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Improving fatigue property of Al-Li alloy by thermo-mechanical treatment[①]

DING Jian(丁 剑), ZHANG Di(张 荻), FAN Tong-xiang(范同祥), LÜ Wei-jie(吕维洁), QIN Ji-ning(覃继宁)

(State Key Laboratory of Metal Matrix Composites, Shanghai Jiaotong University, Shanghai 200030, China)

Abstract: Tension-compression fatigue test was performed to study the effect of the cold working + ageing treatment on the fatigue property of Al-Li alloy under stress-controlled condition. The main results show that: fatigue strength of specimen is improved obviously after cold working + ageing treatment; compared to the simple ageing treatment, the necessary ageing time can be reduced apparently to reach the peak-ageing strengthening effect; the fatigue strength of specimen cut from the vertical direction to cold working direction is higher than that cut from the parallel direction.

Key words: Al-Li alloy; thermo-mechanical treatment; fatigue property

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1 INTRODUCTION

Al-Li alloy has been used widely as a kind of new structural space flight material depending on its high strength and low density[1, 2]. Many research works have been done on Al-Li alloy[3-6], but few of them are about fatigue faliure. Because more than 80% of structural materials' failures are caused by the fatigue failures directly or indirectly[7, 8], it is necessary to study the fatigue property of Al-Li alloy[9-11]. There is obvious ageing strengthening effect when Al-Li alloy is aged below the solubility curve of transient phase δ'. However, the transformation becomes more and more irregular with the strength increasing. The thermo-mechanical treatment is considered as an effective means to enhance the synthetical property of Al-Li alloy. The objective of this work is to study the effect of the cold working + ageing treatment on improving the fatigue property of Al-Li alloy.

2 EXPERIMENTAL

Pure Al (> 99.99%) and pure Li (99.96%) were melted at 800 ℃ in Al_2O_3 crucible in which the melted metal was protected with Ar gas. Al-Li alloy cast ingot was made by pouring the melt into an iron mold. The chemical composition of the cast ingot was analyzed and shown in Table 1.

Table 1 Chemical composition of tested Al-Li alloy (%)

Li	Fe	Cu	Mg	K	Al
1.82	0.003 9	0.009 4	0.000 7	0.003 1	Bal.

The cast ingots were uniformly treated at 570 ℃ for 24 h with Ar gas protection. Then, they were machined to board 6.1 mm thick. After that, they were heat treated at 500 ℃ for 40 min and then quenched into ice water. The cold roller working was applied to make the board thickness from 6.1 mm to 2.1 mm, in which the cold transformation ratio was around 66%. The specimens were cut from the board in the parallel direction and vertical direction to rolling direction. Then they were aged in oil at 150 ℃. The entire specimen surface was polished with fine sand paper and electrically polished before test, in order to take off the Li-poor layer in specimen surface caused by the heat treatment.

The fatigue test was done with Shimatsu fatigue testing machine (stress ratio $R = -1$, $f = 30$ Hz). The fatigue limit was defined as the fatigue strength when the cycle number reached 10^7. The microstructures of specimens were observed and analyzed with Olympus optical microscope and Hitachi X-650S SEM.

3 RESULTS AND DISCUSSION

The fatigue strength of specimen cut from the parallel direction to roller working direction is shown in Fig. 1, where ST denotes solution treatment, CR denotes cold roller working, "∥" denotes the parallel direction to roller working direction. In order to compare with the fatigue strength of simply ageing treated specimen, the fatigue strength of specimens which were solution treated and simply ageing treated at 150

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Correspondence: ZHANG Di, Professor, PhD; Tel: +86-21-62933106; Fax: +86-21-62822012; E-mail: Zhangdi@sjtu.edu.cn

℃ for 500 h were also shown in Fig. 1. The fatigue strength of being thermo-mechanically treated specimen increases with ageing treatment time increasing after cold work. The hardness measurement shows that, the hardness of the specimen reaches the highest value after treatment at 150 ℃ for 167 h for thermo-mechanical treatment specimen. Compared to the simply ageing treated specimen, the critical time of reaching the highest hardness decreases obviously. Furthermore, even the fatigue strength of specimen after cold working and ageing treatment for 67 h is higher than that of specimen after ageing at 150 ℃ for 500 h.

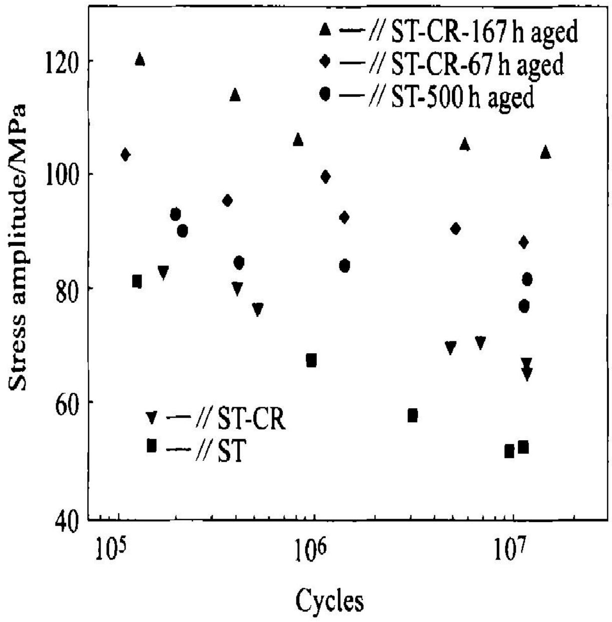

Fig. 1 Fatigue strength of specimens cut from parallel direction to rolling direction

Fig. 2 shows the difference of the fatigue strength of thermo-mechanically treated specimens cut from different directions. "⊥" and "//" denote the vertical direction and the parallel direction to roller working direction respectively. For the thermo-mechanically treated specimens, the fatigue strength of specimen cut from the vertical direction is higher than that cut from the parallel direction under the same heat treatment condition. The difference between them is about 15－20 MPa. Therefore, the fatigue strength indicates the anisotropy of fatigue property for the thermo-mechanically treated specimens. In order to study the anisotropy of fatigue strength, the successive surface observation of the specimen during the fatigue test is done.

Fig. 3 shows the observation of the fatigue crack initiating and propagating behavior in specimen surface which is cut from the parallel direction to cold working direction and then aged at 150 ℃ for 167 h. Some fine slip bands with nearly 45° to the fatigue stress direction are observed in grain inside at the beginning state of the fatigue test. The fatigue crack

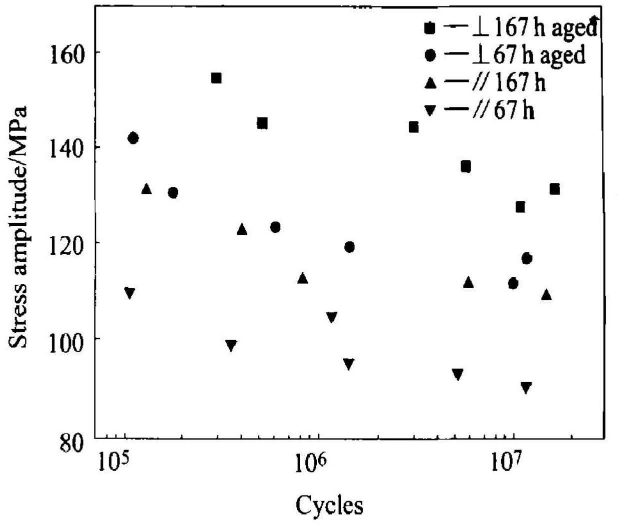

Fig. 2 Fatigue strength of thermo-mechanically treated specimens cut from different directions

initiates firstly from the deformation band generated in cold working in specimen. After that, the fatigue crack propagates fast along the direction vertical to cold working direction, inducing transgranular fracture.

Fig. 4 shows the observation of fatigue crack initiating and propagating behavior in specimen surface which is cut from the vertical direction to cold working direction and then ageing treated under the same condition. The slip bands generate in the grain inside at the beginning state of fatigue test, then, the fatigue crack initiates along the slip bands and propagates in grain with the fatigue cycle increasing. The initiation and propagation route of this kind of fatigue crack are more complex than that shown in Fig. 3. It is considered that more energy is needed for the fatigue crack to propagate.

Fig. 5 shows the fatigue fracture structure of specimen which is cut from the direction parallel to the roller working direction. The arrow shows the propagating direction of the fatigue cracks. The propagating route of the fatigue cracks seems very smooth apparently, and the distances between the fatigue striations are comparatively big.

Fig. 6 shows the fatigue fracture structure of specimen cut from the vertical direction to the roller working direction. The propagating route of the fatigue cracks seems not so smooth, and the fatigue striations show comparatively complex character. Furthermore, the distances between the fatigue striations are much smaller than those in Fig. 5. This fractography result is consistent with the successive observation of the fatigue crack initiating and propagating behavior shown in Figs. 3 and 4. It is due to the difference between fatigue crack initiation and propagation, the anisotropy of fatigue strength occurs in the specimen after thermo-mechanical treatment is induced.

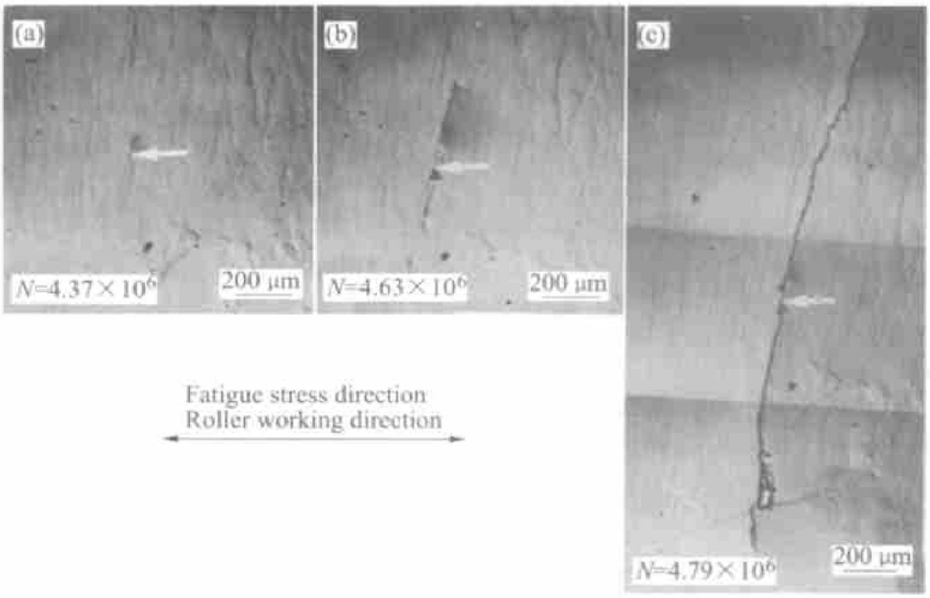

Fig. 3 Fatigue surface observation of specimen cut from direction parallel to cold roller working direction (150 ℃, 167 h, ageing treatment)

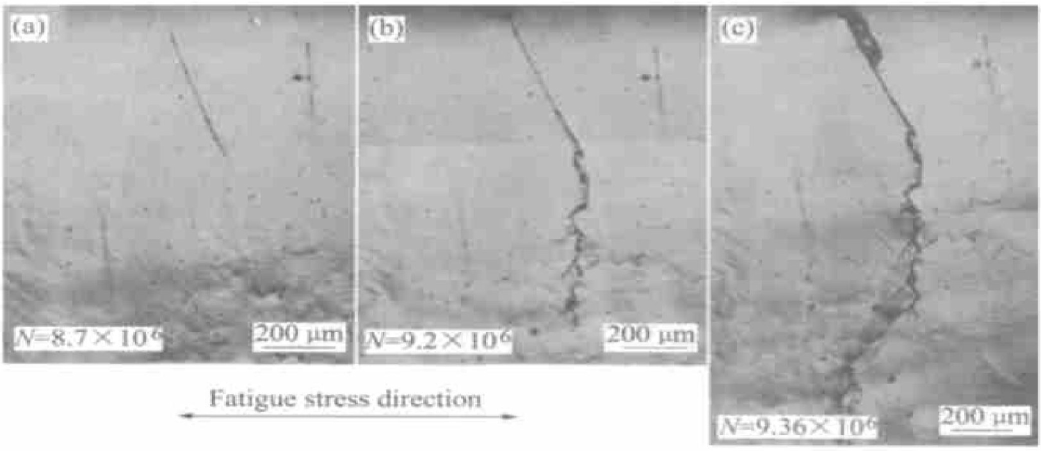

Fig. 4 Fatigue surface observation of specimen cut from direction vertical to cold roller working direction (150 ℃, 167 h, ageing treatment)

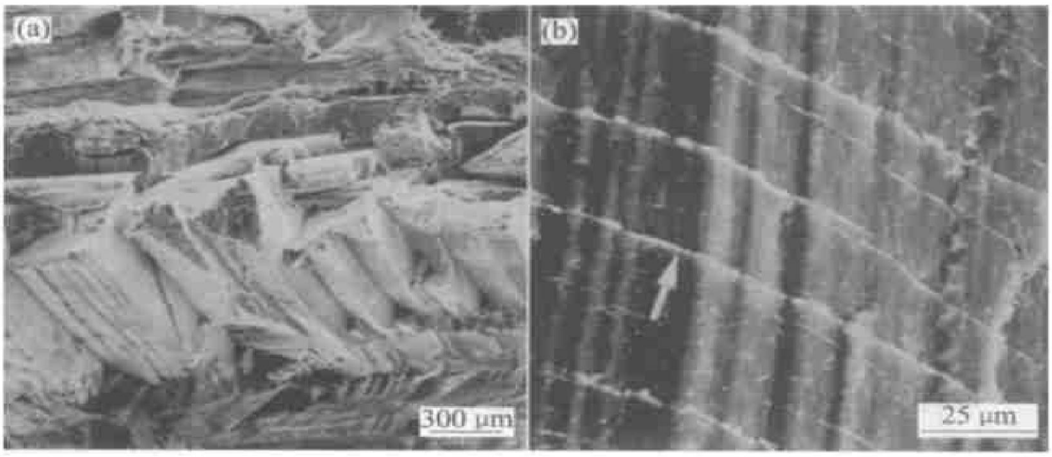

Fig. 5 Fatigue fracture structure in specimen cut from direction parallel to roller working direction, $\sigma_a = \pm 100$ MPa, $N = 1.1 \times 10^5$ cycles
(a) —Intergranular fracture; (b) —Sharp fatigue striations

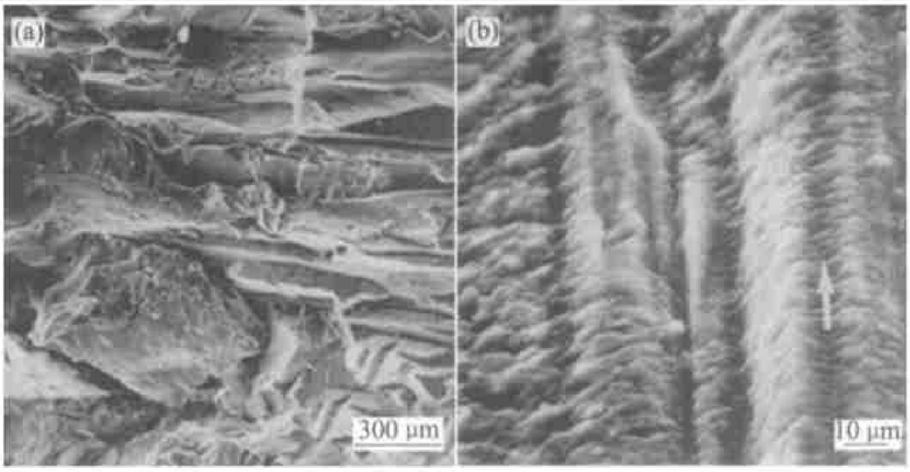

Fig. 6 Fatigue fracture structure in specimen cut from direction vertical to cold roller working direction, $\sigma_a = \pm 110$ MPa, $N = 9.5 \times 10^6$ cycles
(a) —Transgranular fracture; (b) —Unsharp fatigue striations

4 CONCLUSIONS

1) The fatigue strength of the specimen is improved obviously after cold working + ageing treatment. Compared to the simple ageing treatment, the critical ageing time can be reduced apparently to reach the peak-ageing strengthening effect.

2) The fatigue strength of the specimen cut from the vertical direction to cold working direction is higher than that in parallel direction. This is because the fatigue crack initiates from slip bands inside the grain, and then propagates in more complex route for the specimen cut from vertical direction to rolling direction. On the other hand, the fatigue crack initiates firstly in deformation band, then propagates fast with fatigue cycles increasing for the specimen cut from parallel direction to rolling direction.

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