Effect of In-Situ Reinforced Particle on the Failure of TiC/AZ91 Composites

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Abstract. By using image processing, recognition technology and edge extraction technology, the true particle morphology and distribution of TiC / AZ91 composites were obtained, and finite element numerical calculation models of different particle shapes were established. With the help of ansys finite element software, the stress distribution and maximum strain values of TiC/AZ91 composite under different enhanced particle shapes are studied to explore the influence law and mechanism of the material on the failure behavior of the material. The results show that, compared with round particles, square particles are prone to plastic damage and lead to the destruction of magnesium-based composites.

1. Introduction
Particle reinforced metal matrix composites have high specific stiffness and high specific strength and are widely used in aerospace, automobile and other fields [1-2]. A large number of experimental studies have found that enhance particle properties of metal matrix composites has an important effect on mechanical behavior, so need to enhance particle microscopic characteristics and macro performance simulation studies combined.

Studies on the effect of reinforced particles on the mechanical properties of metal matrix composites have shown that many scholars have oversimplified the microstructure of composites and simplified irregular particles into ideal and regular shapes. For example, Azra Rasool simplified the SiC particles into a circular two-dimensional finite element model, under static tensile loading is studied the failure mechanism of SiC particles and aluminum substrates, but the study of reinforcing particles be simplified as the ideal shape, randomly distributed particles position, ignores the true microstructure features, reinforcing particles leads to the simulation results with the actual result differs [3-5]. At present, more advanced treatment methods are based on the real microstructure of composite materials, and the corresponding finite element model is established to realize two-dimensional or three-dimensional simulation. Such as Li [6] using Image J, WinTopo Pro software such as complex image processing and edge detection, a complete reflects the original particles morphology, and to build a finite element model of real microscopic, room-temperature uniaxial tension simulation, studied the A356/TiB$_2$ composite materials mechanics performance. Zhang [7] et al. established SiC/Al composite finite element model based on real microstructure to study the effect of particle agglomeration on the mechanical properties of composite materials. Liang [8] et al. established the finite element model with real microstructure, and analyzed the influence of SiC/Al composite microstructure on its mechanical properties based on the micro-reconstruction algorithm of this model.
Micro particles of metal matrix composites reinforced failure law research is currently a research focus at home and abroad, but for the most part, the matrix material is aluminium alloy. With magnesium alloy as the matrix material, the study of regular microscopic damage of reinforced particles has not been reported.

The real structure of TiC/aZ91 composite based on two-dimensional finite element model is constructed by image processing and recognition and edge extraction, and the criterion of material failure is established to research the effect of Reinforced Particle Shape of TiC/AZ91 Composite on Mechanical Properties, so as to provide a theoretical basis for optimizing the mechanical behavior of TiC / AZ91 composites.

2. Experimental Materials
Considering TiC has high melting point, elastic and hardness, excellent comprehensive performance. Simultaneously, it is one of the reliable reinforcing particles in the magnesium matrix composite, the AZ91 alloy extensively applied in industry. Therefore, this paper chooses the TiC as enhancement phase, the AZ91 magnesium alloy as the matrix material. The Physical properties of AZ91 magnesium alloy and TiC particles can be seen in table 1.

| Materials | Ep  | Poisson’s ratio | Yield strength | Density      |
|-----------|-----|----------------|----------------|--------------|
| AZ91      | 45 GPa | 0.35         | 121 MPa        | 1.8 g/cm³    |
| TiC       | 460 GPa | 0.15        | 280 MPa        | 4.93 g/cm³   |

3. Finite Element Model

3.1. Image Processing
In this paper, in situ TiC/AZ91 composites were obtained through experiments, and no mesophase formation between TiC and Mg, and the strengthening phase was closely bound to the matrix, and no intermediate phase was formed. So as to clearly reflect the particles and matrix, the experiments for organization chart, using only two kinds of grey value, had a higher degree of differentiation, guarantee the particles and matrix does not display the constitution diagram of α-Mg and β phase in figure 1a. Due to the TiC particles irregularity, the finite element modeling can lead to greater difficulties, in order to guarantee the accuracy, this paper Matalab image processing software for testing, using Roberts operator and Sobel operator edge detection and make the necessary boundary pruning. Due to the identification problem of finite element software, the TiC/AZ91 composite material should be vectorized through Adobe Illustrator to obtain the TiC/AZ91 composite material vector diagram, as shown in figure 1b.

![Figure 1](image-url)
3.2. Grid Division
In the past, Boselli [9] found that the free boundary would have a great effect on the finite element analysis process. At present, the common method is using \( r/\omega \) parameter to evaluate the effect of free boundary on it. This paper set the value of \( r/\omega \) between 0.006 and 0.009, and import vector graphics into CAD software to get models. The CAD model as shown in figure 2a was obtained by trimming the lines, closing the broken lines and drawing the boundary of the matrix. And through CAD format conversion, and imported into the finite element software ANSYS, to the grid as shown in figure 2b, the model contains 24881 units, according to the theory of composite material [10], the Failure Criteria set in the TiC/AZ91 composite material Failure Criteria.

![Figure 2. TiC/AZ91 composite models: (a) CAD model, (b) finite element mesh model.](image)

Second strength theory: no matter what stress state the material is in, once the maximum tensile strain exceeds the limit value that the material can bear, the material will break. Maximum tensile strain expression:

\[
\varepsilon_1 = \frac{[\sigma_1 - \mu(\sigma_2 + \sigma_3)]}{E}
\]

\( \varepsilon_1 \) is maximum tensile strain; \( \sigma_1, \sigma_2, \sigma_3 \) are three main stresses ; \( E \) is elastic modulus.

To simplify the calculation, AZ91 composite is considered as a homogeneous material in the finite element analysis, and its elastic-plastic stress-strain relationship can be showed by the following formula:

\[
\sigma = (A + B\varepsilon^\ast)(1 + Cn\varepsilon^\ast)
\]

\( \sigma \) is Quasi-static flow stress; \( \varepsilon \) is equivalent strain; \( \varepsilon^\ast \) is relative equivalent plastic strain rate; \( n \) is hardening index.

4. Results and discussion
Figure 3 shows the stress-strain curves of the TiC/AZ91 composites with different particle shapes. Figure 4 is the stress cloud diagram of circular particle model, irregular shape particle model (original model) and square particle model. As can be seen from figure 3, compared with the original model and the circular particle model, the stress predicted by the square particle model is higher. The stress distribution inside and around the particle is also different with different particle shape. See from figure 4, no matter what kind of model, the stress distribution in the matrix is relatively uniform, but inside the particles exist stress concentration phenomenon, of the TiC particles carrying TiC/AZ91 composites most tension, this is because the material stress, matrix will force to particles. Due to the yield flow of magnesium matrix, severe stress concentration occurs at the sharp Angle of the square
particles, causing extensive damage to the matrix and particles, thereby optimizing the properties of TiC / AZ91 composites.

Figure 3. Stress-strain curves of different particles.

Figure 4. Stress clouds of: (a) square particles, (b) original models, and (c) circular particles.

Compared with circular particles, square particles contain more sharp angles, which may lead to more serious stress concentration of composite materials and more failure of composite materials. Figure 5 is set after composite material failure criterion of strain in the case of simulation for different particle shape as a result, it can be seen that the boundary conditions in the same square particle composites have a more strain, once, as the change of the load bearing ahead of circular particle composite material failure, the reason is that particles pointed at high stress concentration, easy appear holes nucleation, resulting in composite material failure. This conclusion is consistent with the research results of Helmut [11] and Zhang [12] et al.

Figure 5. Strain results of different particle shapes.
5. Conclusion
For TiC/AZ91 composite materials, square particles are liable to cause extensive damage to the matrix and particles. In the case of other conditions remain unchanged, the maximum strain of square particles is 0.085 greater than that of circular particles, and the TiC particles are square, which is more likely to cause the failure of magnesium matrix composites.

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