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Analysis of Oxidation and Surface Characteristics in Hot Strip Rolling

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Deformation characteristics of the oxide scale in hot strip mill have not been quantified before and the principle of the effect of oxide scale deformation in the roll bite on strip surface roughness has not yet been revealed. In this paper, analysis of the thin secondary oxide scale formed in hot metal rolling and its surface roughness micro deformation is carried out by experiments and finite element analysis. Simulation results are compared with the measured values, which show that they are in close agreement. Surface roughness transfer during hot metal rolling is also discussed.

KEY WORDS: Oxidation; Oxide scale; Surface characteristics; Finite element method

1. Introduction

Oxidation of the rolled metal and deformation of the produced secondary oxide scale in hot strip mill have a significant influence on the surface finish and mechanical features of the deformed metal. It also affects lubrication and friction at the metal/tool interface during metal forming. In general, there is a layer of oxide scale on the surface of strip in hot strip rolling. Previous research on the morphology of the oxide scale layer shows that the scale on the steel surface contains three layers[1~3], named hematite (Fe_2O_3), magnetite (Fe_3O_4) and wustite (FeO) and it is confirmed by experiment even when the oxidation duration is less than 0.6 s[4]. The outer surface of the oxide scale is Fe_2O_3 and Fe_3O_4. Their fracture strains are still less than 0.2% at the temperature of 900°C. It is involved in high normal compressive stress from the work roll, tensile stress due to elongation of the steel and shear stress between the roll and bulk material in the roll bite. It is believed that the layer of oxide scale can act as a lubricant if it is thick and ductile, or as abrasive in the three-body wear mechanism if it is hard and brittle. In recent years, lubrication has been introduced into the production line of hot strip mill. The mixed circumstances in the roll bite make the interface of roll/bulk materials rather complicated and will result in changes of the required rolling forces, torques and power consumption, as well as overall roll wear and surface quality. The study on the mechanical and tribological characteristics of the oxide scale in hot strip rolling is of great interest in recent years[5~11]. Krzyzanowski and Beynon[8] conducted hot tension tests for producing scales of 10~300 μm in thickness and found a noticeable plastic deformation in the temperature range of 830~1150°C.

There are two surface roughness profiles in the hot strip. One is the oxide scale surface which contacts with the work rolls and the other is the oxide scale/steel interface which does not contact with the work rolls directly. Obviously, both surface roughness profiles[12] will be deformed in hot rolling process. This paper aims to investigate the deformation of the thin secondary oxide scale formed in hot metal rolling and the surface roughness transfer. Under rolling conditions, the surface asperity micro deformation of a secondary oxide scale occurs in hot finish rolling process. The secondary thin oxide scale is analysed using finite element software MSC-MARC package. The mechanics of the micro forming of oxide scale and surface roughness are obtained. Simulation results are compared with the measured values, which show that they are in close agreement. A model for the rolling of hot strip covering thin secondary oxide scale is obtained and the surface features with micro deformation are discussed.

2. Experimental

Hot rolling experiments have been carried out on a mild steel at temperatures from 850~1025°C in lab under lubrication by oil mist uniformly sprayed onto the roll surfaces or no lubrication. There is only one sample being heated in the furnace each time. After being soaked in the furnace for 5 min, the oxide scale of the sample was removed from surface by tapping on its surface. Before the sample moved into the roll bite, the secondary oxide scale was formed. Reduction was from 7.6 to 41.5%, rolling speed at 0.12 m/s. Then the samples were stored into a nitrogen-connected box for cooling directly after rolling. Rolling force and torque were collected with a Pentium III computer during the rolling test. The secondary oxide scale was selected from each rolled sample. The specimens were then mounted into cold resin and ground in a standard procedure after solidifying for 24 h as described in literature [3], so that the deformation behaviour of the oxide scale could be analysed. A Leico optical microscope was used to measure the oxide scale thickness.

A surface roughness meter was used to measure

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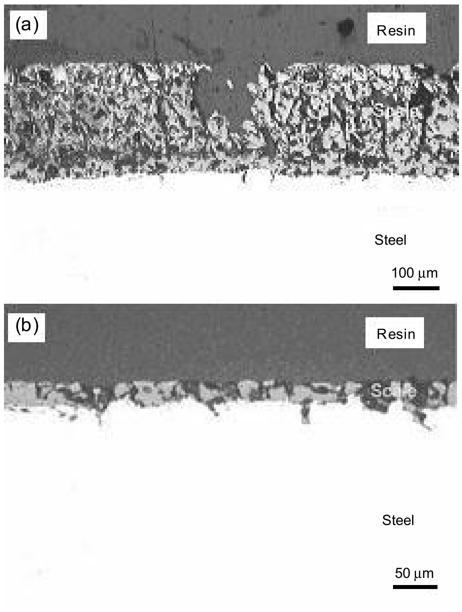

Fig.1 Thickness of primary (a) and secondary (b) oxide scales after rolling

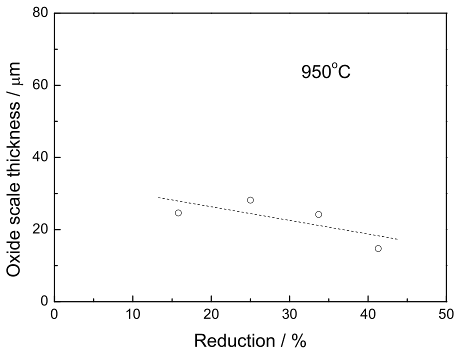

Fig.2 Effect of reduction on oxide scale thickness

the roughness transfer of the work roll for every 5 passes of rolling. The rolled strip surface roughness was measured by a Surtronic surface profilometer. Typical samples from the hot rolling test were selected for characterizing their topographic features by a Nanoscope IIIA atomic force microscope (AFM) from digital instrument. The digital nanoscope software version 5.12r3 was used to analyse the surface roughness characteristics of the tested samples.

2.1 Morphology of oxide scale after rolling

For bulk material reduction of 24.6%, rolling temperature of 900°C, rolling speed of 0.12 m/s, the metallography of the oxide scales is illustrated in Fig.1. The thickness of the primary oxide scale formed in furnace (1200°C) was 238.3 μm and the secondary oxide scale 25.5 μm. Comparing with the thickness of primary oxide scale, the secondary oxide scale is thin.

2.2 Oxide scale deformation

Figure 2 shows the effect of the reduction on deformation behaviour of the secondary oxide scale under oil-lubrication at temperature 950°C, the rolling speed is 0.12 m/s. It can be seen that the thickness of secondary oxide scale reduces linearly with reduction and it verifies the deformability of the oxide scale. This demonstrates the oxide scale to be likely able to perform extensive micro plastic deformation when hot rolling is carried out under oil-lubrication condition. This result also implies that the mechanical properties of the oxide scales[13] will be changed in hot rolling process, which will affect the quality of the produced products.

3. Finite Element Modelling

3.1 Two-layer model

Oxide scale has FeO, Fe_2O_3 and Fe_3O_4 layers, and FeO layer has most thickness of the whole scale layer[1]. For simplicity, the oxide scale layer is considered that it is just formed by FeO. Because the oxide scale layer is developed on the surface of fresh steel and the scale layer is thin, it is assumed that the thickness of oxide scale layer is uniform. Under this assumption, the surface profiles of the secondary oxide scale and strip should be the same. The measured real strip surface roughness by AFM is a random pattern as shown in Fig.3. Applying 2D random surface roughness generation model[12], a surface profile with random roughness can be generated. In order to be similar to the practical case, a two-layer model was developed as shown in Fig.4. The profile on the top of Fig.4 is a surface profile of the secondary oxide scale that contacts with the work roll and the second profile (down) is the interface of the thin secondary

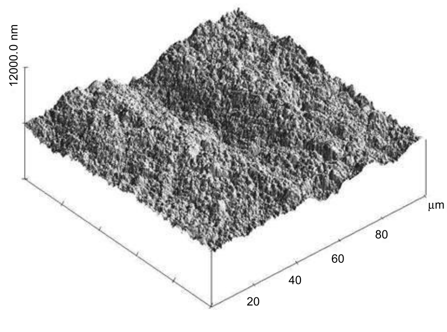

Fig.3 3D surface image of the strip at reduction 41.5%, rolling speed 0.12 m/s and temperature 900°C

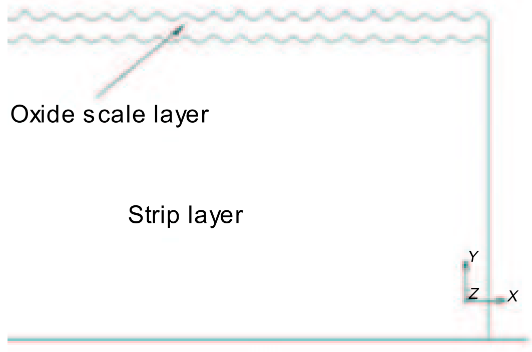

Fig.4 Two-layer surface roughness

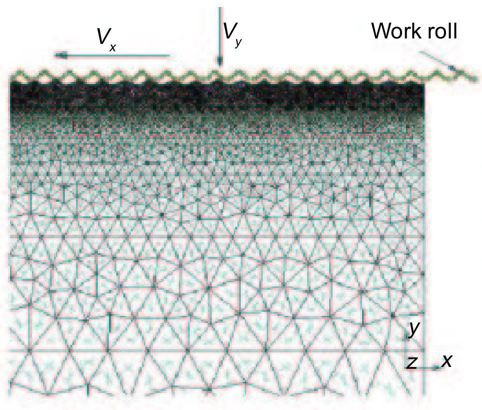

Fig.5 FE mesh with rough roll surface

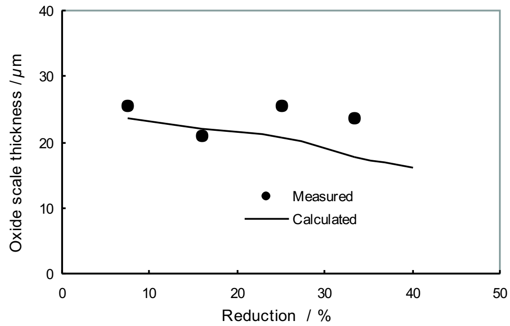

Fig.6 Comparison of the calculated values with measured values of oxide scale thickness

oxide scale and strip.

3.2 FE mesh

In hot strip rolling process, the strip width is much larger than its thickness. So the deformation along the width direction can be neglected, and the rolling is considered as a plane strain deformation process. As the work roll is harder than the hot strip, it is considered as a rigid body. The rolling process can be taken as a symmetrical system, only considering the upper half of the strip[14]. The finite element model for general rolling process including the secondary oxide scale layer and surface roughness with meshing is shown in Fig.5.

To explore the effect of the work roll surface roughness on the final surface roughness of the secondary oxide scale and strip, a random surface roughness was applied to the work roll surface in the simulation. Therefore, the FE model in Fig.5 has a random roll surface roughness. Starting roughly from the same initial strip surface roughness, the rolling process can be simulated with different work roll roughness[12].

4. Results

Based on the analysis of the developed finite element model, a simulation was carried out on a PC using software MSC-MARC package. The calculated surface roughness of the secondary oxide scale and

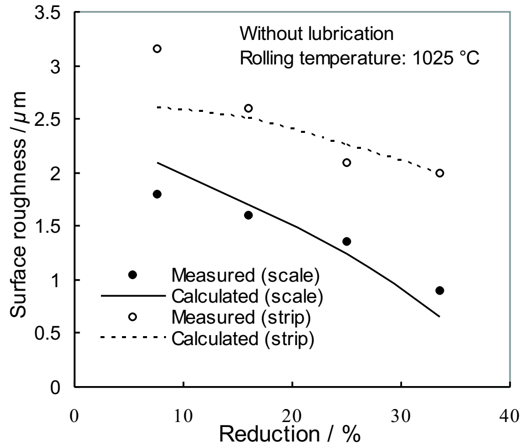

Fig.7 Effect of reduction on surface roughness

strip, and the micro-deformation of the oxide scale were obtained, which are compared with the measured values. Surface roughness of the secondary oxide scale and strip was measured by a Surtronic surface profilometer.

4.1 Oxide scale deformation

Simulation conditions are rolling temperature 950°C, rolling speed 0.12 m/s, oxide scale thickness 25.5 μm, work roll surface roughness 0.45 μm and without lubrication applied. Comparison of the calculated deformation of oxide scale thickness with measured values is shown in Fig.6. It can be seen that the thickness of oxide scale decreases with an increase of reduction, and the calculated results are fairly close to the measured values.

If the rolling conditions change, the simulation of the micro-deformation of the thin oxide scale is stable. Therefore, the developed finite element model is applicable for determining the deformation of the secondary oxide scale thickness in hot strip rolling.

4.2 Surface roughness transfer

For no oil lubrication, rolling temperature 1025°C and rolling speed 0.12 m/s, the effect of the reduction on the surface roughness of the secondary oxide scale and strip is shown in Fig.7. It can be seen that the oxide scale and strip surface roughness decreases with an increase of reduction, and the calculated surface roughness is close to the measured values. It can also be seen that the strip surface roughness is larger than that of the oxide scale.

4.3 Rolling speed effect

Rolling speed has an influence on the oxide scale surface roughness as shown in Fig.8. It can be seen that the oxide scale surface roughness decreases when the rolling speed increases, and the oxide scale surface roughness decreases when the rolling temperature decreases, which implies that the mechanical properties of the oxide scales will be changed in hot rolling process, and the calculated roughness is fairly close to the measured value.

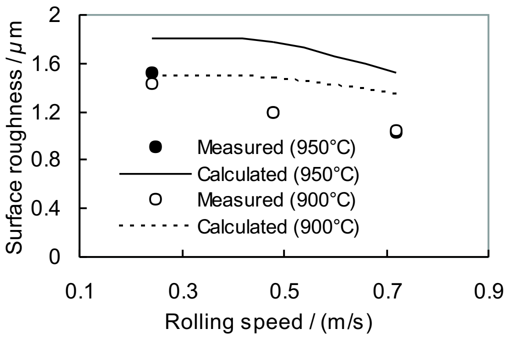

Fig.8 Effect of rolling speed on surface roughness

5. Conclusion

The mechanics of surface roughness transfer and micro-deformation of the thin secondary oxide scale formed in hot strip rolling have been analysed using finite element method. Surface roughness of the secondary oxide scale and strip decreases with bulk material reduction, and the oxide scale surface roughness decreases with a decrease of rolling temperature, which implies that the mechanical properties of the oxide scales change in hot strip rolling. The surface roughness reduces with an increase of rolling speed.

The thickness of the secondary oxide scale decreases with an increase of reduction. Simulation results show that the strip surface roughness can be reduced through rolling process and the calculated results are close to the measured values. Therefore, the developed finite element model is applicable for determining the deformation of secondary oxide scale in hot strip rolling and for predicting the mechanics of the surface roughness transfer of the oxide scale and strip.

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