Effect of TiB$_2$ on Properties of TiAl-based Alloy

Bin Yan$^a$, Liying Yang$^a$, Zheng Sun$^b$ and Qimeng Wang$^c$

School of Mechanical Engineering, University of Jinan, Jinan250022, China

*Corresponding author e-mail: eo_yangly@ujn.edu.cn, a1540723356@qq.com, b1970048064@qq.com, c1637046102@qq.com

Abstract. In this paper, we added particle reinforced phase TiB$_2$ in TiAl-based composites, TiB$_2$/TiAl matrix composites were prepared by using powder metallurgy vacuum hot pressing sintering technology, and the effects of TiB$_2$ particle reinforced phase on the mechanical and tribological properties of TiAl-based alloy were studied. It was found that the hardness and density of TiAl-based alloy composites increased with the addition of TiB$_2$, the friction coefficient and the wear loss decreased with the increase of TiB$_2$ content in TiAl-based alloy. The wear resistance of TiAl-based alloy can be improved by adding TiB$_2$ particles.

1. Introduction

As a new type of lightweight and high temperature resistant structural material, TiAl-based alloys are characterized by strong corrosion resistance, high specific strength, high specific stiffness, excellent high temperature mechanical properties and high temperature oxidation resistance. These advantages make it become the most competitive material in aviation, aerospace, military machinery, water conservancy engineering and other fields [1, 2, 3]. Therefore, the study of TiAl-based alloys as a substitute material has become a hot spot of current research.

TiAl-based alloys have been studied since 1950s [4]. In some specific cases, TiAl-based alloys have been used as substitutes for traditional alloys. TiAl-based alloys have been applied in aero engine blades, low-pressure turbine blades and automobile engines. TiAl-based alloys has significant effect on reducing the weight of automobile engine [5]. Although TiAl-based alloys has many advantages, some problems still need to be solved in order to make TiAl-based alloys be widely used, such as poor creep resistance at high temperature, low plasticity at room temperature, difficult processing and poor tribological properties, which hinder the development and application of TiAl-based alloys [6]. In view of the problems existing in TiAl-based alloys, many researchers have devoted themselves to improving the comprehensive properties of TiAl-based alloys in recent years, and have made significant progress.

It is found that the comprehensive properties of TiAl-based alloys can be effectively improved by adding particle reinforced phase. The thermal expansion coefficient of TiB$_2$ is similar to that of TiAl matrix, and it has good chemical compatibility with TiAl alloy matrix, and can significantly improve the strength, creep resistance and hot working performance of TiAl-based alloys. Therefore, TiB$_2$ can be used as the preferred particle reinforcement phase for TiAl-based alloy [7, 8].

Xiao Shu long [9] added TiB$_2$ into TiAl matrix and prepared TiAl matrix composites by vacuum induction melting with water-cooled copper crucible. It was found that TiB$_2$ could improve the micro hardness and room temperature tensile strength of the composites and improve the plasticity at high temperature. Chen Yuqing [10] used SPS technology and added TiB$_2$ into TiAl based alloy. It was found
that adding TiB₂ into TiAl-based alloy could reduce the initial temperature of rapid densification of SPS. It can refine the grain size, distribute the phases evenly and improve the tensile strength at room temperature. Therefore, TiB₂ as a reinforcing phase for improving the comprehensive properties of TiAl-based alloys has important research significance.

Based on Ti46Al2Cr2Nb, a new TiAl matrix composite containing TiB₂ was prepared by adding particle reinforced TiB₂ powder and vacuum hot pressing sintering process. The effect of TiB₂ on the mechanical and tribological properties of TiAl matrix alloy was studied, so as to provide useful theoretical guidance and basis for further study of TiAl matrix composite.

2. Experimental procedures

2.1. Preparation of Test Materials

The test materials in this paper are Ti powder, Al powder, Cr powder, Nb powder and TiB₂ powder. The specifications of various materials are shown in Table 1.

| Materials | Purity (wt %) | Grain size (g/cm³) |
|-----------|---------------|-------------------|
| Ti        | 99.99%        | 300               |
| Al        | 99.9%         | 300               |
| Cr        | 99.5%         | 300               |
| Nb        | 99.95%        | 300               |
| TiB₂      | 99.9%         | 3-5 μm            |

According to the atomic ratio of Ti-46Al-2Cr-2Nb, mixed metal powders, and TiB₂ powders with 0%, 5%, 10% and 15% mass fraction were added. Then put mixed metal powders into QM-1SP2 ball mill for ball milling. The speed of ball mill is 200 rpm/min. The milling time is 4h. Al₂O₃ balls are selected as the grinding medium. The mass ratio of balls to powder is 10:1. In order to prevent the oxidation of powders during ball milling, vacuum pumping and argon charging were applied to the ball mill. After ball milling, metal powder was put into graphite abrasive tool with inner diameter of 40 mm, and cold pressed for 3 minutes under pressure of 30 MPa. Finally, ZT-70-20Y vertical vacuum hot-pressing sintering furnace was used for hot-pressing sintering. The sintering process route is as follows Fig.1:

![Figure 1. Sintering process route.](attachment:image.png)
2.2. Density Testing
Archimedes drainage method was used to measure the actual density of treated TiAl-based samples. In order to eliminate the influence of errors, five times were measured for each sample, and then the average value was calculated as the actual density measurement value.

2.3. Hardness Testing
The Rockwell hardness of the samples was measured by using the HBRVU-187.5 Blovi optical hardness tester. Considering the influence of errors, the average hardness of each sample measured five times is taken as the actual hardness.

2.4. Bending Strength Testing
In order to test the bending strength conveniently, the specimens were first processed into rectangular specimens of 3.0mm x 7mm x 38mm in size. The three-point bending tests of composite materials were carried out at a speed of 0.5 mm/min using a 30 mm span bending test machine. Four kinds of composite materials with different components were measured three times, and the average pressure was calculated three times. Finally, the bending strength of four kinds of composite materials was calculated.

2.5. Friction Behaviour Testing
Friction and wear tests were carried out on the treated specimens using RTEC friction and wear tester. Si3N4 ceramic balls were selected for the grinding accessories. The experimental load is 10N, 20N, 30N, 40N. The test time is 20min and the test frequency is 4HZ. The friction coefficient and wear loss under different loads are tested. The friction coefficient can be obtained directly from the computer. The wear loss can be calculated by testing the mass loss of composite materials.

Finally, scanning electron microscopy (SEM) was used to observe the wear surface morphology of TiAl matrix alloy composites after friction testing.

3. Results

3.1. Mechanical Properties of Different Composites
Table 2 shows the mechanical properties of composites. TiAl matrix composites containing 0%, 5%, 10% and 15% TiB2 were named TB0, TB5, TB10, and TB15. It can be seen from the table that the density and hardness of the composites increases with the increase of TiB2 content. However, with the increase of TiB2 content, the bending strength first increases and then decreases. A small amount of TiB2 can refine the organization, however, when there are too many TiB2 particles in TiAl matrix, TiB2 particles aggregate, which has adverse effects on the mechanical properties of composites.

Therefore, in order to ensure that TiAl-based alloys have good comprehensive properties, it is not appropriate to add excessive TiB2 into TiAl-based alloys.

| Materials | Density g/cm³ | hardness HRC | Bending strength MPa |
|-----------|--------------|--------------|----------------------|
| TB0       | 4.02         | 33.97        | 625                  |
| TB5       | 4.03         | 37.24        | 681                  |
| TB10      | 4.05         | 38.95        | 660                  |
| TB15      | 4.06         | 43.04        | 590                  |

3.2. Wear and Friction Coefficient of Composites
Fig.2 shows the friction coefficients of the four composites under different loads. From the figure, we can conclude that the friction coefficients of the four composites show the same trend with the change of load, and all decrease with the increase of load.
Fig. 3 shows the curve of the wear loss of the composites with the different mass fraction of TiB$_2$ under 10N and 20N loads. It is found that the wear loss of the composites decreases with the increase of TiB$_2$ content. And it can be seen that the wear loss increases with the increase of load. By adding TiB$_2$ hard phase in the composite materials, the hardness of the materials is improved, so that the wear resistance of the alloy is improved and the wear loss is reduced. The wear resistance of Ti-Al alloy can be improved by adding TiB$_2$.

S. Kumar [11] studied the effect of TiB$_2$ particles on the wear properties of Al-4cu alloy. It was found that the plough caused by abrasive wear decreased with the increase of the hardness of the composites. The wear caused by sliding wear is as follows:

$$ V = \frac{kPL}{H} $$

(1)

V denotes wear volume loss, P denotes applied load, L denotes sliding distance, H denotes hardness of specimen denotes wear coefficient. As shown in the above formula, the wear volume of the composites is inversely proportional to its hardness.
Figure 3. Wear loss curve of composite materials with different mass fraction of TiB$_2$

3.3. Analysis of Wear Morphology and Mechanism of Composites

Fig. 4 is a scanning electron microscope photograph of the wear surface morphology of four composites sliding with Si$_3$N$_4$ ceramic ball under 20N load. It can be seen from the figure that under the same experimental conditions, four kinds of composite materials have different wear conditions, but the wear forms are basically similar. Composite materials have abrasive wear, and there are grooves generated by sliding in the direction of friction and sliding, and some matrix flakes into small pits because of wear. It can be seen from the figure that the wear of TiAl matrix composites without TiB$_2$ is the most serious, and with the increase of TiB$_2$ content, the wear degree of TiAl matrix composites decreases gradually. This shows that TiB$_2$ can effectively improve the wear resistance of composites.
4. Conclusion
TiAl matrix composites with different mass fractions of TiB$_2$ were prepared by powder metallurgy vacuum hot pressing sintering technology, and their mechanical and tribological properties were studied. The results of the study can draw the following conclusions.

1. When TiB$_2$ is added into TiAl matrix, the hardness and density of the composites increases with the increase of TiB$_2$ content, but the bending strength of the composites increases first and then decreases.
2. TiB$_2$ particles can reduce the friction coefficient of TiAl matrix composites in a small range, and the friction coefficient decreases with the increase of load.
3. There is a great relationship between wear losses with TiB$_2$ content. With the increase of TiB$_2$ content, the wear loss decreases and the wear resistance of the material is improved.
4. TiB$_2$ particles as reinforcing phase can improve the wear resistance of TiAl-based alloys. TiB$_2$ particles can improve the wear resistance by increasing the hardness of Ti-Al based alloys and some of the TiB$_2$ particles can act as load-carrying agents.

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