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Microstructure Analysis on 6061 Aluminum Alloy after Casting and Diffuses Annealing Process

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Abstract

One factory using semi-continuous casting process produce the ϕ200×6000mm 6061 aluminium alloy barstock, and then rotary forged for car wheels. 6061 distorting aluminium alloy is an forged aluminum alloy, and mainly containing Mg, Si, Cu and other alloying elements. The main strengthening phase is Mg2Si, and also has few phase of (FeMn) 3Si2Al15. In order to eliminate the segregation and separation which present in the crystal boundary, and make the distortion to be uniform, and does not present ear and fracture defects after the forging. So the 6061 distorting aluminium alloy adopt the diffusion annealing heat treatment before the forging process.According to the current conditions, we use the diffusion annealing which have the different heating temperature and different holding time.The best process we can obtain from the test which can improve the production efficiency and reduce the material waste, improve the mechanical properties, and eliminate the overheated film on the surface.Then,we using OM,SEM and EDS to analyse the microstructure and the chemical composition of compound between the surface and centre. The result shows that the amount of segregation were different in the surface and in the center, and the different diffusion annealing can cause the phase change in the surface and the center.

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Keywords: distorting aluminium alloy; rotary forged ;strengthening phase; diffusion annealing

1. Introduction

One factory using semi-continuous casting process produce the Φ200 × 6000mm 6061 distorting aluminum alloy barstock,and then rotary forged for car wheels. The factory uses the diffusion annealing heat treatment before forging process, which to make the distortion to be uniform and does not present the defects like ear and fracture.

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The commonly heating temperature of diffusion annealing were 570℃, and then keep the temperature 4~6h. But large numbers of ears and fracture defects present after the forging,and can not satisfies the practical requirements. In order to solve this problem, we increased the heating temperature to 573 ℃ and keep the heating temperature 8h, which no longer present the ear and fracture defects after the forging process.However, this heat treatment cycle is too long, and the surface present 0.7~0.8mm overheated film and increasing the forging margin, which cause the material waste and can not meet the production needs.Therefore, according to the current conditions, we using the different heating temperature and different holding time for diffusion annealing, in order to obtain the best process which can improve the production efficiency and reduce the material waste, improve the mechanical properties, and eliminate the overheated film on the surface.Then,we use optical microscope,SEM and EDS to analyse the microstructure and the composition of compound which in the 6061 aluminum alloy. The result shows that the amount of segregation were different in the surface and in the center after the casting process, and the different diffusion annealing can cause the phase change. Through the principle of phase change during the diffusion annealing,we obtained the best process.

2. Testing materials and chemical composition

We use the direct-reading spectrometer to test the 6061 aluminum alloy chemical composition of barstock.The testing chemical composition result and the national standard were show in the Table 1.From the Table 1,we can see that the main elements in the 6061 aluminum alloy are within the national standard.

Table 1. Chemical composition of 6061 aluminum alloy（wt％）

Element	Cu	Fe	Mg	Si	Mn	Cr	Zn	Ti	Al
Test	0.21-0.23	0.22	1.05-1.1	0.73-0.76	0.07	0.11-0.12	0.005	0.017	allowance
GB	0.15-0.4	0.7	0.8-1.2	0.4-0.8	0.15	0.04-0.35	0.04-0.35	0.15	allowance

3. Experimental process and equipment

The test need to cut the casting rods into specimen(Φ200 × 15mm) and test bars(Φ200 × 250mm), use the heating temperature of per 5℃ from 555℃ ~ 610℃ and select two holding time 4h and 6h. Then analyze the microstructure and the mechanical properties of the specimen(Φ5mm).Because aluminum alloy is very sensitive to temperature,so when the metallographic microstructure and mechanical properties meet the requirements,we selected the good diffusion annealing heat treatment we have obtained before, and change the heating temperature ± 2℃ for different holding time 3h, 4h, 5h, 6h, 7h, 8h in order to obtain accurate diffusion annealing process.

4. The analysis and discussion of the results

The 6061 aluminum alloy belongs to one kind of wrought aluminum alloy. The main chemical composition have elements such as Al,Mg,Si,Cu.The main strengthening phase is Mg2Si and has small number of（FeMn）3Si2Al15 and CuAl2 phase. The 6061 aluminum alloy may present some impurity phases such as AlMnFeSi, AlFeSi and AlCrFeSi(Zhang Ming-qiang,2008) .

When the percentage of copper is small and the ratio of Mg and Si is 1.73, the main strengthening phase is Mg2Si, and all copper melt in the base. If the percentage of copper are much more and the ratio of Mg and Si is less than 1.08 ,there may form ω phase (Al4CuMg5Si4).When the ratio of Mg and Si beyond 1.73, there may be have θ phase (CuAl2) and S phase (Al2CuMg).The above three-phase in the structure can partly dissolved and have strengthening function, but the effect is small compared to the phase of Mg2Si.

Table 1,as the ratio of Mg and Si is 1.433 which less than 1.73, it's main phases are α-Al+Mg2Si+Si(Zhang Ming-qiang,2008;Xiao Ya-Qing,2005;Li Jiong-hui,etc.,2007),and the eutectic point of the alloy is 577℃,and the eutectic point of α-Al + Mg2Si is 595℃.Because of the percent of Si element in the aluminium alloy is higher,so the blue grey and polygonal of primary phase become chip shape.The structure may be present phase of

(FeMn)Si2Al15,which have the needle shape and light metal gray before erosion.The phase of Mg2Si have bone shape and has become light blue before erosion(Tian Rong-zhang,2006;Wang Qun-jiao,2008;Sun Ye-ying,2003).

4.1. Original structure of 6061 aluminum alloy

Using Φ200 × 6000mm 6061 aluminum casting rods, we cut the specimen from surface and centre.Then we examine the structure after the following process of polishing and 0.5% HF corrosion.

Fig.1 shows the chilled surface area of the casting rod, Fig.2 shows the grain shape in the center after the deep corrosion.The base structure have white light α- Al phase,and have the precipitates both inside and outside of the grain. The grain has the same equiaxed shape in the surface and center.

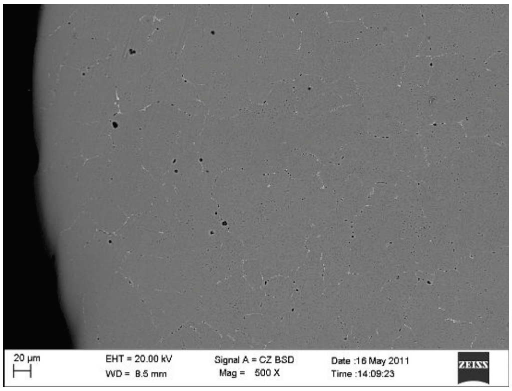

Fig.1 the chilling zone of surface 500×

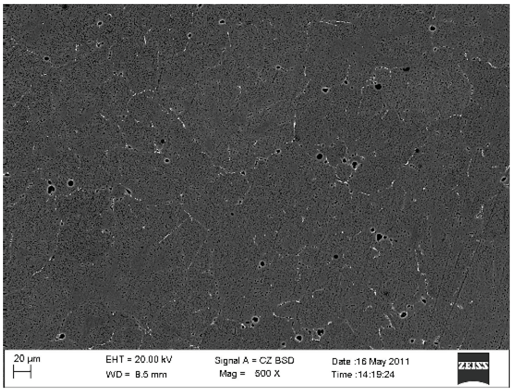

Fig.2 the central crystal zone 500×

Fig.3, Fig.4, Fig.5 are the surface structure.From the Fig.3,there are Mg2Si phase which have the bone-like shape and the impurity phase FeMnSiAl. Fig.4 was the EBSD image, which has the white needle-like phase.From the Fig.5,we can see the chip si phase in the bone-like structure. Use SEM electron spectrum analyse the chemical composition of needle-like compounds(Fig.6), shows that the compound was the FeMnSiAl impurity.

Fig.7, Fig.8, Fig.9 are the central structure which have less Mg2Si, FeMnSiAl compounds and chip si phase than in the surface. The present of bone-like Mg2Si and needle FeMnSiAl will reduce the plasticity of the aluminum alloy. Diffusion annealing can improve the characteristics.But,different heating temperature and holding time have different effect.

4.2. Structure change after the diffusion annealing of aluminum alloy

The heating temperature are 555 ℃ and keepg 6 hours, bone-like Mg2Si partly reserved and needle FeMnSiAl impurity compounds still exist (Fig.10). The heating temperature are 565 ℃ and keep 6 hours, bone-like Mg2Si basicly disappeared and melting into the base, and needle FeMnSiAl compounds have a tendency to fuse(Fig.11).

Heated by 570 ℃ and keep 6 hours, needle FeMnSiAl compounds become the intermittent network pattern(Fig.12).

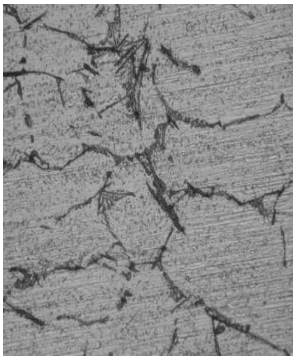

Fig.3 the Mg2Si phase of surface

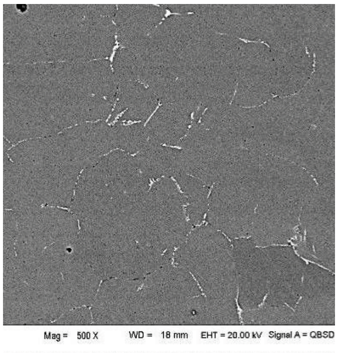

Fig.4 the FeMnSiAl phase of surface

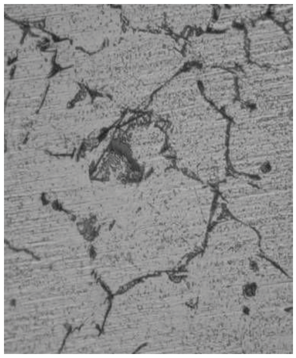

Fig.5 the flake of Si

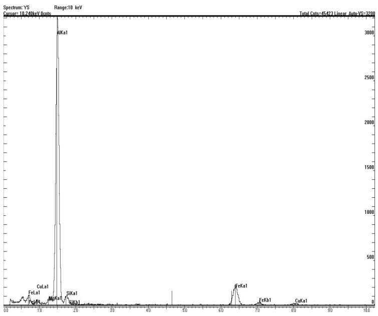

Fig.6 EDS spectra

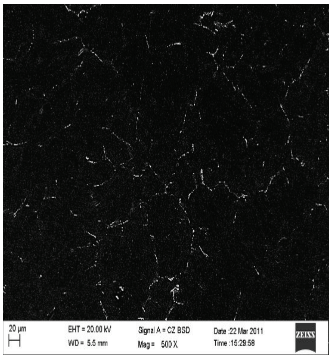

Fig.7 the central phase of Mg2Si 500×

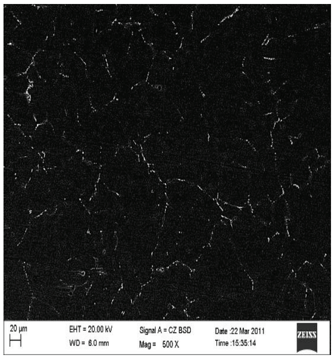

Fig.8 the central phase of FeMnSiAl 500×

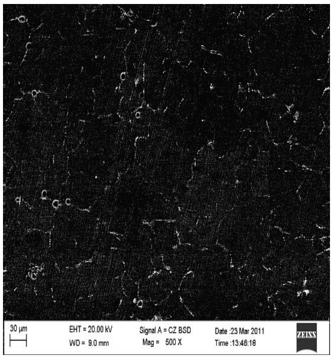

Fig.9 the central phase of flake Si 500×

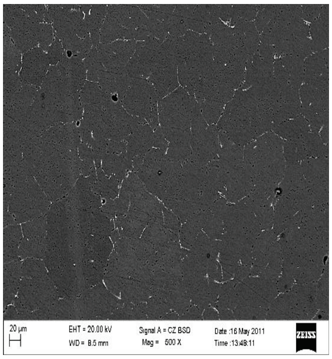

Fig.10 the central phase of Mg2Si,FeMnSiAl

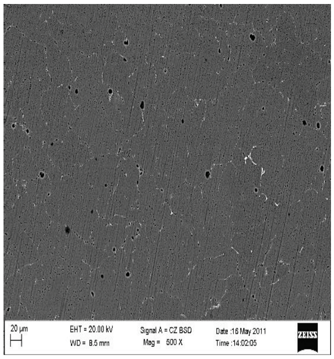

Fig.11 the central phase of Mg2Si,FeMnSiAl

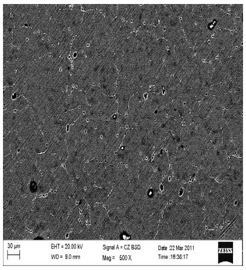

Fig.12 the central phase of

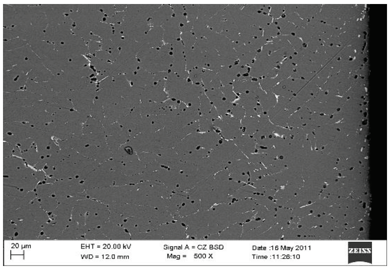

Fig.13 the dot shape of FeMnSiAl in FeMnSiAl 500×

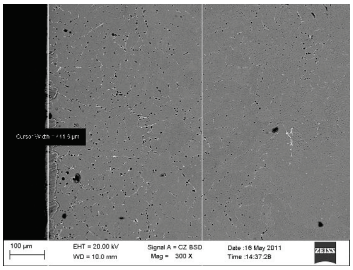

Fig.14 the overheated structure of surface central

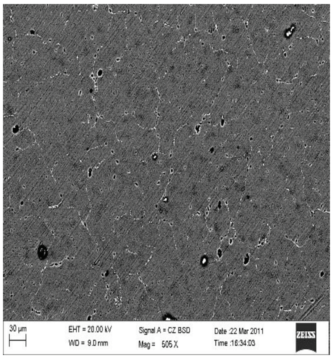

Fig 15 the dot shape of FeMnSiAl

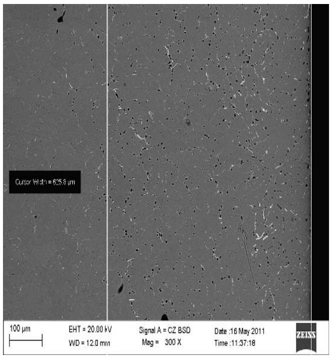

Fig 16 the overheated structure of surface

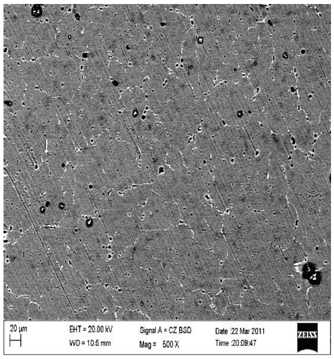

Fig 17 the central hole

Continue to increase the heating temperature to 573 ℃, keep 6 hours,there are a further improving for the patterns of needle FeMnSiAl compounds(Fig.13).We can view the overheated film approximately 0.4mm on the surface(Fig.14).

When the heating temperature increased to 575℃,needle FeMnSiAl compounds basicly become dots(Fig.15). Overheated film has increased to 0.6mm(Fig.16). Heated by 580℃,there are some holes in the central part,which were formed after some of the compounds melting into the base (Fig.17).

Heated by 585℃, overheated film has increased to 1mm.Needle FeMnSiAl impurity compounds basicly become dots(Fig.18). The EBSD images(Fig.19). Use SEM electron spectrum analyse the chemical composition of the dot compounds. And compared with Fig.6, percent of Si and Mg decreased, Fe element increased,which indicated that Mg2Si has melted into the base, and the remaining compounds should be FeMnSiAl .

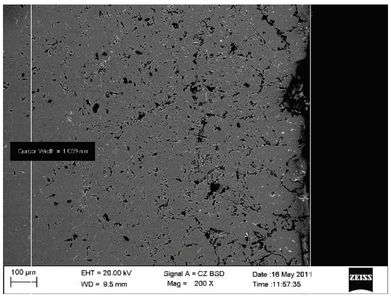

Fig 18 the dot shape of FeMnSiAl

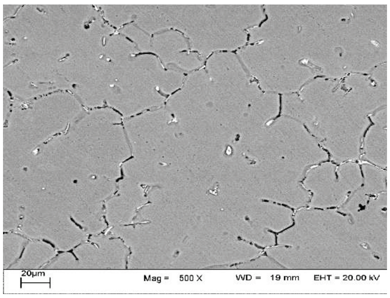

Fig 19 the dot shape of FeMnSiAl

Heated by 595℃, overheated film has increased to 1.2mm. The central part around the grain boundary present the white ribbon area(Fig.20). Part region also appear the layered tablets structure (Fig.21). The temperature(595 ℃) is close to the eutectic point of α-Al+Mg_2Si, so appear the eutectic structure.

Heated by 605℃, overheated film has increased to 1.5mm.There are holes and triangular grain boundary in the center (Fig.22). Heated by 615℃, the surface has been overheated seriously(Fig.23). Center of the grain boundary has been widen, and there were eutectic structure, triangle grain boundaries and re-melting ball,all which shows a comprehensive overheated phenomenon(Fig.24).

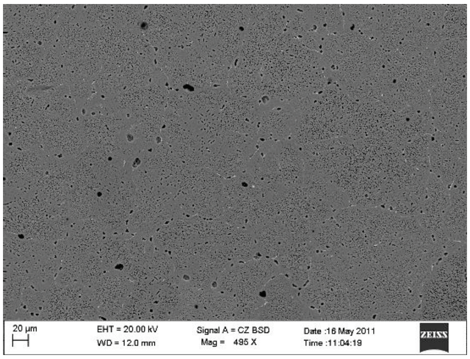

Fig 20 the white zone in central 500×

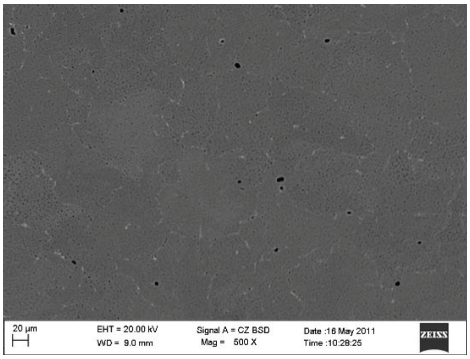

Fig 21 the eutectic microstructure zone in central 500×

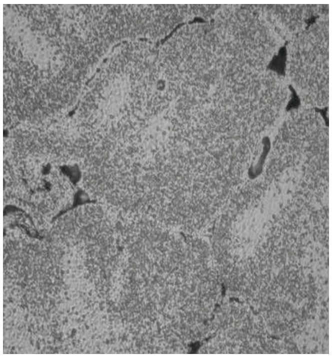

Fig 22 the triangular grain boundary in central

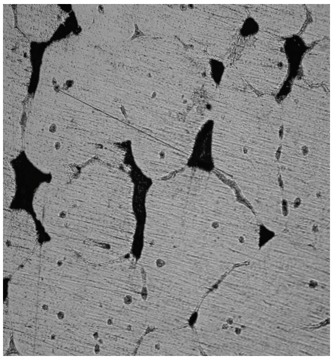

Fig 23 the overburned structure in surface

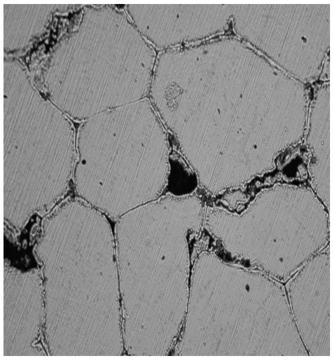

Fig 24 the eutectic belt in central

Experiment shows that the chilling film of the surface of the specimen and test bars began to present overheated film from 573℃.With the increasing of the temperature,the status of overheating become serious.Centre structure have changed, particles have tendency to grow up which from the inside of grain, compounds within the grain begin to dissolve, part of the needle-like compounds began to fuse along the grain boundaries (575 ℃). As the temperature increases further, most of the high melting point compounds dissolved within the grain,grain boundaries gradually disappeared,the part around the grain boundary melted into the particle becoming white ribbon.

Temperature increasing to 585 ℃, holes began to appear within the grain. Temperature increasing to 595 ℃ ,needle-like compounds basicly become particles.Tensile strength and elongation reach the requirements of forging performance.But the chilling film and overheated film do not meet the requirements of production quality.Temperature increase to 605 ℃ ,grain boundaries began to melt,the melting ball and the triangle grain boundary appeared.Temperature increasing to 610 ℃, the specimen softened.

4.3. Diffusion annealing of the 6061 aluminum alloy

6061 aluminum alloy is mainly used for forging parts. According to the requirements for parts, the casting rods need to have a lower tensile strength and good plasticity(Aluminum test standard[M],2008;Ding Hui-lin,Xin Zhi-hua,2007;ZHANG Hongwen et al.,2002).To improve forging performance, eliminate ear and crack defects after the forging process and make the plastic deformation uniform.The aluminum alloy must be diffusion annealed after casting.Diffusion annealing is designed to eliminate grain segregation and precipitates in the grain boundaries.And make the structure become uniform in the base,and the elements precipitated from solid solution.Ultimately,it can achieve the purpose that eliminating the stress, improving the plasticity and reducing the deformation resistance.

In the process of diffusion annealing, the atomic diffusion is mainly happen in the grain which can only eliminate grain segregation and has little effect on the regional segregation. As the diffusion annealing is carried out in the temperature of below the eutectic line, the insoluble material and non-metallic inclusions between the grains can not eliminate by the process of dissolution and diffusion(DAI Xiao-yuan et al.,2010). But diffusion annealing can dissolve and diffuse the metal compounds and the strengthening phase which enriched in the grain boundaries, and make the solid solution precipitate and diffuse,and make the structure uniform and improve the machining performance(NAGA R P et al.,2007).

In order to accelerate the uniform,we can increase the temperature of diffusion annealing which is commonly 0.9-0.95Tm or below the temperature of eutectic melting point 5-40℃ of the alloy(LIU Wen-jun et al.,2010). The 6061 aluminum alloy melting temperature is 652℃ and solid phase temperature is 582℃,so do not exceed the overhested temperature of 6061 aluminum alloy(580-582℃)(LIU Wen-jun,ZHANG et al.,2010). The reference shows that the melting point of Mg_2Si is 575℃,eutectic temperature of α-Al+Mg_2Si is 575℃, melting point of Mg_5Al_8 is 452℃, eutectic temperature of Al-Si is 577℃, eutectic temperature of Al+$CuAl_2$ is 547℃, melting point of $CuAl_2$ is 591 ℃.Low melting point eutectic structure melt is the over-burning. After over burning,the mechanical properties, fatigue and corrosion of the alloy can be reduced(BUHA J et al.,2008). An over-burning production can not be eliminated through heat treatment and machining,so it will become waste. But as for light burning, because of more fully solid solution about the second phase, over-burning things are very small and grain boundary has not been damage widly,the mechanical performance improved(WU L M, WANG W H, HSU Y F, 2008).

Through the above analysis,the overheated temperature of 6061 aluminum alloy is 582 ℃.The plasticity improving with the increasing of the temperature until 595℃But the surface appeared small overheated film in 583 ℃,so this temperature can not be adopt(ZENG Bin et al.,2008;Wang Zhixiang et al.,2010;You Yuping et al.,2011).This experiment use double level uniformity processing, the first level temperature is 570℃, and keep 4 hours,which can fully dissolve and diffuse the compounds on the surface of grain boundaries; the second level temperature is 575 ℃ and keep 2 hours which can make center structure fully uniformity,improve plasticity,and the surface do not appear the over-burning, and have an satisfactory effect(Sun Dong li et al.,1999;Li Z, Morris J G, Ding S X et al.,1992;LI Qinglin et al.,2010).

5. Conclusion

Through the reserach of the original structure and the structure change after the diffusion annealing of the 6061 aluminium alloy,we deeply analyse the features of compounds and the process of the diffusion,which provided fundamental theories for the production process of the diffusion annealing(GE Liang-qi,2007). This test successful obtained the parameters of the diffusion annealing process, eliminate the defects after the forging such as ear and crack,and reduce the production cycle of diffusion annealing process, and solved the overheated problem on the surface.It will be reduce the cost,improve the mechanical properties,improve the production efficiency and research a new kind of diffusion annealing heat treatment process of the 6061 aluminum alloy .

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