The Research of Reinforced Cu-SiCp/ZA40 and Cu-SiCp/AZ91D Metal Matrix Composites’ Mechanisms

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Abstract. In this paper, the strengthening mechanism of the SiCp on two different kinds of metal matrix composites was studied by adding SiCp with a diameter of 4 micron in AZ91D alloy and ZA40 alloy. The study found that the strengthening mechanism was the dispersion strengthening when 0.5-1.5\% Wt SiCp was added into ZA40 zinc alloy. In order to solve the wettability of the ZA40 and the SiCp, Cu layer was coated on the surface of SiCp. When Cu-SiCp was added into the ZA40 alloy, \(\alpha\)-Al phase blocked by Cu-SiCp at the stage of solidification and crystallization. Therefore, the \(\alpha\)-dendrite in the crystalline tissue was decreased and the grain was refined, and the strength of the alloy was improved significantly. SiCp was added to the AZ91D composite, the strengthening mechanism was solid solution strengthening when the adding amount was less than 10\% Wt. The SiCp reacted with \(\beta\)-Mg\textsubscript{17}Al\textsubscript{12}, generated new Al\textsubscript{3}C\textsubscript{3} phase and strengthened phase Mg\textsubscript{2}Si, formed Mg-Al solid solution. The formation of Al\textsubscript{3}C\textsubscript{3} played a key role in grain refined and the formation of Mg\textsubscript{2}Si replaced the harmful divorced eutectic \(\beta\)-Mg\textsubscript{17}Al\textsubscript{12} phase in the material that improved the strength and hardness of the alloy. When SiCp adding amount was more than 10\% Wt, in order to alleviate the agglomeration and the wettability of the SiCp and the liquid AZ91D, a Cu layer was coated on SiCp surface, the strengthening mechanisms were both solid solution strengthening and dispersion strengthening.

1. Introduction

Metal matrix composite has high specific modulus, high specific strength, good wear resistance, good electrical conductivity, good thermal conductivity, heat resistance, radiation resistance, shock absorption, low thermal expansion coefficient and so many excellent properties. As advanced composite material, it gradually replace traditional metal material and widely used in information, energy, aerospace, advanced weapons and other important fields [1]. Metal matrix composite is made by dispersing a reinforcing material into a metal matrix. Matrix composites, carbon-carbon composites, ceramic matrix composites and nanocomposites formed a modern composite material system. Composite materials can be divided into granule reinforced composites, laminated composite materials and fiber reinforced composites. Silicon carbide particles are often used as reinforcement material for metal matrix composite. Compared with traditional materials, metal matrix composite not only has high plasticity, high toughness, high strength and high hardness, but also make the material isotropic, so it has attracted more and more attention [2].

Silicon carbide particle reinforced metal matrix composite is one of the fastest growing and widely used reinforced materials in the world in recent 20 years, the effect of reinforcement was particularly obvious for magnesium alloy and aluminum alloy. However, little high-quality silicon carbide particle
reinforced metal composite has been made in our country. It is true that some properties had reached
the level of foreign products, but there is still a big gap in the precision of the product. In addition, the
manufacturing costs are very high and there is still a long way for industrial production. Therefore, it’s
very important to study the silicon carbide particle reinforced metal composite.

The present paper based on the silicon carbide particles which surface plated copper (Cu-SiCp)
reinforced high Al-Zn composites and AZ91D composite materials. The mechanism of the reinforced
metal matrix composites was studied, provided a reference for further research and practical
application of reinforced metal matrix composites for silicon carbide particles.

2. Cu-SiCp’s reinforcement mechanism of ZA40 high alumina zinc composite

2.1. Surface pretreated of SiCp

Solid-soluble strengthening, fine grain strengthening and dispersion strengthening are common
reinforcement strengthening mechanisms for particle reinforced composites. Solid solution
strengthening is the additives reacts with compound materials to generate solid solution phase, the
purpose is reinforcing composite materials. Such reinforcement does not need to consider the
wettability of the adding particles and the composites. For the fine grain strengthening and the
dispersion strengthening, the particles need to be pretreated to improve the wettability of the
composites and the particles.

In order to improve the wettability of the SiCp and the metal matrix composites, the common
methods are coating materials on the surface of the metal, preheat the particles, ultrasonic vibration
method and adding metal elements to the liquid metal to improve the wettability [3].

Cu-SiCp is silicon carbide particles coated with a thin layer of copper, which makes it better
integrated with metal matrix composites. In order to improve the bond strength between the substrate
and the coating layer, at first, the SiCp particles were degreased and coarsened to increase its surface
area. After the deoiling and coarsening, sensitizing and activating were taken to make the surface of the
SiCp particles more active. At last, copper was plated on the surface of SiC particles. Xue Penghao
indicated that [4] proper temperature and pH value can greatly shorten the incubation time; the proper
temperature will also increase the amount of copper deposition per unit time and improve the plating
effect. He also found that the amount of copper deposition per unit time can increase by adding
appropriate amount of potassium sodium tartrate. At 40°C when the bath is consisted of EDTA 24g/L,
potassium ferrocyanide 0.05g/L, HCHO 20ml/L, CuSO4 16g/L and sodium potassium tartrate 24g/L,
the effect of copper plating is the best.

2.2. Structure of composite materials

The properties of composite materials can be enhanced by adding 1wt% Cu-SiCp in high Al-Zn metal
composites, the particle size of the SiCp is 4 micron. Figure 1 shows the microstructure of SiCp-
Cu/ZA40 composites and ZA40 [4]. Figure 1a is the microstructure of the original sample of the cast
ZA40 high zinc aluminum alloy. The grey phase in the figure was a dendrite of α-phase (aluminum
phase). The black phase (dark phase) of the discontinuous reticular distribution of α-crystals was the
eutectic group η-phase (the solid solution with Zn as the mainly body). At the same time, there were
bright-white ε-phase (rich copper phase) at the junction of dendrite and eutectoid. Figure b and c were
SEM of the preparation of Cu-SiCp/ZA40 (high-Al-Zn matrix composites), the microstructure were
made of gray phase (α) and black phase (α+η), and Cu-SiCp existed in the crystal boundary of matrix.
It could be seen from the field of view that the Cu-SiCp was not have a reunion phenomenon and the
dispersion was uniform. Figure d was metallographic structure of Cu-SiCp/ZA40 composites under
optical microscopy, it could be seen from the figure that the casted structure of Cu-SiCp/ZA40
composites was composed of the solid solution α-phase of rich Al- Zn solid solution.

Because of the existence of Cu-SiCp, the α-phase was blocked by Cu-SiCp and it was difficult to
form dendritic skeleton at the stage of Cu-SiCp/ZA40 crystallization. In turn, a smaller elliptical α-
phase region was formed and the growth directivity was weakened, so that the α-dendrite in the
crystalline tissue was decreased. Therefore, the whole tissue was more homogeneous and it had been
refined, which played a role of dispersion strengthening.
2.3. Mechanical properties of composite materials

The hardness of Cu-SiCp is very high and its Moh’s hardness can reach 9.5, which is much higher than that of ZA40 [5]. As can be seen in Figure 1b and c, Cu-SiCp was added into high Al-Zn composite materials, the dispersed distribution of Cu-SiCp prevented the growth of α-dendrites and the strength of alloy can be improved significantly. The Cu-SiCp were dispersively distributed in the α boundary, and the highest hardness phase of the alloy was formed. Thus, the hardness of ZA40 high Al-Zn alloy was higher than that of original ZA40 alloy. The dispersed distribution of Cu-SiCp prevented the growth of α-dendrite, made the tissue smaller and more uniform, and the hardness of the alloy was improved. Dispersed distribution of Cu-SiCp can also hamper the migration of α-grain boundary, which made the migration resistance increased, and thus the internal stress of Cu-SiCp/ZA40. Under the action of stress strengthening mechanisms, the yield phenomenon of Cu-SiCp/ZA40 during stretching and the strength was improved.

3. Strengthening mechanism of AZ91D magnesium alloy

3.1. Microstructure of composite materials

Adding SiCp to AZ91D alloy can enhance the property of the material, the particle size of SiCp is 4 micron and the adding amount is 10wt%. As shown in Figure 2[6], AZ91D magnesium alloy was made of gray α-Mg matrix phase, the uneven distribution of β-Mg_{17}Al_{12} phase and small amount of white segregative Al-Mg phase. When SiC particles were added into AZ91D, as shown in Figure b, the size of α-Mg grains became smaller significantly and some of the skeletal β-Mg_{17}Al_{12} remained, most of which were transformed into the uniformly distributed gray-white Mg_{2}Si phase. When the Cu-SiCp was added in, the amount of skeletal β-Mg_{17}Al_{12} phase became smaller and the white β-phase disappeared completely, α-Mg refined and the distribution of the tissue was uniform. α+β phase formed in the peripheral cambium of Mg_{2}Si phase.
The addition of SiCp into AZ91D is solid solution strengthening and the reaction was made by the following formula [7]:

$$2\text{Mg}_{17}\text{Al}_{12} + 17\text{SiC} + C = 17\text{Mg}_{2}\text{Si} + 6\text{Al}_2\text{C}_3$$

With the addition of SiCp, the $\beta$-$\text{Mg}_{17}\text{Al}_{12}$ was consumed and reacted to form new $\text{Al}_4\text{C}_3$ phase, hard-strengthening phase $\text{Mg}_2\text{Si}$ and $\text{Mg}$-$\text{Al}$ solid solution. The formation of $\text{Al}_4\text{C}_3$ can refine the grain [8] and the properties of the material were improved. $\text{Mg}_2\text{Si}$ distributed uniformly in the material instead of harmful $\beta$-$\text{Mg}_{17}\text{Al}_{12}$ phase, which enhanced the strength, hardness and plasticity of the alloy.

3.2. The Mechanical properties of composite materials

The tensile strength of AZ91D composites with SiCp addition is higher than that of AZ91D magnesium alloy matrix and the strengthening mechanism was mainly solid solution strengthening. When SiC particles were added into AZ91D alloy, the $\text{Mg}_2\text{Si}$ phase was formed and distributed in the interior of the $\alpha$-$\text{Mg}$ matrix, the strength of the material was improved. The strength of $\text{Mg}_2\text{Si}$ was higher and the distributed uniformly. $\text{Mg}_2\text{Si}$ in AZ91D magnesium matrix composites can effectively load the load transferred from the matrix, so the tensile strength of the material was improved [6].

The crystal structure of magnesium is closely packed with six square structures, only three geometric slip systems exist when the shape changes. In the AZ91D alloy, cubic $\beta$-$\text{Mg}_{17}\text{Al}_{12}$ has more slip systems, but these slip movements need more shear stress. Therefore, under the comprehensive effect of various slip resulted cracks initiated at the interface between $\beta$-$\text{Mg}_{17}\text{Al}_{12}$ and $\alpha$-$\text{Mg}$ phase, cracks continued to expand and resulted in brittle fracture of AZ91D [6]. When added the SiC particles into AZ91D magnesium alloy formed solid solution strengthening, separated out hard-strengthening $\text{Mg}_2\text{Si}$ phase and $\text{Al}_4\text{C}_3$ phase solid solution. $\text{Mg}_2\text{Si}$ on the base of $\alpha$-$\text{Mg}$ distributed uniform distribution, on the one hand replaced the strengthening effect of harmful divorced eutectic $\beta$-$\text{Mg}_{17}\text{Al}_{12}$ phase, on the other hand the strengthening $\text{Mg}_2\text{Si}$ phase played an important role of stress transferred [6], so load transferred from matrix to reinforcements and the reinforcement was mainly undertakers for the load. The formation of $\text{Al}_4\text{C}_3$ solid solution phase can refine grain, according to the Hall-Patch formula:

$$\sigma = \sigma_i + \frac{K_l}{\sqrt{d}}$$

In the formula, the yield strength of the material is $\sigma$, the yield strength of the crystal is $\sigma_i$ and the grain size is $d$, $kL$ is a constant and proportional with Taylor factor $M_2$ and the shear stress $\tau$ ($k \approx M_2 \tau$). Upper form shows, the higher the grain size is and the smaller the dendrite spacing is, the higher the yield strength is and the better the hardness is. In addition, the grain refinement leads to the increase of dislocation density and the strengthening mechanism of Owanro [8], which improves the room temperature mechanical properties of the material.
Some SiCp did not participate in the reaction when the adding amount of SiCp was more than 10wt%, therefore the wettability between the matrix and the substrate should be considered. When Cu-SiCp was added into AZ91D, the α-Mg was refined and the Mg2Si phase was formed by the reaction of β-Mg17Al12, which distributed uniformly and formed a lamellar α+β phase at the periphery of the Mg2Si phase [6]. The dispersion of Cu-SiCp in grain boundary made the dendrite finer and the properties of the material were improved. The strengthening mechanism was the combination of solid solution strengthening and dispersion strengthening, and the strengthening effect was obviously better than adding SiCp in it.

4. Conclusions

4.1. The amount of SiCp
For dispersion strengthening, the adding amount is very small and is about 1%Wt for ZA40; for solid solution strengthening, the adding amount is more and is about 10wt % in AZ91D magnesium alloy.

4.2. Solution to the wettability between the SiCp and the substrate
For dispersion strengthening, in order to make the SiCp distribute uniformly in the material, the wettability problem must be solved. In the present paper, a copper layer was plated on SiCp surface. However, solid solution strengthening lead to a new strengthened phase between SiCp and alloy, so the wettability problem doesn’t need to be considered.

4.3. Enforcement
The strengthening mechanism of Cu-SiCp for ZA40 high Al-Zn alloy was dispersion strengthening. In the solidification and crystallization stage of Cu-SiCp/ZA40, the α-phases were blocked by Cu-SiCp, which made it difficult to form a dendrite skeleton. The weakening of the growth direction lead to the reduction of α dendrites in the crystalline structure and the whole microstructure was more uniform. It played an important role of dispersion strengthening. The effect of dispersion strengthening had been observed, and the strength of the alloy can be remarkably improved by the dispersion of Cu-SiCp on α grain boundary. The addition of SiCp in AZ91D composites is solid solution strengthening. With the addition of SiCp, the Al4C3 solid solution phase and hard-strengthening phase Mg2Si were formed. The formation of Al4C3 can refine grain. Mg2Si distributed uniformly in the material and replaced the harmful divorced eutectic β-Mg17Al12 phase, which lead to the improvement of the strength, hardness and plasticity of the alloy. When more SiCp was added, in order to reduce the agglomeration, the wettability of SiCp and liquid AZ91D must be solved, and Cu should be coated on the surface of SiCp. Other more, the strengthening mechanism also had the dispersion strengthening of the unreacted Cu-SiCp alloy. The two strengthening mechanisms had fine grain strengthening, in which SiCp had a dispersion strengthening phase in the solution strengthening of AZ91D magnesium alloy and the strengthening effect was better than that of Cu-SiCp strengthening of ZA40 alloy.

5. References
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