Effect of Temperature on Tribological Properties of TiAl Based Self-Lubricating Composites

Zheng Sun, Liying Yang*, and Shouren Wang
School of Mechanical Engineering, University of Jinan, Jinan, China

*Corresponding author: eo_yangly@ujn.edu.cn

Abstract. A kind of TiAl based alloy with high temperature self-lubricating property was prepared by vacuum hot pressing sintering technology, and its mechanical and physical properties were tested. The friction and wear experiments were carried out at different temperatures, and the high-temperature tribological properties of the new TiAl based alloy were studied. The results show that the new TiAl based self-lubricating material with TiC, TiB2 and CaF2 can effectively improve the mechanical and physical properties of the matrix, and make it have good mechanical and physical properties as well as good tribological properties above 500 °C.

Keywords: Alloy, Powder metallurgy, Tribological properties.

1. Introduction

TiAl based alloy is expected to become a new generation of lightweight superalloy because of its low density, high elastic modulus, excellent high temperature oxidation resistance and creep resistance. [1] At present, TiAl based alloy has been widely used in different fields, one of which is to make exhaust valve, the key component of valve train [2]. With the progress of engine technology, energy saving and emission reduction has become the direction of engine technology development, and reducing the weight of exhaust valve is an effective measure. Some documents have proved that by reducing the weight of the exhaust valve, the first is to increase the opening frequency of the valve and improve the working efficiency of the engine; the second is to reduce the impact force between the valve and rocker arm, so as to reduce the noise of the engine running; the third is to reduce the spring force on the valve and reduce the friction between the valve guide and the valve. Some studies have shown that the fuel quantity of engine can be reduced effectively by reducing the mass of exhaust valve.

Although TiAl based alloys have the above advantages, they also have disadvantages. The high brittleness and poor tribological properties of TiAl based alloys restrict their development. In order to improve the defects of TiAl alloy, Nb, Mo, W, Cr, Mn, V, Si, C, B and Y elements can be added to the alloy to improve the room temperature plasticity, strength, creep properties, high temperature properties, fracture toughness and oxidation resistance of TiAl alloy.[3] The results show that the properties of TiAl alloy can be greatly improved by adding 5% - 10% Nb. In addition, ceramic fibers such as Al2O3 and SiC, refractory metal fibers such as W and Mo, or ceramic particles such as SiC, TiB2, Al2O3, Ti2AlC, TiC, Ti3Si3 and other ceramic particles are added into the TiAl alloy matrix.[4] It can significantly improve the creep resistance, fracture toughness and high temperature strength of TiAl Matrix, and improve the hot workability of TiAl alloy without sacrificing other mechanical
properties. Among these materials, TiB₂ and TiC have similar thermal expansion coefficient with TiAl Matrix, and have good chemical compatibility with TiAl alloy matrix, and can significantly improve the strength, toughness, creep resistance and hot working performance of TiAl alloy, so they are the first choice of particle reinforced TiAl Matrix Composites [5].

In the face of high temperature and heavy load working environment, CaF₂ and BaF₂ are good high temperature self-lubricating materials. The self-lubricating mechanism of CaF₂ and BaF₂ has been deeply studied. The research shows that CaF₂ and BaF₂ have lubricity from 500 °C and high temperature oxidation resistance. They can be used up to 900 °C without oxidation failure. [6]

In this paper, TiAl Matrix and TiAl based self-lubricating composites were prepared by adding TiC and TiB₂ particles as reinforcing phase and CaF₂ as lubricating phase, respectively, with Ti₄₅Al₈Nb as matrix and CaF₂ as lubricating phase.

2. Sample preparation and performance test

Test materials. The materials used in this experiment include Ti powder, Al powder, Nb powder, TiC powder, TiB₂ powder and CaF₂ powder.

Test process route. Firstly, the powder was weighed with an electronic balance, and then the powder was milled. The ball mill pot needs to be cleaned before ball milling. After the ball milling tank is cleaned with water, anhydrous ethanol and steel ball are added into the ball mill. The diameter of the steel ball is 10 mm. It is repeatedly cleaned in the ball mill for 5 times. After cleaning, the ball mill and steel ball are dried with a vacuum drying oven, and then the mixed powder is put into the ball mill pot with the ball material ratio of 10:1. After the ball mill pot is sealed, the ball mill pot is vacuumed and filled with argon to prevent powder oxidation. The process parameters of ball milling are shown in the table. The ball milled powder is placed in the graphite mold, and the size parameters of the graphite mold are shown in the figure. It is convenient to put the nitrided graphite into the mould to prevent the graphite from sticking with the graphite powder before it is put into the mould. Graphite gasket is used to separate the powder of different components. A piece of thin graphite paper is placed between the powder and graphite gasket to prevent the specimen from adhering to the graphite gasket.

The graphite mould containing powder was placed on the press to form the powder by cold pressing. The test parameters were as follows: pressure 45 MPa, pressure speed 2 min / mm, holding time 10 min. The hot-pressing sintering process route is shown in the figure. The maximum sintering temperature is 1300 °C, the pressure is 30MPa, and the vacuum degree is 10⁻²Pa. The hot-pressing sintering process is as follows: raising the temperature from room temperature to 600 °C at 10 °C / min, holding for 30min at the heating rate of 5 °C / min, increasing from 600 °C to 900 °C and holding for 30min at 5 °C / min, increasing from 900 °C to 1300 °C at 5 °C / min, holding time for 30min and sintering pressure of 30MPa. Finally, the specimens were obtained by cooling. The specimens were ground, cleaned, dried and polished. Then the mechanical and physical properties of the samples were tested the sintering process route is shown in Figure. 1:

![Vacuum hot pressing sintering process](image-url)
Test result. The performance test results of the materials are shown in Table 1:

| Material Science | Bending strength (MPa) | Fracture toughness (MPa m$^{1/2}$) | Density (g/cm$^3$) | Hardness (HV) |
|------------------|----------------------|-----------------------------------|------------------|---------------|
| TiAl Matrix      | 419                  | 9.5                               | 3.798            | 548           |
| TiAl Matrix Composites | 511              | 11.4                               | 4.136            | 587           |

It can be seen from Table 1 that the mechanical and physical properties of TiAl Matrix can be effectively improved by adding TiC, TiB$_2$ and CaF$_2$ powders.

3. High temperature friction and wear experiment

In order to study the high temperature self-lubricating mechanism of TiAl Based Self-lubricating Materials, the friction and wear experiments of TiAl Based Self-lubricating Materials at different temperatures were carried out. The effects of temperature on the friction coefficient and wear rate of the alloy at 350 ℃, 500 ℃, 650 ℃ and 800 ℃ were investigated. The test load was set at 300N. The friction coefficient and wear rate of the alloy are shown in Fig. 2.

![Fig. 2 Trend of friction coefficient and wear rate of alloy](image)

As shown in the Figure. 2, under a certain load, the friction coefficient and wear rate of the alloy increase from 350 to 500 ℃ because CaF$_2$ does not provide lubrication at this time and the hardness of the alloy decreases with the increase of temperature, so the wear rate and friction coefficient increase. At the stage of 500 to 800 ℃, CaF$_2$ in the matrix is extruded by thermal expansion and gradually precipitates on the surface of the alloy. Under the condition of friction with the abrasive parts, it gradually forms film, which reduces the friction coefficient of the alloy.

4. Conclusions

In this paper, TiAl matrix and new self-lubricating TiAl matrix composites were prepared by vacuum hot-pressing sintering. The bending strength, fracture toughness, density and hardness of the two composites were tested. The results show that the mechanical and physical properties of the new self-lubricating Titanium-aluminium matrix composites are better than those of the matrix. The friction coefficient of the new self-lubricating titanium-aluminium matrix composites decreases with the increase of temperature in the temperature range of 350 ~ 800 ℃. It is proved that CaF$_2$ plays an obvious role in reducing the friction coefficient of the alloy at high temperature. Meanwhile, the wear rate of the alloy decreases with the increase of temperature, which indicates that the alloy has excellent tribological properties.
Acknowledgments
This work was financially supported by Shandong Key R&D Program (2019GGX104090) fund.

References
[1] Lapin J. TiAl based alloys: present status and future perspectives [J]. Metals, 2009, 19-21(5): 1-12.
[2] Xinhua Wu. Review of alloy and process development of TiAl alloys. 2005, 14(10):1114-1122.
[3] Kumar K S et al. Composites Science and Technology [J], 1994,52: 127.
[4] Nathan M et al. J Mater Sci Lett [J], 1993, 12(20): 1622
[5] Qu Xuanhui et al. Acta Metall Sin [J],
[6] Harold E. Sliney. Self-Lubricating Composites of Porous Nickel and Nickel-Chromium Alloy Impregnated with Barium Fluoride-Calcium Fluoride Eutectic. 2008, 9(4): 336-347.