High Temperature Deformation Bahavior of SiCp/2124Al Metal Matrix Composites

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Key Words: SiCp/2124Al Composite, Zener-Hollomon Parameter, Load Transfer Theory, Quadrat Method, Dynamic Recrystallization, Dynamic Precipitation

Abstract

The high temperature deformation behavior of SiCp/2124Al composite and 2124Al alloy was investigated by hot compression test in a temperature ranged 400~475℃ over a strain rate ranged 10^{-3}~$1s^{-1}$. The billets of 2124Al alloy and SiCp/2124Al composite were fabricated by vacuum hot pressing process. The stress-strain curve during high temperature deformation exhibited a peak stress, and then the flow stress decreased gradually into a steady state stress with increasing the strain. It was found that the flow-softening behavior was attributed to the dynamic recovery, local dynamic recrystallization and dynamic precipitation during the deformation. The precipitation phases were identified as S' and S by TEM diffraction pattern. Base on the TEM inspection, the relationship between the Z-H parameter and subgrain size was found based on the experiment data. The dependence of flow stress on temperature and strain rate could be formulated well by a hyperbolic-sinusoidal relationship using the Zener-Hollomon parameter.

1. Introduction

Particle reinforced aluminum composites are good candidates for high-performance structural materials due to their low density, high specific strength, high specific modulus and superior mechanical properties at elevated temperature [1-4]. The particle reinforced aluminum composites can be fabricated by conventional deformation process for metals, such as forging, rolling and extrusion. However, for the deformation processing of the metal matrix composite, the process conditions for monolithic alloys cannot be applied owing to the presence of hard ceramic reinforcements that significantly affect their deformation characteristics. Thus, it is necessary to understand the hot restoration mechanism and the effects of the deformation conditions, which is important for controlling the deformation structure.

A large number of researches have been carried out on the high temperature deformation of aluminum matrix composites during decades [2-7]. It was indicated that DRV and DRX are the major softening mechanisms during the high temperature deformation.

The purpose of this study is to provide further information on mechanical and microstructural behavior and to determine the restoration mechanisms involved during hot deformation of 2124Al/SiCp composites. Base on the stress-strain curves and TEM observations, the softening was attributed to the DRV, local DRX and dynamic precipitation.

2. Experimental Procedures

The 2124Al alloy and 2124Al matrix composites reinforced with 5vol%, 10vol% and 20% vol. % SiC particles were fabricated by powder metallurgy route. 2124Al powders with an average diameter of 20 ㎛ and α-SiC particles of average diameter of 8 ㎛ [8]were wet mixed in ethanol-solvent by mechanical stirring. The mixed powders were dried and hot pressed under a pressure of 90MPa at 570℃ for 10min in vacuum condition. Cylindrical compressive specimens with a diameter of 8mm and a height of 12mm were machined from the billets of 2124Al alloy and SiCp/2124Al composite. The compression tests were conducted at the temperature ranged 400~475℃ over a strain rate range of 10^{-3}~$1s^{-1}$ in vacuum of 10^{-1} torr. In order to investigate the microstructural evolution during the deformation, the specimens were quenched from the test temperature by flowing liquid nitrogen immediately after deforming to a true strain of 0.9. Transmission electron microscopy (TEM) was used to examine the microstructure of the deformed specimens. TEM specimens were sectioned from the billet parallel to the compression load axis and mechanical ground to ~40um and then jet-polished with a solution of 30% nitric acid and 70% methanol at -55℃.

3. Results and Discussion

3.1 Flow stress-strain curves:

Examples of the flow curves determined over the range of temperature and strain rate for both the matrix alloy and the composite are shown in Fig.1. For both the

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matrix alloy and the composite, the flow stress decreased with increasing in temperature and decreasing in strain rate. Under all deformation conditions, the flow stress of the composite was higher than that of the alloy. However, for a given strain rate, the above difference in flow stress decreased as the deformation temperature increasing.

3.2 Load transfer theory:

The relationship between the measured flow stress and the calculated normalized Zener-Hollomon parameter (Z/A) using the obtained parameters of A, α, n and Q is shown in Fig. 2. The normalized Zener-Hollomon parameter (Z/A) was used to exclude the effect of initial microstructure and composition. As a result, the peak stress of SiCp/2124Al composite was higher than that of 2124Al alloy at the same normalized Zener-Hollomon parameter. Generally, the load transfer occurs from matrix to reinforcement during the deformation of metal matrix composites, and the stress applied to matrix becomes lower than that applied to composite. An effective stress, defined as the stress applied to matrix in composite, could be obtained by the generalized shear-lag model [9] as expressed in the following equation (1):

$$\frac{\sigma_{eff}}{\sigma_c} = 1 - \frac{V_f(S_{eff}/2+1)}{V_f(S_{eff}/2+1)+V_m} \qquad (1)$$

where σ_{eff} is effective stress on matrix of composite, σ_c is stress on composite S_{eff} is effective aspect ratio of reinforcement, V_f is volume fraction of reinforcement, V_m is volume fraction of matrix.

In the generalized shear lag model, the effective aspect ratio of spherical particle was calculated as 1.25[9]. By considering the effective flow stress on matrix, the relationship between the effective peak stress and the normalized Zener-Hollomon parameter was shown in Fig. 2(b). The effective stress of the SiCp/2124Al composite was the same as that of 2124Al alloys. Therefore, it is concluded that the higher peak stress of metal matrix composite compared with that of 2124Al alloy was caused by load transferring from matrix to reinforcement during high temperature deformation.

3.3. Microstructure:

From the optical microstructure, as shown in Fig. 3, it was found that the matrix grain size in the SiCp rich region, nearly 2~3μm, is smaller than that in the SiCp poor region at $0.1S^{-1}$. However, at low strain rate the grain was elongated even at the SiCp rich region. These results indicated that the configuration of grain size was affected by the distribution of SiCp and the deformation condition.

To confirm the softening mechanism during the hot deformation, the microstructures of the hot deformed composites were also examined by TEM. It is apparent that the cellular substructure developed in both MMCs and alloy at entire deformation conditions, which indicate that the DRV was the main softening mechanism. However, the substructure developed in the different way despite the similar grain shape configuration. Elongated subgrains were observed at higher strain rate, where at lower strain rate, the subgrain had equiaxied shape. The size of the substructure changes with the test temperature and with strain rate. The relationship of the Zener-Hollomon parameter and subgrain size for the 5vol% SiCp/2124Al composite and 2124Al alloy is given in Fig.4. This is consistent with the equation (2):

$$d_{sg}^{-1} = A + B\log Z \qquad (2)$$

where d_{sg} is subgrain size, Z is Zener-Hollomon parameter, A and B are material constants.

It is also apparent from TEM that the precipitation was observed under all test conditions. The precipitation phases were identified as S' (Al_2CuMg) and S phases by TEM diffraction pattern, as shown in Fig.5 (c) [11]. The specimen before the deformation compared with as-deformed one, it is evident that most of the precipitation were generated during the deformation.

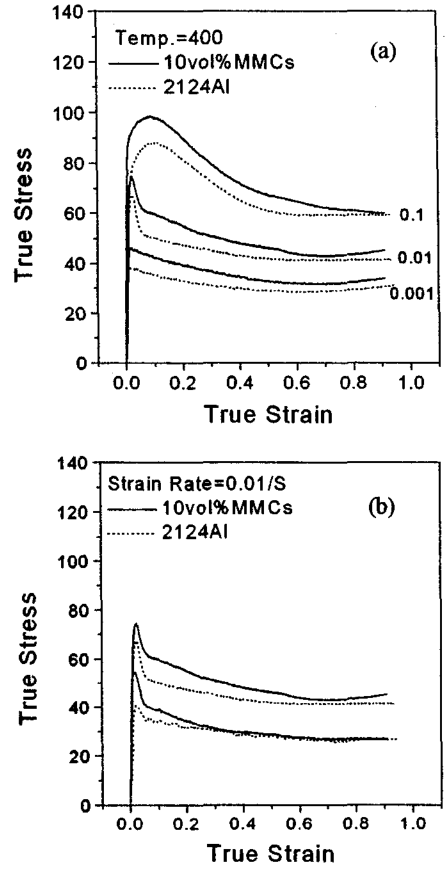
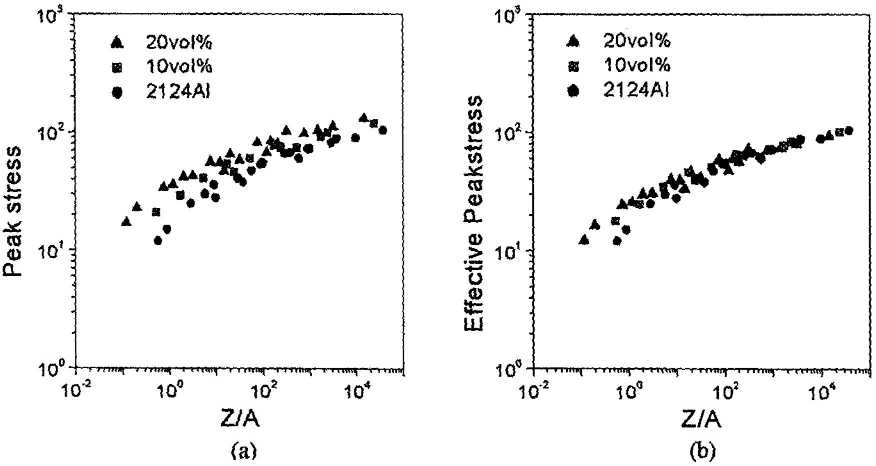


Fig.1. Stress-strain curves of 2124Al and 10vol% SiCp/2124Al MMCs, (a) 400°C, (b) 0.01/s.



(a) (b)

Fig.2. (a) Peak stress and (b) effective peak stress with varying the normalized Zener-Hollomon parameter (Z/A) of 2124Al, 10vol and 20vol% SiCp/2124Al composites.

Precipitation kinetics in composite being faster than that in monolithic alloys owing to increased nucleation rate and higher diffusion coefficient due to core diffusion mechanisms due to the presence of SiCp [12]. During the deformation prior to the peak stress, due to the presence of SiCp, the effect of precipitation harden in MMCs was more significant than that in 2124Al. Thus, as shown in Fig.2 (b) in the lower Z/A region, the effective peak stress of the MMCs was still higher than that of alloy. This effect can be neglected in the higher Z/A region due to the shorter period of the deformation. An incubation time of about 2 hours was observed for the S' in the aging treatment, however, during the deformation the rate of precipitation accelerated significantly, 1~100 seconds. The precipitation coarsening occurred during the deformation with increasing strain as shown in Fig.5, which could explain the peak stress difference in Fig.2. (b) at low Z./A region.

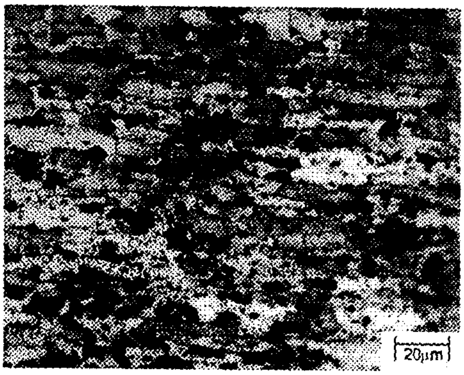


Fig.3. Optical microstructure of 10vol% SiCp/2124Al composite deformed at 475°C with strain rate of 0.1/s up to strain 0.9.

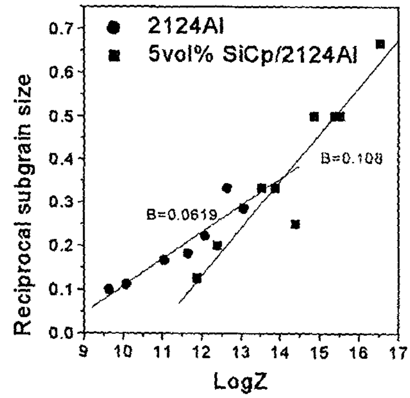


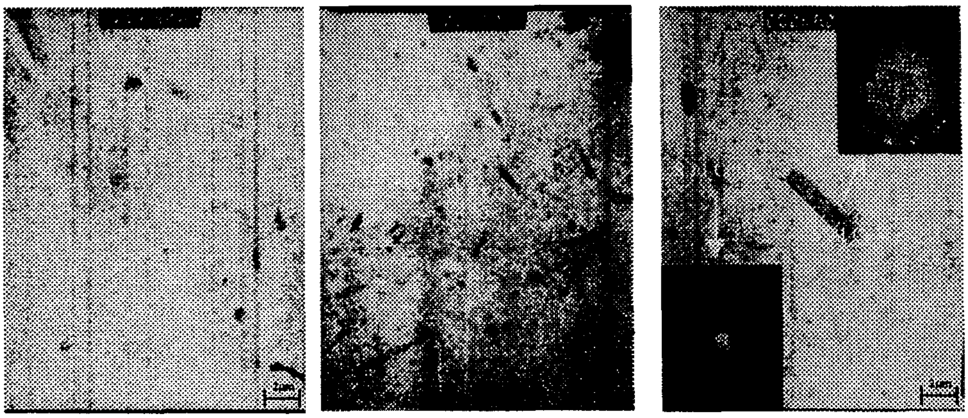
Fig.4. Reciprocal subgrain size vs. logZ for 2124Al and 5vol% SiCp/2124Al composite.

4. Conclusions

1.Using the normalized Zener-Hollomon parameter and the effective stress on matrix based on the load transfer analysis, the peak stress of SiCp/2124Al composite estimated is similar to that of 2124Al alloy.

2.It was indicated, through optical microstructure analyses, that the configuration of the grain was affected by the distribution of SiCp and deformation condition.

3.Based on the stress-strain curves and TEM observation, the presence of SiCp changed the precipitation kinetics during the deformation, the softening at lower strain rate was mainly attributed to the precipitation coarsening, however at higher strain rate, the stress decrement was due to the DRX and dynamic precipitation. The fraction of DRX increases with increasing SiCp volume fraction.



(a) (b) (c)

Fig.5. Transmission electron micrographs of 5vol% SiCp/2124Al composites (a) before deformation, (b) after deformation up to ε=0.35 at 450°C, (c) after deformation up to ε=0.9 at 450°C.

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