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Microstructure of asymmetric twin-roll cast AZ31 magnesium alloy

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Abstract: The microstructural distribution along thickness of asymmetric twin-roll cast AZ31 magnesium alloy slab was investigated. It was found that the microstructure along the thickness of the slab was significantly inhomogeneous. There were many deformed bands with flow form near the upper surface of twin-roll cast plate. Very few deformed bands could be seen in the central part of the plate where the dendrites were thick. Fine dendritic structures dominated near the lower surface of the twin-roll cast strip. It is concluded that the shear strain caused by linear velocity difference between surfaces of upper and lower rolls results in the deformed bands of the twin-roll cast slab. Aluminum, zinc and manganese segregate to the boundary of dendrites, while silicon distributes inside the α-Mg solid solution.

Key words: AZ31 magnesium alloy; asymmetric twin-roll casting; deformation bands; precipitate

1 Introduction

Twin-roll casting is a near-net-shape process, by which the plate with thickness of less than 10 mm can be produced directly from metal melt [1]. The metal melt endures rolling force during fast solidification. The cooling rate of the melt can reach 10^2−10^3 K/s during twin-roll casting, which is two orders of magnitude higher than that of the normal semi-continuous casting [2]. Compared to the normal casting, the cast plate exhibits higher solid supersaturation, finer microstructure, dispersed compounds and lighter element segregation [3].

Asymmetric twin-roll casting, in which the two rolls have different surface linear velocity, is developed from normal continuous twin-roll casting process. The rolls of the asymmetric twin-roll casting have effects on the thermal conductivity and shear strain of the metal in the roll-casting zone. The shearing force increases the deformation of the asymmetric rolled plate and refines the microstructures of plates [4−6]. The plates of magnesium alloy processed by asymmetric and symmetric rolling have different texture [7−8]. Some researchers investigated the microstructure of normal twin-roll cast magnesium alloy plate [9−10]. The sheet of AZ31 magnesium alloy produced by normal twin-roll casting consists of α-Mg, interdendritic $Mg_{17}Al_{12}$ eutectic and some dispersive fine precipitates [11]. However, there are few reports about the microstructure and its formation mechanism of asymmetric twin-roll cast magnesium alloy plate.

The aim of this study is to investigate the formation mechanism of microstructures in the asymmetric twin-roll cast plate by observing the distribution of dendrites and precipitates of the plate along thickness. Besides, the distribution of alloying elements of the plate is also observed.

2 Experimental

The experimental material was AZ31 magnesium alloy and its chemical composition is listed in Table 1. The plate of AZ31 magnesium alloy was produced by the asymmetric twin-roll casting process and its schematic diagram is shown in Fig. 1. The rolls with the same radius had different velocity of rotation. The radius of curvature for oxidation film between the nozzle and upper roll with the rotational speed of ω_1 was larger than that between the nozzle and lower roll with the rotational speed of ω_2, i.e., $r_1>r_2$. The ratio of surface linear velocity for the upper and lower rolls was set at 1.3 that was equal to $\omega_1:\omega_2$ in this study. The alloy melt was first refined at 700 °C for 30 min and then was transferred

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Table 1 Chemical composition of AZ31 magnesium alloy (mass fraction, %)

Al	Zn	Mn	Si	Fe	Cu	Ni	Mg
2.82	0.85	0.35	0.025	0.007	0.001 5	0.000 6	Bal.

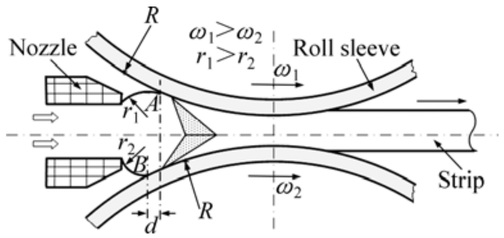

Fig. 1 Schematic diagram of asymmetric twin-roll casting for AZ31 magnesium alloy

into the front box with preheated temperature of 670 °C. The alloy melt in the front box flowed into the rotating rolls with gap of 5.5 mm through the nozzle, so that the 6 mm thick strip was produced in the process with the casting speed of 2.4 m/min.

The samples were cut from the twin-roll cast plate for observing the microstructure of the plate on rolling plane, side face and transverse surface, as shown in Fig. 2. The samples were ground, polished and etched with picric acid and ethylic acid solution (5 g picric acid+ 5 mL ethylic acid+100 mL ethanol+10 mL distilled water). And then, the microstructure was investigated by optical microscope. The JEOL−2000 scanning electron microscope was used to observe the element distribution of the plate near the center.

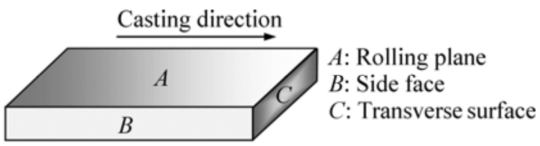

Fig. 2 Schematic diagram of microstructure observation

3 Results

3.1 Microstructure

The microstructure of asymmetric twin-roll cast AZ31 magnesium alloy plate at side face along the thickness is indicated in Fig. 3. It is shown that the microstructure near the upper surface of the plate was fine and the deformed bands with flowing form were found. The dendrite arms of primary dendrites and secondary dendrites near the center of the twin-roll cast slab were thicker, where no obvious deformed bands among dendrites could be seen. The microstructure near the lower surface was finer, where the dendrite arms were slightly elongated.

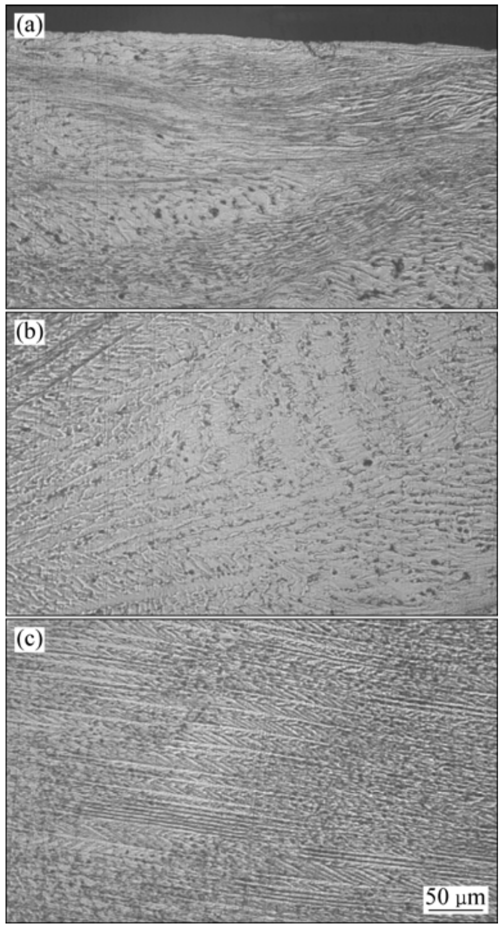

Fig. 3 Microstructures of asymmetric twin-roll casting plate at side face along thickness near upper surface (a), center (b) and lower surface (c)

The microstructure of asymmetric twin-roll casting plate at transverse surface along thickness is shown in Fig. 4. The microstructure near the upper surface was fine with no dendrite characteristics. With the increase of the distance from the upper surface, the nonuniform dendrites appeared with disordered orientation. The dendrite arms became thicker and their spacing was larger near the center of the plate. The microstructure became finer with dendrite characteristics near the lower surface of the plate.

There is great difference of the microstructure on the rolling plane along thickness, as shown in Fig. 5. Advanced dendrites with disordered orientation and long secondary dendrite arm were found near the upper surface of the twin-roll cast plate. The dendrites arms were thicker near the center of the plate. The dendrites parallel to each other were orientated along the casting direction with large dendrite arm spacing at the lower surface of the twin-roll cast plate.

3.2 Precipitates

In order to observe the alloying element distribution

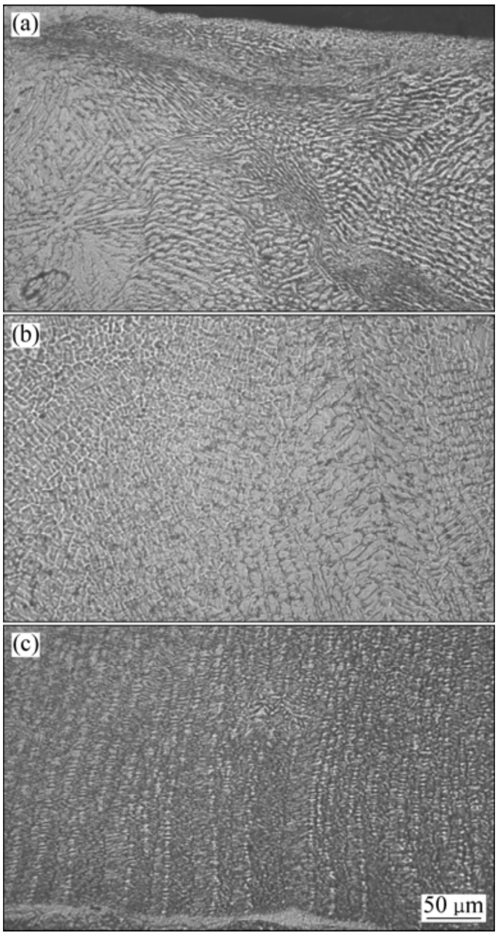

Fig. 4 Microstructures of asymmetric twin-roll cast plate at transverse surface along thickness near upper surface (a), center (b) and lower surface (c)

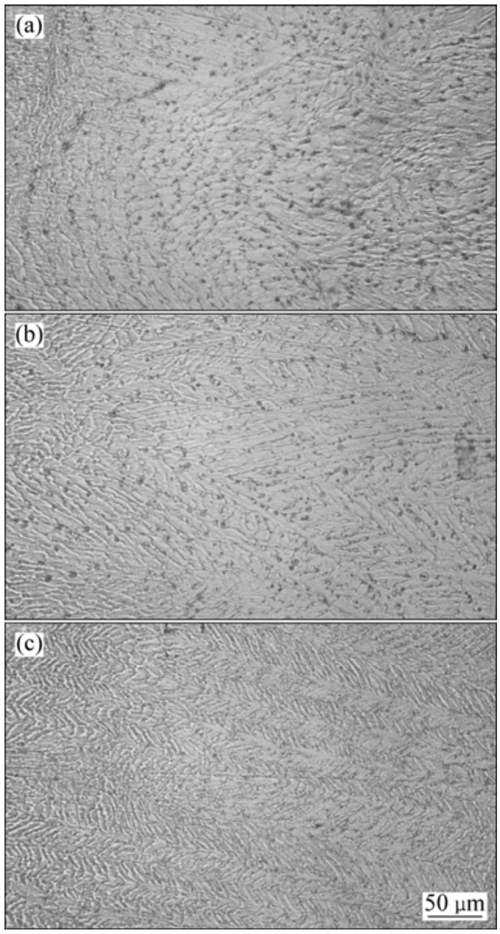

Fig. 5 Microstructures of asymmetric twin-roll cast plate on rolling plane along thickness near upper surface (a), center (b) and lower surface (c)

in the plate, the sample was investigated by SEM and the results are shown in Figs. 6 and 7. It is found that the size of the compounds varies from 1 to 3 μm, as shown as arrows in Fig. 6.

The area scanning of the alloying elements is shown in Fig. 7. It is found that there are some districts with less magnesium, and Al segregates to the districts among the dendrites. Zn slightly segregated to the grain boundary, while Si uniformly distributed in the investigated district with some concentrated districts. Al and Mn are easy to form the compound of Al_8Mn_5 [12−13], which results in the concentrating of Mn as shown in Fig. 7(e).

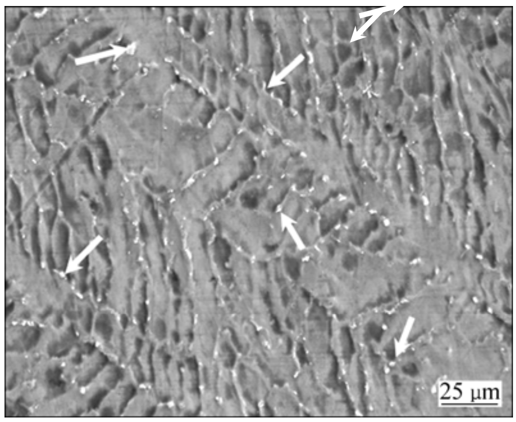

Fig. 6 SEM image of twin-roll cast AZ31 magnesium alloy

4 Discussion

The microstructure of traditional casting consisted of fine equiaxial dendrites, columnar crystals and coarsened isometric crystal from surface to the center [14]. However, this microstructure characteristic disappeared in the asymmetric twin-roll cast magnesium alloy plate and there were no obvious fine equiaxial dendrites and columnar crystals. It was reported that the microstructure of normal twin-roll cast AZ31 magnesium alloy was axial symmetric and consisted of fine equiaxial and columnar dendrites [15].

The microstructure of asymmetric twin-roll cast plate on the side face reflects the flowing characteristics along casting direction, and its microstructure schematic diagram is shown in Fig. 8. The alloy near the upper surface suffers violent plastic deformation during

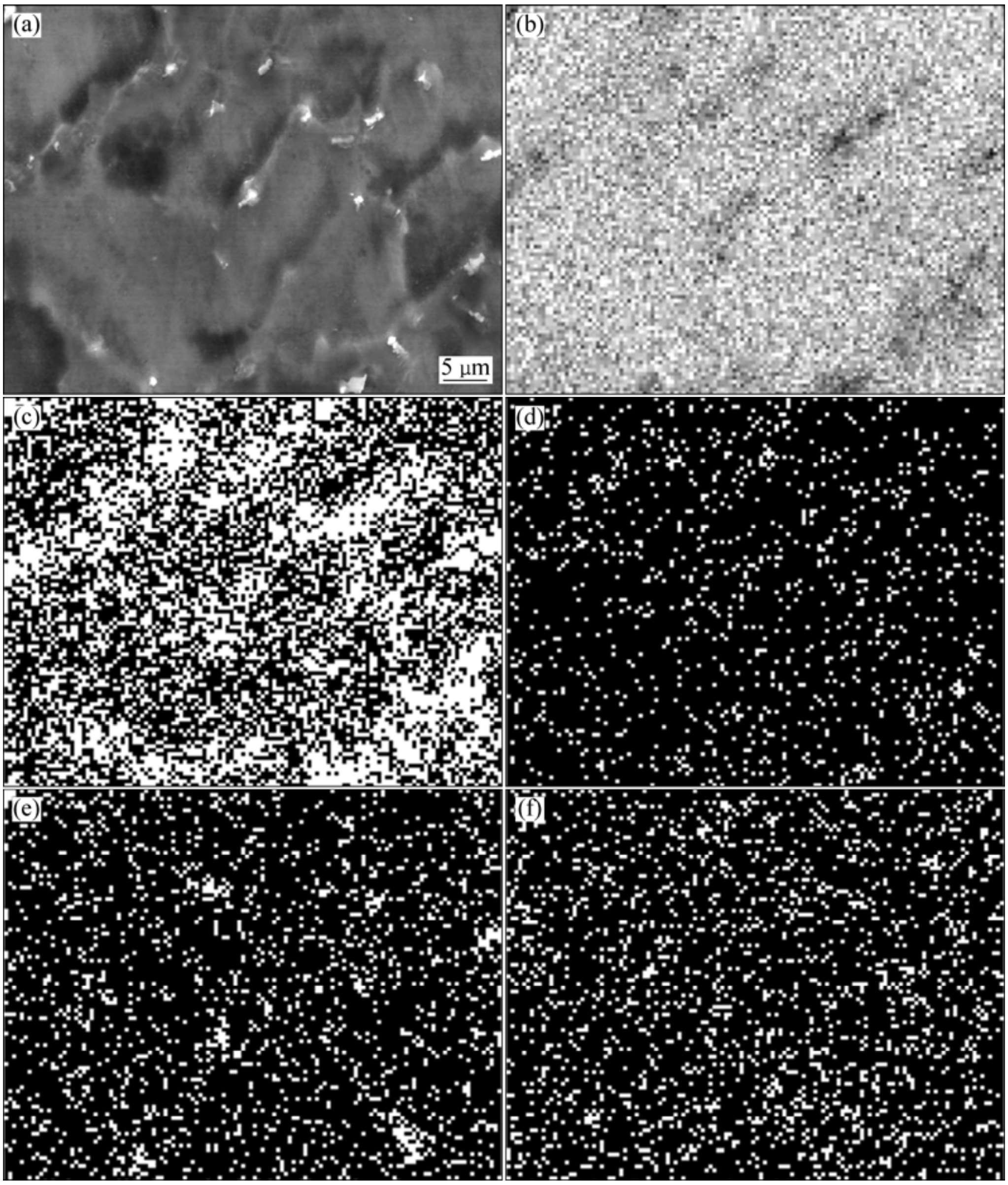

Fig. 7 Area scanning of elements in twin-roll cast AZ31 magnesium alloy: (a) SEM image; (b) Mg; (c) Al; (d) Zn; (e) Mn; (f) Si

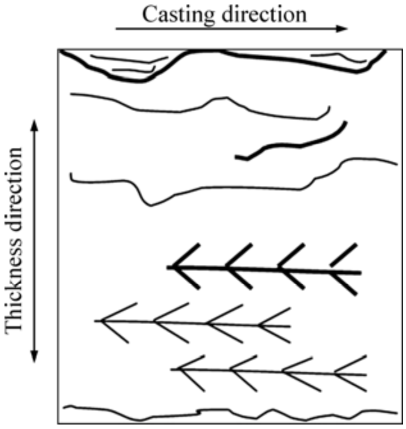

Fig. 8 Schematic diagram of microstructure at side face along thickness direction

solidifying in the roll-casting zone, which makes the melt flow with vortexes. The surface linear velocity of upper roll is higher and the cooling rate of melt near the upper roll is lower. Because of the higher temperature, alloys in the roll-casting zone have strong plastic deformation ability and the just-solidified dendrites are elongated and the deformation bands with flow characteristics are formed. The alloy flow below the upper surface is relatively stable and the solidified dendrites are elongated along the casting direction. The dendrite arm spacing is small because of high cooling rates. With the increase of the distance from the upper surface, the cooling rate of the alloy becomes smaller and the solidification time becomes longer, so that the dendrites have enough time to grow, which results in the thick dendrite arms. The metal melt near the lower surface of the twin-roll cast plate is the first to contact with the roll and the solidification shell is formed with high cooling rate. And then, the heat is transferred to the environment through the solidification shell. The linear velocity of the lower roll is lower and the magnesium melt suffers higher cooling rate, so that the finer dendrite arms are formed.

During asymmetric rolling, the rolls have different surface linear velocity. The strain rate state of the asymmetrical rolling is shown as [16]:

$$\dot{\varepsilon}_{i,j} = \begin{Bmatrix} -\dot{\varepsilon} & 0 & -p\dot{\varepsilon} \\ 0 & 0 & 0 \\ 0 & 0 & \dot{\varepsilon} \end{Bmatrix}_{\mathrm{RD,TD,ND}} \tag{1}$$

where RD is the rolling direction, TD is the transversal direction, ND is normal direction, and p is the shear coefficient. In conventional rolling, the state is nearly plane strain so that the p is equal to zero. During asymmetric twin-roll casting, the difference of roll surface linear velocity that is similar to asymmetric rolling results in the shear strain rate along thickness of strip, which causes deformation bands in the strip.

The schematic diagram of microstructure of the asymmetric twin-roll cast plate on rolling plane along thickness is shown in Fig. 9. The primary and secondary dendrites near the upper surface are bent because of faster rotation velocity of the upper roll, so that the just-solidified dendrites are elongated. At the center of the twin-roll cast plate, under the effect of the upper and lower rolls, the alloy solidifies as the complex flowing occurs, resulting in the dendrites with different orientations. Near the lower surface of the twin-roll cast plate, the dendrites are rapidly formed and then elongated along the casting direction right away. With the increase of the distance from the lower surface, the cooling rate decreases and thus thicker dendrite arm with larger dendrite arm spacing is formed due to the enough time for the alloy to solidify.

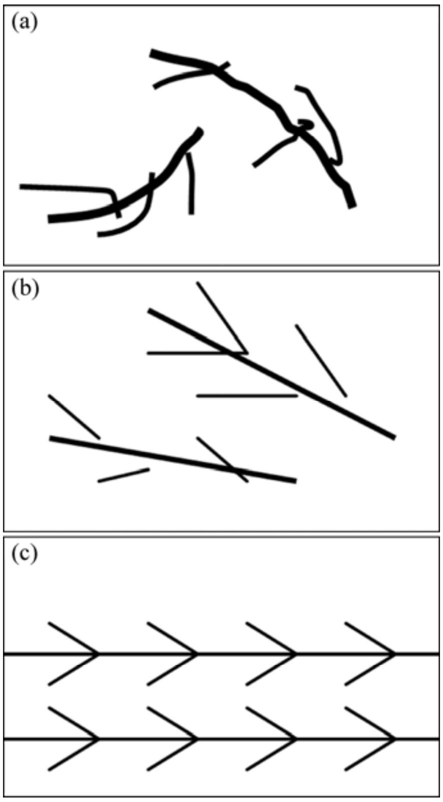

Fig. 9 Schematic diagram of microstructure on rolled plane along thickness direction near upper surface (a), center (b) and lower surface (c)

5 Conclusions

1) The microstructure of the asymmetric twin-roll cast plate near the upper surface consisted of deformation bands and dendrites. Meanwhile, the microstructure near the center consisted of thick dendrites and the microstructure near the lower surface consisted of fine dendrites.

2) The deformed bands near the upper side of the plate were caused by the shear strain derived from the difference of the surface linear velocity between the rolls during asymmetric twin-roll casting.

3) There were many precipitates at the boundary of dendrites. Aluminum, zinc and manganese segregated to the boundary of dendrites, while silicon distributed inside the α-Mg solid solution.

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AZ31 镁合金异步铸轧板的显微组织

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摘 要：研究 AZ31 镁合金异步铸轧板坯沿厚度方向的显微组织分布。结果表明，板坯组织沿厚度方向具有较明显的不均匀性。在板坯的上表面附近存在较多的流线型变形带组织；在中心处观察不到变形带组织，枝晶臂较粗大；在板坯下表面附近枝晶组织较细密。板坯上表面附近的流线型变形带是由上、下铸轧辊表面线速度差产生的剪切应变而引起的。Al、Zn 和 Mn 在枝晶晶界处发生偏聚，Si 均匀分布在 α-Mg 固溶体内。

关键词：AZ31 镁合金；异步铸轧；变形带；析出相

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