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Effect of reinforced particle volume fraction on the failure behavior of TiC/AZ91 composites

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Effect of reinforced particle volume fraction on the failure behavior of TiC/AZ91 composites

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Abstract: The two-dimensional finite element model based on microstructure combined advanced image processing technology with the finite element model can truly reflect the plane particle morphology and distribution of composite materials. In this paper, with the help of image processing and recognition technology, a finite element model of TiC/AZ91 magnesium matrix composite was established, and the longitudinal tensile test of magnesium matrix composite was simulated by finite element method to analyze the influence of enhanced particle volume fraction on the failure rule of its microstructure. The results showed that the TiC/AZ91 magnesium matrix composites were more likely to fail as the volume fraction increased.

1. Introduction

Particle reinforced magnesium matrix composite has high specific strength and specific stiffness, and its outstanding performance is highly sought after by various countries. Some developed countries in Europe and America have begun to enter the development and application stage of particle reinforced magnesium matrix composite [1]. Some studies have found that reinforced particles have a great impact on the mechanical properties of composites, such as the shape, distribution and volume fraction of reinforced particles [2-3]. Therefore, it is necessary to simulate and study the microstructure and macroscopic properties of composite materials.

In the study of the influence of reinforced particles on the mechanical properties of metal-matrix composites, A few years ago, the finite element method (FEM) has been used to study the mechanical properties of particulate metal matrix composites. For example, Azra Rasool, Tvergaard, etc. reduced SiC particles to a circle to establish a two-dimensional finite element model. The damage mechanism of SiC particles and aluminum matrix under static tensile loads was studied, but the enhanced particles in the above study were simplified to a better shape. The random distribution of particle position ignores the true microscopic structure characteristics of the enhanced particles, resulting in a large difference between the simulation results and the actual results[4-5]. Although it is simple to use regular graphics to approximate the reinforced particles, and then establish a finite element model of microstructure to simulate them, the simulation results are often too idealized because the regular geometry is far from the actual morphology of the reinforced particles. But in recent years, image processing and recognition technology can more truly reflect the original morphology of particles, and then establish the relevant finite element model.For example,Yuan Meini et al[6]. studied the effect of different particles on the failure of aluminum matrix composites.Zhang Peng et al[7]. A finite element

model of SiC/Al composites was established based on the real microstructure to study the effect of particle agglomeration on the mechanical properties of the composites.

Research on the failure law of reinforced particles to metal matrix composites is a hot topic at home and abroad at present. However, the majority of metal matrix is aluminum alloy, while magnesium alloy is the metal matrix. Therefore, this article with the help of image processing and recognition technology and edge extraction technology, build the TiC/real microstructure of AZ91 magnesium matrix composites two-dimensional finite element model, in order to research and enhance the particle shape, volume fraction and the distribution of TiC/AZ91 composite failure behavior, the influence mechanism, to optimize the TiC/AZ91 composites provide theoretical basis for the mechanical properties of composite materials.

2. Experimental materials

With the development of technology, modern material requirements are increasingly high, and it is easy to cause material failure under harsh environment. The failure of composite materials mainly includes: material fracture, particle fragmentation and interfacial deadhesion. Considering that TiC has excellent comprehensive properties such as high melting point, high hardness, excellent chemical stability and corrosion resistance, and is one of the ideal reinforced particles for magnesium matrix composites, AZ91 magnesium alloy is an industrially widely used magnesium alloy. TiC was chosen as the enhancement phase and AZ91 magnesium alloy as the matrix material. Parameters of TiC particles and AZ91 magnesium alloys are shown in Table 1.
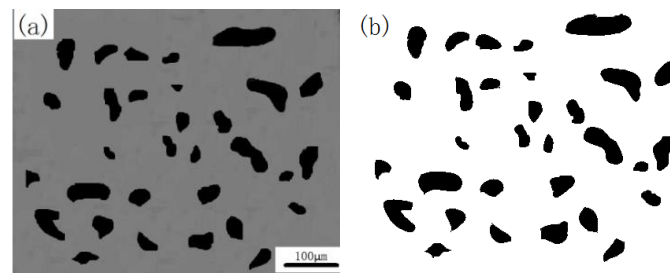
Table 1. basic parameters of AZ91 magnesium alloy and TiC particles.

materials	Ep	Poisson's ratio	Yield strength	Density
AZ91	45GPa	0.35	121MPa	1800 kg/m^3
TiC	460GPa	0.15	280MPa	4930kg/m^3

3. Establishment of finite element model
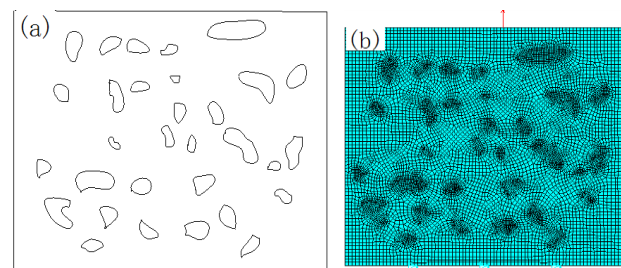
3.1 Image processing and edge extraction.

TiC/AZ91composites were obtained in situ autogenic through experiments, and TiC particles did not react with magnesium matrix, There is no mesophase between reinforcing phase and matrix. Compared with the regular geometric figure, the size, shape and distribution of internal particles are closer to the real material, which makes the subsequent finite element simulation better reflect the effect of internal particle reinforced composites on load. In order to reflect the appearance of particles and matrix more clearly, only two gray values are used to process the microstructure map obtained from the experiment, so as to ensure a high degree of discrimination between particles and matrix without displaying other phases in the microstructure map, as shown in Figure 1 (a). The surface of TiC particles is very irregular. Finite element modeling is difficult to simulate the exact shape of the particles. In order to ensure its accuracy, Matalab image processing software is used to detect the particles. Sobel operator and Roberts operator are used to extract the edges and trim the edges. The TiC/AZ91 composites were vectorized by Adobe Illustrator, and the vector diagram of TiC/AZ91 composites was obtained, as shown in Figure 1 (b).

Figure 1 TiC/AZ91 composite microstructure diagram (a) vector diagram (b).

3.2 Grid division of finite element model.

Boselli[8] In the study, it is found that the free boundary will have a great influence on the numerical simulation process. The current ideal approach is to use r /ω parameters to assess the impact of the free boundary on it. The r /ω value in this article is mainly concentrated between 0.006 and 0.009. The vectorgraph is imported into CAD software to eliminate noise points and redundant lines, and the disconnected lines are closed. Then the boundary of matrix and peripheral area is drawn, and the geometric model shown in Figure 2 (a) is obtained. And generate the corresponding finite element model as shown in Figure 2(b),the entire model contains 24,881 units, which can ensure computational accuracy.

Figure 2. CAD model (a) and finite element mesh model (b)
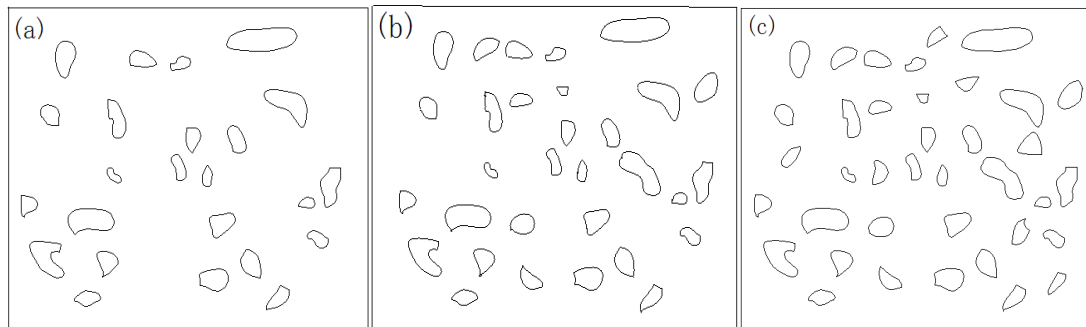of TiC/AZ91 composite materials.

In the finite element analysis of composite materials, AZ91 magnesium alloy is a homogeneous material, and its elastic-plastic stress-strain relationship satisfies the Johnson cook material model:

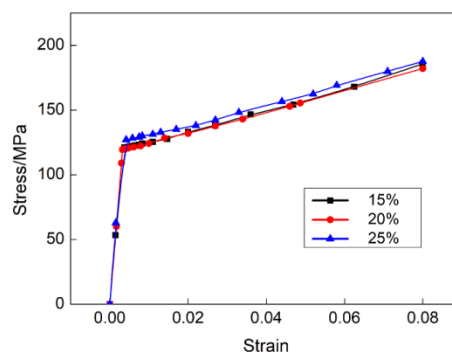$$\sigma = (A + B\varepsilon^n)\left(1 + CIn\varepsilon^*\right)$$

σ is Quasi-static flow stress; ε is equivalent strain; ε^* is relative equivalent plastic strain rate; n is hardening index.

4. Results and discussion

Figure 3 shows the model with particle volume fraction of 15%, 20% and 25% respectively. Figure 4 is the stress-strain curve corresponding to the three models. It can be observed that the slope (elastic modulus) of the elastic phase of TiC/AZ91 composite increases with the increase of particle volume fraction. Secondly, the stress predicted by the model increases with the increase of volume fraction. Because the increase of particle volume fraction can easily lead to the increase of particle skewness and the increase of stress transferred from matrix to particles, the failure strain of composite material can easily be reduced.
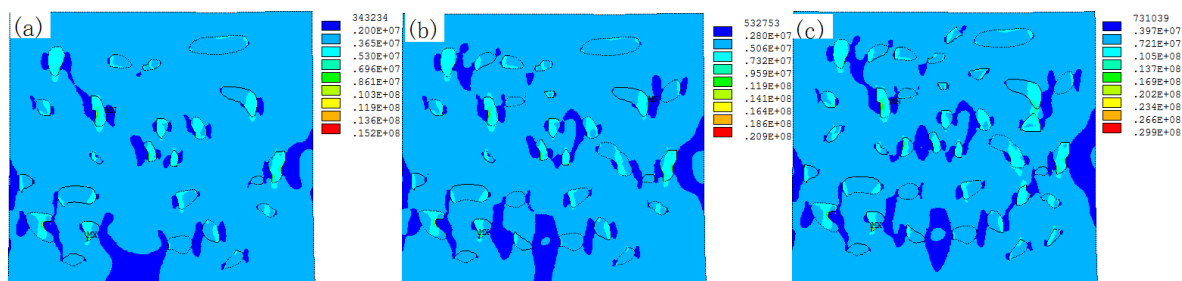
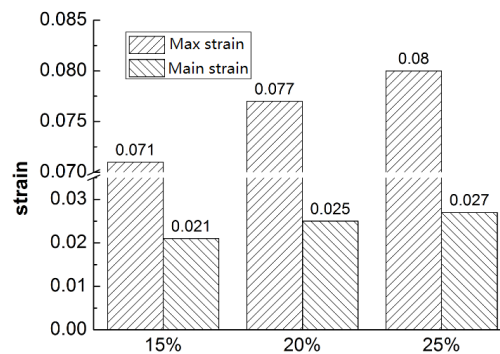**Figure 3.** different volume fraction model (a) 15%; (b) 20%; (c) 25%.

Figure 4. stress-strain curves of different volume fractions.

Figure 5 shows the stress cloud diagram of different volume fraction models, and Figure 6 is the strain result of different volume fraction models after setting failure criteria of composite materials. It can be seen that the maximum strain of TiC/AZ91 composite increases with the increase of TiC particle volume fraction, and the material is more prone to large deformation, which makes the composite more likely to fail. For the low-volume fraction model composite materials, there is a large gap between the particles, which reduces the interaction between the particles and causes less strain damage of the matrix due to the similar stress transfer mechanism between the particles. However, as the volume fraction increases, the particle spacing decreases, leading to the increase of the interaction between particles and the enhancement of the constraint between particles and the matrix. Therefore, when the material is subjected to tension and deforms, the matrix will soon be in a high strain hardening state and quickly reach the material limit state, which will result in failure and seriously affect the material bearing capacity.

Figure 5. stress map of different volume fractions (a) 15%; (b) 20%; (c) 25%.

Figure 6. strain results of different volume fraction models.

5. Conclusions

1) With the increase of the particle volume fraction of TiC/AZ91 composite, the restraining ability of the particles to the matrix is obviously enhanced. The matrix will quickly reach its own limit state and then fail, thus reducing the failure strain of the composite.

2) Under the same boundary conditions, the maximum strains of the composites with volume fraction of 15%, 20% and 25% are 0.071, 0.077 and 0.08 respectively, which may lead to the failure of the composites.

Acknowledgements

Reference

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