

Effect of SiCp on Microstructure and Mechanical Properties of Mg-Zn-Ca-Mn Matrix Composites

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Abstract: Mg-Zn-Ca-Mn matrix composites reinforced with two volume fractions (1 and 3 vol%) of SiC particles (1 μm) were fabricated by a semisolid stirring assisted ultrasonic vibration method, and then extruded at 350 $^{\circ}\text{C}$ with the extrusion ratio of 15:1. The microstructures of the composites were examined by optical microscopy (OM), scanning electron microscope (SEM) and transmission electron microscopy (TEM). The microstructure analysis shows that the relatively uniform SiCp distribution and the refined grains are obtained in the 1 vol% SiCp/Mg-Zn-Ca-Mn and 3 vol% SiCp/Mg-Zn-Ca-Mn composites after the extrusion. The introduction of SiCp can improve yield strength and ultimate tensile strength. Both of the yield strength and ultimate tensile strength increase with the increase of SiCp content.

Key words: composite; microstructure; tensile property

Magnesium alloys are structurally and strategically important materials due to their high specific strength, good welding ability, good cast ability, high thermal conductivity and resistance to electromagnetic radiation. Therefore, magnesium and its alloys are widely studied in the aerospace, military, especially in the automotive industries^[1-4]. However, the major restricting factors of magnesium and its alloys in critical industrial and commercial applications include poor mechanical properties, comparatively low friction and wear resistance^[5,6]. Therefore, the improvement of the tensile strength of magnesium and its alloys is very important. Most of these drawbacks can be overcome by adding the high modulus and strength reinforcements into the magnesium matrix. Recently, the researchers interest in developing SiCp reinforced magnesium matrix composites has grown obviously. Nie et al.^[7] fabricated the nano-sized SiCp/AZ91 composites by stir casting and ultrasonic dispersion, and it was found that the introduction of nano-sized SiCp resulted in the simultaneous enhancement of tensile strength and yield strength of magnesium alloys. Study of Deng et al.^[8] on the tensile behaviour of the AZ91 magnesium reinforced with submicron SiCp illustrated that a little amount of SiCp (~200

nm) had a significant effect on grain refinement and mechanical properties of the AZ91 magnesium alloy. Some researches have been done on 10 μm SiCp reinforced magnesium matrix composites, and these researches revealed that the introduction of 10 μm SiCp led to a significant improvement of fracture, yield strength and ultimate strength^[4]. These investigations on the SiCp reinforced magnesium matrix composites confirm that the size, content and the shape of particles have a great influence on the mechanical properties of magnesium alloys^[9-11]. However, until now few results have been reported in the literatures on magnesium matrix composite reinforced by 1 μm SiC particles, especially fabricated by a semisolid stirring assisted ultrasonic vibration method^[12-14].

Therefore, the primary aim of the present study is to illustrate the effects of 1 μm SiC particles on the microstructure and mechanical properties of magnesium matrix composites extruded with extrusion ratio of 15:1.

1 Experiment

In the present study, the Mg-Zn-Ca-Mn magnesium alloy ingots with chemical composition (Zn-4.514, Ca-1.167,

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Mn-0.055, Mg-balance) were used as the matrix alloys. The SiCp with an average particle size of $\sim 1 \mu\text{m}$ was used as reinforcements. The $1 \mu\text{m}$ SiCp reinforced Mg-Zn-Ca-Mn magnesium matrix composites were fabricated by a semisolid stirring assisted ultrasonic vibration method, and the details of fabrication were given in Ref. [15].

The Mg-Zn-Ca-Mn alloy and SiCp/Mg-Zn-Ca-Mn composites ingots were extruded at $300 \text{ }^\circ\text{C}$ with the extrusion ratio of 15:1 at a constant ram speed of 15 mm/s , and then cooled in air.

The microstructures of the as-extruded SiCp/Mg-Zn-Ca-Mn composites and Mg-Zn-Ca-Mn alloy were observed by optical microscope (OM) and scanning electron microscope (SEM). The average grain size was obtained by Image Pro-Plus software. The tensile tests were carried out on an Instron-1186 tension machine at room temperature and the crosshead speed was 0.5 mm/min . The dimensions of tensile specimens were described in Ref. [15].

2 Results and Discussion

2.1 Microstructures

The optical micrographs of the as-extruded SiCp/Mg-Zn-Ca-Mn magnesium matrix composites with different particle contents are shown in Fig.1. Fig.1a illustrates that the average grain size of the Mg-Zn-Ca-Mn alloy is about $3.5 \mu\text{m}$ after hot extrusion. Compared with the Mg-Zn-Ca-Mn alloy, much smaller grain size can be found in the as-extruded SiCp/Mg-Zn-Ca-Mn magnesium matrix composites. When the volume fraction of SiC particle is 1vol%, the average grain size of the as-extruded SiCp/Mg-Zn-Ca-Mn composite is about $3.0 \mu\text{m}$, but the recrystallization is not fully finished. Its grain distribution with large grains of $13 \mu\text{m}$ and small grains of about $1\sim 3 \mu\text{m}$ is inhomogeneous. However, the average grain size of the as-extruded SiCp/Mg-Zn-Ca-Mn composite is about $2.5 \mu\text{m}$ when the volume fraction of SiC particle is 3 vol%. The dynamic recrystallization (DRX) in the composite is more complete than that in the 1 vol% SiCp/Mg-Zn-Ca-Mn composite. It can be attributed to two reasons: (1) the hot extrusion plays a significant role in refining the microstructure of matrix; (2) the addition of SiC particles may stimulate DRX of the magnesium matrix. Moreover, we can see from Fig.1b and 1c that the size and degree of DRX near particle-rich zones are smaller than that near particle-poor zones. This is attributed to the manifold effect, and the SiCp makes an indelible contribution to this situation. Some researches showed that DRX in the SiCp/Mg-Zn-Ca-Mn composite is sensitive to the SiCp content on a local scale. And the stored energy and the larger driving force would make the contribution to the nucleation of matrix in the SiCp-rich and SiCp-clusters zones.

As shown in Fig.2, it can be observed that most of the SiC particles are distributed along the extrusion orientation in the as-extruded composites. The reason is that the flow velocity of

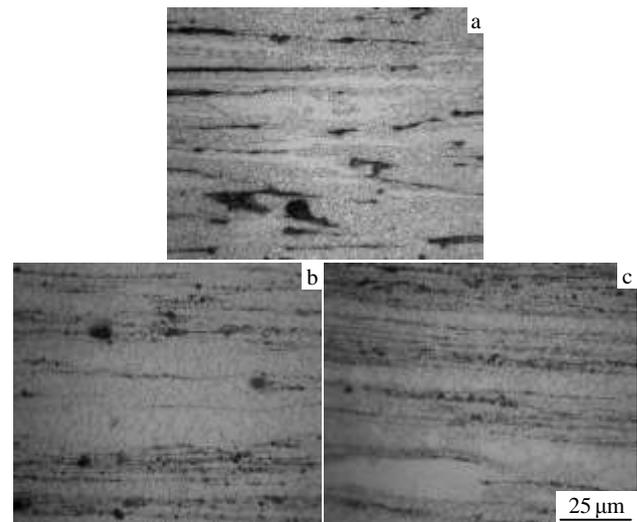


Fig.1 OM micrographs of Mg-Zn-Ca-Mn alloy (a), 1vol% SiCp/Mg-Zn-Ca-Mn composite (b), and 3vol% SiCp/Mg-Zn-Ca-Mn composite (c)

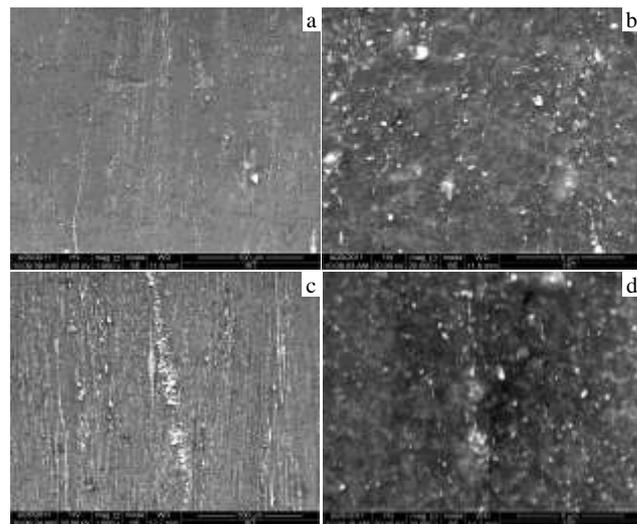


Fig.2 SEM micrographs of 1vol% SiCp/Mg-Zn-Ca-Mn composite (a, b) and 3vol% SiCp/Mg-Zn-Ca-Mn composite (c, d)

matrix is faster than that of reinforcing phase during hot extrusion. In addition, two kinds of regions exist in the extruded SiCp/Mg-Zn-Ca-Mn composites: SiCp-rich and SiCp-poor zones, as shown in Fig.2. This is attributed to the uneven distribution of SiCp in the cast SiCp/Mg-Zn-Ca-Mn composite. The higher magnification images of the SiCp/Mg-Zn-Ca-Mn composites are shown in Fig.2b and 2d. It is illustrated that the SiCp distribution is relatively uniform, and the good wetting property between SiCp and Mg-Zn-Ca-Mn alloy is observed in the SiCp/Mg-Zn-Ca-Mn composites.

Fig.3 shows the TEM image of the SiCp/Mg-Zn-Ca-Mn composites after hot extrusion. It illustrates that the good

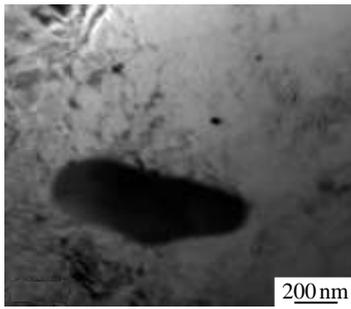


Fig.3 TEM micrograph of SiCp/Mg-Zn-Ca-Mn composites

interfacial bonding between matrix and the SiCp is obtained in the SiCp/Mg-Zn-Ca-Mn composites. Moreover, no reaction products are found in the interface between the SiCp and the AZ31B alloy.

2.2 Tensile properties

Fig.4 shows the strain-stress curves of the as-extruded Mg-Zn-Ca-Mn alloy and the SiCp/Mg-Zn-Ca-Mn composites. The yield strengths ($\sigma_{0.2}$), ultimate tensile strengths (σ_b) and elongations (δ) of the as-extruded Mg-Zn-Ca-Mn alloy and SiCp/Mg-Zn-Ca-Mn composites are shown in Table 1. It can be seen from Table 1 that the yield strength and ultimate tensile strength of the 3vol% SiCp/Mg-Zn-Ca-Mn composite are significantly improved, while elongation is reduced compared with that of as-extruded Mg-Zn-Ca-Mn alloy. The results reveal an appropriate integration of the Mg-Zn-Ca-Mn alloy with higher strength of SiCp. The results are consistent with the findings that were studied in other SiCp reinforced magnesium matrix composites. The higher strength values of the SiCp/Mg-Zn-Ca-Mn composites can make the large difference between matrix and SiCp. The difference in the bearing capacity between SiCp and matrix may lead to the effective transfer of load from matrix to SiCp. Therefore, the strength values of the SiCp/Mg-Zn-Ca-Mn composites are enhanced due to the addition of SiCp, as shown in Table 1. In addition, the yield strength and the ultimate tensile strength of the SiCp/Mg-Zn-Ca-Mn composite increase as the volume fraction of SiCp increases. Firstly, it can be attributed to the decrease of grain size caused by increasing of the content of SiCp. In general, the yield strength of magnesium matrix increases with the decrease of grain size. The strengthening effect of grain refinement can be discussed on basis of the Hall-Petch relation: $\Delta\sigma_g = k_y d_g^{-1/2}$, where σ_g is the yield strength, k_y is Hall-Petch coefficient, and d is the average grain size of matrix [16,17]. Second, the difference in the coefficients of thermal expansion (CTE) between SiCp and matrix results in that the SiCp/AZ31B composites generate a multidirectional thermal stress at the particles/matrix interface, and induce geometrically necessary dislocations with the increase of particle contents. All of these factors lead to the significant increase in the yield strength of composites.

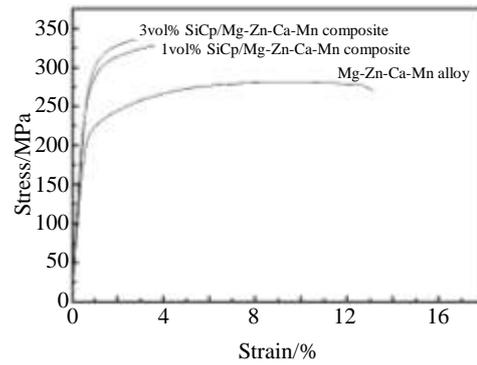


Fig.4 Tensile curves of Mg-Zn-Ca-Mn alloy and SiCp/Mg-Zn-Ca-Mn composites

Table 1 Tensile properties of SiCp/Mg-Zn-Ca-Mn composites extruded at 300 °C

SiCp content/vol%	σ_b /MPa	$\sigma_{0.2}$ /MPa	δ /%
0	285	198	13.1
1	327	264	3.6
3	335	284	2.8

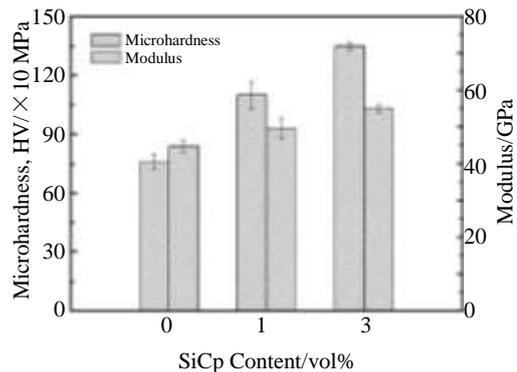


Fig.5 Microhardness and modulus of Mg-Zn-Ca-Mn alloy and SiCp/Mg-Zn-Ca-Mn composites

The elastic modulus and the microhardness of the Mg-Zn-Ca-Mn alloy are improved due to the addition of SiCp, as shown in Fig.5. The elastic modulus and microhardness of the SiCp/Mg-Zn-Ca-Mn composites increase with the increasing of volume fraction of SiCp. The increased elastic modulus and microhardness of the Mg-Zn-Ca-Mn alloy is mainly attributed to the high modulus of introduced SiCp and good interfacial bonding between SiCp and matrix. It is noted that the good matrix-reinforcement interfacial bonding will lead to a significant increase in internal stress between reinforcement and matrix resulting in the enhancement of elastic modulus and microhardness.

3 Conclusions

1) The SiCp reinforced Mg-Zn-Ca-Mn magnesium matrix composites can be fabricated by a semisolid stirring assisted

ultrasonic vibration method.

2) The SiCp can reduce the grain size of the Mg-Zn-Ca-Mn matrix, and the grain size decreases with the increase of volume fraction of SiCp (to 3 vol%).

3) Two kinds of zones are formed in both 1vol%SiCp/Mg-Zn-Ca-Mn and 3vol%SiCp/Mg-Zn-Ca-Mn composites during extrusion, and the average grain size near the SiCp-rich zone is smaller than that far away from SiCp-rich zone.

4) The yield strength and the ultimate tensile strength of the as-extruded SiCp/Mg-Zn-Ca-Mn composites exceed those of the monolithic Mg-Zn-Ca-Mn alloy, and they increase with the increase of the volume fraction of SiCp.

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SiCp 对 Mg-Zn-Ca-Mn 复合材料的力学性能及微观结构的影响

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摘要: 2 种不同体积分数的 SiCp 被选作为增强体, 利用半固态结合超声处理法制备了 Mg-Zn-Ca-Mn 复合材料, 然后在 350 °C 用 15:1 的挤压比进行了热挤压。利用 OM、SEM 和 TEM 对材料的微观结构进行了检测。热挤压后的微观结构显示 SiC 颗粒的分布较为均匀且在 1vol% SiCp/Mg-Zn-Ca-Mn 和 3vol% SiCp/Mg-Zn-Ca-Mn 复合材料中晶粒被显著细化。SiCp 的引入可以改善屈服强度和抗拉强度。屈服强度和抗拉强度是随着颗粒含量的增加而增加。

关键词: 复合材料; 微观结构; 拉伸性能

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