Processing of Al–Zn–Mg–Cu/SiC composite prepared by mechanical alloying

E I Kurbatkina, A A Shavnev, O I Grishina and A V Gololobov

Federal State Unitary Enterprise «All-Russian Scientific Research Institute of Aviation Materials» (VIAM)

E-mail: elena.kurbatkina@mail.ru

Abstract. In the present work, using powder metallurgy method, mechanical alloying and extrusion, the metal matrix composite material Al–Zn–Mg–Cu/10% SiC was obtained. Phase transformations occurring during heat treatment were studied. After deformation aluminum solid solution, MgZn₂ and SiC are present in the composite material. The X-ray phase analysis and TEM results showed that when the composite material is heated for quenching, the MgZn₂ phase is completely dissolved. Study of the aging kinetics showed that the peak of aging of the composite material was achieved in 15 h, which is much faster than in the matrix alloy (24 h). After aging, the solid solution decomposition products appear in the form of a metastable η’-phase (MgZn₂), looking like rods located in three mutually perpendicular directions <100> Al.

Currently, composite materials with an aluminum matrix are widely used due to such properties as high specific strength, low density, low thermal coefficient of linear expansion and high processability of these materials [1–5]. Most often, in aluminum matrix composites, silicon carbide is used as a reinforcing component because it has high hardness and resistance to aluminum matrix. The addition of SiC increases the elastic modulus and tensile strength of the composite material [6–12]. Silicon carbide particles and features of the technological process can affect the phase transformations occurring in the composite material [13, 14]. For example, some papers concluded [15, 16] that the difference in thermal expansion coefficients between the matrix and SiC leads to an increase in the residual thermal stresses and density of dislocations. Also, the reinforcing component can affect the formation of nucleation centers of secondary phases at the interfaces, chemical reactions between the matrix and the reinforcing component, which lead to enrichment and depletion of local zones in the composite [17]. For aluminum alloys of the Al–Zn–Mg–Cu system, which belong to the group of dispersion-hardening alloys, the addition of silicon carbide can have an effect on the dissolution/precipitation of phases [18–21]. Due to the structural features of the composite material, time ranges of heat treatment, especially of aging, may change [22, 23].

The purpose of this work is the analysis of phase transformations occurring in a composite material based on the Al–Zn–Mg–Cu dispersion-strengthened alloy reinforced with SiC particles.

As the initial materials, we used a spherical powder of an Al–6% Zn–2.5% Mg–2.5% Cu–0.5% Mn aluminum alloy with a particle size of 10–100 μm, as well as silicon carbide powder with a particle size of 2–10 μm. Mass of the initial components, loaded into the mill for processing, was selected based on the content of silicon carbide in the composite material - 10%. Powders were mixed in a V-shaped mixer for 30 min, then were subjected to the mechanical doping in a planetary mill Fritsch Pulversisette 5 for
30 min in inert gas. The weight ratio of balls to powder charge was 20:1. After mechanical alloying composite granules were hot extruded on a 500 ton press at a temperature of 575°C with extrusion ratio of 15:1. Microhardness was determined using a HV-1000 (Time Group) tester. Microstructure of the composite material was studied using scanning electron microscopy (SEM) on a JEOL JSM-6490 LV microscope and transmission electron microscopy (TEM) on a Tecnai G2 F20 S-TWIN microscope. X-ray phase analysis was carried out using a Rigaku D/MAX-2500 diffractometer.

Study of the structure of the composite material after extrusion using scanning electron microscope showed that it contains matrix aluminum alloy and particles of a reinforcing component uniformly distributed in it (figure 1a). The particles of silicon carbide have a size from tenths to 5 μm. The particles of silicon carbide are crushed during the process of mechanical alloying and have a size from tenths to 5 μm. X-ray phase analysis showed (figure 1b) that after extrusion structure contains aluminum solid solution, silicon carbide and MgZn2 phase. Quenching according to the regime typical of aluminum alloys of the Al–Zn–Mg–Cu system: temperature of 465°C, holding time for 1 h, leads to dissolution of this phase (figure 1b) in an aluminum solid solution.

![Figure 1. (a) Structure and (b) X-ray diffraction pattern of the composite material](image)

To determine the heat treatment mode, leading to the maximum strength properties of the composite material, samples were aged in the time range from 0 to 35 h. Based on the results, the kinetic curves of aging (the dependence of the microhardness of the matrix aluminum alloy on the aging time at a temperature of 120°C) were obtained (figure 2).

![Figure 2. Kinetic curves of aging of the composite material and the matrix alloy](image)

Peak-aging of the composite material is reached in 15 h. After the peak-aging, the microhardness decreases, which is probably associated with overaging. The comparison of kinetic curves showed that an increase in the strength of the composite material occurs much faster than that of the matrix alloy.

Analysis of the composite material aged according to the established regime (15 h, 120°C) using transmission electron microscope showed the formation of solid solution decomposition products, metastable η'-phase (MgZn2), which has the form of rods located in three perpendicular directions <100> Al (figure 3).


**Figure 3.** η’-phase in a composite material (phase rods are oriented perpendicular to the image).

**Acknowledgments**

The work was carried out with the financial support of the Russian Scientific Fund Agreement (no. 17-73-1032).

**References**

[1] Saheb N, Khalil A, Hakeem A S and Laoui T 2013 *J. Nano Res.* **21** 29–35
[2] Pal S, Mitra R and Bhanuprasad V V 2008 *Mater. Sci. Eng. A* **480** 496–505
[3] Li B, Luo B, He K, Zeng L, Fan W and Bai Z 2015 *J. Alloys Comp.* **649** 495–499
[4] Wang Z, Li C, Wang H, Zhu X and Wu M 2016 *J. Mater. Sci. Tech.* **32** 1008–12
[5] Papazian J M 1988 *Metall. Trans.* A **19** 2945–53
[6] Ludtka G M and Laughlin D E 1982 *Metall. Trans.* A **13** 411–418
[7] Oguocha I N A and Yannacopoulos S 1997 *Mater. Sci. Eng. A* **231** 25–33
[8] Hunt E, Pitcher P D and Gregson P J 1990 *Scripta Metall. Mater.* **24** 937–941
[9] Guo J and Yuan X 2009 *Mater. Sci. Eng. A* **499** 212–214
[10] Arsenault R J and Wu S B 1988 *Scripta Metall.* **22** 767–772
[11] Chawla N and Shen Y L 2001 *Adv. Eng. Mater.* **3** 357–429
[12] Ganesh V V and Chawla N 2005 *Mater. Sci. Eng. A* **391** 342–353
[13] Cottu J P, Couderc J J, Viguier B and Bernard L 1992 *J. Mater. Sci.* **27** 3068–74
[14] Badini C, Marino F and Verné E 1995 *Mater. Sci. Eng. A* **191** 185–191
[15] Hadianfard M J, Mai Y W and Healy J C 1993 *J. Mater. Sci.* **28** 3665–69
[16] Lin G, Zhen-zhu W and Bin X U 2005 *Transac. Nonferr. Met. Soc. China* **16** 387–391.
[17] Hayoune A and Hamana D 2009 *J. Alloys Comp.* **474** 118–123.
[18] Cheng N, Zeng S and Liu Z 2008 *J. Mater. Process. Tech.* **202** 27–40
[19] Gouma P I, Lloyd D J and Mills M J 2001 *Mater. Sci. Eng. A* **319–321** 439–442
[20] Liu P, Wang A, Xie J and Hao S 2015 *Transac. Nonferr. Met. Soc. China* **25** 1410–18
[21] Choi H J, Min B H, Shin J H and Bae D H 2011 *Compos. Part A: Appl. Sci. Manufact.* **42** 1438–44
[22] He Y, Wang N, Qiao B, Feng L and Chen Z 2010 *Chinese J. Nonferr. Met.* **20** 1302–08
[23] Bhaduri A, Gopinathan V, Ramakrishnan P and Miodownik A P 1996 *Mater. Sci. Eng. A* **221** 94–101