Effect of TiC and TiB₂ Content on Properties of TiAl Based Alloys

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Abstract. In this paper, we added different content of TiC and TiB₂ particles powder into TiAl based alloy as particle reinforcement, and prepared different components of TiAl based composite. We also studied the influence of the content of TiC and TiB₂ particles on the physical and mechanical properties of TiAl based composite. The results show that in a certain range, the physical properties of TiAl based alloy increase with the increase of TiC and TiB₂ particle content, and the mechanical properties first increase and then decrease with the increase of TiC and TiB₂ particle content. It is proved that the physical and mechanical properties of TiAl alloy can be effectively improved by adding the proper amount of TiC and TiB₂ particles.

1. Introduction

TiAl based alloy is a new type of light and high temperature resistant material. TiAl based alloys have the advantages of low density, high specific strength, high temperature resistance, oxidation resistance and corrosion resistance [1-3]. But because of its brittleness and poor tribological properties, it is necessary to strengthen it to achieve the purpose of engineering application.

In order to improve the properties of TiAl alloy, some alloying elements can be added properly in the composition design to improve the strength of the alloy, refine the grains and make the structure uniform, so as to improve the comprehensive mechanical properties of the alloy.

The strength and toughness of TiAl alloy can be effectively improved by adding particles to the alloy matrix. The choice of reinforcement phase should not only ensure the thermal expansion coefficient of TiAl Matrix is similar, but also ensure the chemical reaction between reinforcement and matrix and ensure the interface compatibility [4]. Among the particle reinforcements of TiAl alloy, TiB₂ and TiC have similar thermal expansion coefficient with the matrix of TiAl alloy, and have good chemical compatibility, and can effectively improve the physical and mechanical properties of TiAl based alloy. Therefore, TiC and TiB₂ are ideal particle reinforcements for strengthening TiAl alloy [5, 6].

Akio Hirose and Misuo Hasegawa et al. prepared TiB₂ reinforced Ti-43Al composites. The results show that the composites have the best tensile strength when TiB₂ content is 5%. At 900°C and 1000°C, (5-7)% TiB₂/Ti-34Al composites have 45-65MPa and 55-70MPa higher yield strength than Ti-34Al matrix alloys respectively, and the tensile plasticity reaches (9-12)% [7].

Based on Ti₄₅Al₈Nb₀.₃Y, a new TiAl matrix composite material was prepared by adding TiC powder and TiB₂ powder. The effects of TiB₂ and TiC on mechanical and physical properties of TiAl-
based alloys were studied, which provides theoretical guidance and basis for the following research on TiAl-based alloys.

2. Test steps
The experimental materials include Ti, Al, Nb, Y, TiC and TiB₂ powders. Among them, the atomic ratio of TiAl alloy matrix is Ti₄₅Al₈Nb₀.₃Y, the mass fraction of TiC is 0, 3%, 6%, 9%, the mass fraction of TiB₂ is 0, 3.5%, 7%, 10.5%.

2.1. Preparation of TiAl based composite
The experimental materials include Ti, Al, Nb, Y, TiC and TiB₂ powders. Among them, the atomic ratio of TiAl alloy matrix is Ti₄₅Al₈Nb₀.₃Y, the mass fraction of TiC is 0, 3%, 6%, 9%, the mass fraction of TiB₂ is 0, 3.5%, 7%, 10.5%.

At first, Ti powder, Al powder, Nb powder and Y powder are mixed according to the atomic ratio of Ti₄₅Al₈Nb₀.₃Y, then the corresponding mass fractions of TiC powder, TiB₂ powder are mixed respectively. Then, the mixed powder is milled by a planetary ball mill, and argon is introduced into the ball mill tank to prevent the blended powder from being oxidized during the milling process. The ball milling parameters are ball material ratio of 10:1, milling time of 2h, rotation speed of 240r/min.

After ball grinding, the powder is poured into prepared graphite mold and put into hydraulic test machine for cold pressing at 40MPa and 3min. After cold pressing, the graphite mold made of shaped powder is put into vacuum hot-pressing sintering furnace for hot-pressing sintering. The highest sintering temperature is 1300°C, pressure is 30Mpa, vacuum is 10⁻²Pa. The Hot-pressing Sintering Process is: from room temperature to 600°C at the rate of 10°C/min, holding time is 30min, from 600°C to 800°C at the rate of 5°C/min, holding time is 30min, temperature rises from 800°C to 1000°C at the rate of 5°C/min, holding time is 30min, and holding time rises from 1000°C to 1300°C at the rate of 5°C/min. The holding time is 40min and the sintering pressure is 30MPa. Finally, the sample is cooled in an oven. Grind, clean, dry and polish the surface of the specimen. The flow chart is shown in Figure 1:

![Figure 1. Process chart of hot pressing sintering.](image)

2.2. Density test
The Archimedes drainage method is used in the density test, which has the advantages of simple operation and no special requirements for the shape of the specimen. In order to reduce the experimental error, the density test was carried out five times, and then the average value was taken as the actual density value.

2.3. Bending strength test
The flexural strength is measured by the three-point bending method. Before the bending test, the sample was first made into a strip sample of 36mm × 5mm × 3mm. The test is conducted 5 times and the average is taken. The bending test parameters are: loading speed 0.5mm/min, span 30mm.
2.4. Fracture toughness test
Before the test, the test piece was made into a "40.0mm × 3.0mm × 4.0mm" long strip sample by wire cutting technology, and then a V-shaped notch with a depth of 1mm was cut at the bottom of the alloy. The test conditions were: span of 30mm, loading rate of 0.5mm/min. Take the average number for 5 times.

2.5. Hardness test
The Vickers hardness tester was used as the hardness tester. The loading force is set to 600N. In order to reduce the error, this test uses the average value of the hardness values of 10 points collected at different positions of the test piece as the actual hardness value.

3. Test results and analysis
Table 1 shows the effect of different contents of TiC and TiB₂ on the properties of TiAl based alloys.

| Numble | TiC (wt%) | TiB₂ (wt%) | Density (g.cm⁻³) | Hardness (HV) | Flexural strength (MPa) | Fracture toughness (MPa.m¹/²) |
|--------|-----------|------------|-----------------|--------------|------------------------|-----------------------------|
| 1      | 0         | 0          | 3.798           | 548          | 419                    | 9.5                         |
| 2      | 0         | 3.5        | 3.827           | 564          | 432                    | 10.1                        |
| 3      | 0         | 7          | 3.841           | 571          | 430                    | 9.8                         |
| 4      | 0         | 10.5       | 3.985           | 586          | 425                    | 9.6                         |
| 5      | 3         | 0          | 3.854           | 552          | 432                    | 9.9                         |
| 6      | 3         | 3.5        | 3.905           | 572          | 457                    | 10.8                        |
| 7      | 3         | 7          | 3.933           | 587          | 448                    | 10.5                        |
| 8      | 3         | 10.5       | 4.081           | 595          | 441                    | 10.4                        |
| 9      | 6         | 0          | 3.871           | 560          | 477                    | 11.2                        |
| 10     | 6         | 3.5        | 3.97            | 587          | 519                    | 12.1                        |
| 11     | 6         | 7          | 4.054           | 612          | 494                    | 11.7                        |
| 12     | 6         | 10.5       | 4.106           | 624          | 506                    | 10.9                        |
| 13     | 9         | 0          | 3.861           | 584          | 456                    | 9.3                         |
| 14     | 9         | 3.5        | 3.972           | 597          | 508                    | 10.7                        |
| 15     | 9         | 7          | 3.998           | 629          | 501                    | 11                          |
| 16     | 9         | 10.5       | 4.071           | 634          | 502                    | 10.2                        |

The data in Table 1 are arranged into a line chart to study the influence of TiC and TiB₂ content changes on the mechanical and physical properties of materials, as shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. TiAl matrix composites containing 0%, 3.5%, 7% and 10.5% TiB₂ were named 0TiB₂, 3.5TiB₂, 7TiB₂, and 10.5TiB₂.

![Figure 2. Material density curve.](image-url)
It can be seen from Figures 2 and 3 that the hardness of the material increases with the increase of the TiC and TiB$_2$ mass fraction, and the material density increases first and then decreases with the increase of the TiC mass fraction, and increases with the increase of the TiB$_2$ mass fraction. It shows that adding TiC and TiB$_2$ particles can effectively improve the physical properties of TiAl alloy, but excessive TiC will reduce the density of the alloy and reduce the physical properties of the alloy.

It can be seen from Figures 3 and 4 that the flexural strength and fracture toughness of the material increase first and then decrease with the increase of TiC and TiB$_2$ mass fractions. When the TiB$_2$ mass
fraction is 3.5% and the TiC mass fraction is 6% when the material has the best mechanical properties. It shows that proper amount of TiC and TiB\textsubscript{2} particles can effectively improve the mechanical properties of TiAl alloy through grain refinement and dispersion, but excessive TiC and TiB\textsubscript{2} particles will reduce the mechanical properties of TiAl alloy.

4. Conclusion
In this paper, a new type of TiAl-based composite material was prepared by vacuum hot-press sintering, and the effects of TiC and TiB\textsubscript{2} particle mass fraction changes on the physical and mechanical properties of TiAl-based composite material were studied. The results show that a certain content of TiC and TiB\textsubscript{2} particles can significantly improve the mechanical and physical properties of TiAl-based composites through refinement and dispersion strengthening, proving that TiC and TiB\textsubscript{2} are ideal reinforcing phase materials for TiAl alloys. Too much TiC and TiB\textsubscript{2} will reduce the mechanical properties of TiAl alloy.

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