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Microdistortion behavior of Al alloy reinforced by SiC_p

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Abstract: Al alloy reinforced with SiC_p was fabricated by the method of pressureless infiltration. The effects of factors such as SiC_p size, volume fraction, matrix material and heat treatment process on microdistortion behavior of Al alloy were investigated. The results show that microdistortion decreases along with lessening of SiC_p size and increasing of SiC_p volume fraction. Matrix material has influence on the microdistortion behavior, and solution-aging can improve the microdistortion behavior. Stress and residual strain related to microdistortion behavior were simulated by FEM. It is found that the distribution of strain and stress is not symmetrical; residual strain and stress at interface are higher than those at the other places; at the sharp-angled area of a particle, matrix has the highest strain and stress where plastic distortion is caused at first; the microdistortion and stress far from the interface are smaller.

Key words: microdistortion behavior; Al alloy; SiC_p; FEM analysis; residual strain

1 Introduction

Al alloy improved by SiC_p has some excellent characters: low density, high elastic modulus, high wear-resistance, low expansion coefficient and so on, so it is applied widely in many fields such as military, aircraft, automobile, machinery and electronic packaging[1−2]. In modern aero-industry, a more rigorous demand is made on the synthetical performance of Al alloy, especially for its microdistortion behavior [3−6]. For example, in the optical level reflector[7−8] of inertia navigation, aerospace field, a slight microdistortion may decline the apparatus accuracy, which leads to measuring error, even to failure. Therefore, it is very important to study the microdistortion behavior of Al alloy. Now, researchers pay more attention to micron-nanometer level SiC_p on Al alloy[9−10], but study on microdistortion behavior of Al alloy reinforced by biggish size SiC_p was not reported which has more applicability and abroad future. In this paper, advanced experiments are carried out to obtain experimental data, and then by using FEM method the microdistortion behavior is simulated. It is proved that the study is effective for making clear the microdistortion behavior of Al alloy reinforced by SiC_p.

2 Experimental

ZL101(Al-7.2%Si-0.35%Mg), ZL301(Al-10.5%Mg) and LY12(Al-0.58%Mn-1.3%Mg-4.0%Cu) Al alloys were chosen as matrix material, and SiC_p as reinforcement particle to enhance the mechanical properties of Al alloys. Three different nominal particle sizes of 140, 90 and 70 μm were evaluated, hereafter denoted as Al alloy(ZL101，ZL301, LY12) + (140, 90 and 70 μm) SiC_p respectively. The samples of Al alloys reinforced by SiC_p were fabricated by pressureless infiltration method, and the actual volume fraction of SiC_p was 35% or 50% respectively. Because heat-treatment process has important influence on the property of the Al alloy, its effect was also investigated. The heat-treatments used are as follows:

1) ZL101 reinforced by SiC_p. Annealing: heating for

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4 h at 400 ℃ and then cooling in stove. Solution-aging: heating for 4 h at 535 ℃, and then quenching in water, heating for 16 h at 255 ℃ in stove and at last air cooling in air.

2) ZL301 reinforced by SiC_p. Annealing: heating for 4 h at 400 ℃ and then cooling in stove. Solution-aging: heating for 4 h at 435 ℃, then cooling in water.

3) LY12 reinforced by SiC_p. Annealing: heating for 4 h at 400 ℃ and then cooling in stove. Solution-aging: heating for 4 h at 500 ℃, and then quenching in water, heating for 10 h at 190 ℃ in stove and at last cooling in air. The dimension of the test specimen is shown in Fig.1.

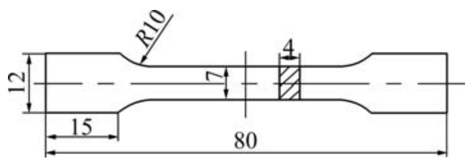

Fig.1 Testing specimen of microdistortion (unit: mm)

The specimens were tested by a continuous uniaxial tension method in static state. The continuous tension was performed with a load control mode at a low rate of 500 N/min. As the loading speed is very slow, the rigidification phenomenon of Al alloy can be negligible. Meantime, the heat brought by non-reversible work disperses quickly to environment, thus the sample temperature is basically constant[11]. The whole tension process can be measured accurately under identical conditions. Thus, the measured value can reflect truly the microdistortion of Al alloy reinforced by SiC_p[12].

3 Results and discussion

3.1 Effect of SiC_p grain size on microdistortion of Al alloy

From Fig.2, it is shown that, under the same loading, the microdistortion decreases with lessening of SiC_p size. This means that the alloy has better microdistortion behavior if finer SiC_p is used and thus the property of the Al alloy can be improved. In solution-aging, the SiC_p particles are easy to disperse along with the decrease in SiC_p size, so the average distance between grains becomes smaller. By using TEM, LI[13] researched the Al alloy reinforced by SiC_p and found that dislocation is pinned strongly by SiC_p particle, which can effectively hamper dislocation moving, meantime, small SiC_p has more combined interfaces between particle and matrix, which increases moving resistance of dislocation. Thus, the Al alloy matrix composite has better microdistortion behavior and its stability in dimension under low loading is increased. Research works[14−16] indicate that the elasticity, strength, stiffness and microdistortion

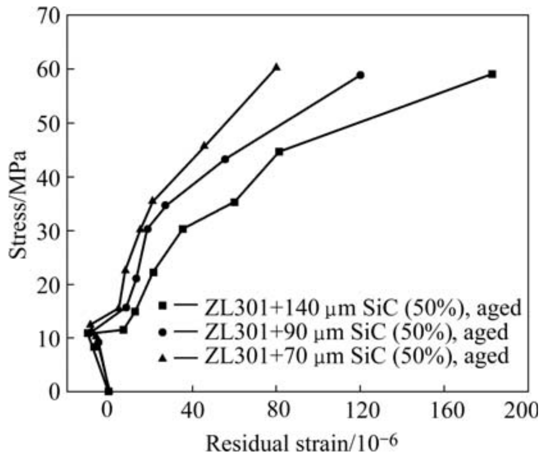

Fig.2 Stress—residual strain curves of SiC_p/ZL301composite in solution-aging state

behavior(dimensional stability) of Al alloy improved by SiC_p are more excellent than those of Al alloy matrix.

3.2 Effect of SiC_p volume fraction on microdistortion of Al alloy

The volume fraction of SiC_p is an important parameter to affect the mechanical properties of Al alloy. According to mixture principle, the larger the volume fraction of SiC_p, the better the microdistortion of the Al alloy. However, larger volume of SiC_p brings larger residual stress. Thus, the SiC_p content has perplexing influence on the microdistortion. In this paper, two cases are analyzed: in annealing, ZL101+70 μm SiC_p, and volume fraction of SiC_p is 30% and 50% respectively. The result is shown in Fig.3.

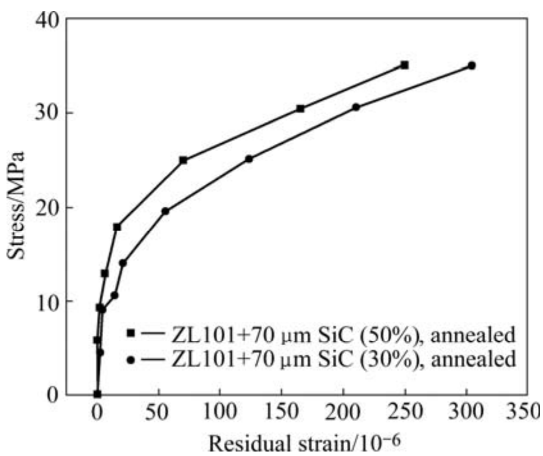

Fig.3 Stress—residual strain curves of SiC_p/ZL101 composite in annealing state

It is shown that, when the other conditions are constant, the microdistortion value lessens with increasing the volume fraction of SiC_p, thus the microdistortion behavior of Al alloy can be improved greatly by increasing the volume fraction of SiC_p. On account of the increase of the SiC_p volume fraction, more interfaces generate between SiC_p and Al alloy matrix, which hold back the moving of dislocation, and bring about more dislocation defect and strengthening phase. These make dislocation slip more difficult and increase the critical shearing strength of dislocation moving. As a result, big loading is needed to bring microdistortion; meanwhile, along with the increase of the SiC_p fraction, the SiC_p will support much load and the matrix will receive little load. It was said that[17], the fewer loads the Al alloy matrix receives, the better the microdistortion behavior of the Al alloy. However, high volume fraction of SiC_p will lead to increase of the residual stress in the alloy, so that the other properties will be weakened.

LEE[18] found by TEM observation that, initial yielding generates in crystal interface or impurity dislocation and continues until it meets one obstacle such as the other crystal interface. In this way, microdistortion behavior is a function of stress depending on dislocation sourse. When the stress of crystal interface gradually increases, it finally becomes much great so as to start up another new dislocation source of crystal interface. Thus, in the higher strain level, strain caused by stress increment is bigger than that caused by starting up of the existed dislocation source.

3.3 Effect of matrix material on microdistortion of Al alloy

Matrix material has influence on microdistortion behavior. In different matrix, its microdistortion behavior is different. When taking ZL101, LY12 as matrix and 90 μm SiC as reinforcement, after solution-aging, the stress—residual strain curves are shown in Fig.4.

Fig.4 shows that, for the same heat treatment of solution-aging and the same SiC_p size, the microdistortion behavior of LY12+90 μm SiC_p is better than that of ZL101+90 μm SiC. The possible reason is that LY12 contains Cu, Mg and Mn elements, while ZL101 only contains Si and little Mg. During solution-aging, LY12+90 μm SiC_p forms GP zone and strengthening secondary structure, such as $\theta'(Al_2Cu)$, $S'(Al_2CuMg)$, which comes into being precipitation strengthening and dispersion strengthening so that a lot of dislocation is produced to hamper the slip of crystal grains[19−20]. As a result, after solution-aging, LY12+ 90 μm SiC_p has better microdistortion behavior.

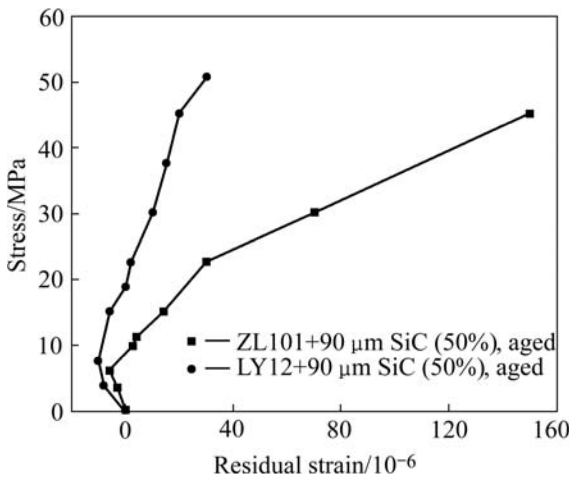

Fig.4 Stress—residual strain curves of ZL101+90 μm SiC and LY12+90 μm SiC after solution-aging

3.4 Effect of heat treatment process on microdistortion of Al alloy

Heat treatment, such as annealing or solution-aging, influences effectively the microstructure and residual stress of the Al alloy improved by SiC_p, so that its microdistortion behavior is affected greatly, as shown in Fig.5. It is shown that the microdistortion behavior of ZL101+70 μm SiC_p after solution-aging is better than that after annealing. During annealing, it does not form any strengthening secondary structure but the matrix is intenerated. However, during solution-aging, since ZL101 matrix contains a little Mg, it can form dispersive strengthening structure of Mg_2Si. On the other hand, the aging process makes for the stabilization of dislocation structure and the uniform distribution of dislocation density. Consequently, the solution-aged Al alloy has better microdistortion behavior. During solution aging, as shown in Figs.2 and 4, at the beginning, microshrinkage occurs in Al alloy reinforced by SiC_p, but its mechanism is not clear.

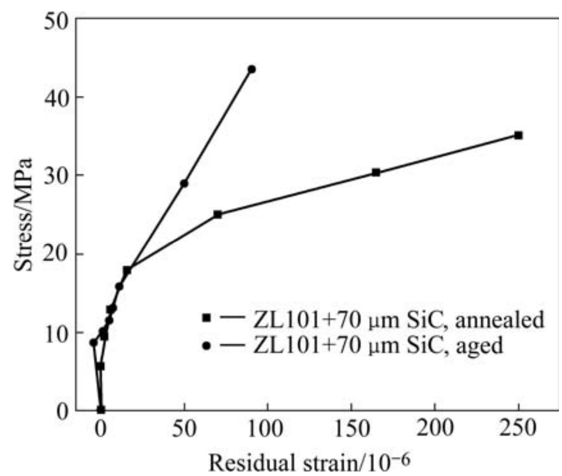

Fig.5 Stress—residual strain of ZL101+70 μm SiC_p after annealing and solution-aging

3.5 Simulation analysis of ZL101 containing different volume fraction of SiC_p

FEM is applied to simulate the microdistortion of Al alloy reinforced by SiC_p, where the axis-symmetric model is used as shown in Fig.6. l/4 cell is analyzed, and the distribution characteristic of the local stress—residual strain under loading is simulated. In solution aging, the results for ZL101+70 μm SiC (the volume fraction of SiC_p is 30% and 50% respectively) under loading are shown in Figs.7−10.

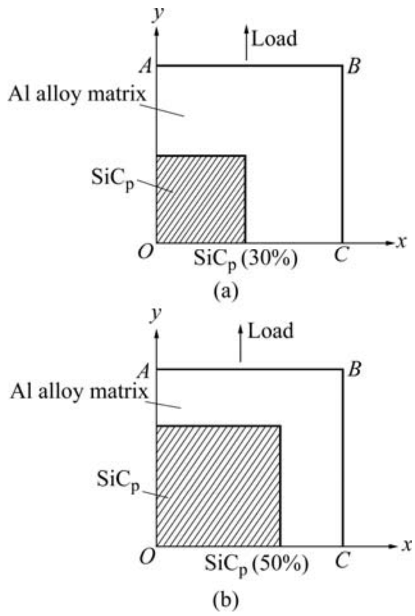

Fig.6 Axis-symmetric model

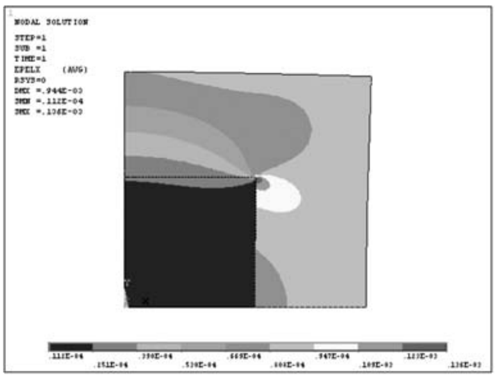

Fig.7 Residual strain distribution simulated for ZL101+70 μm SiC (30%)

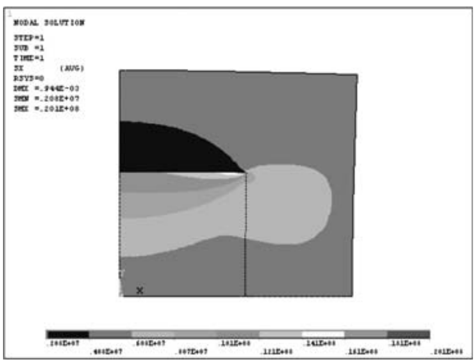

Fig.8 Residual stress distribution simulated for ZL101+70 μm SiC (30%)

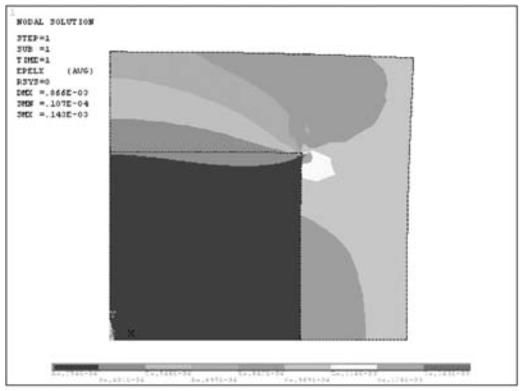

Fig.9 Residual strain distribution simulated for ZL101+70 μm SiC (50%)

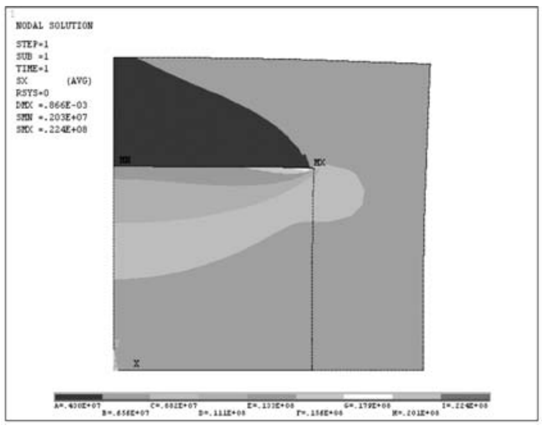

Fig.10 Residual stress distribution simulated for ZL101+70 μm SiC (50%)

It is known from Figs.7−10 that the distribution of stress—residual strain of Al alloy reinforced by SiC_p is not uniform. The residual strain and stress at the interface of matrix/SiC_p and at the sharp-angled place of the grain reach the maximum value. In good condition of interface combining, because of the difference in the elasticity modulus between the matrix and SiC_p, the microdistortion appears firstly in the matrix, while the microdistortion and the stress far from the interface are very little. For composite material, the magnitude and the uniformity of residual strain and stress have vital influence on its microdistortion behavior. Under the same loading, the Al alloy containing 30% SiC_p receives more load than that containing 50% SiC_p, and thus the microdistortion is produced more easily in the former. That is, the Al alloy containing 50% SiC_p has better microdistortion behavior as shown in Fig.7 and Fig.9. During solution aging of Al alloy reinforced by SiC_p (50%), its residual strain—stress curves of simulative data and experimental data are compared in Fig.11, and it is found that the two curves agree well.

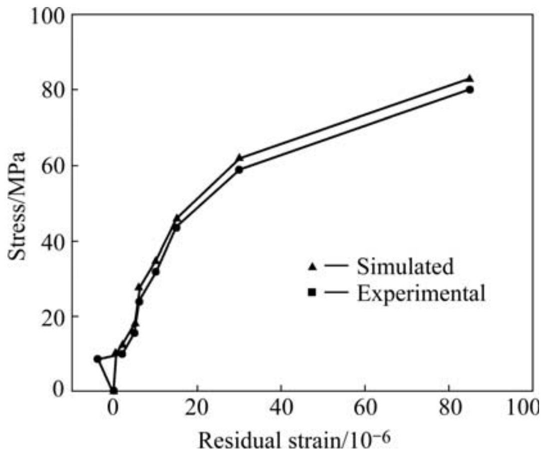

Fig.11 Residual strain—stress obtained from simulation and experiment

4 Conclusions

1) Microdistortion of Al alloy improved by SiC_p decreases along with lessening of SiC_p size and increasing of SiC_p volume fraction.

2) Al alloy matrix has important effect on the mircodistortion.

3) Solution-aging process can reduce the microdistortion of Al alloy improved by SiC_p, so the microdistortion behavior can be improved.

4) It is found by FEM simulation that, the distribution of strain and stress is not symmetrical; residual strain and stress at interface are higher than those at other places; in the matrix at the sharp-angled area of a particle the highest strain and stress generate and there appears the initial plastic distortion; and the microdistortion and stress are very small at the places far from the interface.

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