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Microstructure and thermal stability of mechanically alloyed Al_3Ti/ Al alloy①

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[Abstract] The microstructure stability of Al_3Ti/ Al alloy prepared by mechanical alloying (MA) was investigated in the simulating environment in which they may be used. The results show that the MA alloy possesses fine microstructure (the grain size is about 0.5 μm). After cycling loaded followed by heat exposure at 350 ℃ for 24 h, no microstructure coarsening of the alloy occurred, which means that the Al_3Ti/ Al alloy behaves good microstructure stability at high temperature. The compression yield strength of the alloy reaches up to 247 MPa at 350 ℃.

[Key words] mechanical alloying; Al_3Ti/ Al alloy; microstructure stability; thermal stability
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1 INTRODUCTION

Mechanical alloying is one of the important methods to prepare new materials with superior properties[1~5]. The materials prepared by this method possess fine microstructure with dispersive strengthening phases, resulting in their properties superior to the materials prepared by conventional methods[3,6,7]. In comparison with the traditional Al alloy and Ti alloy, Al_3Ti/ Al alloy prepared by MA at low temperature with liquid nitrogen as the cooling agent behaves low density and high strength at elevated temperature, especially at 350 ℃. If this material is used in aircraft to replace Ti alloy used at 300~400 ℃ partially, it is expected to promote the rate of propulsion mass of the engine[4]. Therefore, it is necessary to investigate the thermal stability of the microstructure at elevated temperature (i. e., 300~400 ℃). In this study, the thermal microstructure stability and mechanical properties of the Al_3Ti/ Al alloy at elevated temperature prepared by MA at low temperature will be studied.

2 EXPERIMENTAL

The mechanical alloyed Al_3Ti/ Al alloy used in the study was made in Exxon Res. & Eng. Co. in America. The powders with the composition of Al+ 10% Ti were alloyed in a ball grinding machine at low temperature in the liquid nitrogen. After that, the powders were heated to 400 ℃ to eliminate the gases, and then extruded at 400 ℃. The MA alloy with the composition of Al+ 27% Al_3Ti alloy was obtained.

The compression property at high temperature was measured. The dimension of the compression samples was d6.62 mm × 12 mm. To study the thermal microstructure stability at the temperature and loading condition in which the alloy is used, the loading state of the alloy at 350 ℃ was imitated on an MTS-880 materials test machine. The test parameters of dynamic loading were listed in Table 1. The samples with no deformation and deformed at cycle loading condition at 350 ℃ were sealed in silicon tubes with argon atmosphere, and heated to 350 ℃ for 24 h. The development of microstructures was observed by TEM. The TEM foils were prepared by double jet, and TEM observation was conducted on a Hitachi H-800 transmission electron microscopy.

Table 1 Parameters of dynamic loading test

Temperature / ℃	Wave type	Frequency / Hz	σ_{min} / MPa	σ_{min} / MPa	Stress rate(R)	Number (N)
350	Triangle	1	− 227	22.7	10	1×10^4

3 RESULTS AND DISCUSSION

3.1 Microstructure

Figs. 1(a), (b) are the TEM micrographs of Al_3Ti/Al prepared by MA. The microstructure of Al_3Ti/ Al alloy is very fine with the average grain size of about 0.5 μm, and the grains are in equiaxial shape, as shown in Fig. 1(a). The enlarged photograph shows that, due to their hardness and fragileness, Al_3Ti phases are inclined to be broken or extrude into Al particles during ball grinding, resulting in the outside surface of Al_3Ti particles covered with a layer of Al, as shown in Fig. 1(b). In the Al particles, especially at the interfaces, high density of dis-

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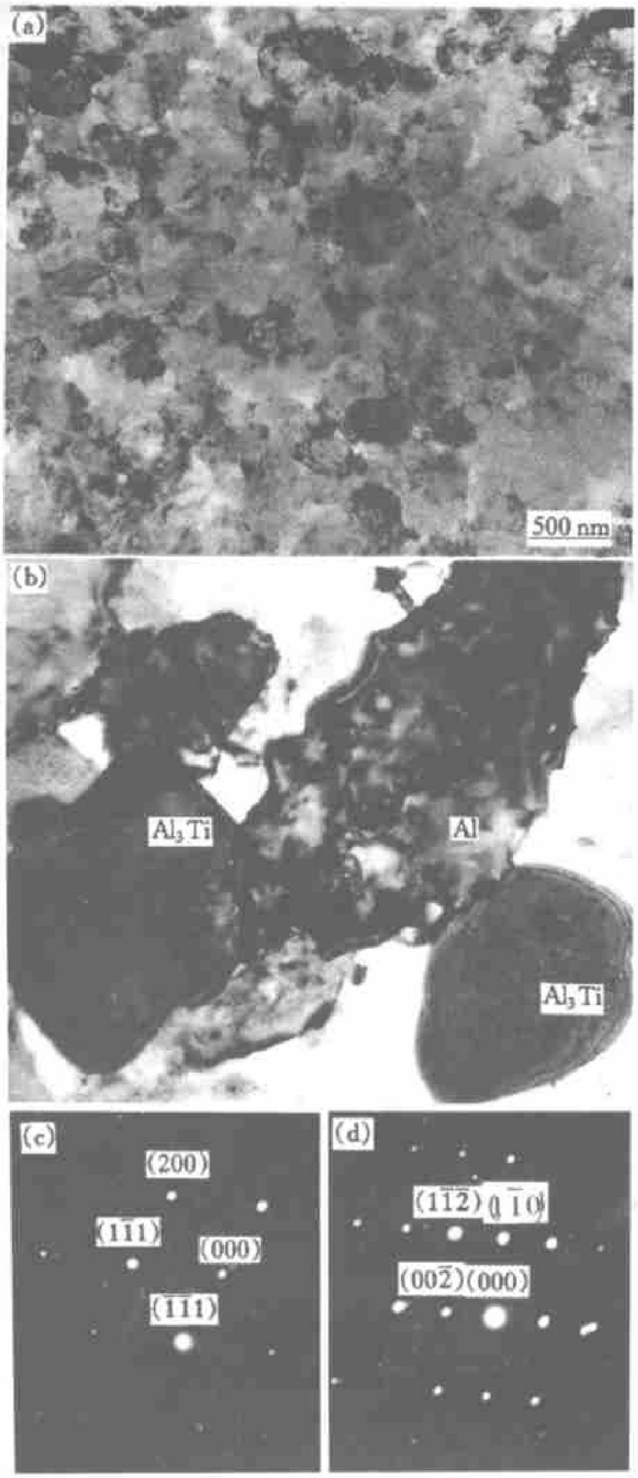

Fig. 1 TEM micrographs and diffraction patterns of Al_3Ti/Al alloy

(a), (b) —Microstructures of Al_3Ti/Al alloy;
(c) —Diffraction pattern of Al phase, B= [011];
(d) —Diffraction pattern of Al_3Ti phase, B= [110]

locations can be observed under TEM. Figs. 1(c), (d) are the diffraction patterns and the index determination of Al and Al_3Ti phases respectively. Al_3Ti behaves $D0_2$ structure, whose lattice parameters are $a = b = 3.85$ Å, $c = 8.06$ Å, while the parameter of Al is $a_{Al} = 4.0696$ Å. Thus, $c \approx 2a_{Al}$, which means that the interface between Al_3Ti and Al particles is highly coherent. It is benefit to the thermal stability of the alloy at elevated temperature. Fig. 1(b) also illustrates that a number of fine particles with the sizes ranging from 10~ 30 nm distribute dispersively in the Al_3Ti phases. The formation of these particles are attributed to the decomposition of C_6H_{14} and reaction with Ti atoms to form TiC during ball grinding[8]. These fine carbides distributing dispersively in Al_3Ti phases are very stable at high temperature, which can impede the growth of the grains.

3.2 Compression property

Fig. 2 illustrates the relationship between the compression yield strength and temperature. It can be seen that, when the temperature rises from room temperature to 350 ℃, the yield strength decreases from 420 MPa to 247 MPa. Otherwise, when the temperature rises to 425 ℃, the yield strength decreases to 95 MPa. Thus, under 350 ℃, the Al_3Ti/Al alloy can keep high strength, but the strength decrease strongly with increasing temperature, especially the temperature is over 350 ℃.

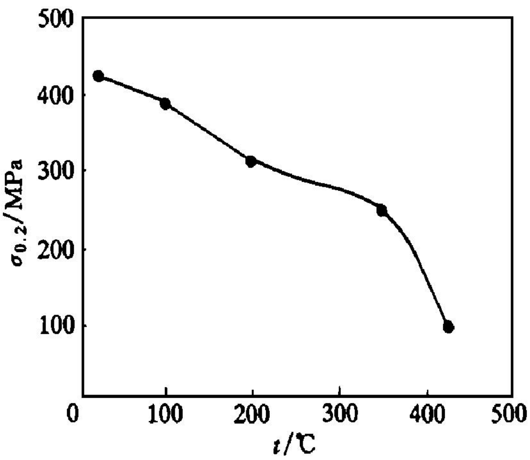

Fig. 2 Relationship between yield stress and temperature

As it well-known, the traditional aluminum alloy are often used under 200 ℃[4]. For an example, compression yield strength of 2014-T_6 alloy is about 500 MPa, slightly higher than that of Al_3Ti/Al alloy at room temperature, but it decreases to 100 MPa, when the temperature rises to 300 ℃. When temperature is over 400 ℃, the yield strength loses almost completely[9]. While, for the 7075-T_6 alloy, the compression yield strength is over 500 MPa at room temperature, but its thermal stability is very low. When the alloy is loaded at 125 ℃ or 175 ℃ for 100 h, its strength will decrease by 10% at 125 ℃, or by 70% at 175 ℃. Therefore, the alloy is often used at the temperature lower than 120 ℃[10]. As a result, Al_3Ti/Al-MA alloy possesses high strength at elevated temperature compared with traditional aluminum alloys.

3.3 Microstructure stability of Al_3Ti/Al alloy

Fig. 3 illustrates the microstructure of Al_3Ti/Al after cycle loaded followed by thermal exposure at 350 ℃ for 24 h. Compared with the original microstructure, the microstructure of the alloy has no obvious change after the treatment mentioned above. The grain size is still very fine, and no trace of the grain boundary immigration has been observed under TEM. It is attributed to the high thermal stability of the intermetallic phases of Al_3Ti distributing dispersively in the alloy, which can impede the growth of the grains effectively and results in the high strength at elevated temperature.

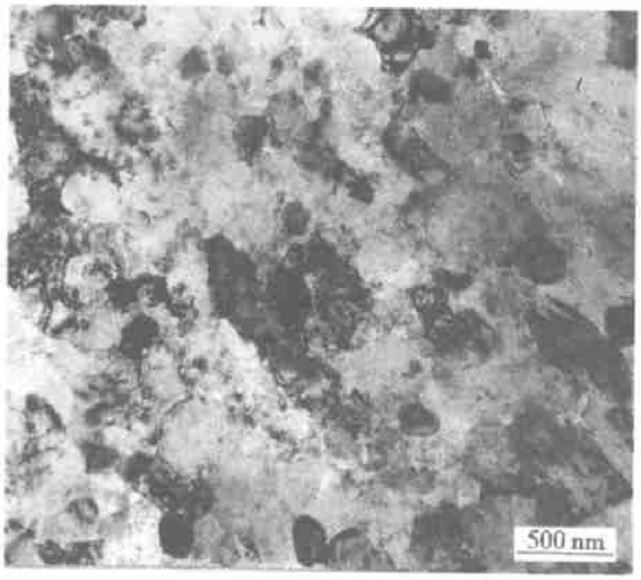

Fig. 3 TEM microstructure of sample after cycle loading followed by thermal exposure at 350 ℃ for 24 h

Fig. 4 exhibits the dislocation morphologies in the Al phases of the samples after heat-treated at elevated temperature. It can be seen that, for the samples heat-treated at 350 ℃ for 24 h with no deformation, the density of dislocation in Al phases, especially at the grain boundaries where the dislocations piling up originally, becomes lower in comparison with original sample. It means that, after thermal exposure for a certain time, the number of dislocations in the Al phases decreases, resulting in the decrease of stress concentration degree caused by dislocations piling up at the grain boundaries. For the samples after stable or dynamic loading followed by heat-treatment, the dislocations in the Al phases are curved, but not twisted. In comparison with original samples, the dislocation density in the Al phases of the samples after treatment mentioned above remains high, as shown in Fig. 4(b). It indicates that the workhardening caused by the deformation at elevated temperature has not been eliminated during the followed heat-treatment. From the point of strengthening, the decrease of the number of dislocations will lower the strength of the alloy. However, for the Al_3Ti/Al-MA alloy, the strength of the alloy seems independent on the density of the dislocation. It may be associated with primary strengthened mechanisms of the super fine grain and dispersion of the intermetallics in the alloy. The hardness test results of the samples at different conditions show that hardness of the samples after thermal exposure are identical to the original alloy, as listed in Table 2, which also indicates that the MA alloy behaves high thermal stability[11].

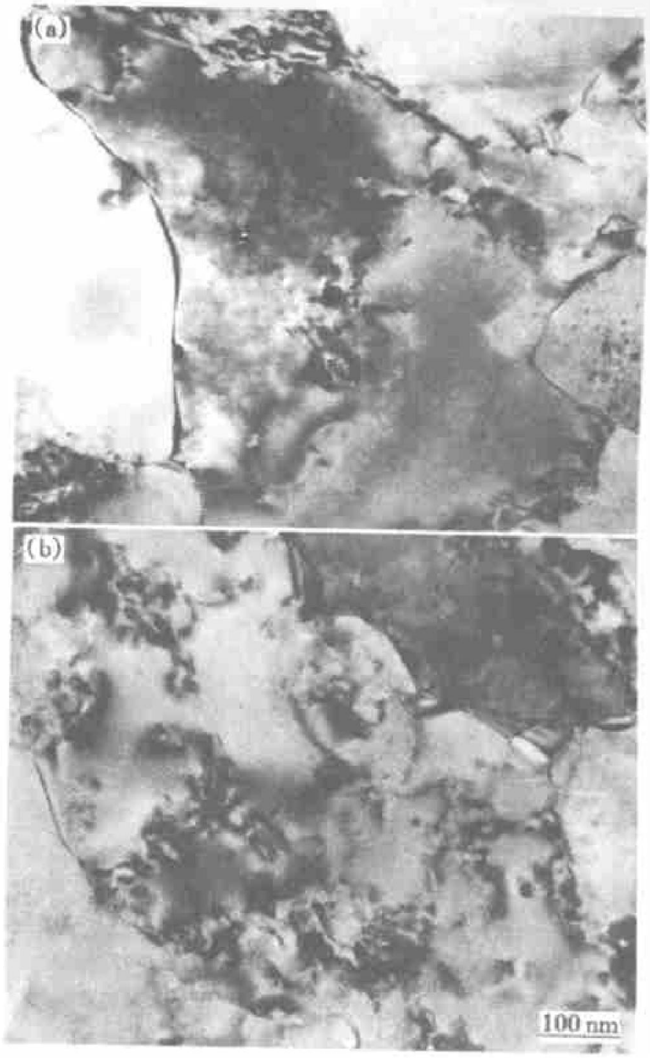

Fig. 4 Dislocation morphologies in Al phases of s8amples after heat-treatment at elevated temperature
(a) —At 350 ℃ for 24 h; (b) —After cycle loading followed by thermal exposure at 350 ℃ for 24 h

Table 2 Microhardness of samples under different treatment conditions

Sample No.	Treatment condition	Microhardness HV
1	Original condition	64.9
2	350 ℃, 24 h	61.1
3	After cycle loading followed by thermal exposure at 350 ℃ for 24 h	65.8

From all above, it can be seen that the Al_3Ti/Al alloy prepared by mechanical alloying at low temperature possesses fine microstructure, and no coarsening has occurred at elevated temperature. It means that the MA alloy behaves high thermal stability.

4 CONCLUSIONS

1) The grains of the Al_3Ti/Al alloy by mechanical alloying are very fine, and the average grain size is about 5 μm. A number of TiC particles with the size ranging from 10~ 30 nm distribute dispersively in the Al_3Ti phases.

2) No grain coarsening has occurred in the samples after compression deformation at high temperature and cycle loading followed by thermal exposure, which means that the MA alloy behaves good stability at elevated temperature.

3) The strength of Al_3Ti/Al alloy decreases with the increase of temperature, but even at 350 ℃, the yield strength still keeps at about 247 MPa.

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