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Current Status of Research and Industries of Al Sheets in China

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During the last ten years, with the development of Chinese economy, there is a fast increase of aluminum industries in China. Chinese demand for aluminum is expected to increase about 20% to 17 million metric tons in 2010. Among the whole aluminum products in China, about 5 million tons are Al sheets which include Al strip and foil products. In this lecture, the developments of production and production capacity of Aluminum sheets of Chinese industries are presented and discussed. Technologies related to casting, hot-rolling and cold-rolling have been developed significantly for the Al sheet products in China. Both the production line and technology developments of Al sheets in China will be discussed related to the potential market development in the lecture. Cooperation with industries, scientists in many universities and research institutes are conducting researches which are related with Al sheets in different areas, such as casting, rolling and applications. A few examples of these kinds of industries related researches on Al sheets are presented in this lecture. These studies are mainly focused on AA3014 and AA1050 aluminum alloys. Phase transformation of the particles during homogenization, microstructure evolution of aluminum alloys during cold-rolling, and especially the effect of the particles on microstructure were presented and discussed in more detail.

Keywords: *Aluminum sheet, aluminum foil, Chinese aluminum industry, AA3014, AA1050*

1. Production and Production Capacity of Aluminum Sheets

China's economy has been expanding since the introduction of market reform about 30 years ago, and has been further accelerated by China's entry into the World Trade Organization in 2001. A growth in gross domestic product of 9 % in 2009 has been reported. To meet the expanding of economy, China consumes a huge amount of aluminum. According to the Aluminum Association's Aluminum Statistical Review, the aluminum consumption per person in China has grown at an average rate of 14% per year since 1998. In fact, Chinese aluminum consumption had been grown with a rate of 80% per year during the period of 2004 and 2010. The latest Statistic shows that annually the consumption of aluminum is about 9 kg per person, and the consumptions of aluminum plate and foil, aluminum extrusion products have reached up to 2.5kg, 5.1 respectively. Chinese demand for aluminum is expected to increase about 20% to 17 million metric tons in 2010, fueled by the recovering economy, according to Aluminum Corp of China Ltd (Chinalco).

The aluminum plate and foil production of China experienced a full speed development. The production of aluminum plate reached as high as 4850 kt/a in 2009, while it was only 346kt/year in 2000. It grows up 14 times in 9 years [1]. In 2006, the aluminum foil production of China reached to 788kt/year which was over to that of USA for the first time and became to the biggest aluminum foil production country in the world [2]. The growth of aluminum plate and foil production in China during the last ten years is shown in Fig.1

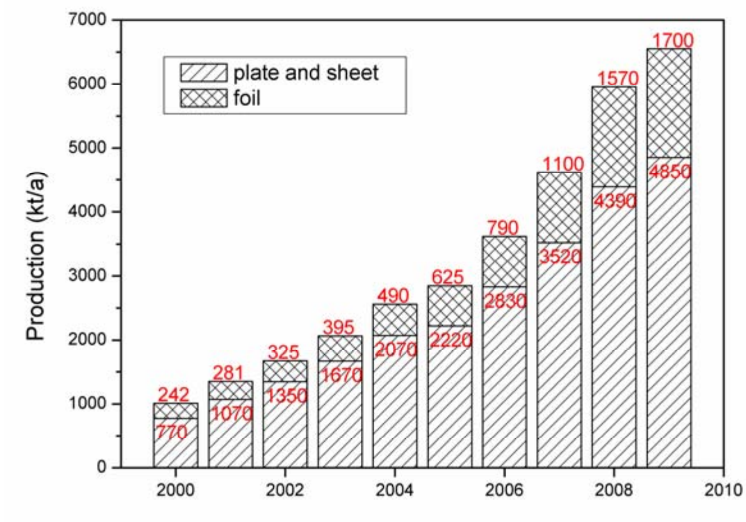

Fig.1 Production of aluminum plate and foil in China

On the other hand, the production capacity of aluminum plate grow up to 7500kt/year in 2010 from 1060kt/year in 2000. The production capacity of aluminum foil has reached to 1850kt/year in 2010 from 275kt/year in 2000[1]. The growth of aluminum plate and foil production capacity is shown in Fig.2, Fig.3 respectively.

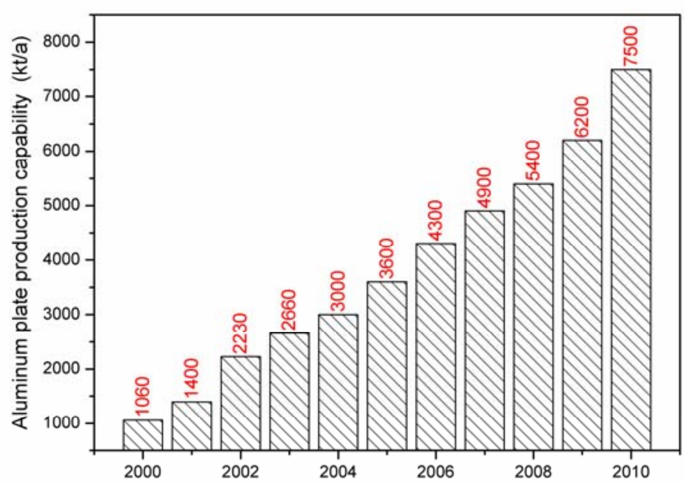

Fig.2 Production Capacity of the aluminum plate in China

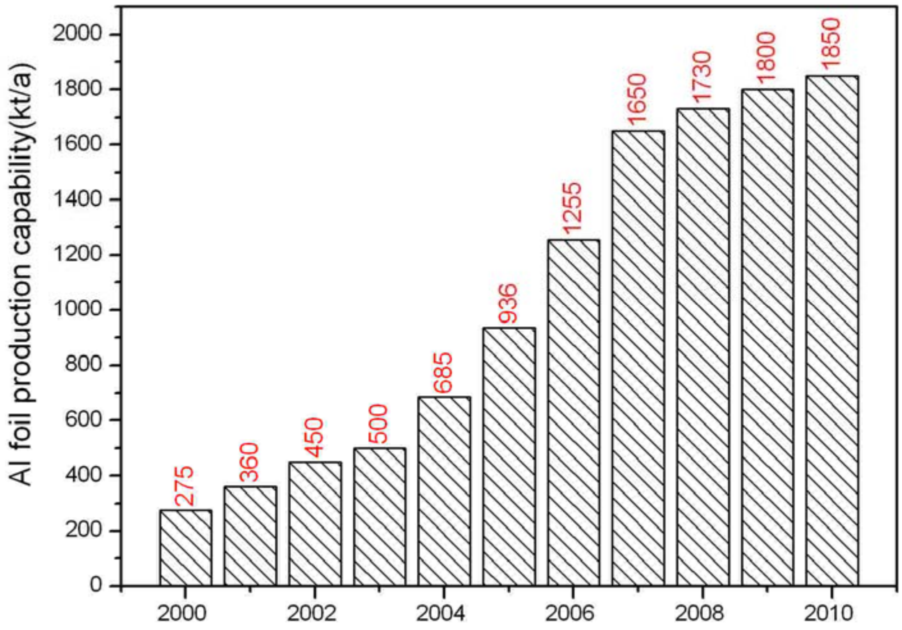

Fig.3 Production capacity of the aluminum foil in China

The apparent consumption (apparent consumption=import-export + production) increased nearly 75 times from 13kt/year in 1984 to 960kt/year in 2008. The export amount of aluminum has exceeded the import amount, and the import is about -350kt in 2009. However, China is still aluminum plate net import country, the exported and the imported amount of the aluminum plate are 460kt and 497kt respectively in 2007 [3]. The import and export changes of aluminum plate and foil in China from 2000 to 2010 are shown in Fig.4 and Fig. 5.

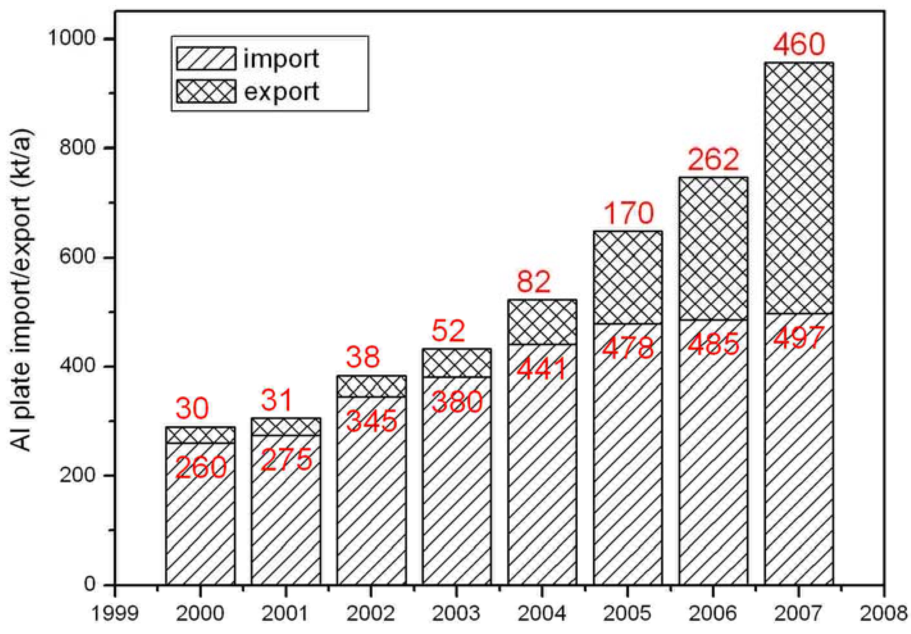

Fig.4 The imported and exported amount of the aluminum plate in China

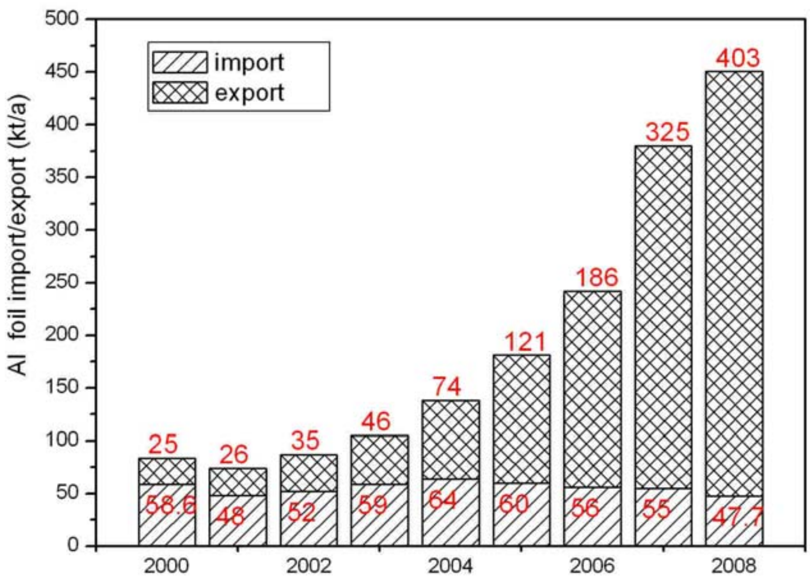

Fig.5 The imported and exported amount of the aluminum foil in China

2. Current Status of Al Sheet Industries

With a fast development of the aluminum sheet industries, many aluminum plate /foil factories have been built up during the last ten years. However, comparing with those advanced aluminum sheet factories in the world, China is still far behind on technology and management of the aluminum sheet products. Among the 450 aluminum plate factories with 20000 kt/year capacity, there are 220 factories with 5000kt/year capacity in China. Among the250 aluminum foil factories with 5000 kt/year capacity, there are 130 factories with 1500kt/year capacity in China. The average production capacity of Aluminum sheets in China is only 12kt/year, which is relatively small comparing with the average production capacity of 35kt/year in the world. This difference of the production capacity is even bigger comparing to those in USA, Germany, Japan and Russia. For example, there are only 50 aluminum plate/foil production factories in USA, the average production capacity is about 5700kt/year which is ten times of the average production capacity in China [4-8].

The top five biggest aluminum sheet production factories in China and their equipments, production capacity are listed in Table 1.

3. Current Status of Technology Development of Aluminum Sheets in China

The manufacture technology innovation of Chinese aluminum plate /foil manufactures includes two aspects: one is the optimization of manufacture technology such as melting, casting, modification of hot/cold rolling parameters, and another is the development of the manufacture equipments, partly by introducing production lines from the developed countries.

Table 1. Top five biggest aluminum sheet production factories in China

	Manufacturer	Equipimnets of the Production Lines	Capacity (kt/year)
1	Southwest Aluminium	one (1+1) 2800mm hot rolling mill; one (1+4)2000mm hot rolling mill; two 1600mm casting rolling mills one 2800mm cold rolling mill; two 1850mm cold rolling mills; one 1400mm cold rolling mill; two 1700mm foil rolling mills.	700
2	Mingtai Aluminium	one (1+4)2000mm hot rolling mill; four 1650mm casting rolling mills; one 1500mm cold rolling mill; one 1930mm cold rolling mill; five 1650 raw cold rolling mills; four 2000mm cold rolling mills.	200
3	Henan Xintai Aluminium	two 1450mm cold rolling mills; one 2050mm cold rolling mill; seven 1600mm casting rolling mills; two 1750mm casting rolling mills; two 2100mm casting rolling mills.	150
4	Nanping Aluminium	two 1600mm casting rolling mills; one 1800mm casting rolling mill; five cold rolling mills.	150
5	Zhengzhou Aluminium	five 1600mm casting rolling mills; four 1900mm casting rolling mills; one 1400mm cold rolling mill; three 1400mm foil mills; three 1850mm cold rolling mills.	100

The manufacture technology and equipments of aluminum sheets in China has developed rapidly during the last ten years. Many advanced manufacture technologies have been used in the factories, which include as: (1) application of aluminum flux online super purify treatment, low metal level casting technologies, control of melting quality，application of continuous online hydrogen tester and new online electromagnetic stir system; (2) high precision plate height and shape control technology based on artificial neural networks has been used, with which fuzzy control can be realized. The precision level of hot rolling temperature can reach ±10℃; (3) technologies for producing the following products have been developed: thin foils (less than 0.01mm) with a width of 2150 mm; cold-rolled sheets with a width of 3500mm; hot rolled plates width a width of 5400mm and 250-300mm pre-stretched thick plates.

The developments of the equipments for aluminum sheets in China depend on both introducing technology from the advanced countries and technology developments within China during the last 20 year. The recent developments of the equipments for aluminum sheets in China are: 1) 2000mmCVC cold rolling production line which was introduced from Germany; 2) 2800mm hot-rolling mill with a capacity 240kt/year manufactured by China 1st Heavy Machine Group Corp; 3) 1700mm and 1850mm cold-rolling production lines are under design and manufacture within China.

4. Examples of Researches on Aluminum Sheets in China

4.1. Microstructure of AA3104 aluminum ingot after casting and homogenization.

DC-casting (Direct Chill casting) and LHC-casting (Low Head Composite casting) are two common processes to produce aluminum ingots. However, there are significant differences on structure of the ingots produced by these two processes. A comparison study was made on AA3104 aluminum ingots casted by the two processes. Fig.6[9] shows that the DC-casting ingots have thicker transition zones with big grains and coarse intermetallics comparing

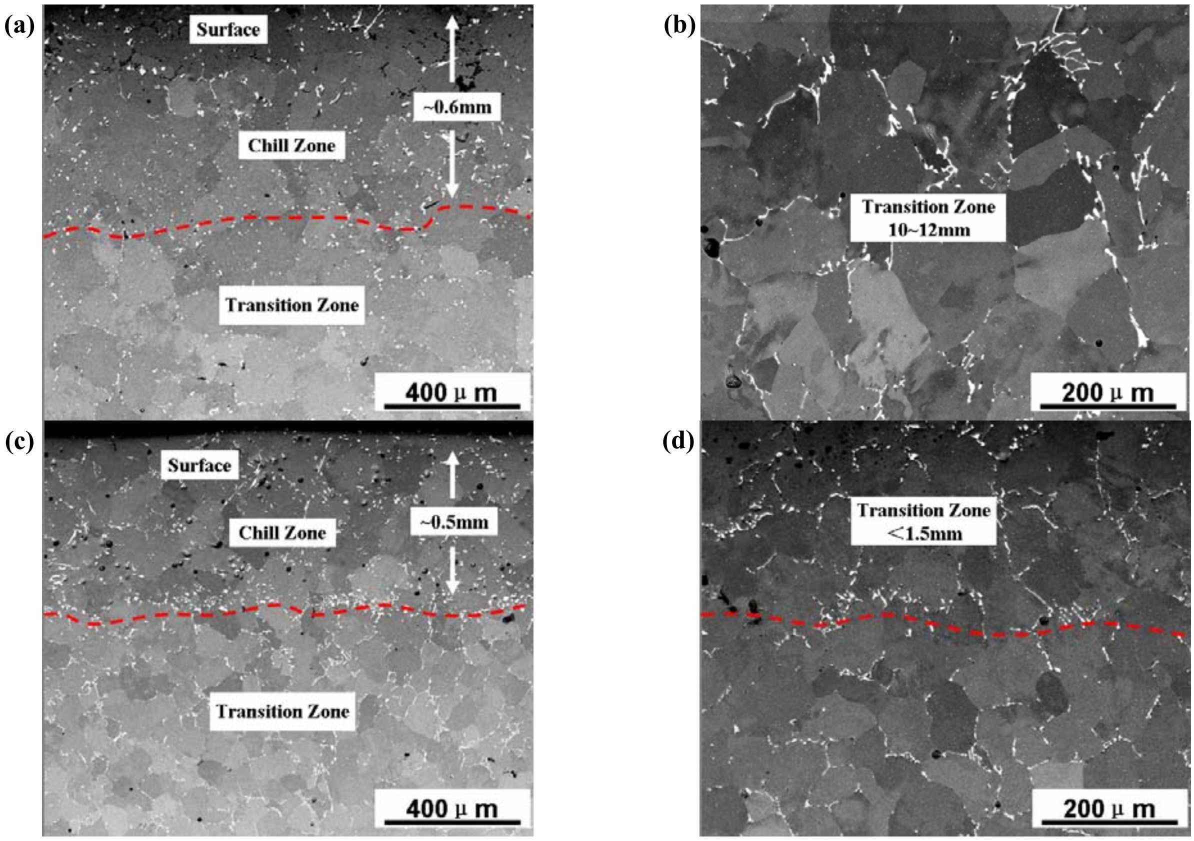

Fig.6 BSE immages of: different Zones in (a)～(b) DC-casting and (c)～(d) LHC-casting aluminum alloy AA3104 [9].

A control of the size and distribution of α-$Al_{12}(Fe,Mn)_3Si$ in AA3104 aluminum ingot is required during manufacturing. Most of the α-phases are transformed from $(Fe,Mn)Al_6$ during homogenization and the transformation happens from about 400℃ [2]. Two examples of a study on the phase transformation from $(Fe,Mn)Al_6$ to α-phases are shown in Fig.7[10]. It can be noted that the transformation (part transformation) will make boundaries between transformed and non-transformed phases, these boundaries seems weak during later rolling process thus promote the particle breaking up.

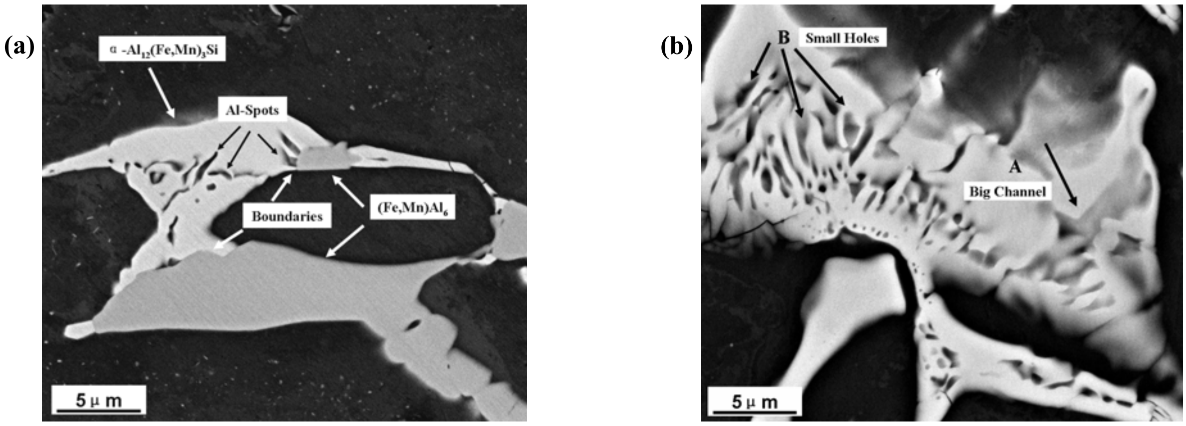

Fig. 7 BSE image of (a) partly transformed $(Fe,Mn)Al_6$ and (b) shape of Al-spots within α-phase [10].

Most of the dispersoids (usually AlMnSi particles), which have a strong effect on the recrystallization behavior of the alumimu alloys significantely, are precipitated from Al matrix during homogenization process. Fig. 8 shows two kinds of the precipitates, one is the long-rod like and another is the spot-like dispersoids. It was found that the the long-rod like ones usually distribute in one or two areas within a grain, while the spot-like dispersoids distribute uniformly within whole grain. For Mg containing AA3xxx alloys, the precipitation of Mg_2Si needles also make something different, slow heating-rate will let Mg_2Si needles to nucleate and precipitate firstly [11].

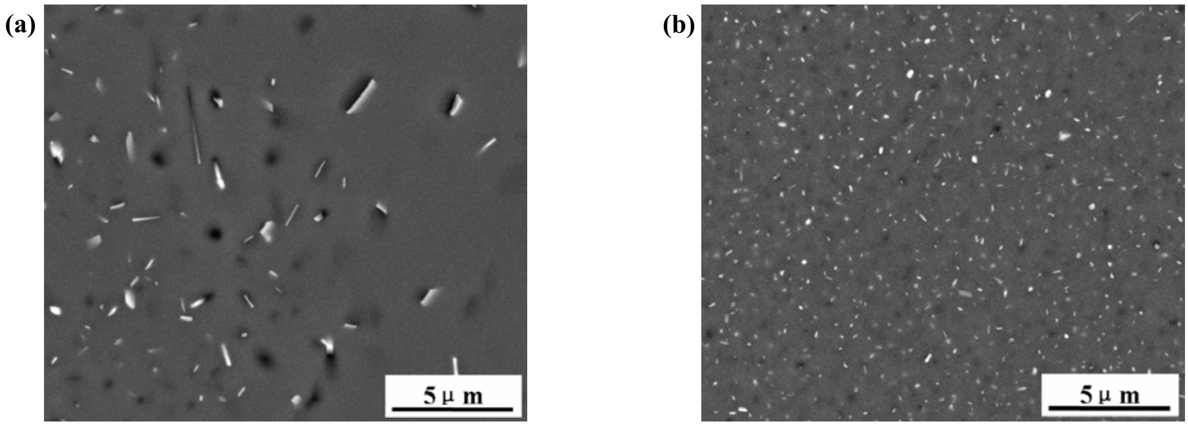

Fig. 8 (a) Long-rod like dispersoids, (b) spot-like dispersoids.

4.2. Microstructure evolution of AA1050 and AA3104 during cold-rolling

Large numbers of previous studies [12-16] on the evolution of dislocation boundary structure of alumium during rolling process have been carried out, although most of these studies have focused on pure metals. However, few studies on the evolution of the dislocation boundary structure of particle-containing alloys during cold rolling have been reported [17,18]. Upon deformation of a matrix containing large non-deformable particles, deformation incompatibilities occur at matrix/particle interfaces, and lead to the formation of so-called deformation zones around the particles [19, 20]. Only a limited amount of quantitative data concerning lattice rotations in deformation zones in particle-containing polycrystals has been reported.

Fig.9 shows the microstructure of AA3104 aluminum after hot rolled and its texture evolution during the subsequent cold-rolling to different reductions. Several types of the particles are present in the hot-rolled sample and the texture evolves into typical cold rolling deformation texture components of Brass+S+Copper with a intensity of the texture increase with the increase of strain.

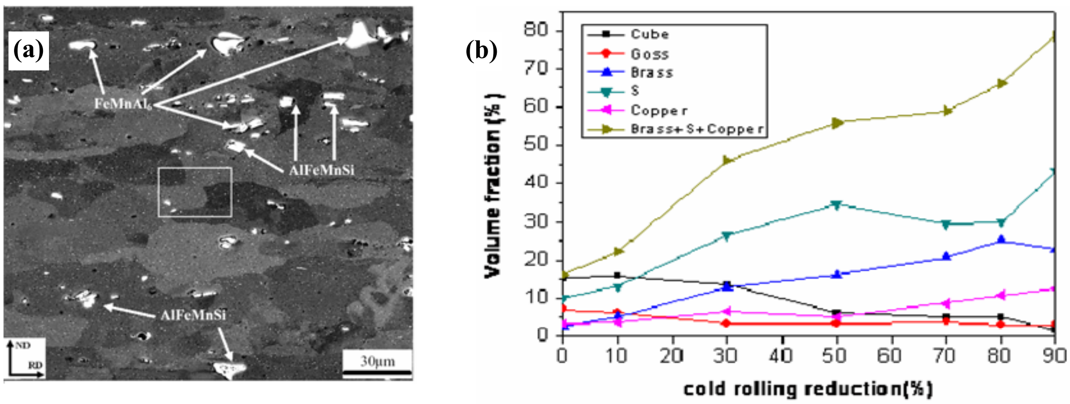

Fig. 9 (a) ECC image of undeformed AA3104, (b) texture evolution of AA3104 with different reductions.

The evolution of the dislocation boundary structure during the cold rolling of the AA3104 aluminum alloy has been investigated using electron channeling contrast (ECC) imaging and electron backscattered diffraction (EBSD) techniques [21]. It was found that there is a strong correlation between the dislocation boundary structure and the grain orientation. No strong effect of strain level or second-phase particles on the structure-orientation correlation is found. Based on these observations, the microstructures can be classified into one of three types: type A grains, containing two sets of geometrically necessary boundaries (GNBs), type B grains, containing one set of GNBs, and type C grains, consisting of a structure of large dislocation cells. Fig.10 shows examples of deformation microstructures of AA3104 aluminum alloy after cold-rolling to a reduction of 30%. Further more, the grains with different types of structure were identified by EBSD, and it was found that grains with a type A microstructure have orientations near the copper, brass, and Goss orientations; grains with a type B microstructure are primarily near the S orientation; and grains with a type C microstructure have orientations near the cube orientation. In fact, this kind of correlation between grain orientation and deformation structure is the same as that found in the cold-rolled pure aluminum [12]. In addition to the AA3104, similar results were found on cold-rolled AA1050 aluminum alloy [22, 23]. Fig. 11 shows the orientations of grains with different types of deformation structures.

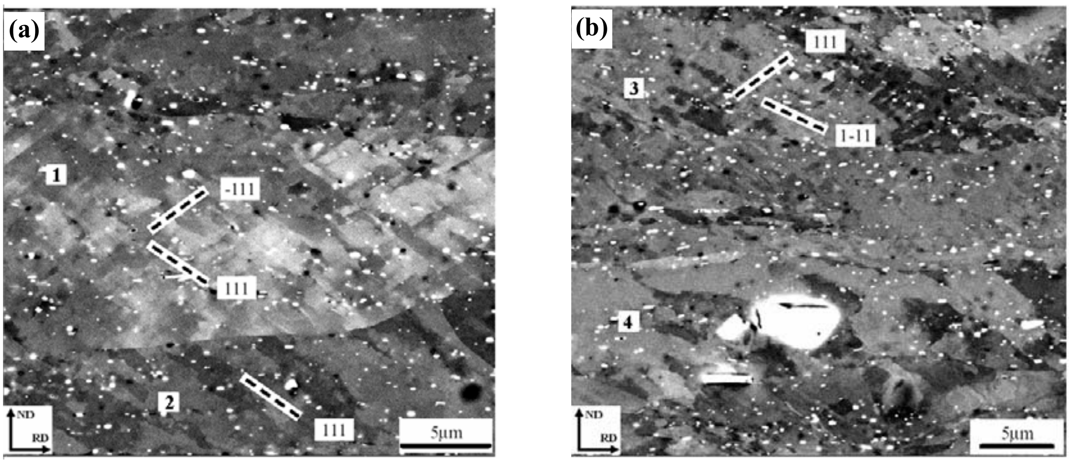

Fig. 10 Deformation microstructures of AA3104 alloy after 30 pct cold rolling reduction: Two sets of GNBs: grains 1 and 3; one set of GNBs: grain 2; and structure of large cells: grain 4 [21].

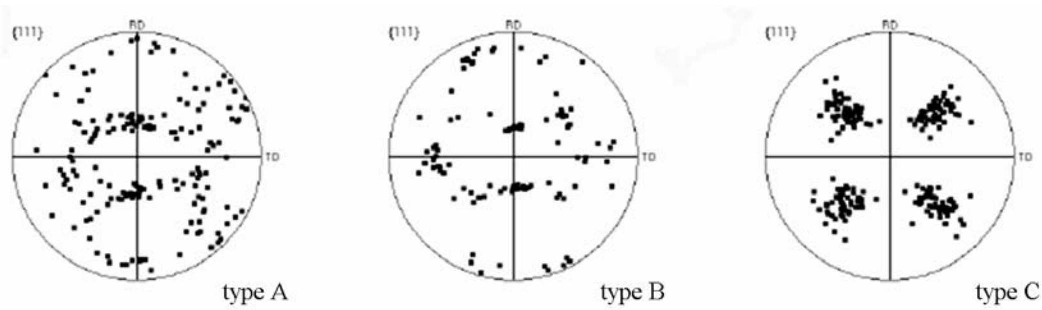

Fig. 11 The {111} pole figures of AA1050 aluminum alloy (125 grains) showing the orientation of grains with microstructures of: type A (two sets of GNBs), type B (one set of GNBs), and type C (large cell structure) [22].

With increasing strain, it was found that the microstructure evolves into a lamellar structure, within which most of lamellar boundaries (LBs) are parallel to rolling direction (RD). Two mechanisms contribute to the microstructure transition, i.e., a gradual reorientation of the cell–block boundaries toward to RD due to the cold rolling deformation (Mechanism I, which is the dominant importance) and the realignment of boundaries to RD as a result of the shearing introduced by S–bands structure (Mechanism II). During thses processes a significant number of high angle boundaries (HABs) are created. Fig. 12 shows deformation microstructures of AA3104 alloy after 90% and 96% cold-rolling[24].

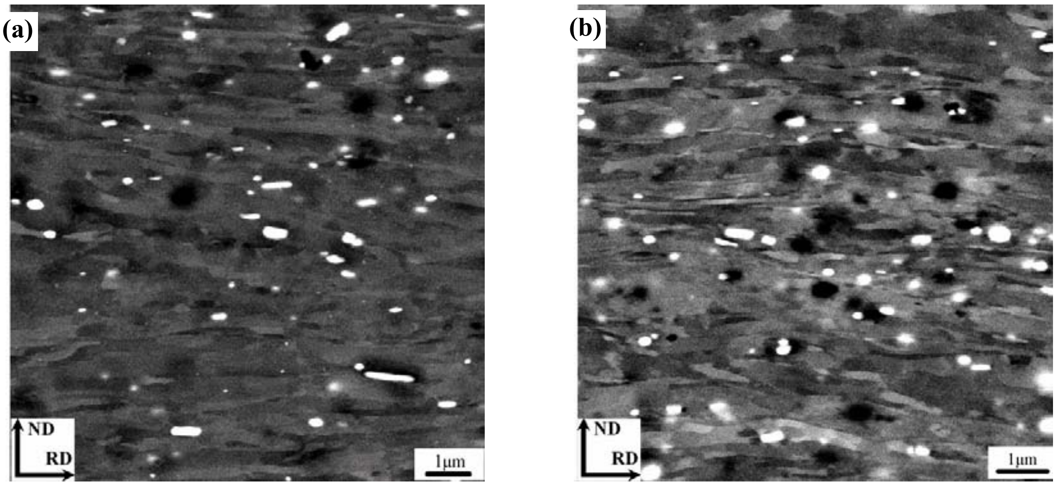

Fig. 12 Deformation microstructures of AA3104 alloy after (a) 90% and (b) 96% cold rolling[24].

It was found that the influence of the particles on the deformation microstructure depends on the particle size. Fine dispersoids have no clear effect on the grain orientation dependence of the dislocation structures. However, large scale structural heterogeneities, in the form of deformation zones, are formed near coarse constituent particles, leading to significant local distortions of the deformed microstructure. The EBSD data show that significant orientation gradients are developed in the deformation zones around large particles, within the deformation zones the largest lattice rotations occur at the tips of plate-shaped constituent particles, a typical example was shown in Fig.13 [25].

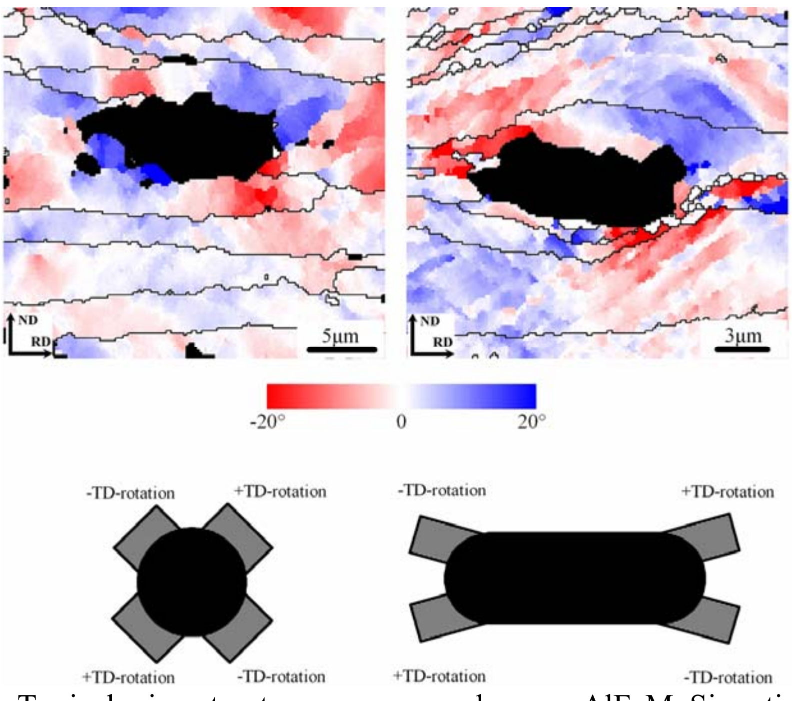

Fig. 13 Typical microstructures seen around coarse AlFeMnSi particles [25].

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