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Effect of heat-treatment on microstructure and properties of SiC particulate-reinforced aluminum matrix composite

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Abstract: The effects of solid solution and aging processing on the microstructures and mechanical properties of the multi-layer spray co-deposited 7090Al/SiC_p composite were investigated. The experimented results show that fine grains and homogeneous microstructures can be obtained, the average grain size of the as-solid solution treated and as-aged composites after extrusion is under 3.0 μm. A large amount of the Cu-rich phase particles form in the as-extruded samples, and solve into the matrix after solid solution treatment. After aging, the size of the precipitate phases, mainly $MgZn_2$ and $CuAl_2$ is less than 1.0 μm, which homogeneously distribute inside the grains and at the grain boundaries. The ultimate tensile strength of the composite treated at T6 state, i.e. solid solution treated at 475 ℃ for 1 h then aged at 120 ℃ for 24 h, is up to 765 MPa.

Key words: aluminum matrix composite; spray deposition; heat-treatment; fracture morphology

1 Introduction

Particulate reinforced aluminum alloy matrix composites have received attention over many years due to their excellent yield and tensile strengths, high specific elastic modulus and isotropic properties compared with the conventional alloy materials, which makes them the good candidate materials for structural applications in the fields of aerospace, automotive, electronics industry[1−3]. During the last decade, considerable efforts have been made to improve the strength of precipitation hardening aluminum alloy matrix composites, such as developing new preparation technologies or suitable heat-treatments.

It has been shown that spray co-deposition technique is one of the most effective methods for preparation of ceramic particulate reinforced metal matrix composite(MMCp)[4−5]. In this work, 7090Al/SiC_p composite was prepared by the spray deposition technique, extrusion deformation and different heat treatments processing were applied to improve the strength, the influence of which on the microstructures and mechanical properties of the composites were investigated.

2 Experimental

The preform of Al-Zn-Mg-Cu/SiC_p composite, with the chemical composition as listed in Table 1, was produced by multi-layer spray deposition technology. Fig.1 shows the principle of this technology. The average diameter of silicon carbide particles is about 10 μm, and the volume fraction is controlled at about 15% (volume fraction).

Table 1 Composition of matrix alloy (mass fraction, %)

Zn	Mg	Cu	Ni	Zr	Al
10.15	3.63	1.8	0.15	0.3	Bal.

The composite preform was firstly chipped into a billet of *d* 200 mm in diameter and about 250 mm in length and then hot extruded to bar of *d* 20 mm in diameter. The extruding temperature is 420 ℃.

The samples taken from the bar were heat-treated at T6 state, which involved solution at 475 ℃ for 1 h, then quenched with water and aged at 120 ℃ for 24 h. Microstructural characterizations of the as-extruded bars and the as-solid solution treated and the as-aged

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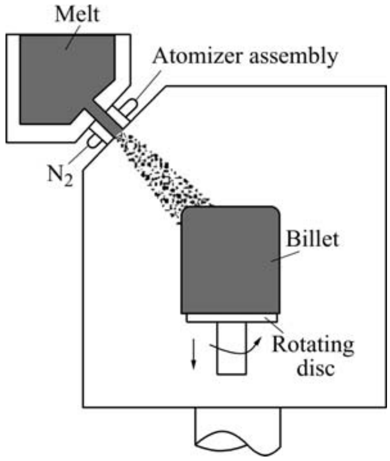

Fig.1 Principle of multi-layer spray deposition

specimens were carried out by optical microscopy(OM), scanning electron microscopy(SEM), transmission electron microscopy(TEM) and X-ray diffraction(XRD). Mechanical properties of the samples (standard samples with 10 mm in diameter) in different states, such as the as-extruded, as-solid solution treated and as-aged, were tested with tensile machine. The fractures of the samples were examined by SEM.

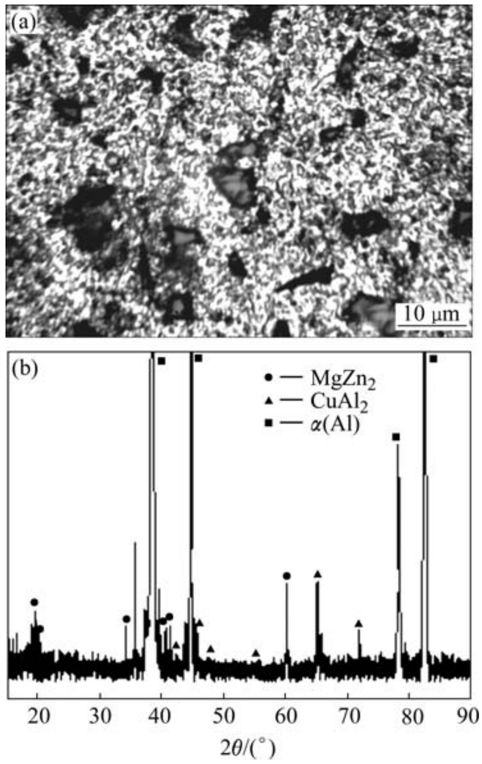

Fig.2 Microstructure and XRD pattern of as-extruded composite

3 Results and discussion

3.1 Microstructure of as-extruded sample

Fig.2 shows the microstructures and XRD pattern of the as-extruded sample. It can be seen that SiC particles uniformly distribute in the α(Al) matrix, the size of the grains is less than 3.0 μm and some small secondary phase particles with the size about 2.0 μm distribute in the grains and along their boundaries. From the XRD pattern shown in Fig.2(b), the precipitate phases include $MgZn_2$ and $CuAl_2$. The fine microstructure resultes from the rapid solidification effect of the alloy melt during spray deposition processing. For the atomized droplets, the cooling rate can be as high as 10^3-10^5 ℃/s[6]. The relatively cool SiC particles co-deposited with the droplets on the surface of the substrate can further raise the cooling rate, which can contribute to the total heat transfer coefficient by 12%−14%. In the multi-layer spray deposition technology, when the droplets impinge on the upper surface of the deposit, it can cool down at a rate about 10^3-10^5 ℃/s, owing to the large heat transfer coefficient between the flattered droplets and relatively cool solid-state surface[7−9].

3.2 Microstructure of as-aged sample

The microstructures of the heat-treated samples, solid solution treated at 475 ℃, water quenched and then aged at 120 ℃ for 24 h, are shown in Fig.3, and Fig.4 shows the TEM microstructures of as-solid solution treated and as-aged composites. Besides the SiC particles,

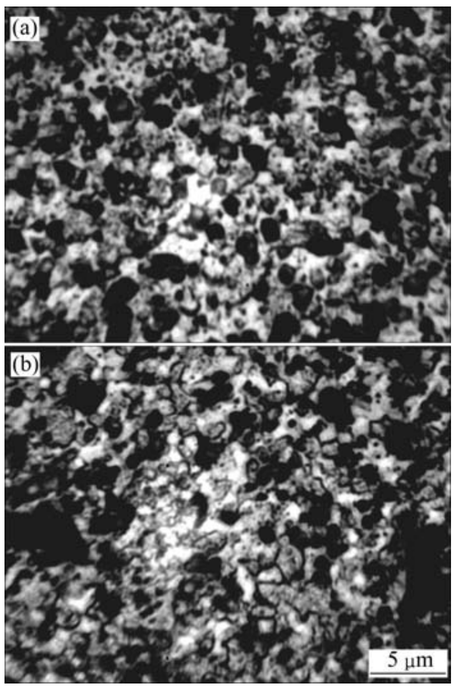

Fig.3 Microstructures of composite after solution treatment at 475 ℃ for 1 h (a) and solution treatment at 475 ℃ for 1 h then aging at 120℃ for 24 h (b)

numerous precipitates with the size less than 1.0 μm are shown at the interface between the alloy matrix and SiC particles and along the boundaries of the grains with the

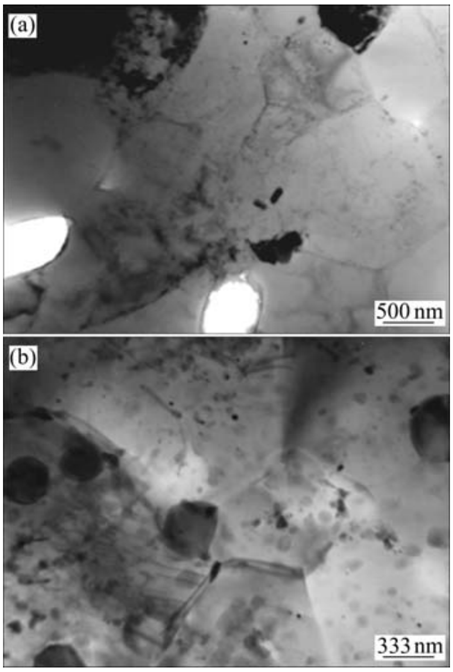

Fig.4 TEM microstructures of composite after solution treatment (a) and aging (b)

size about 2−3 μm. The reason for the precipitates aggregation along the boundaries is that the lump of defects causes the supersaturated solid solution to precipitate easily[10−12]. For Al-Zn-Mg-Cu series alloy, after solid solution treatment, the as-formed supersaturated solid solution will precipitate during the following aging processing in the following sequence[13]: sss→GP zones→ η'→ η.

The equilibrium precipitate η-$MgZn_2$ has a hexagonal crystal structure and an incoherent interface with the matrix and the meta-stable precipitate η' presents similar composition and crystal structure with η-$MgZn_2$ but shows semi-coherent interface with aluminum. The Guinier-Preston Zones (GP zones) have a composition close to that of MgZn and are fully coherent with the matrix[14].

In this work, about 1.8%(mass fraction) copper was added into the alloy to accelerate the precipitation process and to improve the temperature stability of the phases η' and η. The equilibrium precipitate forms at 200−300 ℃ and can dissolve at above 300 ℃. Since the temper is attained by ageing for 24 h at 120 ℃, it is reasonable to accept that the majority of the precipitates are η', as determined in the present work.

3.3 Mechanical properties

The mechanical properties of the as-processed composites are listed in Table 2. The fracture strength of the as-aged sample is 765 MPa, which is much higher than that of the as-extruded and the as-solid-solution treated samples, but the elongation is the smallest.

Table 2 Mechanical properties of 7090/SiC_p

Sample No.	Heat treatment	σ_b/MPa	δ/%	E/GPa
1	As-extruded	390	4.5	
2	475 ℃, 1 h	610	2.0	
3	475 ℃, 1 h+120 ℃, 24 h	765	1.0	96.8

The low elongation of the composite can be explained by the fracture models shown in Figs.5(a) and (b)[15]. Actually, these models are not individual and they are connected with each other. In the first model shown in Fig.5(a), when the shear stress acted on the SiC particles reaches the ultimate, they will fracture and become the source of cracks. In the separation model shown in Fig.5(b), due to the effect of shear stress on the interface of matrix/reinforced particle, the cracks will appear at the weak interface and extend when the stress increases.

The SiC particles exert influence on the mechanical

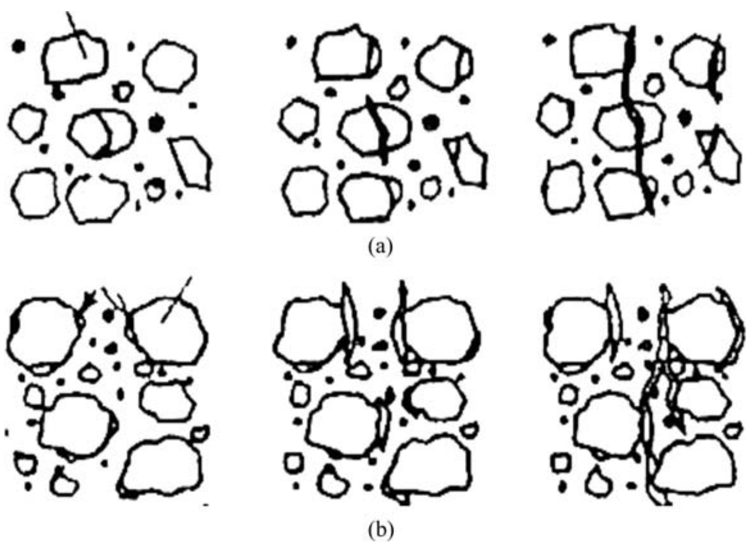

Fig.5 Fracture model of Al/SiC_p composite[15]: (a) Fracture model of SiC particle; (b) Separation model of Al/SiC_p interface

properties of the composites by two ways, direct and indirect mechanisms[16]. For the direct mechanism, the particles bear part of the load exerted on the composites when the load is transferred from the matrix with shear action of the boundary, especially when the size of SiC particles is larger than 20 μm. For the indirect mechanism, the particles affect the microstructure of the composite in two aspects. On one hand, the SiC particles can refine the microstructure. On the other hand, the tangling effects of dislocations around the particles may also result in the increase of the strength. The decrease of elongation mainly results from the fracture of SiC particles and micro-cracks form along the interface between the SiC particles and the matrix.

Fig.6 shows the fracture surface of the as-aged samples. It is clear that cracks form both at the interface between the SiC particles and at the broken SiC particles.

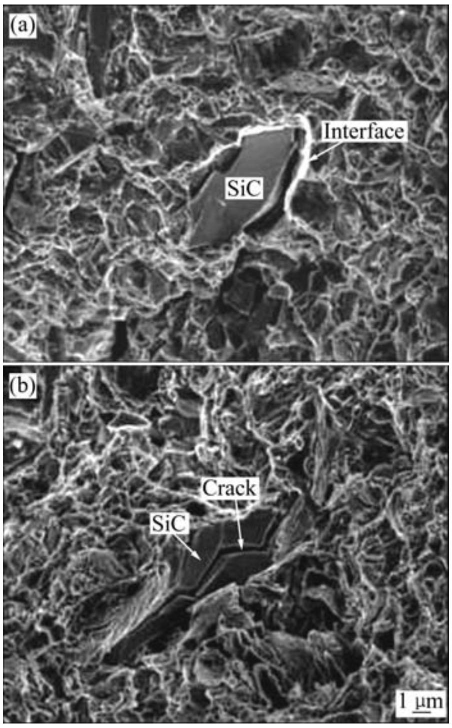

Fig.6 Morphologies of tensile fractures of composites after aging

4 Conclusions

1) 7090/SiC$_p$ composite billet was prepared by spray co-deposition technique. The grain size is less than 3.0 μm after extrusion, and the main precipitate phases are $MgZn_2$ and $CuAl_2$ with size less than 2.0 μm.

2) The as-formed precipitates in the as-extruded and as-aged samples distribute mainly at the grain boundaries and within the grains.

3) The ambient tensile strengths of the as-extruded, as-solid solution treated and the as-aged samples are 390, 610 and 765 MPa, respectively with the elongations of 4.5%, 2.0% and 1.0%, respectively. The low elongation is attributed to the fracture of the SiC particles and the interface between the SiC particles and the alloy matrix.

References

[1] ZHAO Nai-qin, NASH P, YANG Xian-jin. The effect of mechanical alloying in SiC distribution and the properties of 6061 aluminum composites [J]. Journal of Materials Processing Technology, 2005, 170: 586−592.
[2] PANDE A B, MAJUMDAR B S, MIRACLE D B. Effect of aluminum particle in the fracture toughness of a 7093/SiC/15p composites [J]. Mater Sci Eng A, 1999, 259: 296−307.
[3] TRIFONOVA V G, KAMALOVA I V, ROMANOVA V S, PLATONOV V N. Hot deformation regimes, their influence on structure and mechanical properties of silumin based composites materials and specific features of this influence [J]. Mater Sci Eng A, 1997, 234/236: 242−244.
[4] CHEN Zhen-hua, JIANG Xiang-yang, YANG Fu-liang, et al. Technology of multi-layer spray deposition [J]. The Chinese Journal of Nonferrous Metals, 1985, 5(4): 66−69. (in Chinese)
[5] CHEN Zhen-hua, HUANG Pei-yun, JIANG Xiang-yang, et al. Multi-layer spray deposition law [J]. The Chinese Journal of Nonferrous Metals, 1985, 5(4): 70−72. (in Chinese)
[6] GUTIERREZ M E, LAVERNIA E J, TRAPAGA G M. Mathematical model of the spray deposition process [J]. Metall Mater Trans A, 1989, 20: 71−85.
[7] SINGER A R E, OZBEK S. Metal matrix composites produced by spray co-deposition [J]. Powder Metall, 1985, 28(2): 72−78.
[8] YUAN Wu-hua, XU Hai-yang, XIA Wei-jun. Preparation of heat-resistant aluminum alloy pipe blanks by multi-layer spray deposition [J]. Aerospace Mater & Technol, 2001, 31(6): 51−54.
[9] LIANG X, LAVERNIA E J. Evolution of interaction domain microstructure during spray deposition [J]. Metall Mater Trans A, 1994, 25: 2341−2355.
[10] SUGIMURA Y, SURESH S. Effects of SiC content on fatigue crack growth in aluminum alloys reinforced with SiC particles [J]. Metall Mater Trans A, 1992, 23(8): 2231−2242.
[11] WU Yue, LAVERNIA E J. Interaction mechanisms between ceramic particles and atomized metallic droplets [J]. Metall Mater Trans A, 1992, 23(10): 2923−2937.
[12] SRIVATSAN T S, LAVERNIA E J. Review: Use of spray techniques to synthesize particulate-reinforced metal matrix composites [J]. J Mater Sci, 1992, 27: 5965−5981.
[13] FERRAGUT R, SUMOZA A, TOLLEY A. Microstructural evolution of 7012 alloy during the early stages of artificial ageing [J]. Acta Mater, 1999, 47(17): 43−55.
[14] VIANA F, PINTO A M P, SANTOS H M C, LOPES A B. Retrogression and re-ageing of 7075 aluminum alloy: microstructure characterization [J]. Journal of Materials Processing Technology, 1999, 92/93: 54−59.
[15] REDMILOVIC V, THAMAS G. Microstructure of α-Al base matrix and SiC particulate composite [J]. Mater Sci Eng, 1991, 32(8): 171−179.
[16] GNJIDIC Z, BOZIC D, MITKOV M. The influence of SiC particles on the compressive properties of metal matrix composites [J]. Mater Characterization, 2001, 47(2): 129−138.

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