Al과 Al-1% Si 용융조에서 용융 도금된 탄소강의 경도, 산화 및 미세조직의 특성

Charactrerization of microstructure, hardness and oxidation behavior of carbon steels hot dipped in Al and Al-1% Si molten baths

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초 록: Medium carbon steel was aluminized by hot dipping into molten Al or Al-1%Si baths. After hot-dipping in these baths, a thin Al-rich topcoat and a thick alloy layer rich in Al_5Fe_2 formed on the surface. A small a mount of FeAl and Al_3Fe was incorporated in the alloy layer. Silicon from the Al-1%Si bath was uniformly distributed throughout the entire coating. The hot dipping increased the microhardness of the steel by about 8 times. Heating at 700-1000 °C however decreased the microhardness through interdiffusion between the coating and the substrate. The oxidation at 700-1000 °C in air formed a thin protective α-Al_2O_3 layer, which provided good oxidation resistance. Silicon was oxidized to amorphous silica, exhibiting a glassy oxide surface.

1. 서론

Aluminizing by hot dipping steels in molten aluminum baths is an effective and economical method to form diffusion coatings to improve the oxidation and corrosion resistance of steels. It is widely used in transportation, petrochemical, oceanographic and building industries. The liquid-solid reaction between molten aluminum and steel results in the formation of the Al-rich topcoat in the steel surface and the underlying Fe-Al alloy layer. Hot dip aluminizing with and without silicon addition has been applied for many steel substrates such as carbon steels, Cr-Mo steels, stainless steels, martensitic steel, high Si iron, and Fe-30%Mn-8%Al-0.8%C alloy. The thickness and morphology of aluminized layers are influenced by the dipping time, temperature and composition of the molten Al or Al alloy baths, fluxing, and the composition and surface roughness of the substrates. Hence, there are many processing parameters that affect the hot dip aluminizing. Until now, various, sometimes inconsistent metallurgical changes in the aluminized layers and the high temperature oxidation behavior of hot dip aluminized steels have been reported. The present research aims to investigate the microstructure, hardness, and high temperature oxidation properties of the carbon steel hot dipped in Al and Al-1%Si molten baths.

2. 본론

A medium carbon steel plate with a composition of Fe-0.44C-0.30Mn-0.25Si-0.019S-0.016P in wt.% was cut to a size of 80x30x3 mm^3 to be used as substrates for hot dipping. A hole was drilled at the top center of each specimen to hang the specimen with a steel wire. The substrates were cleaned ultrasonically in alcohol, immersed in 10 vol.% HCl solution to remove surface oxides, and subjected to the liquid flux treatment with 20 vol.% KCl+AlF_3 (in 4:1 weight ratio) solution in water. After drying, they were immersed in either pure Al or Al-1%Si molten baths, on top of which a solid flux (KCl+NaCl+AlF_3 in 2:2:1 weight ratio) was spread to protect the molten baths from oxidation. After dipping at 800 °C for 10 min, the specimens were pulled out at the speed of 20 cm·min^{-1}, and cooled to ambient temperature in air. The hot dipped specimens were further cleaned using 5 vol.% HNO_3 solution to remove any flux adhered on the aluminized surface. For the microstructural analysis, they were cut into small coupons, mounted in the epoxy, ground, and polished to 0.3 μm alumina emulsion. For oxidation tests, they were placed inside a furnace heated at temperatures of 700, 800, 900 and 1000 °C for 20 or 100 h in static air. The hot dipped and subsequently oxidized specimens were examined using a SEM equipped with EDS, XRD, and TEM equipped with an EDS. The microhardness of the aluminized layer was measured along the coating depth with a Vickers microhardness tester under an indentation load of 200 g for 5 s with 50 mm indentation interval.

Fig. 1 shows the SEM/XRD/EDS results of the Al hot dipped steel. The aluminized surface was relatively smooth and featureless (Fig. 1a). Fig. 1b indicates that the coating consisted primarily of Al, together with a small amount of AlFe , and Al_5Fe_2. Fig.1c indicates that the inner coating consisted primarily of Al_5Fe_2, together with a small amount of Al, AlFe and Al_3Fe. In Figs.1b and c, a small amount of the α-Al_2O_3 surface layer was also detected. In Figs.1d and e, three distinct regions can be identified: a thin Al topcoat (~16 mm-thick), a thick alloy layer that consisted of Fe-Al intermetallics (~240 mm-thick), and the Al-free steel substrate. The average composition of the Al top coat (spot ① in Figs. 1d and f) and the alloy layer (spot ② in Figs. 1d and f) was about 96%Al-4%Fe, and 72%Al-28%Fe, respectively (Fig. 1f). In brief, Figs. 1b to f indicate that the Al hot dipping resulted in the formation of a thin Al-rich topcoat, and a thick alloy layer rich in Al_5Fe_2. A small amount of FeAl and Al_3Fe was incorporated in the alloy layer. Depending on substrate materials and hot dipping conditions, the alloy layers that consisted primarily of Al_3Fe+Al_3Fe+Fe_2Al_5, Al_5Fe_2+$FeAl_2$, and Al_3Fe+Al_5Fe_2 were reported to form. On the other hand, the interface between the substrate and the alloy layer was highly irregular with peaks orientated towards the steel. This tongue-like morphology originated from the preferential growth of Al_5Fe_2 along the diffusion direction. Al_5Fe_2 has an orthorhombic structure with 30% of voids along the c-axis. Hence, diffusion occurs rapidly in Al_5Fe_2. The reason for the formation of the tongue-like morphology was attributed to the inward diffusion of Althrough Al_5Fe_2 to the Al_5Fe_2 / steel reaction front, or the outward diffusion of Fe from the substrate through the Al_5Fe_2 / steel reaction front into the Al_5Fe_2 phase, or the combination of these two reasons. Another possible reason maybe the atomic size mismatch between Al atomic radius;0.143nm) and Fe atomic radius;0.126nm).

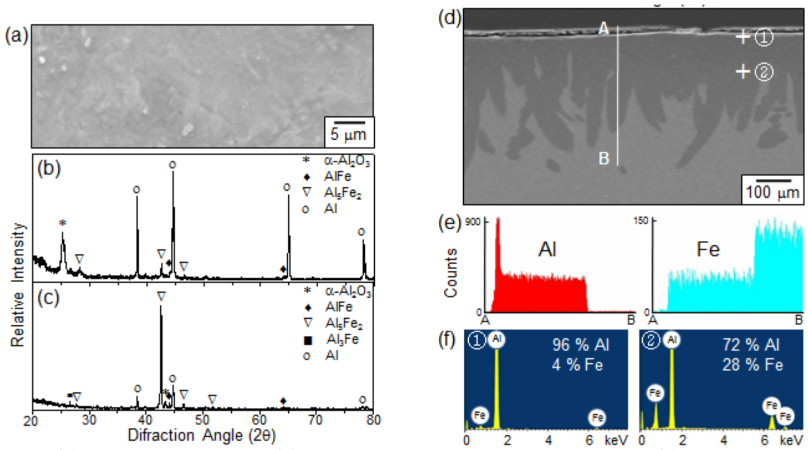

Fig. 1. Al hot dipped steel. (a) SEM top view, (b) XRD pattern before grinding, (c) XRD pattern after grinding off the outer coating layer, (d) cross-sectional SEM image, (e) EDS line profiles of Al and Fe, and (f) EDS spectra of the spot ① and ②.

3. 결론

The microstructure, microhardness, and high temperature oxidation behavior of carbon steel hot dipped in the molten Al and Al-1% Si bath were investigated. In case of hot dipping in the molten Al bath, the coating consisted primarily of a thin Al topcoat which contained a small amount of Fe, and an alloy layer that consisted of Al_5Fe_2 as the major phase and (FeAl, Al_3Fe) as minor ones. Hot dipping in the Al bath increased the microhardness by about 8 times. When oxidized at 700-1000 °C for 20-100 h, the Al topcoat oxidized to α-Al_2O_3, and the Al_5Fe_2-rich alloy layer transformed to the AlFe layer owing to the interdiffusion between the coating and the steel. In case of hot dipping in the molten Al-1% Si bath, the dissolution of Si in the entire coating occurred. Because of this, the Si addition was a little more effective in increasing the microhardness of the steel. However, the original microstructure, existing phases, the structural and compositional changes during oxidation, and the oxidation resistance were basically similar in both Al and Al-1% Si hot dipped steels.

감사의 글

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