

# Effect of aging treatment on the creep resistance of Al-Cu-Mg-Ag alloy

Ping Liu, Xiaoyan Liu \*, Zhenhua Cui and Fei Gao

College of Materials Science and Engineering, Hebei University of Engineering,  
Handan 056038, China

\*Corresponding author e-mail: x918y@126.com

**Abstract.** The effect of the aged treatment on the creep resistance of Al-Cu-Mg-Ag alloy was investigated by creep test, metallographic and transmission electronic analysis. The results indicate that the creep rate of the under-aged sample is lower to than that of the peak-aged sample in the tested conditions. This means that the under-aged Al-Cu-Mg-Ag alloy possess higher creep resistance both in the pure creep tests and the cyclic creep tests. The grains in the crept samples are elongated along the stress loading direction and the larger deformation is observed in the peak-aged sample. The precipitations are distributed dispersive in the matrix and their size is smaller than that in the peak-aged sample. This results in the higher creep resistance of the under-aged Al-Cu-Mg-Ag alloy.

**Key words:** Al-Cu-Mg-Ag alloy; deformation; precipitation; mechanical property; corrosion resistance.

## 1. Introduction

Al-Cu-Mg-Ag alloy attracts much attention for its high strength at elevated temperature and excellent creep resistance [1-5]. Various heat treatments have been used to enhance its properties further, such as homogenization treatment, solution treatment and different aged treatment [6-11].

Aged treatment is one of the most efficient ways to enhance its properties of the aged hardening Al alloy. The solution atoms precipitate form the matrix and form the strengthening phases during the aging process, leading to higher properties. Usually, the peak aging treatment is employed. However, Liu et al. [12] reported that the under-aged Al-Cu-Mg-Ag alloys possess the higher thermal stability compared with the peak-aged alloy. In this paper, Al-Cu-Mg-Ag alloy is treated by under-aged and peak-aged, respectively. The effects of the aged treatment on the creep resistance are tested by pure creep and cyclic creep. The mechanism are discussed by metallographic and transmission electronic analysis.

## 2. Experimental

The Al-4.88Cu-0.71Mg-0.58Ag-0.31Mn-0.14Zr alloy was prepared by semi-continuous casting. The as-casted Al alloy was homogenization at 515°C for 24 h, and then hot rolled to 6 mm, and finally cold rolled to 2 mm. All samples were solution treated at 515°C for 1.5 h and then aging at 185°C for 2 h (under-aged) and 4 h (peak-aged), respectively.

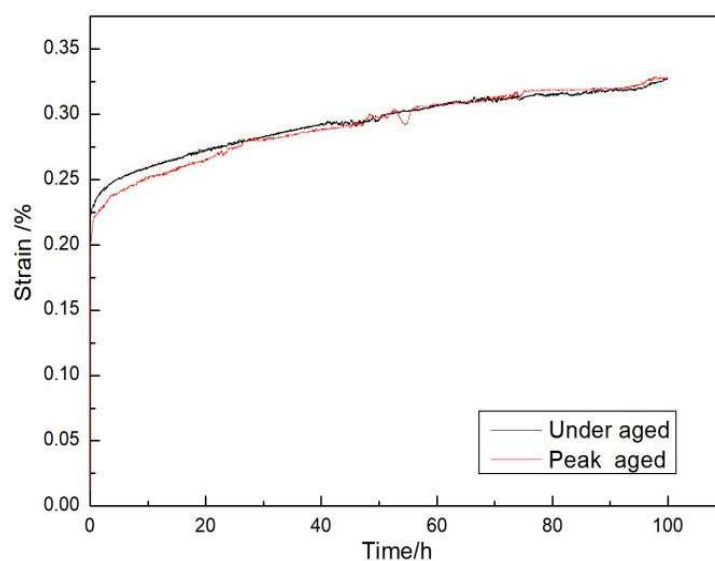


The creep property was tested on electrical creep machine and the tested sample was machined according to ISO 204. The upload waveform of the stress is trapezoidal wave, the holding time is 30 min, and time for loading and unloading is 60s. The optical and transmission electron microstructure were observed on Olympus DSX500 optical microscopy and TECNAI G2F30 transmission electron microscopy, respectively.

### 3. Results and discussion

#### 3.1. Creep behavior of Al-Cu-Mg-Ag alloy treated by different aging

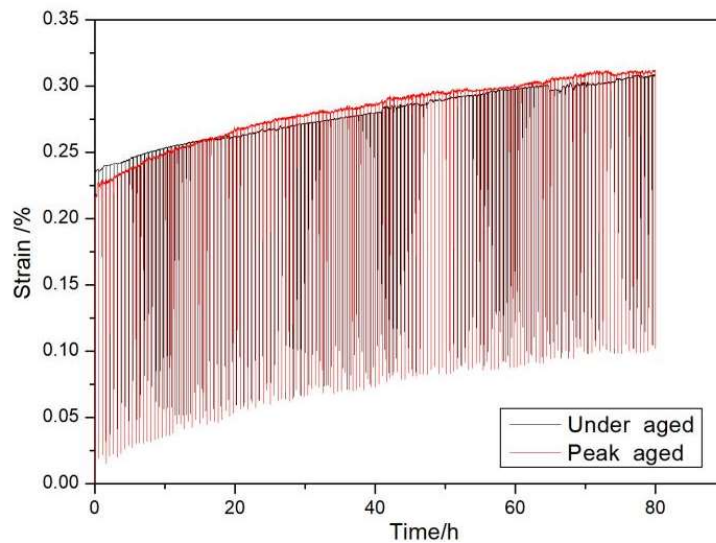
Figure 1 shows that after solid solution at 515°C/ 1.5 h, the Al-Cu-Mg-Ag alloy is treated under aged ( $t_1 = 2\text{h}$ ) and peak aged ( $t_1 = 4\text{h}$ ) at 185°C, respectively. A pure creep test was performed to obtain a strain-time curve comparison chart.



**Figure 1.** Comparison of pure creep strain-time curves of alloys

It can be seen from Fig. 1 that the creep of the alloy under the experimental conditions has undergone two processes of creep deceleration and steady state creep. After strain loading, the strain of the alloy increases rapidly. It can be seen from the initial stage of creep that the initial strain of the under aged sample is higher than that of the peak aged alloy. Subsequently, the creep rate of the two aged treated samples gradually decreased and entered the steady-state creep process. During steady-state creep, the creep rate of the under aged sample is lower than that of the peak aged sample. The creep rate of the under aged pure creep specimen is  $2.5 \times 10^{-7}\text{s}^{-1}$ , the creep rate of the peak aged pure creep specimen is  $2.748 \times 10^{-7}\text{s}^{-1}$ . The creep rate of the under aged sample is reduced by 9.35% compared to the creep rate of the peak aged sample. When the creep time is about 23 h, the strain of the under aged sample and the peak aged sample are the same, and then the strain of the peak aged sample is higher than the under aged sample because of that the creep age rate of the under aged sample is lower than that of the peak aging sample.

The Al-Cu-Mg-Ag alloy was subjected to under-aged and peak aged treatment at 185°C after solid solution at 515°C/1.5 h, and then the cyclic creep properties of the two samples were tested. The cyclic creep loading waveform adopts a trapezoidal wave, and the obtained strain-time curve is shown in Fig 2.

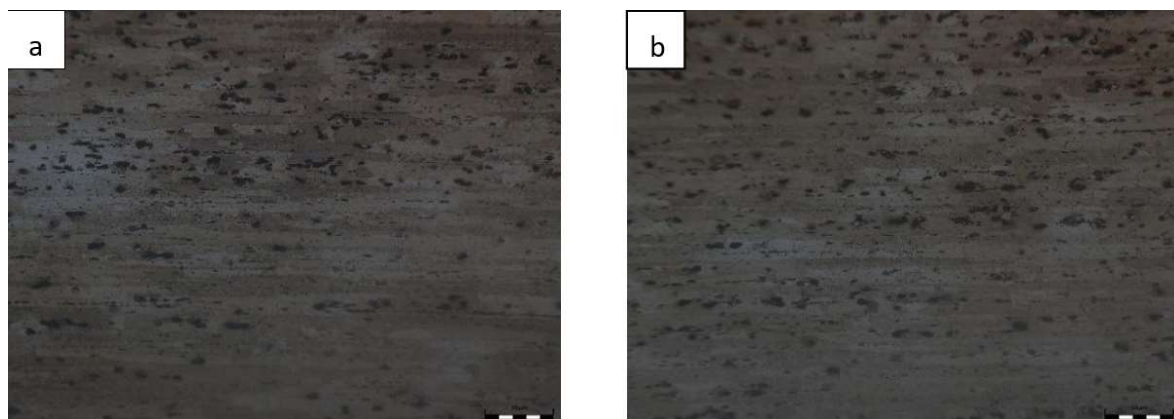


**Figure 2.** Comparison of cyclic creep strain-time curves of alloys

It can be seen from Figure 2 that the creep of Al-Cu-Mg-Ag alloy under cyclic loading conditions also undergoes two processes of creep deceleration and steady state creep. As with pure creep, the initial strain of the under-aged specimen is higher than that of the peak-aged specimen, but in the steady creep phase, the creep rate of the under-aged specimen is lower than that of the peak-aged specimen, so that the creep proceeds. At 19 h, the strains are the same, and then the strain of the under-aged alloy is lower than that of the peak-aged alloy. The creeping rate of the under-aged cyclic creep specimen is  $2.245 \times 10^{-7} \text{s}^{-1}$ , the creeping shift rate of the peak-aged cycle creep specimen is  $2.624 \times 10^{-7} \text{s}^{-1}$ . The creep rate of the under-aged sample is reduced by 16.88% compared to the creep rate of the peak-aged sample.

### 3.2. Metallographic observation

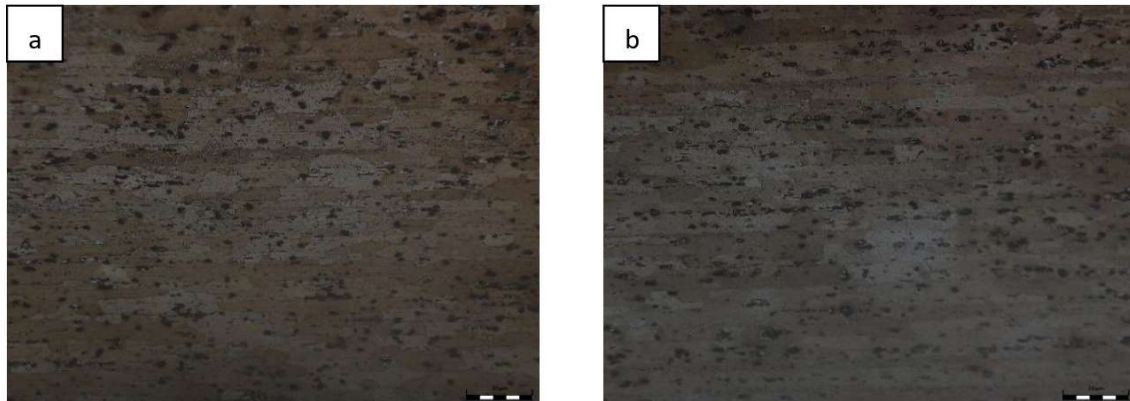
Fig. 3 shows the metallographic photographs of the under-aged and peak-aged Al-Cu-Mg-Ag alloys observed after 80 h of creep under constant load using a metallographic microscope OLYMPUS.



**Figure 3.** Metallographic photographs of pure creep samples after different aging treatments:  
a. Under-aged sample; b. Peak-aged sample.

It can be seen from Figure 3 that after the alloy has undergone under-aged and peak-aged pure creep tests, the grains are elongated along the creep direction. The grain of the peak aged sample is more elongated along the stretching direction than the under-aged sample.

Fig. 4 shows the metallographic photographs of the under-aged and peak-aged Al-Cu-Mg-Ag alloys observed by metallographic microscope OLYMPUS after 80 h of creep under cyclic loading.

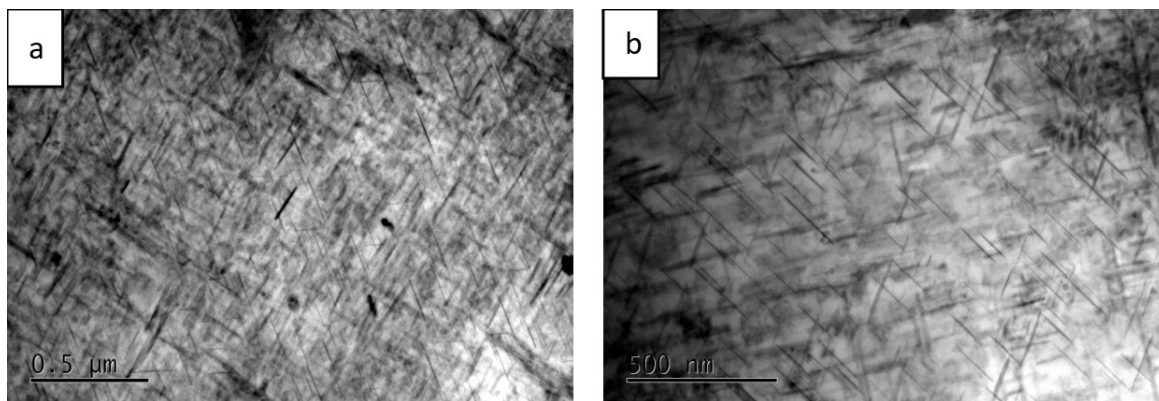


**Figure 4.** Metallographic photographs of cyclic creep samples after different aging treatments:  
a. Under-aged sample; b. Peak-aged sample.

It can be seen from Fig. 4 that the alloy still deforms along the rolling direction after the cyclic load creep. As with the pure creep trend, the peak aged sample is more deformed than the under-aged sample.

### 3.3. TEM observation

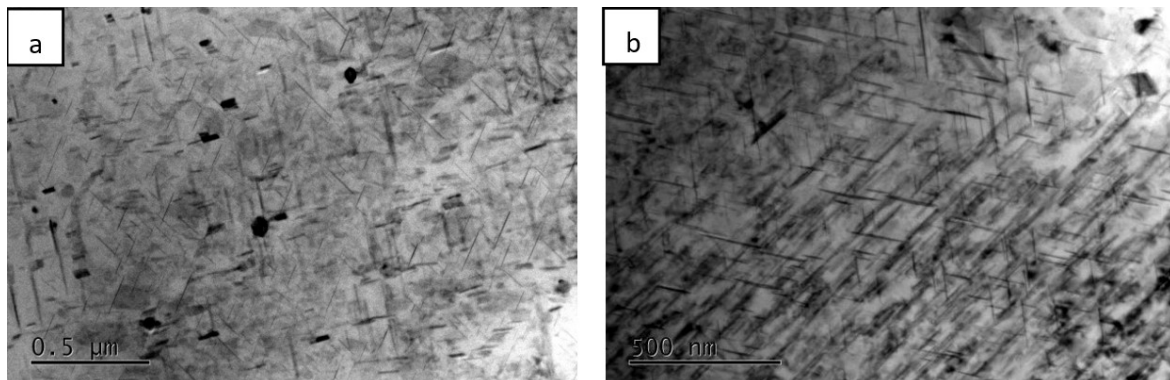
Fig. 5 shows that the Al-Cu-Mg-Ag alloy is subjected to peak-aged and under-aged treatment after solid solution at 515°C/1.5 h, and then the pure creep test of 185°C/150MPa is performed uniformly for different samples. TEM photographs of grain in each sample obtained by transmission electron microscopy.



**Figure 5.** TEM photograph of pure creep specimen after different aging treatment  
a. Under-aged sample; b. Peak-aged sample.

Fig. 5 shows the TEM structure of pure creep of Al-Cu-Mg-Ag alloy after different aged treatments. It can be seen from the figure that after different aged treatments, there are some fine strengthening precipitations  $\Omega$  with less  $\theta'$ . The precipitated phase  $\Omega$  in the under-aged alloy has a small phase size with an average size of about 100 nm (Fig. 5(a)); the precipitated phase in the peak aged alloy has a large size, and the average is about 140 nm (Fig. 5(b)). After creeping at 185°C/150MPa for 80 h, the precipitation phase in the peak aged alloy is less than that in the under-aged state.

Fig. 6 shows the peak aged and under-aged treatment of Al-Cu-Mg-Ag alloy after solid solution at 515°C/ 1.5h, followed by cyclic creep test on different samples, and each obtained by transmission electron microscopy.



**Figure 6.** TEM photograph of cyclic creep specimens after different aging treatments  
a. Under-aged sample; b. Peak-aged sample.

Fig. 6 shows the TEM structure of the cyclic creep of Al-Cu-Mg-Ag alloy after different aged treatments. It can be seen from the figure that strengthening precipitations are also  $\Omega$  with less  $\theta'$  in the two samples. The precipitated  $\Omega$  phase in the under-aged alloy has a small phase size with an average size of about 90 nm (Fig. 6(a)); the precipitated phase in the peak-aged alloy has a large size, and the average is about 130 nm (Fig. 6(c)). After creeping at 185°C/150MPa for 80h, the precipitation phase in the peak aged alloy is less than that in the under-aged state. Comparing Fig. 6(b) and (d), it can be seen that the grain boundary of the under-age alloy is more uniform than the peak near the grain boundary of the peak aged alloy, the impurity and the precipitate phase are more dispersed and evenly distributed, and the precipitated phase is finer.

It can be seen from the TEM analysis that the precipitated phase size is smaller and the distribution is more diffuse, resulting in the creep resistance of the under-aged alloy is superior to that of the peak-aged alloy, both for the pure creep or the cyclic creep.

#### 4. Conclusion

The aged treatment has a great influence on the creep resistance of Al-Cu-Mg-Ag alloy. The initial strain of the under-aged sample is higher than that of the peak-aged sample. However, with increasing the testing time, the creep rate of the under-aged sample is lower than that of the peak-aged sample both in the constant loading and the cyclic loading. This might be due to that the precipitations are smaller in the under-aged sample than that in the peak-aged sample.

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