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Three-dimensional modeling of effect of surface intermetallic phase on surface defects of Al−Fe−Si aluminum foils during twin-roll casting

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Abstract: Scanning electron microscopy and X-ray energy dispersive spectrum analysis show that the clusters of intermetallic AlFeSi particle are distributed on or near the aluminum foil stock surfaces heterogeneously. 3D finite element modeling shows that these clusters of hard particles induce the fracture of the nano-scale lubricant oil film at first and further lead to severe deformation in the nearby aluminum foil substrate along the rolling direction. Consequently, the optical property in this region differs from that in the surroundings, resulting in surface defects.

Key words: Al−Fe−Si alloy; precipitated phase; aluminum foils; lubricant oil film; twin-roll cast; 3D modeling

1 Introduction

Aluminum foils are widely used in the food, medical, and electronics industries. These foils are usually thinner than 100 μm, and some are even as thin as several microns. Minor defects such as pores, secondary precipitates, and inclusions will lead to the deterioration of the surface quality and mechanical property of foil products. Thus, the microstructure of the alloy used for foils should be strictly controlled. The effects of multiple factors on aluminum foil surface defects have been investigated [1,2]. KELES and DUNDAR [3] studied the influence of inclusions on aluminum foil surface defects during the foil rolling process. ZHU et al [4] related these surface defects with secondary precipitates in the alloy.

The morphology, size, and distribution of hard secondary precipitates in aluminum foils largely depend on the microstructure of aluminum foil stock before foil rolling. In turn, this microstructure is strongly affected by the fabrication process. There are two commonly used methods for producing aluminum foil stock, namely, hot rolling (HR) and twin-roll casting (TRC). HR is a traditional method of aluminum foil stock production. In this method, billets with thicknesses of 50−150 mm are first obtained by casting, and then they are hot- or cold-rolled into 0.3−0.5 mm thick aluminum foil stock. The HR technology for aluminum foil production is well established. On the other hand, twin-roll casting is a novel method in which billets with thicknesses of less than 10 mm are produced. This method is simpler, more energy efficient, and more economical than the traditional HR process. The production of aluminum foil stock using TRC sheets is very interesting. However, the initial thicknesses of TRC sheets are usually much lower than those of as-cast billets using the traditional HR method, although subsequent hot- and cold-rolling processes are also required to produce aluminum foils via the twin-roll casting method. Sheets for foils produced by twin-roll casting have different microstructural characteristics from those produced by HR. In twin-roll casting, liquid aluminum is cooled by two rotating rollers with circulating cooling water. The grain size of the billet is much smaller than that of the traditional as-cast billet prepared using HR. The distribution of particles, solute atoms, and eutectic phases in the TRC billet along the thickness direction is much more heterogeneous than that in HR billets [5−7]. A much lower reduction rate may also occur in the

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production of aluminum sheets by twin-roll casting. Therefore, there are some difficulties in the fabrication of aluminum foils with TRC sheets. For instance, the 1xxx and 8xxx series of aluminum are typical alloys for aluminum foil production. Aluminum foils with stable and high surface quality can be obtained when the aluminum foil stock is produced by the HR method using these alloys [8,9]. However, matte defects often occur on the surface of aluminum foils fabricated from TRC aluminum stocks [10,11]. The intermetallic phase of Fe in the alloy has been reported to result in surface matte defects because of the interaction of these intermetallic phase particles with the lubricants in the foil rolling process [12−14]. The interaction of intermetallic phases in very thin foils with thickness of several nanometers is not clear.

In this work, the interaction between the secondary hard phase and ultra-thin lubricant oil in foil rolling was investigated to gain a deep insight into the connections between the secondary hard phases and matte defects on the surfaces of foils produced by twin-roll casting. The expected results may be helpful to control secondary hard particles in TRC foil stocks during their fabrication process. .

2 Experimental

Billets of AA1235 alloy with 7 mm thickness were produced by the twin-roll casting technique and hot rolled into sheets with 4 mm thickness at 580 °C. The sheets were tempered for 2 h at 480 °C and further cold-rolled into sheets with 0.35 mm thickness, hereafter denoted as TRC foil stocks. Typical AA1235 aluminum foil stocks with 0.35 mm thickness were also prepared by the traditional HR process for comparison. The HR AA1235 aluminum foil stocks were produced under the same heat treatment process as the TRC foil stocks. Both TRC and HR stocks with 0.35 mm thickness were subsequently rolled into foils with 0.01 mm thickness on the same foil rolling mill. Matte defects on the surfaces of both types of foils were carefully checked.

A field emission scanning electron microscope (FESEM, FEI Sirion 200) attached with an energy dispersive spectroscope (EDS) analyzer and a transmission electron microscope (TEM, Hitachi H-800) were used to study the effect of intermetallic particles on the surface quality of the aluminum foils.

The effects of hard intermetallic phases on the surface quality, such as matte defects, were investigated by both experiment and finite element modeling (FEM), for which Abaqus 6.8 was used.

3 Results

Both TRC and HR foil stocks were rolled into foils with 0.01 mm thickness in a foil rolling mill. The surface qualities of the foils were checked carefully. Matte defects are found on the surface of TRC foils but not on that of HR foils (Fig. 1(a)). The defects are almost linearly arranged in a zone with tens of microns width along the rolling direction (Fig. 1(b)). Traces of shearing are visible along the matte defect zone, and the zone boundaries vertical to the rolling direction are irregular (Fig. 1(a)). A high-magnification image of the TRC foil surface microstructure reveals a cluster of secondary precipitates within the matte defect zone (Fig. 1(c)). These hard intermetallic particles have been considered as the main reason for the matte defects of TRC foils [4].

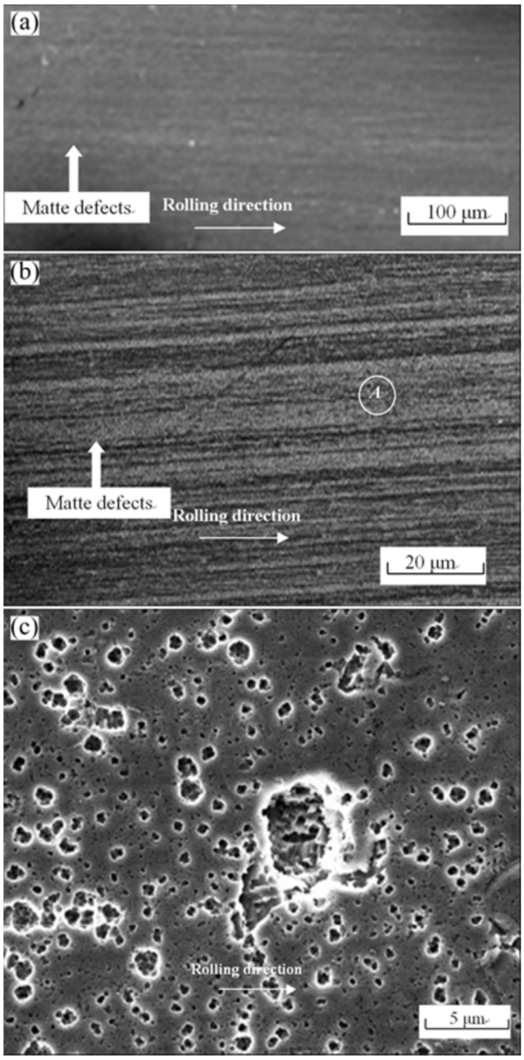

Fig. 1 Micrographs of a typical matte defect: (a) Matte defect (in bright white zone); (b) Magnification of matte defect zone; (c) Typical details of matte defect zone (region *A*)

The microstructures of the transverse section near the surface of the TRC and HR sheets are compared in Fig. 2. It shows a wavy boundary and obvious defects near the TRC sheet surface, with clusters of precipitates forming within or around the defects (pores, inclusions,