EFFECTS AND MECHANISMS OF EXTRINSIC STRENGTHENING DURING AGING FOR AL ALLOY 2090+Ce①

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ABSTRACT

The influence of aging temperature and time on fracture feature of monotonic tensile samples of aluminum-lithium alloy 2090+Ce was investigated. The effects and mechanisms of extrinsic strengthening during aging for this alloy with a flat unrecrystallized structure were discussed. The mechanisms were analysed from four aspects. The theory of extrinsic strengthening from the delamination strengthening was presented. The results in this research show that the strength and ductility of aluminum-lithium alloy with a flat unrecrystallized structure are superior to those with recrystallized structure. Several reasons have been advanced for the ductility improvement effect of flat uncrystallized structure, including wedging action between flat grain, action of short-transverse delamination on impeding the growth of main crack, action on the reduction in the detrimental influence of weak grain boundaries and action on impeding the intergranular fracture on main fracture surface. The strengthening effect of flat uncrystallized structure is attributed to the extrinsic strengthening derived from delamination strengthening. From underage to peakage, the fracture mode of this alloy is transgranular fracture plus short-transverse delamination. The tendency of short-transverse delamination increases with aging, thereby enhancing the delamination strengthening effect. Under overaging condition, the fracture mode is predominately intersubgranular, which results in the loss of delamination strengthening.

Key words: Aluminum-lithium Alloy Aging Extrinsic Strengthening Delamination Strengthening Grain Structure

1 INTRODUCTIION

There have been considerable investigations on determining the change of microstructure during aging for aluminum-lithium alloys in recent years[1-2]. The relationships among the precipitate phases, precipitate free zones (PFZ's), equilibibrium phases at grain boundaries, and aging temperature and time have been obtained, and the influence of aging on microdeformation behaviour has been documented. Besides intrinsic strengthening mechanisms during aging, there are extrinsic strengthening mechanisms. Although the extrinsic strengthening effect has been reported in some studies on aluminum-lithium alloy to date, there is no paper in which the effects and mechanisms of extrinsic strengthening have been discussed specifically. This paper is concerned with the influence of aging temperature

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and time on fracture feature of aluminum-lithium alloy 2090+Ce and emphasis has been placed on determining the effects and mechanisms of extrinsic strengthening.

2 EXPERIMENTAL PROCEDURES

The test material was a 2 mm thick plate. The chemical compositions (wt.−%) is 2.30Li, 2.54Cu, 0.01Zr, 0.01Mg, 0.05Ti and the balance Al. The hot rolling was carried out at 480 ℃ to achieve a 5~ 7 mm thick plate, which was then annealed at 450 ℃ for 1 h, and rolled at 320 ℃. The 2 mm thick plate was solutionized at 532 ℃ for 0.5 h, then water quenched, stretched by 4%, and aged at 150, 165 and 175 ℃. Optical metallography showed that the unrecrystallized pancake-shaped grain was elongated along the rolling direction, in which subgrain can be observed. The plate tensile samples 10 mm × 40 mm were machined. Tensile test was carried out at room temperature on INSTRON 1195 with a strain rate of 1 mm / min. The elongation was measured with an extensometer.

3 RESULTS

The influence of grain structure on monotonic tensile properties is shown in Table 1. The pancake-shaped unrecrystallized grains exhibit better strength and ductility as compared with recrystallized grains, i. e., a 10 pct improvement in strength and a 50 pct improvement in elongation.

Fig.1 shows the variation of monotonic tensile properties with aging time. The increase of monotonic strength with aging time at 150 ℃ can be observed. The peakstrength can be achieved by aging at 165 ℃ for 30 h or 175 ℃ for 12 h. A conclusion is drawn that a better strength-ductility combination can be obtained by aging at lower temperature for longer time. The peakstrength changes with aging temperature.

Scanning electron micrographies of monotonic tensile fracture surface are shown in Fig.2 for aging at 150 ℃, Fig.3 165 ℃ and Fig.4 175 ℃. From underage to peakage, the fracture mode consists transgranular splitting and intergranular short-transverse delamination, i. e., the ligaments isolated by intergranular secondary cracks. The transverse surface of ligaments results from transgranular shear fracture on the main fracture surface,and

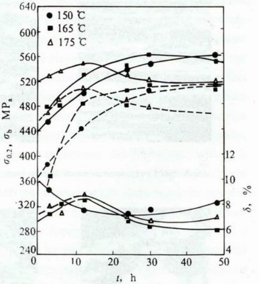


Fig.1 Variation of monotonic tensile properties with aging for 2090+Ce

Table 1 Influence of grain structure on monotonic tensile properties of aluminum-lithium alloy 2090+Ce

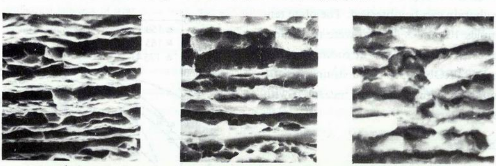
Processing	Grain structure	UTS / MPa	YS / MPa	EL / %
Solution at 480 ℃+cold rolling solution at 532 ℃+peakage	recrystallized grains	514	509	5.8
Annealed at 450 ℃+rolling at 320 ℃ solution at 532 ℃+peakage	Pancake-shaped uncrystallized grains	564	532	8.8

the secondary cracks results from short-transverse delamination. Firstly, the thickness of ligaments decreases with aging, which indicates an increasing tendency of short-transverse delamination. The slip stripes on the transverse surface of ligaments decreases with aging, which is associated with poor slip ability in grains. Thirdly, the necking of ligaments is exhibited. Evidently, the plastic deformation can still be carried after the occurrence of short-transverse delamination. When overaged, the fracture mode is predominately intersubgranular and the plastic deformtion on fracture surface is not evident.

(a) (b) (c)

Fig.2 SEM's of monotonic tensile fracture surface of aluminum-lithium alloy 2090+Ce aged at 150 ℃ (×2,800)

(a)—aging for 3 h; (b)—aging for 24 h; (c)—aging for 48 h



(a) (b) (c)

Fig.3 SEM's of monotonic tensile fracture surface of aluminum-lithium alloy 2090+Ce aged at 165 ℃ (×2,800)

(a)—aging for 3 h; (b)—aging for 24 h; (c)—aging for 48 h

(a) (b) (c)

Fig.4 SEM's of monotonic tensile fracture surface of aluminum-lithium alloy 2090+Ce aged at 170 ℃ (×2,800)

(a)—aging for 3 h; (b)—aging for 24 h, (c)—aging for 48 h

4 DISCUSSION

On the contrary, aluminum-lithium alloys exhibit weak grain boundaries and high stress concentration. The weak grain boundaries are attributed to preciptitate free zones, and grain boundary segregation of trap elements such as Na and K. The high stress concentration is attributed to planar slip, precipitate free zones and equilibrium precipitates at grain boundaries. Due to these, the aluminum-lithium alloys suffer from marked tendency of intergra- nular fracture. Consequently, they show the low ductility and fracture toughness, and poor short crack growth resistance. Several investigations reported that the strength-ductility combination of pancake-shaped unrecrystallized grains is superior to that of recrystallized grains. At present a theory for this has been accepted by many investigators. Because the low degree of misorientation between neighboring unrecrystallized grains reduces the effectiveness of grain boundaries as a slip barrier, the dislocation can pass through the grain boundaries into neighboring grains, which in turn results in a decrease in stress concentration associated with the dislocation pile-ups at grain boundaries. Consequently, the tendency of intergranular fracture decreases. Although the present research is not contrary to the above theory, its results show that other important mechanisms exist. The SEM analysis of fracture surface revealed the pancake-transverse delamination. It is difficult to explain this fracture feature by the above theory. Moreover, the present research has discovered that the significant improvement in strength-ductility combination is associated with the occurrence of short-transverse delamination. Thereby, a problem is raised, what is the mechanism of enhancing strength and enhancing ductility for pancake-shaped unrecrystallized grains in aluminum-lithium alloys? Several reasons can be advanced for this. Firstly, the misorientation between neighboring unrecrystallized grains is lower as compared with recrystallized grains, even if so, dislocation can not pass through grain boundaries due to the barrier role coming from equilibrium precipitates at grain boundaries. For this reason, the stress concentration at grain boundaries is high, which results in intergranular splitting. However, when the loading axis of samples is parallel to either the longitudial or long transverse orientation, the prominent part of grain boundaries for pancake-shape unrecrystallized grains is parallel to load axis. As a result, the intergranular spliting takes generally the form of short-transverse delamination, rather than induces the fracture of samples. On the contrary, the intergranular splitting of recystallized grains will result in the fracture of samples. Secondly, the shape effect and wedging action of pancake-shape grains can play a role of inhibiting the intergranular splitting along main fracture surface. Finally, the short-transverse delamination, which is normal to the main crack can impede the main crack advance through destroying its growth continuity. Most studies on alumiunm-lithium alloy have reported that their low ductility is attributed to the weak grain boundaries and stress concentration there. Thereby, there is no question that strengthening grain boundaries and minimizing stress concentration at grain boundaries will help to improve ductility. It is important to note that aluminum-lithium alloys possess an enhancing ductility mechanisms associated with short-transverse delamination. For this reason, the change of ductility with processing treatment for aluminum-lithium alloy is different from that for traditional high strength aluminum alloys.

The strengthening effect from shorttransverse delamination is more evident than the enhancing ductility effect. It is known that the strength of a material is dependent primarily on its plastic deformation resistance. Once short-transverse delamination occurs, which does not induce the fracture of samples, there is no constraint between ajacent grains, then each grain may deform as an individual ligament, including slip, necking and final shear fracture. When plastic deformtion is constrained in the ligaments isolated by short-transverse delamination, plastic deform resistance is increased, which results in a higher level of strength. This strengthening effect is called delamination strengthening. The strengthing effect is achieved through an extrinsic mechanism which impedes the plastic deformationm by increasing the microstructural deformation resistance. Conversely, the solution strengthening, precipitate strengthening, etc., belong to intrinsic strengthening associated with an increase in microstructural deformation resistance.

The short-transverse delamination is especially sensitive to the strength difference between grain-in and grain boundary and the stress concentration at grain boundaries. From underage to peakage, the precipitation in grains increases grain-in strength, and the precipitate free zones decreases strength at grain boundary. Consequently, the strength difference between grain-in and grain boundary is increased. On the other side, the increase in stress concentration at grain boundary results from the presence of δ' precipitates, precipitate free zones and equilibrium precipitates at grain boundaries. This is sufficent to explain why the delamination strengthening increases from underage to overage.

When overaged, the subgrain boundary weakening and stress concentration at subgrain boundaries, associated with the presence and growth of precipitae free zones and equilibrium precipitates at subgrain boundaries, in turn dominate the fracture behaviors. Consequently, the delamination strengthening effect becomes negligible or nonexistent, which is associated with a lower level of strength and ductility.

The intrinsic strengthening mechanisms of aluminum-lithium alloys not described is still one primary mechanism. In other words, the aging strengthening of aluminum-lithium alloys is associated with intrinsic and extrinsic strengthening.

The distinctions between intrinsic and extrinsic strengthening for aluminum-lithium alloys are as follows: firstly, although both intrinsic and extrinsic strenghening effect are sensitive to the microstructure, their mechanisms are different. According to intrinsic strengthening mechanisms, higher levels of strength can be achieved through increasing microstructual deformation resistance. However, extrinsic strengthening comes from other action which impedes the deformation by changing the extrinsic condition. Secondly, intrinsic strengthening, which belongs to three dimensions strengthening, does not increase the anisotropy of properties. However, extrinsic strengthening belonging to two dimensions strengthening induces anisotropy, i. e., the strengthening in the longitudinal and long transverse orientation is associated with a reduction in strength in short-transverse orientation. It is a logical explanation why the anisotropy of aluminum- lithium alloys is enhanced from underage to peakage. Thirdly, the strength improved by intrinsic strengthening effect is associated generally with a reduction in ductility, but it is possible to achieve an improvement in strength and ductility utilizing extrinsic strengthening effect. This is the reason why the increase in ductility can be observed at peakaging. Forthly, extrinsic strengthening effect has been shown to be associated with pancake-shaped unrecrystallized grains which induces a fracture feature consisting of shorttransverse delamination. According to intrinsic strengthening mechanisms, grain boundaries weakening and stress concentration at grain boundaries have a harmful influence on properties, but they enhance the extrinsic strengthening effect through promoting the shorttransverse delamination. Finally, when the fracture toughness is referred, the plane strain condition at crack tip is changed to the plane stress condition due to the occurrence of short-transverse delamination, which results in a significant improvement in fracture toughness. This effect is called delamination toughening which belongs to extrinsic toughening. This is a logical explanation, for both of them, why the increase in the strength and fracture toughness of aluminum-lithium alloys can be achieved from underage to peakage[3]. Such behaviours contrary to that observed on traditional high strength aluminum alloys.

The large amount of research on aluminum-lithium alloys that needs to be continued today demonstrates that the weak grain boundary and stress concentraion at grain boundary are difficult to overcome entirely. On the other hand, their harmful influence on properties can be alleviated in pancake-shaped unrecrystallized grains. Furthermore , they can provide a contribution to enhancing strength, ductility, and toughness, and utilizing extrinsic strengthening and extrinsic toughening effect. Evidently, this is an effective method to optimize strength, ductility and toughness. On the contrary, it plays only a role of optimizing properties in two dimensions.

5 CONCLUSIONS

(1) The strength-ductility combination of aluminum-lithium alloys with pancake-shaped unrecrystallized grains is superior to that with recrystallized grains. Several reasons can be provided for this, such as wedging between pancake-shaped grains, impeding on main crack growth from shorttransverse delamination, alleviating of detrimental influence of weak grain boundary and stress concentration at grain boundary, increasing of deformation resistance from ligament strengthening.

(2) From underage to peakage, the fracture mode of pancake-shape unrecrystallized grains for aluminum-lithium alloys consists of transgranular splitting and intergranular shorttransverse delamination. When overaged, the fracture mode is primarily intersubgranular, which results in the loss of delamination strengthening.

REFERENCES

1 Starke, E. A. *et al.* Met Tran, 1982, 13A: 2259.
2 Nicholos, J.. J Met Sci, 1987, (22): 1521.
3 Jha, S. C. *3t al.* Acta Metal, 1978, 35(2): 473.
4 Tosten, M. H. *et al.* Metal Trans, 1988, 19A: 51.
5 Venkateswara, K. T. *et al.* Mater Scien Tech, 1989. (5): 882.