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Properties and microstructures of 7075/ SiC_p composites prepared by spray deposition①

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Abstract: The 7075/ SiC_p composites were prepared by spray deposition, extrusion and heat treatment technologies. The microstructures of the deposit, the extruded and heat-treated bars were analyzed. And the mechanical properties and wearing resistance were tested and compared with other aluminum alloys. The results show that the spray deposited preform presents fine microstructure and uniformly distributed SiC particles. Compared with the matrix alloy, the yield strength, modulus and wearing resistance of the peak-aged composites are improved markedly with 50% reduction of elongation. It indicates that the addition of SiC particles greatly contributes to the refining of microstructure and the altering of fracture and wearing mechanisms.

Key words: Al matrix composite; rapid solidification; spray deposition

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1 INTRODUCTION

7075 aluminum alloy is a kind of superior high strength and toughness material used widely in such fields as the frame and pin of the airplanes, etc. With the application of such rapid solidification as spray deposition and effective heat treatment technologies, the mechanical properties($\sigma_b \geqslant 700$ MPa, $\delta \geqslant 10\%$) of the 7075 material were improved markedly in the early 1990s[1-3]. However, there are few attractive results reported about the composites of 7075 alloy, especially those prepared by spray deposition technology. To obtain superior high strength material combined with high modulus, the processing technology, microstructure, mechanical and wearing properties of 7075/ SiC_p composites are investigated in this paper.

2 EXPERIMENTAL

By multi-layer spray deposition(MLSD) technology, proposed in the early 1990s by CHEN et al[4-6], the preform of 7075 aluminum matrix composites (7075/ SiC_p) reinforced with SiC particles was prepared with the diameter and length of 630 mm and 800 mm, respectively, as shown in Fig. 1. The nominal composition of the preform is Al-5.5Zn-2.8Mg-1.8Cu-0.3Mn-1.0Ni-0.8Zr. The average size and volume fraction of the SiC_p reinforcement are about 14 μm and 12%, respectively. After being extruded with the extrusion coefficient of 8.0 at 380-440 ℃,

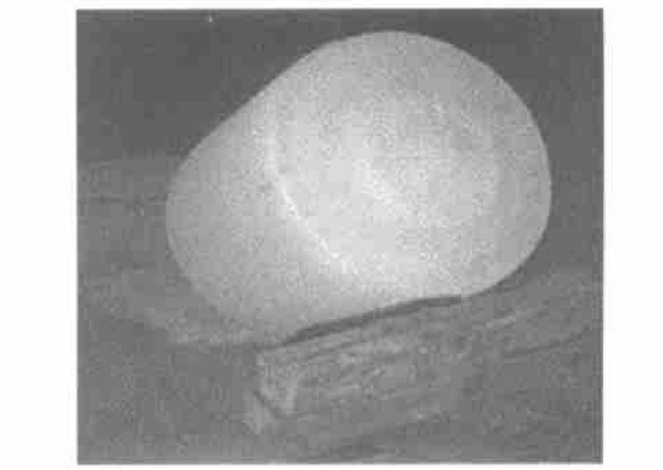

Fig. 1 7075/ SiC_p billet prepared by MLSD

the condensed composites bar with the transverse section of 330 mm × 125 mm was obtained. The samples taken from the bar were solutionized at 470 ℃ for 1 h, then quenched with water and aged at 120 ℃ for different duration between 16 and 36 h. The microstructures of the deposit, the extruded bar and the aged samples were examined by optical microscope (OM), scanning electron microscope(SEM) and X-ray diffraction(XRD). The mechanical properties of the samples(standard samples with 8 mm in diameter) in different states, such as the as-extruded, as-solutionized and as-aged, were tested with Instron tensile machine. And the wearing resistance of the peak-aged composites was compared with such mate-

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rials as Al-25Si alloy and peak-aged 7075 alloy prepared by MLSD and extrusion technologies. The fracture surfaces and the wearing surfaces of the samples were also examined with SEM.

3 RESULTS AND DISCUSSION

3.1 Microstructure of deposit

The microstructures of the spray deposited preforms and the cast block are shown in Fig. 2. The cast block presents large grains with the size more than 50 μm and coarse secondary phases distributed in grains and along their boundaries. Especially, the coarse phases of block eutectic compound, AlZnMgCu (*T*), and black frame compound, $CuMgAl_2$(*S*), are continuously distributed along the grain boundaries, as shown in Fig. 2(a). While in the deposit, as shown in Fig. 2(b), the SiC particles are distributed uniformly in the matrix and the fine eutectic structures occur. From the XRD pattern of the deposit, nominal $MgZn_2$ precipitate phase presents in the matrix.

By comparing Fig. 2(a) with Fig. 2(b), it can be concluded that the deposit shows finer microstructure resulted from rapid solidification during the spray deposition process. The acquisition of rapid solidification was attributed to three parts. Firstly, at the atomization step, the melt was fragmented into small droplets and the steep temperature gradient between the droplets and the atomization gas led to rapid heat transfer from the droplets to the gas, and the droplets were cooled down at a cooling rate about 10^3-10^5 ℃/s[7]. Secondly, while relatively cool SiC particles and high temperature droplets were compacted, the heat transferred to the SiC particles rapidly that contributed 12%-14% to the total heat transfer coefficient, and the droplet cooled down, nucleated and solidified quickly. Finally, in the MLSD technology, when the droplets impinged on the upper surface of the deposit, it cooled down at a rate about 10^3-10^5 ℃/s, owing to the large heat transfer coefficient between flattered droplets and relatively cool solid-state surface[8-10].

Fig. 2 Metallographs of cast and spray deposited billets

(a) —Cast block; (b) —Spray deposited preform

3.2 Microstructures of plastic-deformed and heat-treated composites

The microstructures of the extruded composites bar are shown in Fig. 3. In the transverse section, the uniformly distributed SiC particles appear in α-Al matrix, as shown in Fig. 3(a). And the linearly distributed SiC particles along the extrusion direction are the main characteristics in the longitude direction, as shown in Fig. 3(b).

The microstructures of the extruded and heat-treated bar, solutionized at 470 ℃ for 1 h and then aged at 120 ℃ for 24 h, are shown in Fig. 4. Besides SiC particles, numerous precipitates with the size less than 1 μm are shown at the interface between matrix and SiC and along the boundaries of grains with the size about 3-5 μm. The reason for precipitate aggregation along the boundaries is that the lump of defects cause the supersaturated solid solution to precipitate easily and deposit preferentially[11-13].

3.3 Mechanical properties of composites

The mechanical properties of the as-processed composites are listed in Table 1, showing that the composites, solutionized at 470 ℃ for 1 h and then aged at 120 ℃for 24 h, present excellent combined mechanical properties, i e the fracture strength,

Table 1 Mechanical properties of 7075 alloy and 7075/ SiC_p

Condition	$\sigma_{0.2}$/MPa	σ_b/MPa	δ/%	*E*/GPa
①	192	390	10.0	82
②	570	660	8.0	88
②+ 120 ℃, 16 h aging	670	710	7.0	92
②+ 120 ℃, 20 h aging	670	720	7.0	94
②+ 120 ℃, 24 h aging	660	735	5.8	94
②+ 120 ℃, 28 h aging	630	710	6.0	92
②+ 120 ℃, 32 h aging	645	720	6.0	93
②+ 120 ℃, 36 h aging	630	725	5.0	93
③	610	730	13.0	72

①—Extrusion, 7075/ SiC_p;
②— ①+ 470 ℃, 1 h;
③—7075 alloy, 470 ℃, 1 h+ 120 ℃, 24 h

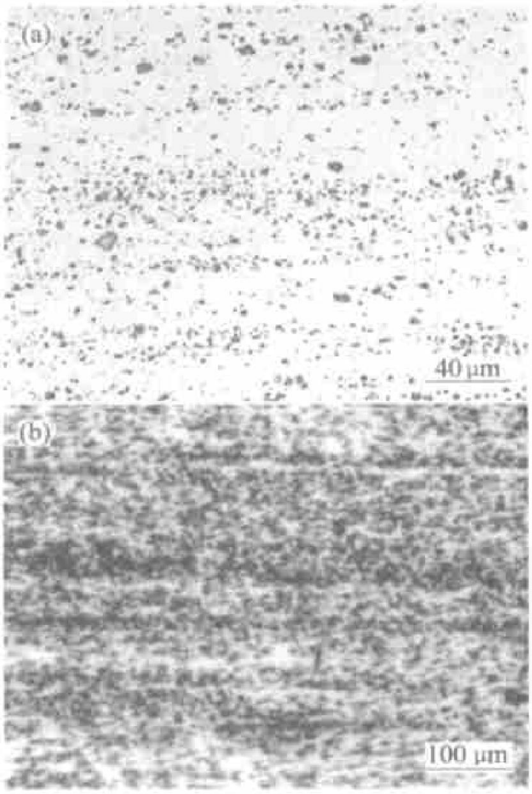

Fig. 3　Metallographs of extruded bar
(a) —Transverse section; (b) —Longitude section

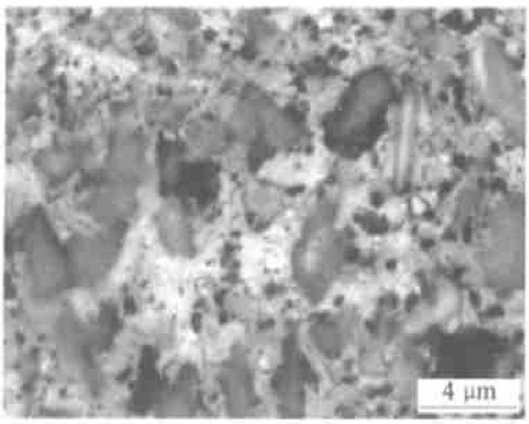

Fig. 4　Metallograph of extruded and heat-treated bar

yield strength, modulus and elongation are 735 MPa, 660 MPa, 94 GPa and 5.8 %, respectively.

Compared with the as-processed 7075 alloy, the composites show higher yield strength and lower elongation. From the strengthening mechanisms of SiC particles, it can be proposed that the differences result from the addition of SiC particles. The SiC particles exert influences on the mechanical properties of the composites by two ways, direct and indirect mechanisms[14]. By 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. By indirect mechanism, the particles affect the microstructure of the composites in two aspects. On one hand, the SiC particles can refine the microstructure of deposit, as shown in Fig. 2. On the other hand, the tangling effects of dislocations around the particles may also result in the increase of the strength[15]. The decrease of elongation mainly results from the fracture of the SiC particles and microcracks emerged along the interface between SiC_p and matrix, as shown in Fig. 5(a). And the porous spots between the gathered SiC particles are also the cracking sources, as shown in Fig. 5(b).

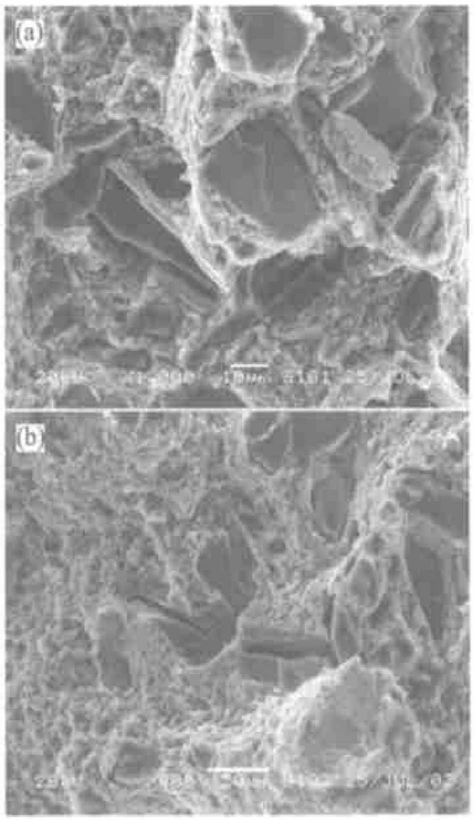

Fig. 5　Morphologies of tensile fractures of composites
(a) —Microcracks along interface between SiC_p and matrix;
(b) —Porous spots between gathered SiC_p

3.4 Wearing resistance of 7075/SiC_p composites

Under the condition of continuous lubrication, the wearing resistance of the composites compared with Al-25Si and 7075 alloys are listed in Table 2. The wear amount increases with the increase of the load on them. And under the same condition, the wear amount of the composites is far less than that of the other two alloys, i e under the load of 98 N, the wear amount of the composites decreases from 67 mg (7075 matrix alloy) to 9 mg.

Considering the wearing mechanism, two factors may contribute to the improvement of wearing resistance of the composites. Firstly, with the addition of SiC particles, the hardness of the composites increases markedly, resulting in the improvement of the wearing resistance. The hardness (HB) of the Al-25Si alloy, peak-aged 7075 matrix alloy and the peak-aged composites are 101, 110, and 140, respectively. The other aspect is the influence of SiC particles on the wearing surface. After the matrix around the SiC particles are abraded with adhesive wearing mechanism, the hard SiC particles are protruded and bear much of the load. So the abrasion area decreases and the oil content between the abrasion faces increases, resulting in the improvement of the wearing resistance, as shown in Fig. 6.

Table 2 Wear amount of different materials (mg)

Load/ N	Al-25Si	7075	7075/ SiC_p
98	40	67	9
196	57	77	13
294	66	82	15

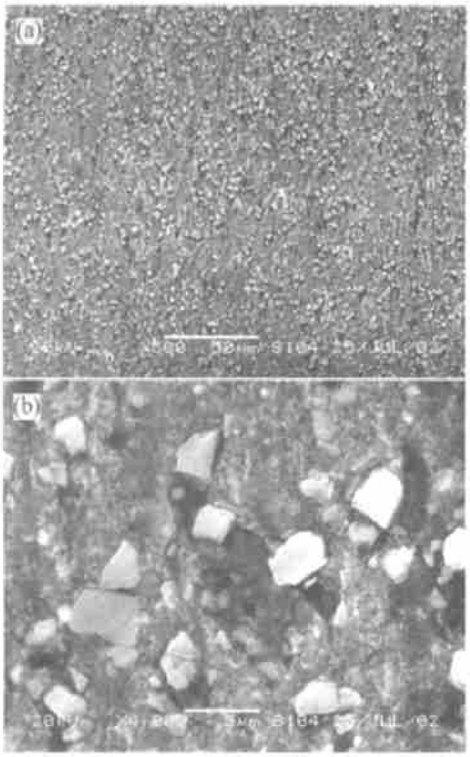

Fig. 6 Morphologies of wearing surface of composites
(a) —Protruded SiC particles;
(b) —Microhole as oil container

4 CONCLUTIONS

1) Due to rapid solidification in the process of spray deposition, the spray deposited 7075/ SiC_p composites present fine microstructure with the main precipitate phase of $MgZn_2$.

2) After extrusion, the SiC particles show linear distribution along the longitude direction. And followed by peak-aged treatment, the precipitates distribute mainly at the grain boundaries and the interfaces of SiC_p/ Al.

3) The peak-aged 7075/ SiC_p composites show higher yield strength, modulus and 50% reduction of elongation compared with 7075 alloy.

4) Compared with the matrix, the wearing resistance of the 7075/ SiC_p composites increases markedly, and is also higher than that of the hypereutectic Al-25Si alloy. The hardness improvement of the composites, bearing of load on the SiC particles and the increase of oil content between the wearing surfaces are the main reasons for the increase of wearing resistance.

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