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Microstructural refinement of aluminium-zinc-silicon coated steels

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ABSTRACT

This paper presents the analysis of microstructural refinement of a 20 μm thin alloy coating, containing (in weight percentage) 55% Al, 43.4% Zn and 1.6% Si, on a 0.42 mm thick steel sheet. Refinement of the 55Al–Zn–Si coating microstructures was achieved without affecting the steel substrate, by rapid thermal processing using a high power laser. A quantitative analysis was conducted based on real-time surface temperatures data obtained using a fast response optical pyrometer during laser processing, and measurements of dendrite arm spacing and microhardness. For refined coatings, it was found that the peak surface temperatures ranged from 800 °C to 1500 °C, and cooling rates on the order of 10^5 °C/s were achieved. The refined microstructures had very small dendrite arm spacing of less than 2 μm compared to 10 μm in untreated coatings. The spacing was reduced from 2.2 μm to 0.9 μm when the processing speed was increased from 0.083 m/s to 0.33 m/s. The rapid processing also increased the hardness of the coatings from about 78 HV up to 135 HV. Such refinement in microstructure can be expected to enhance the corrosion resistance of aluminium-zinc-silicon coated steel sheets.

1. Introduction

Coated steel sheets are widely used in applications such as roofing and wall cladding. Aluminium-zinc-silicon based alloy coatings are formulated to improve the corrosion resistance and service lifetime of steel. Coatings based on Al–Zn–Si provide an important alternative to traditional galvanised products due to their enhanced corrosion resistance, which combines the barrier protection of aluminium with the sacrificial protection of zinc [1–3]. One of these products is 55% Al, 43.4% Zn and 1.6% Si coated steel, which is produced by a continuous hot-dip process similar to that used to manufacture galvanised steel [4–6]. The expected life of these coated steels is 4 to 12 times longer than traditional galvanised products [7].

Selverian et al. [8] showed that the microstructure of 55Al–Zn–Si coatings on steel substrates typically consists of a dendritic microstructure, with aluminium-rich dendrites (Al-rich areas) and zinc-rich interdendritic constituents (Zn-rich areas), as depicted in Fig. 1. The silicon content is usually present as needle-shaped particles in the microstructure and is added to prevent excessive growth of the intermetallic alloy layer at the coating/steel interface [4]. The coating is approximately 20 μm thick and the total thickness of the coated strip is usually about 0.42 mm.

Previous studies reported increased corrosion resistance of Al–Zn based coatings by refining the dendrite arm spacing in coating microstructures to reduce the exposed area of the Zn-rich phases [10–12]. Cleary [13] showed that the dendrite arm spacing in 55Al–Zn coatings decreased with increasing cooling rate during the solidification. Garcia-Villarreal et al. [14] reported for 55Al–Zn–Si alloys a reduction in dendrite arm spacing from 100 μm to 10 μm with increasing cooling rate from 5 °C/s to 45 °C/s.

Other studies on the formation of such coatings have shown that microstructural refinement can be achieved by modifying the nucleation and growth of spangles (or grains) during solidification using thermal or chemical means [15–17]. It was found that increasing the steel substrate temperature prior to hot dip coating enhanced wetting and resulted in smaller spangles, but affected the steel properties and intermetallic layer. The chemical approach to microstructural refinement in aluminium-zinc coatings is by adding alloying elements like magnesium or silicon to the coating bath [4,11,18]. However, the cooling rate of the coating achieved during the manufacturing process is limited to less than 100 °C/s. Under these cooling rates, the chemically modified 55Al–Zn–Si coating microstructures will have smaller spangles, but dendrite arm spacing ranging from about 7 μm to 10 μm [19].

The work presented in this paper used a rapid thermal processing method to achieve very high cooling rates and produce fine microstructures in Al–Zn–Si coatings. The method involved very rapid melting and cooling of the coating using a high energy density source. Previous studies reported on this method include rapid surface melting of aluminium-based alloys using heat sources such as laser beam [20–24], electron beam [25,26], arc [27] and gas plasma [28,29], followed by rapid quenching of the melt. However, most of these previous studies dealt with thick work pieces (thickness > 1 mm) and have focussed on refining shallow regions at the surface of thick work pieces. Also there

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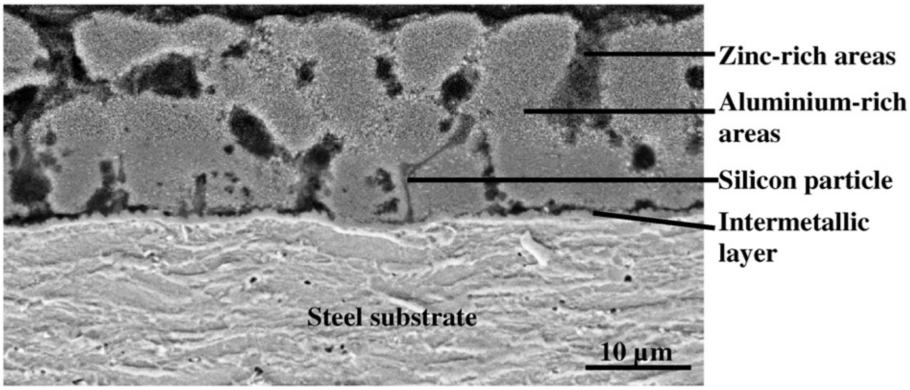

Fig. 1. Microstructure of the 55Al–Zn–Si coating on a steel substrate [9].

are relatively few reports, such as previous work by the authors [30,31], on rapid surface melting and cooling of hot-dip coatings. Some of the rapid processing studies recently reported on thin galvanised coatings were related to welding [32–35].

Previous work by the authors [30,31] showed the possibility of using rapid thermal processing via high power lasers to produce refined coating microstructures in thin 55Al–Zn–Si coated steel sheets without affecting the steel substrate. Observations in the laser-treated coatings were consistent with the melt contour and temperature predictions given by an analytical model adapted from Ashby and Easterling [36].

In this paper, a detailed quantitative analysis of microstructural refinement by rapid thermal processing of thin coated steels is described. The quantitative analysis is based on real-time measurements of surface temperatures and microstructural characterisation of laser-treated 55Al–Zn–Si coated steels.

2. Material and methods

The samples used for rapid thermal processing experiments were Zincalume® coated steel products supplied by BlueScope Steel. They were 0.42 mm thick low carbon steel strips with a 20 μm thick coating of nominal composition 55%Al – 43.5%Zn – 1.5%Si, and a steel substrate with a nominal composition of 0.06%C – 0.3%Mn – 0.02%Si – 0.01%P – 0.02%S – 0.05%Al. The steel was highly cold-formed during cold rolling, and not annealed to achieve minimum yield strength of 550 MPa.

The laser processing was performed in continuous mode using Laserline 3 kW diode laser (LDF 3000, 0.8–0.9 μm wavelength). The laser beam was delivered by a step index glass fibre terminated with collimating and focussing lenses. A laser beam with a circular shape was used for all experiments. The incident laser beam was normal to the sample surface and the processing was done by moving the laser beam relative to the sample.

Surface melting experiments were conducted with laser powers ranging from 700 W to 2300 W, processing speeds of 0.017 m/s to 0.33 m/s and laser spots with radius of 0.3 mm to 0.5 mm. During each trial, the surface temperature of the sample was monitored using a two-colour LASCON optical pyrometer which was setup to give the temperature history at a fixed point on the sample surface. The pyrometer had a response time of less than 0.2 ms and a measuring range of 422–1500 °C. Data logging was performed at a sampling rate of 0.2 ms for all experiments. The measured profiles were then compared with profiles predicted by the Ashby and Easterling analytical model as per Eq. (1):

$$T - T_0 = e^{1/2}(T_P - T_0)\left({}^{t_p}/_{t}\right)^{1/2} exp - \left({}^{t_p}/_{2t}\right) \tag{1}$$

where T = temperature; T_0 = intial temperature; T_p = peak temperature; t = time; t_p = the time required to reach the peak temperature. Further details regarding the calculation of T_p and t_p for near surface treatments are provided by Ashby and Easterling [36].

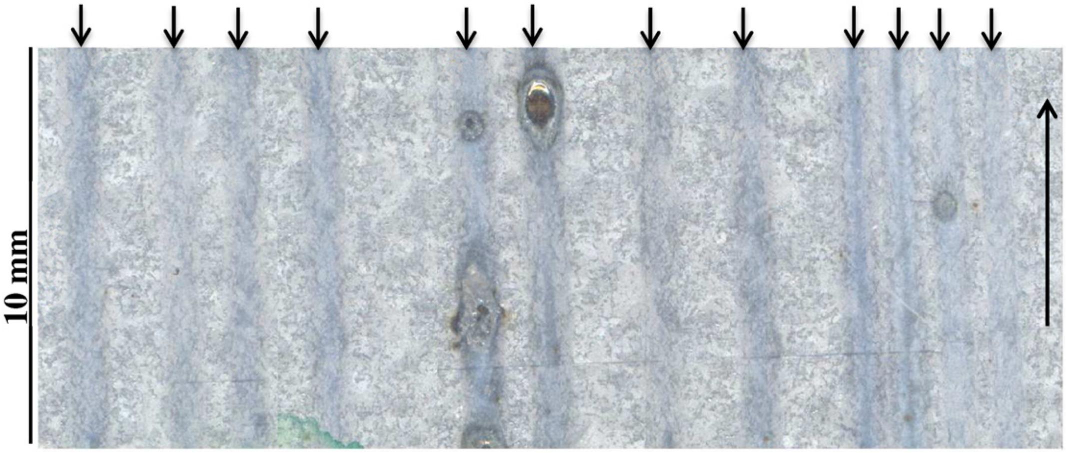

Fig. 2. Macrograph of the surface of a laser-treated aluminium-zinc-silicon coated sample. The small arrows at the top denote the positions of the laser tracks. The long arrow on the right shows the direction of laser processing.