94%, 93%, and 94%. At 1250 ℃, the corresponding value was 93%, 95%, and 96%. At 1300 ℃, the corresponding value was 95%, 95%, and 94%. It is manifested that the oxidation loss increased with elevating temperature and holding time. The experimental results showed that the protective coating reduced the oxidation of stainless steel and the higher the temperature, the better the protective effect. Generally, the metal loss can be reduced by more than 91%.

2.2 Descaling ability of stainless steel

The oxide layers formed on stainless steels during cooling process. The descaling ability test was carried out after oxidizing at 1250 ℃ for 3 h in dry air. The cooling process of coated sample is shown in Fig. 2. Fig. 2(a) is the photo of the moment out of furnace. The coating on the surface assumes the liquid state at that moment. After 1 min, the coating turns into solid state with the decrease of temperature. At the same time, the scale starts to peel. The longer it lasts, the larger "area fraction removed"