IOP Conf. Series: Materials Science and Engineering **230** (2017) 012037 doi:10.1088/1757-899X/230/1/012037

Study on Microstructure and Properties of 105mm Thick 5083 Aluminum Alloy Hot-Rolled Plate

Xinwei She[1,2], Xianquan Jiang[1,2,*], Bao Qi[2], Quan Li[1], Jiangyu Li[3], Jun Li[4], Zhende Ran[4]

[1] Chongqing Academy of Science and Technology, Chongqing 401123, China
[2] Faculty of Materials and Energy, Southwest University, Chongqing 400715, China
[3] Guangxi Liuzhou Yinhai Aluminium Co., Ltd, Guangxi 545006, China
[4] Chongqing Gearbox Co., Ltd, Chongqing 402263, China
*Corresponding author e-mail: 574754298@qq.com

Abstract. The microstructure and tensile property of 105mm thick 5083 aluminum alloy hot-rolled plate in different thickness layers were investigated by optical microscopy, scanning electron microscopy, transmission electron microscopy and tensile tests. The results show that along the thickness direction, the microstructure and tensile property are inhomogeneous, and a “double low” phenomenon, which has low strength and plasticity, occurs in the central area. There are many sub-micron sized second phases in the center and near-center area, which cause two completely different dislocation distribution states. they can effectively prevent the dislocation movement during plastic deformation, and improve the strength of the alloy.

1. Introduction

With the development of global industrialization, the requirement for mechanical properties of 5083 aluminum alloy thick plate become higher and higher. In order to meet the need of large deformation, a wider and thicker plates are produced. However, in actual manufacture, the larger the size is, the more difficult it will be. This is principally because the solidified structure is inhomogeneous for the existence of a large temperature gradient along the direction of thickness and width. At present, researches on 5083 aluminum alloy plate primarily focus on the microstructure, heat treatment process, and the relationship between deformation and properties[1-4], while there are few reports about the inhomogeneity of microstructure and properties, and no test standard for the performance of plates beyond 20mm thick at home. So, it is very necessary to carry out the research in this field, and improve the detection mechanism as soon as possible.

In this paper, the microstructure and tensile properties of 105mm thick 5083 aluminum alloy hot-rolled plate were studied to discuss the factors affecting the inhomogeneity, so that it can provide a theoretical basis for further improving the quality of 5083 aluminum alloy plate.

2. Experiments

The material used in this experiment is 2500mm×105mm(width×thickness) 5083 aluminum alloy hot-rolled plate with a free machining state, and its chemical composition is shown in Table 1.

Table 1. Chemical composition of 5083 aluminum alloy hot-rolled plate(mass fraction/%)

Elements	Si	Mg	Mn	Cr	Fe	All other element	Al
content	0.163	4.434	0.678	0.104	0.238	<0.05	Balance

First, take samples from one end of the plate to the center along the transverse direction, and sign as sample A, B, C and D, respectively. Then, equally divide each sample into ten pieces of blank-parts along the thickness direction, and number them from the top to the bottom, as shown in figure 1. Finally, make tensile specimens, according to the GB/T228-2002 standard.

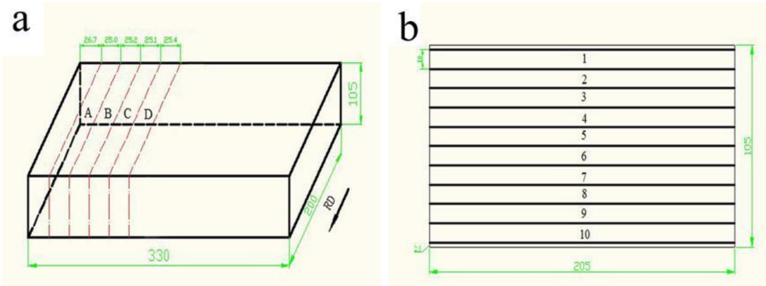

Figure 1. Sketch map of sampling:
a-hot-rolled plate; b-pre-stretching blanks along the sample thickness direction

The tensile tests are carried out at room temperature with a constant displacement rate of 1 mm/min to determine the average value of tensile strength, yield strength and elongation. Cut off metallographic samples from the clamped end of 1-5# tensile specimens, and have a observation on the metallurgical microscope and scanning electron microscope which equips with EDS. Take some wafers near the deformation zone of 4# and 5# tensile specimen, and have a microscope observation by Tecnai G2F20 transmission electron microscope after mechanical thinning.

3. Results and analysis

Figure 2 shows the microstructure of 5083 aluminum alloy. From the figure 2a~2e, the second phases and impurities are mainly distributed in the grain boundaries and elongated along the rolling direction. The phases precipitated in the surface layer of hot-rolled plate is small, dense and continuous, and those in the center is relatively large, dispersive and intermittent. The reason for the result is that in the beginning of hot rolling, the large deformation in the surface layer of plate and the cooling effect of rolling oil emulsion can make the second phase broken and prevent them from growing up suddenly by heat, and in the later period of rolling, the second phase in the center will grow up rapidly because of the high temperature. A further observation can be found the alloy is mainly composed of lamellar grains, which are also elongated along the rolling direction. From the figure 2f~2j, the grains in the center(position 5 in figure 1b) and near-center area(position 4) are nearly equiaxed, and the grain boundary edges are serrated, which means the partial recrystallization occurs in the hot rolling process, and the closer to the center, the greater the degree of recrystallization is.

figure 3 is the SEM image of 5083 aluminum alloy. it can be found that the alloy is composed of α-Al, (Fe, Mn)Al_6, $Al_{12}Fe_3Si$, and a little Mg_2Si via energy spectrum analysis[5]. The results of EDS analysis are shown in Table 2.

Figure 4 shows the dislocation distribution along the crystallographic direction $<111>_\alpha$ in the center and near-center area of 5083 aluminum alloy. It can be observed there are a number of sub-micron sized second phases, and a serious phenomenon of dislocation congestion in these areas. Through the energy spectrum analysis, it is found that these sub-micron sized second phases are mainly AlMg(Mn, Cr). The distribution of dislocation in the central area is very uneven, and approximately persents a characteristic of cell structure. While, the distribution of dislocations in the near-center area is uniform, and it is characterized as Taylor lattice distribution[6]. Comparing figure 4a and 4b, it is observed the number of the sub-micron sized second phase in the center of plate is less than that in the near-center, and the distribution of dislocation clusters is scattered, which may be the reason for the different distribution of dislocations in two adjacent areas.

According to the theory of plate rolling[7], the thicker the aluminum alloy ingot is, the larger the difference of deformation in different stages of hot rolling is. Generally, in the initial stage of rolling, the deformation mainly occurs in the surface layer of the plate. In this case, the dislocation motion

IOP Conf. Series: Materials Science and Engineering **230** (2017) 012037 doi:10.1088/1757-899X/230/1/012037

throughout the central area of the plate is mainly planar slip, and the dislocation state presents Taylor crystal lattice distribution, as shown in figure 4b. In the later period of rolling, deformation is deep into the central area. At this point, dislocation motion is dominated by dislocations climb and cross-slip, and cell structure starts to appear. However, taking into account the partial recrystallization, the opposite sign dislocations cancel out in the cell wall, which results in the weakening of the characteristic of cell structure, as shown in figure 4a.

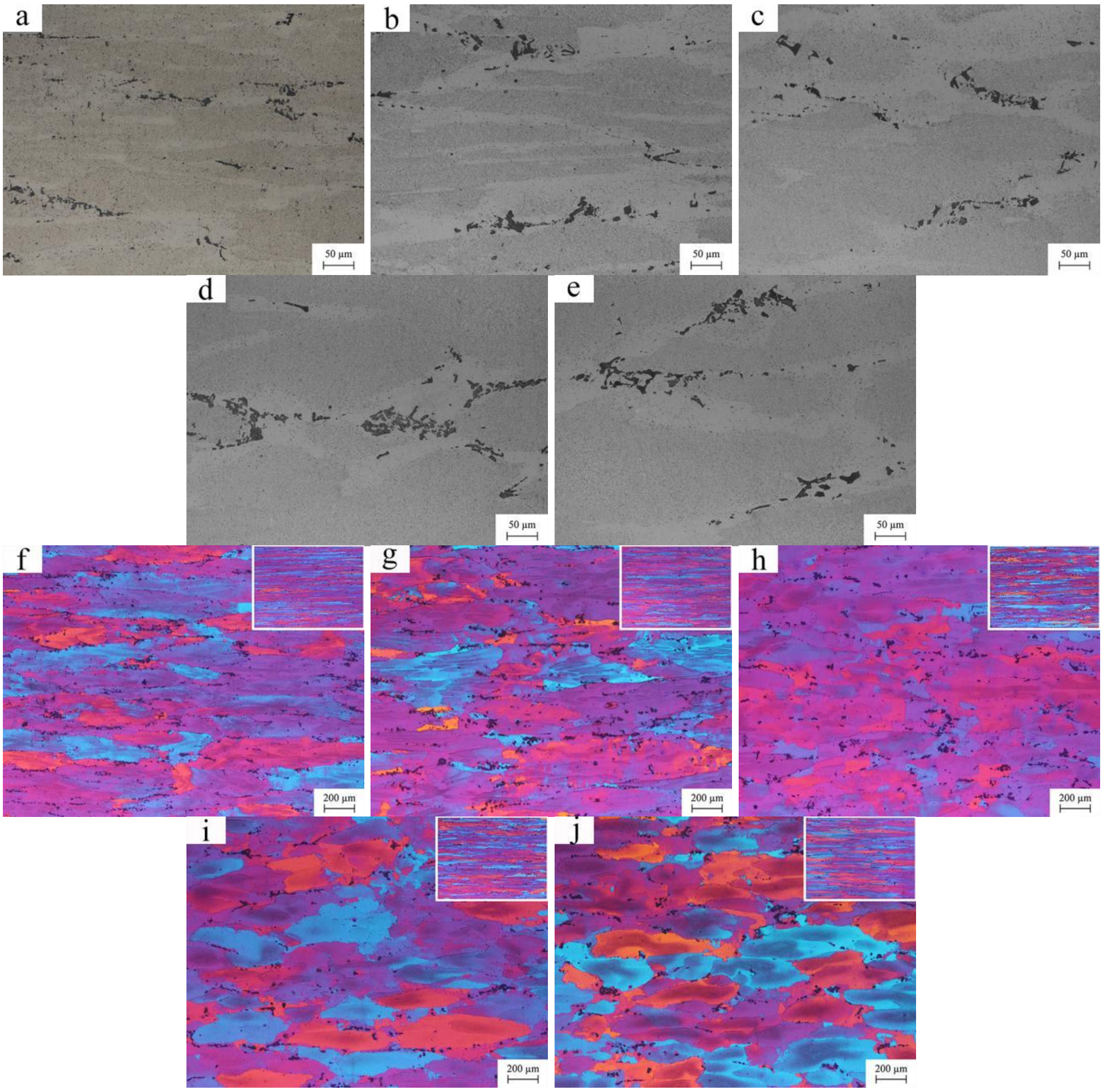

Figure 2. Microstructure of 5083 aluminum alloy: a~e-the second phase precipitation of 1~5# postion; f~j-grain structure of the corresponding postion and grain distribution of the longitudinal section

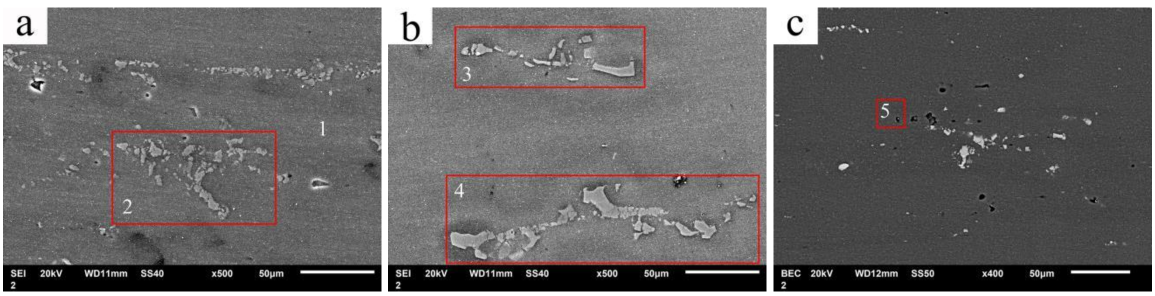

Figure 3. Primary second phases of 5083 aluminum alloy:
a-matrix and skeleton phase; b-irregular-shape phase; c-lump phase

Table 2. EDS analysis of the second phase of 5083 aluminum alloy(atomic/%)

Elements	Al	Mg	Mn	Cr	Fe	Si	Cu	S
1	94.88	5.12	/	/	/	/	/	/
2	87.70	0.98	4.48	0.43	6.41	/	/	/
3	79.12	/	6.23	1.04	8.82	4.79	/	/
4	78.67	/	6.23	0.55	9.25	5.30	/	/
5	38.34	41.48	0.24	0.79	/	19.15	/	/

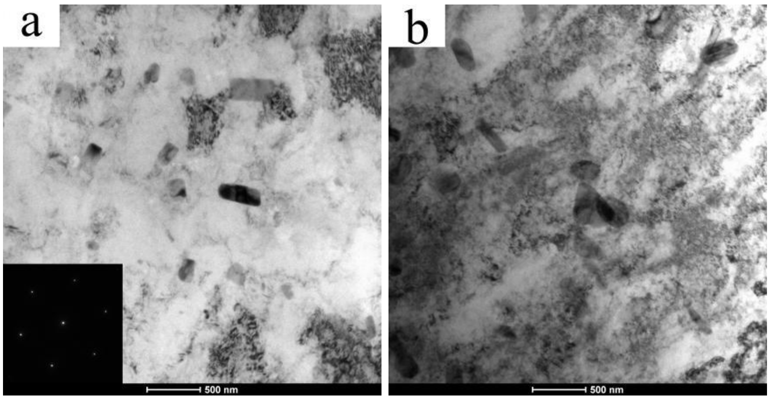

Figure 4. TEM images of 5083 aluminum alloy: a-the central area; b-the near-center area

Figure 5 is the conventional tensile properties of 5083 aluminum alloy hot-rolled plate with different thickness. Along the rolling direction, the tensile properties in different thickness layers are uneven. From the surface to the center, the strength of the plate shows a trend of declining-rising-declining, and the elongation increases at first, then decreases. In particular, a “double low” phenomenon, which has low strength and plasticity, occurs in the central area.

Compared with the high strength of the plate in the near-center area, there are two important reasons for the decrease in the center. On the one hand, the second phase in the central area is more coarser and easy to cause stress concentration. Meanwhile, a large number of inclusions and voids can reduce the effective area of the external load[8, 9]. On the other hand, recrystallization occurs in the hot rolling, which makes the microstructure softening.

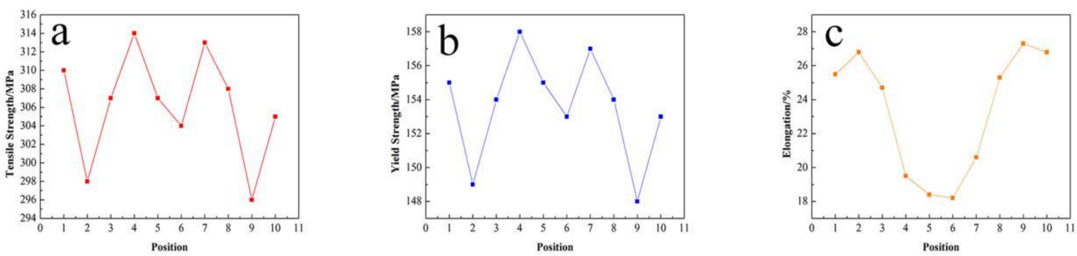

Figure 5. Conventional tensile properties of 5083 aluminum:
a-tensile strength; b-yield strength; c-elongation

From the interaction between dislocations and particles[10], when dislocations meet a couple of particles that are close to each other, they will not be able to cut through these paticles at the same time, and can not be back, so turn to be local bending, and eventually trapped by these particles,

IOP Conf. Series: Materials Science and Engineering **230** (2017) 012037 doi:10.1088/1757-899X/230/1/012037

forming a relatively independent "inner packing" dislocation group, as shown in figure 4a. The experimental results show that the effect of recrystallization on the elimination of dislocation groups is weak. The size of the dislocaiton group is much bigger than that of a single particle, therefore, it has a weak blocking effcet on the dislocation motion. This dislocation group is easier to cause stress concentration, resulting in a decrease in the strength of the plate.

4. Conclusions

(1) The microstructure and and tensile property of 5083 aluminum alloy hot-rolled plate along the thickness direction is inhomogeneous. The "double low" phenomenon appears in the center of the plate with low strength and low plasticity.
(2) there are two important reasons for the appearance of the "double low" phenomenon: on the one hand, a larege number of coarse phases and impurities gathered in the central area, and on the other hand, recrystallization in this area is severer.
(3) There are a number of sub-micron sized second phases throughout the central area, they have a precipitation strengthening effect on the 5083 aluminum alloy hot-rolled plate. However, in the center of the plate, dislocations are trapped by these particles and formed a relatively independent "inner packing" dislocation group, resulting in a decrease in the strength.

5. References

[1] Y. Chen, H. Ding, J.Z. Li, Z.H. Cai, J.W. Zhao, W.J. Yang, Influence of multi-pass friction stir processing on the microstructure and mechanical properties of Al-5083 alloy, Mater. Sci. Eng., A 650 (2016) 281-289.
[2] S.L. Xia, M. Ma, J.X. Zhang, W.X. Wang, W.C. Liu, Effect of heating rate on the microstructure, texture and tensile properties of continuous cast AA5083 aluminum alloy, Mater. Sci. Eng., A 609 (2014) 168-176.
[3] K. Masaki, H. Matsuoka, Y. Murakami, N. Oiwa, Effect of post-weld heating on microstructure and mechanical properties of friction stir welded thick 5083 Al alloy, Proc. 1st Inter. Joint Symp. Joining Weld. (2013) 165-168.
[4] D. Singh, P.N. Rao, R. Jayaganthan, Effect of deformation temperature on mechanical properties of ultrafine grained Al-Mg alloys processed by rolling, Mater. Des. 50 (2013) 646-655.
[5] Z.T. Wang, R.Z. Tian, Handbook of aluminum alloys and their processing, Central South University Press, Changsha, 2000, pp. 292-310.
[6] Z.G. Wu, M. Song, Y.H. He, Effects of rare-earth element Er on microstructure and mechanical properties of an Al-Mg alloy, Mater. Sci. Eng. Powder Metall. 181 (2008) 2262-2266.
[7] L. Zhong, Y.Y. Ma, Y.C. Xie, Production technology of aluminum alloy plate, Metallurgical Industry Press, Beijing, 2009, pp. 52-53.
[8] X.M. Zhang, N.M Han, S.D. Liu, F.X. Song, R.L. Zeng, L.Y. Huang, Inhomogeneity of texture, tensile property and fracture toughness of 7050 aluminum alloy thick plate, Chin. J. Nonferrous Met. 20 (2010) 202-208.
[9] G. Ran, J.E. Zhou, Y.F. Wang, Study on tensile properties and fractography of cast A356 aluminum alloy, Rare Metal Mat. Eng. 35 (2006) 1620-1624.
[10] D.K. Shi, Fundamentals of materials, China Machine Press, Beijing, 2003, pp. 338-341.

Acknowledgements

The authors would like to thank the International Science & Technology Cooperation Program of China under grant No. 2011DFR50950 and Liuzhou Science and Technology Plan Project under No. 2015C020101.