Combination of Superior Strength and Excellent Ductility of Al-3%Cu Alloy with Homogeneous Layer and Lamella Structure

Ruirui Wu [1], Fang Wang [1], Huiqin Chen [1]
1. School of Materials Science and Eng ineering, Taiyuan University Of Science and Technology, No.66 Waliu Road, WanBailin District, Taiyuan city, Shanxi Province, China
*Corresponding address: No.66 Waliu Road, WanBailin District, Taiyuan city, Shanxi Province, China
e-mail: 2018016@tyust.edu.cn

Abstract: A non-uniform layered Al-3%Cu composites was prepared by diffusion bonding process. First, Al-3%Cu alloy sheets with diameter of 15 mm and thickness of 1 mm prepared by cold rolling (CR) and cold rolling + annealing (AR) was alternately superimposed into a cylindrical specimen. The cylinder was then thermally compressed by a thermal simulator, and finally hydraulically compressed into 1 mm Al-3%Cu alloy composites with non-uniform layered structure. The composites were annealed at 200 ℃, 250 ℃, and 300 ℃ respectively for 3h. The results show that the coarse crystal in the soft zone (AR) of Al-3%Cu alloy with non-uniform layered structure is the basis of plasticity. After annealing at 200 ℃ for 3h, the proportion of hard region (CR) in the non-uniform region is the highest, and the hard region can limit the geometric necessary dislocation (GND) generated in the soft region to the greatest extent, resulting in large strain gradient and non-uniform deformation induced stress. Simultaneously, the additional work hardening and the precipitated θ′ and other secondary phases resist dislocation slip and increase the strength. The uniform elongation increases by 97.4%, from 3.8% to 7.5%, compared with that of the unannealed specimens. Meanwhiles, the strength remains almost unchanged, from 311.07 MPa to 308 MPa, means that the comprehensive mechanical properties are improved.

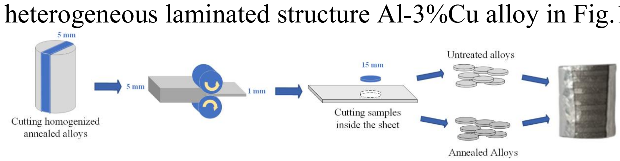
Keywords: Al-3%Cu alloy; anneal; geometric necessary dislocation; mechanical properties

1 Introduction

As an excellent lightweight material, aluminum-copper alloy has become an irreplaceable material in the aerospace and automotive industries because of its high strength and high stiffness [1-4]. However, with the improvement of industrial development level and innovation awareness, from the previous single pursuit of high strength to plasticity, strength, fatigue resistance and other aspects of excellent characteristics, the traditional structure of aluminum-copper alloy has gradually not met people's needs.

2 Experimental procedure

The as-cast Al-3%Cu alloy was homogenized at 500 ℃ for 24h, and then cut into 10 ×8 ×5 mm sheets. A sample of 1 mm thickness was obtained by 80% cold rolling (CR), and the sample was annealed at 575 ℃ for 1h after cold rolling (AR). The CR and AR discs are alternately laminated into a cylinder, the total number of layers in the cylinder is odd, and the middle layer is CR. The preparing processes of heterogeneous laminated structure Al-3%Cu alloy in Fig.1.



3 Result and discussion

microstructure

The dislocation density of Al-3%Cu alloy with non-uniform layered structure decreases during annealing without changing the grain morphology. The subsequent nucleation of the grains is not simultaneous, and the growth rate is different, resulting in a significant change in the size of the new grains, and two types of regions, soft and hard. The soft zone is the aggregation of coarse grains with a grain size greater than 1 μm after annealing. Meanwhile, the hard area is the aggregation of ultra-fine grains due to severe deformation [28].

Fig. 2 is a metallographic microstructure of the non-uniform layers under different annealing conditions of Al-3%Cu alloy. The visibility of the interface layer with a uniform contrast expression as smooth connection without micro-holes and cracks. It shows that during the preparation and annealing process of non-uniform layered structure of Al-3%Cu alloy, the integrity of the interface is maintained reasonable, and there is the continuous interface layer forming between the soft and hard area, thus, the boundary is obvious. Fig.2(a) shows the non-uniform layered of Al-3%Cu alloy without annealing. The surface of CR and AR layers is rough, and the second phaseAl2Cu on the surface is less precipitated. Fig.2(b) shows the non-uniform layered of Al-3%Cu alloy annealed at 200 ℃ for 3h. The bonding rate of the interface is higher, the surface of the AR layer becomes smoother than that of the non-annealed alloy, and the second phase is precipitated on the Al matrix. The defects on the surface of Al2Cu gradually disappear, the number of holes is reduced, and the grain size is basically unchanged, but it still keeps fine grain. Fig.2(c) shows the non-uniform layered Al-3%Cu alloy annealed at 250℃ for 3h. The surface holes appear, the defects increase, the second phase decreases, and the interfacial bonding rate decreases. Fig.2(d) shows the non-uniform layered Al-3%Cu alloy annealed at 300 ℃ for 3h. Under the annealing condition of high temperature and long time, the grains of the CR and AR layers are coarsened completely. The strength is significantly reduced, and minor damage occurs at the interface. After low temperature annealing at 200 ℃ for 3h, 250 ℃ for 3h and 300 ℃ for 3h, the α phase in the non-uniform layered Al-3%Cu alloy produces solid solution strengthening, and the precipitation of the second phase in the CR layer is much higher than that in the AR layer. The strengthening effect of Cu diffusion results in the formation of θ′(Al2Cu) phases, which leads to the increase of the hardness of the alloy [29,30]. When annealed at 200 ℃ for 3h, the metallurgical bonding rate of the interface increases.

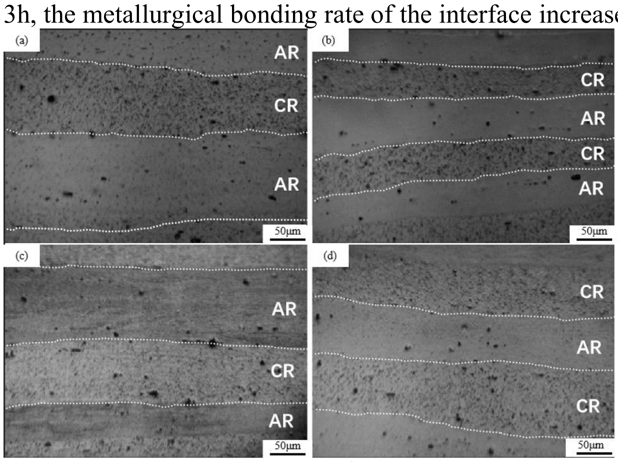


Fig.2 - Metallographic diagram of Heterogeneous Laminated Structure Al-3%Cu Alloy under different annealing conditions ((a) untreated (b) at 200 ℃ for 3h (c) at 250 ℃ for 3h (d) at 300 ℃ for 3h）

4 Conclusion

Starting from the improvement of the ductility and strength of Al-3%Cu alloy, this paper adopts the diffusion connection + hydraulic forming composite process to prepare a non-uniform layered structure Al-3%Cu alloy, performs different annealing treatments for non-uniform layered structure Al-3%Cu alloy, and optimizes the mechanical properties through microstructural design and annealing process adjustment.

(1) Through the comparison of the three annealing processes, it was found that the interfaces of untreated and annealed were free of defects such as micropores and cracks, and the interfaces were metallurgically combined.

(2) At 200 °C annealing for 3h, the metallurgical binding rate of the interface is the highest, the distribution of oxygen elements in the CR layer, AR layer and interface is uniform and the alloy precipitates (Al2Cu, etc.) are generated at the same time.

(3) At the different annealing temperatures, the soft zones are not much different, ensuring the basic plasticity. At 200 °C for 3h annealing process, the hard zone has the highest proportion and the highest strength, and the uniform elongation increases by 97.4%, from 3.8% to 7.5%. In addition, the strength is basically unchanged (311.07 MPa to 308 MPa), and the strength-plasticity match is achieved.

(4) Non-uniform layered structure Al-3% Cu alloy needs to optimize the microstructure through precipitation strengthening, and its hard zone can be maximum constraint on the GND, resulting in a large strain gradient. The strain gradient will produce non-uniform deformation induction stress, which is a kind of back stress strengthening, resulting in additional working hardening and strength. Simultaneously, due to the large density of the hard area, there are a large number of second phase precipitations such as Al2Cu in the non-uniform area, which can resist dislocation slip and increase the strength.

5 Acknowledgments

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