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Characterization of coatings on grey cast iron fabricated by hot-dipping in AlSi11 alloy

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ABSTRACT

Purpose: In this study, grey cast iron was aluminized by hot-dip coating with AlSi11 alloy. The microstructure and chemical composition of the coatings were analyzed to determine the effect of the bath temperature on the thickness of the coating.

Design/methodology/approach: Flake graphite cast iron was aluminized by hot-dipping in AlSi11 alloy at 700°C or 750°C for 20 min. The microstructure and phase composition of the coatings were determined by means of an optical microscope and a scanning electron microscope with an EDS X-ray analyzer.

Findings: It was found that the overall thickness of a coating was dependent on the temperature of the bath. The coatings consisted of an outer layer with the composition similar to the aluminizing bath and an inner intermetallic layer and dispersed graphite. The outer layer was much thicker for coatings fabricated at a temperature of 750°C. The thickness of the inner layer was similar for both bath temperatures. The inner layer was composed of two zones: the Al_5Fe_2 phase, adjacent to the cast iron substrate and the Al_5FeSi phase, adjacent to the Al-Si outer layer. The interface between the layer of the Al_5Fe_2 intermetallic phases and the substrate showed flat morphology. The Al_5FeSi phase-outer layer interface was irregular.

Practical limitations/implications: The results obtained through the investigations show that the temperature of the Al-Si bath has influence on the overall thickness of the coating. The thickness of the outer layer increases with an increase in the bath temperature. The thickness of the inner layer, however, is not affected by the bath temperature.

Originality/value: Coatings produced by hot-dipping in pure aluminium are characterized by a microstructure with a relatively thick inner layer of intermetallic phases.

Keywords: Hot-dip aluminizing; Flake graphite cast iron; Intermetallic phases; Microstructure

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PROPERTIES

1. Introduction

Aluminizing is a process commonly used for ferrous alloys, as well as nickel-based alloys [1], copper [2,3], titanium [2] and magnesium [4,5] to improve their surface properties. The methods used to produce Al-enriched layers include pack aluminizing, thermal spray, vacuum aluminizing, gas aluminizing, cladding, electrolytic coating and hot-dip aluminizing. Hot-dip aluminizing is one of the widely used processes for coating steel and cast iron to improve their oxidation and corrosion resistance. There are two types of hot-dip aluminizing: hot-dipping in pure aluminium [6-8] and hot-dipping in aluminium alloys generally aluminium-silicon [9-13] or aluminium-zinc [14] alloys. The thickness and structure of the coating depend on the following factors: the temperature and chemical composition of the bath, the holding time, and the type and microstructure of the dipped material [12]. The coating microstructure generally comprises an outer layer with a composition similar to that of the molten bath and an inner intermetallic layer, which is very hard and brittle. Coatings produced by hot-dipping in pure aluminium are characterized by a microstructure with a relatively thick inner layer of intermetallic phases. As the literature data shows, the formation of the intermetallic layer can be greatly retarded if silicon is a component of the bath. The presence of silicon causes a reduction of up to a few microns in the thickness of the intermetallic layer [2].

In this study, grey cast iron was aluminized by hot-dip coating with AlSi11 alloy. The microstructure and chemical composition of the coatings were analyzed to determine the effect of the bath temperature on the thickness of the coating.

2. Experimental procedure

GJL200 pearlitic flake graphite cast iron was used as the substrate material. Specimens with dimensions 30x15x10 mm^3 were cut from cast iron. Before dipping, the surfaces were ground with 800-grit paper and washed with ethanol. Hot dip aluminizing was performed under laboratory conditions using a Nabertherm melting furnace furnished with a graphite crucible. First, the AlSi11 alloy was melted in the furnace. Then, the specimens were dipped into the bath at a temperature of 700°C or 750°C for 20 min. The aluminized specimens were sectioned and prepared for a metallographic study. The microstructure of the coatings was investigated using an optical microscope and a scanning electron microscope. For the optical observations the specimens were etched using 5% natal at room temperature. An energy dispersive X-ray analyzer (EDS) was used for phase identification.

3. Results and discussion

Fig. 1a shows an optical micrograph of a cross-section of grey cast iron hot-dip coated with AlSi11 alloy at 700°C for 20 min. The overall thickness of the coating was about 200 μm. A thicker coating (~380 μm) was obtained at the higher bath temperature, i.e. 750°C (Fig. 1b). The coatings obtained at both temperatures consisted of outer and inner layers. In the outer layer, we can distinguish primary α-Al grains in the matrix of the eutectic structure. The eutectic structure is a mixture of α-Al and eutectic silicon. Long plate-shaped phases are also observed in this layer. At a high magnification, two zones are identified in inner layer (Fig. 2): a thinner zone in the neighbourhood of the substrate and a thicker zone, adjacent to the outer Al-Si layer. The interface between the inner zone and the substrate is regular – almost flat. There is no tongue-like morphology of the interface between the inner layer and the substrate, as is the case of hot-dip aluminizing in pure aluminium [6,10]. On the contrary, the boundary between the inner and outer layers is highly irregular. A large number of plate-shaped phases grow from the inner layer and penetrate into the outer layer.

The overall thickness of the inner layer is comparable, for the coatings fabricated at both temperatures, yet the zone adjacent to the substrate is slightly thicker in coatings fabricated by hot-dipping at 750°C. After the hot-dipping process for all aluminized specimens flake graphite was observed in the outer and inner layers.

Figure 3 presents a cross-sectional micrograph of the specimens hot-dip aluminized in AlSi11 alloy at 750°C and EDS linear profiles of the C, Al, Si and Fe distributions along the marked line. From the linear profiles we can see that long plates occurring in the outer layer are probably the Al-Fe-Si phase. The results of the quantitative EDS analysis for the two zones of the inner layer presented in Table 1 show the difference in the Fe, Al and Si concentrations. The zone next to the cast iron substrate (marked A in Fig. 4) is richer in Fe and Al and contains a small amount of Si, while the zone adjacent to the outer layer (marked B in Fig. 4) is richer in Si. The chemical composition of the zone A is similar to the composition of the Al_5Fe_2 phase with a small amount of Si in the solid solution. According to the literature data [15,16] the Si atoms can replace Al atoms in all the binary intermetallics of the Fe-Al system. The solubility of Si in $FeAl_3$, Fe_2Al_5 and Fe_3Al ranges from 1 to 7 at.%. The composition of the zone B matches that of the Al_5FeSi phase. The plate-shaped phases, randomly distributed in the Al-Si outer layer with composition, i.e. 67.76 at.% Al, 18.14 at.% Si and 14.10 at.% Fe are identified as the Al_5FeSi phase.

a)

b)

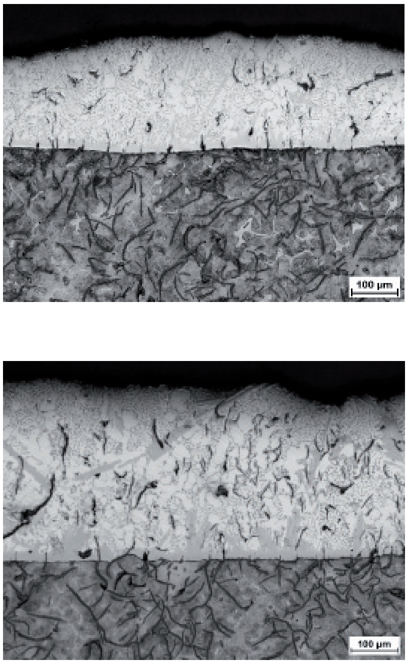

Fig. 1. OM cross-sectional views of grey cast iron hot-dip coated with AlSi11 for 20 min.: (a) 700°C, (b) 750°C

a)

b)

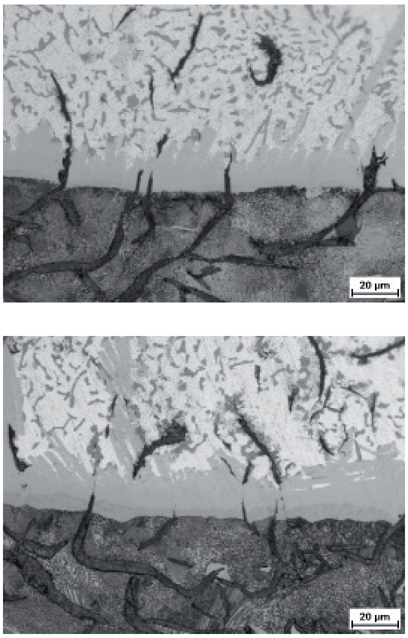

Fig. 2. Microstructure of the inner layer of the specimens aluminized at: (a) 700°C, (b) 750°C

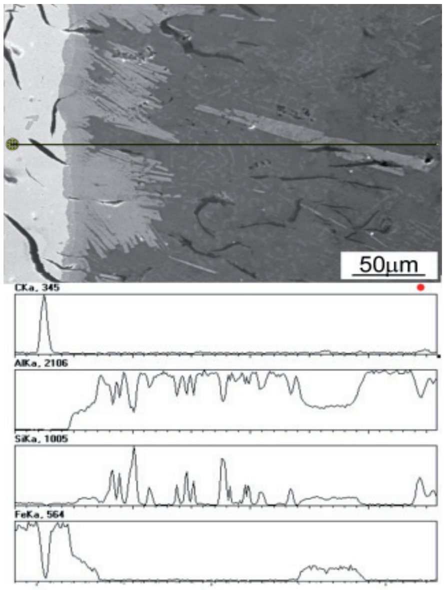

Fig. 3. Cross-sectional SEM micrograph of the cast iron hot-dip coated with AlSi11 alloy and the corresponding EDS linear analysis showing the concentration variations of C, Al, Si and Fe along the marked line

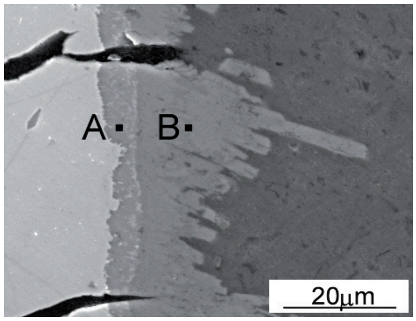

Fig. 4. High magnification SEM image showing the microstructure of the inner layer

Table 1.
Composition of the inner layer zones

Point	Al (at.%)	Si (at.%)	Fe (at.%)
A	70.37	3.59	26.04
B	63.67	17.27	19.06

The results obtained through the investigations show that the temperature of the Al-Si bath has influence on the overall thickness of the coating. The thickness of the outer layer increases with an increase in the bath temperature. The thickness of the inner layer, however, is not affected by the bath temperature. Thus, there is a good agreement between the results presented in this paper and the literature date that Si reduces the rate of diffusion of solid state Al in iron-based alloys, which may prevent the growth of Al_5Fe_2 phase [11,16-18].

4. Conclusions

- The overall thickness of the coatings increased with increasing immersion temperature.
- The coatings fabricated in both temperatures consisted of outer and inner layers.
- The outer layer was thicker in the coatings fabricated at 750°C. For both temperatures of the bath, the outer layer was composed of primary α-Al grains in the matrix of the eutectic structure, long plates of the Al_5FeSi phase, and flake graphite precipitates.
- The overall thickness of the inner layer was comparable for both cases. The inner layer was composed of two zones: the Al_5Fe_2 phase, adjacent to the cast iron substrate and the Al_5FeSi phase, adjacent to the Al-Si outer layer.
- The interface between the inner zone and the substrate was regular – almost flat, while the boundary between the inner and the outer layer was highly irregular.

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