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Full Length Article

Effect of water pressure and soaking time on the selective oxidation of DP980 advanced high strength steel

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ABSTRACT

Due to the limited heating power in non-oxidation furnace of continuous strip processing facilities of heating stage, selective oxidation with higher oxygen pressure is practically inevitable, which will greatly influence the quality of coating during immersion into the zinc bath. In this paper, the oxidation behaviors of DP980 advanced high strength steel are studied during annealing in a pure H_2 atmosphere with controlled water pressure ranging from 0.033 to 0.094 bar (P_{H2O}/P_{H2}) and soaking time from 30 s to 2 h. The oxidation proceeds as a combination of external formation of Mn oxides and internal formation of Mn_2SiO_4, $MnSiO_3$ and SiO_2 from the subsurface of the steel into the matrix. As the water pressure increases from 0.033 to 0.094 bar, it can be seen that the amount of oxide particles and coverage on the surface of the steel seems to decrease initially and increase afterwards. The sequence of oxides determined by oxygen partial pressure was calculated and illustrated using thermodynamics with alloys activity. Oxide growth mechanism during annealing and the effect of water pressure on the amount of oxide particles were also discussed.

1. Introduction

As concerns about environmental pollution and global warming escalate, the reduction of greenhouse gas emissions and energy consumption become increasingly important issues. Advanced high-strength steels (AHSS), e.g. dual phase, with a high strength-to-weight ratio, which allow thinner cross-sections for a given application, are ideal candidates for lightweight automobile applications. Traditionally, the corrosion resistance is of key importance and is mainly assured by hot-dip galvanizing [1–3].

When using conventional hot-dip galvanizing process parameters with the alloy compositions of the AHSS families, however, there can be problems with poor wetting between the liquid zinc and the surface of AHSS. This poor wetting is caused by surface segregation and oxidation of the alloying elements, such as Mn, Si, Al, Cr, i.e. And the formed oxides are not reduced by conventional atmospheres in continuous galvanizing [4]. As these oxide particles or films are not wetted by liquid zinc, the fraction of surface area covered by oxides is a key parameter that determines the quality of the resulting coating [5].

With varying compositions, the observed oxides are different from simple oxides like MnO, Al_2O_3 and SiO_2 to complex oxides like $MnSiO_3$, Mn_2SiO_4 and $MnAl_2O_4$, which all have been observed [4,6]. The presence of film forming surface oxides, in particular the amorphous ***a***-SiO2 oxides, leads to a deterioration of the wettability of the inter critically annealed strip by the molten Zn during the galvanizing process [7]. These oxides are also believed to act as barriers to the interdiffusion of Fe and Zn during the galvannealing process [8,9]. As these Mn-rich oxides do not form oxide films, they are less harmful to galvanizability than the film-forming Si-rich oxides. The reason is that the MnO reduction by Al in the Zn bath is thermodynamically possible, following the equation $3MnO(s) + 2[Al] \rightarrow Al_2O_3(s) + 3[Mn]$, and the thermodynamic driving force for the alumino-thermic reaction is higher than that for SiO_2 [10,11].

To identify ways to reduce surface oxides, many studies were carried out in various annealing conditions; such as the influence of oxygen partial pressure or H_2/N_2 ratio in atmosphere [12,13], Si/Mn ratio [14] or trace elements in steel compositions [15,16] *etc.* The method most relevant to this study is the promotion of internal oxidation over external oxidation. This transition can be induced by raising the dewpoint of the annealing furnace atmosphere [17–19]. Raising the atmospheric dewpoint increases the surface oxygen concentration and the flux of oxygen into the steel, promoting internal oxidation over external oxidation [20].

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Table 1
Chemical compositions of DP980 steels (mass pct).

	Mn	Si	Al	Cr	C	Mo	P	Fe
DP980	2.118	0.297	0.029	0.428	0.093	0.294	0.008	balance

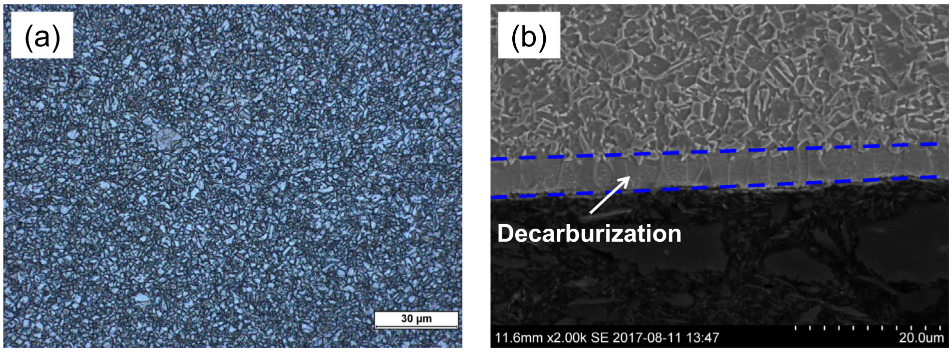

Fig. 1. Microstructure of DP980 steel after annealing at 810 °C with water vapor 0.033 bar: (a) LOM image of surface; (b) Second electron image of cross section.

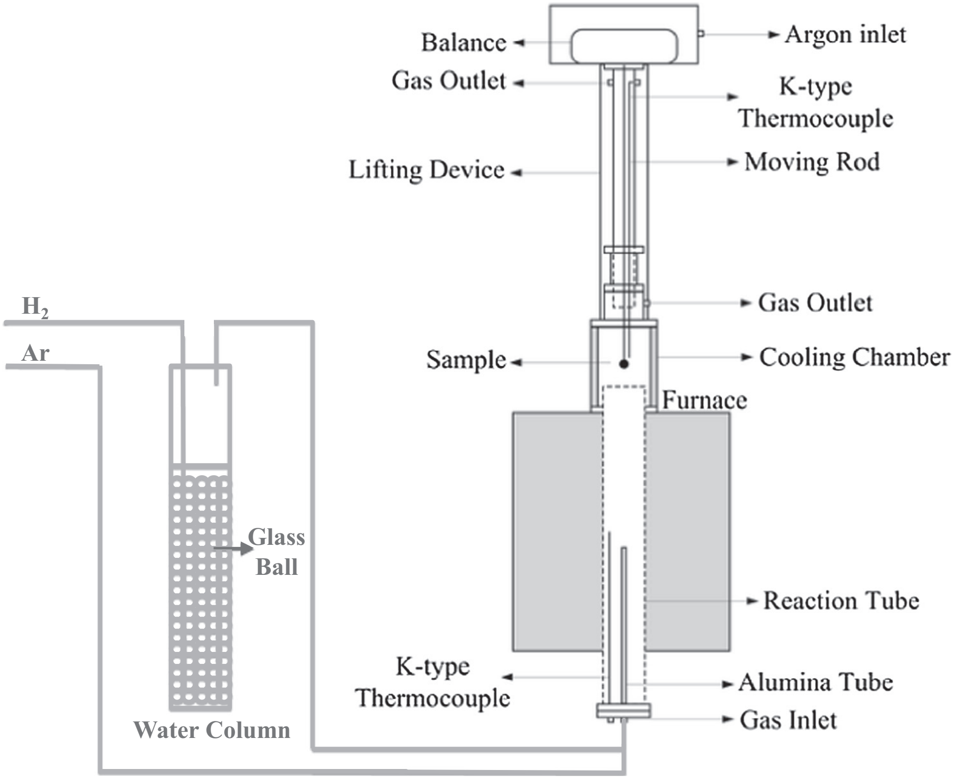

Fig. 2. Schematic illustration of experimental setup.

It is well known that the strip will pass through the first zone of the direct fired furnace or non-oxidation furnace and then slightly reducing atmosphere in the next zone that is commonly used [21]. Due to the limited heating power in continuous strip processing facilities of heating stage, selective oxidation in the ferritic or inter critical region with higher oxygen pressure is practically inevitable [22,23]. Consequently, it has to be taken into account when studying the selective oxidation during annealing process. Furthermore, although many references [14,23–25] have reported internal oxidation problems under high oxidation conditions, the evolution of oxides under these conditions is still poor understood.

The aims of the current study is to further investigate the oxide evolution on DP980 AHSS steel with different soaking times and further determining whether the oxidation is influenced by the high water pressure. Longer holding times were performed to collect a more completed set of kinetic data via internal oxidation depths and to better understand the mechanism of the oxide growth.

2. Experimental methods

Table 1 shows the chemical compositions of DP980 AHSS. Samples were cut, ground, and polished into pieces 20 × 15 × 0.8 (mm)