Preparation and mechanical properties of powder metallurgy Ti-3Al-2.5V alloy

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Abstract. Using TiH2 powder, Al-V alloy powder and V powder as raw materials, Ti-3Al-2.5V alloy was prepared by ordinary pressing and vacuum sintering, and the structure and mechanical properties of the alloy were studied. The results show that the powder metallurgy Ti-3Al-2.5V alloy is a near-α type alloy, with a relative density of about 98%. The data of tensile strength, yield strength and elongation are more prominent, and the key performance reaches forged Ti-3Al-2.5V alloy level.

1. Introduction
Titanium alloy has low density (4.51g/cm³, about 40% of steel), high strength (up to 1,000 MPa or more), good fatigue resistance (fatigue limit is twice that of steel), corrosion resistance and excellent biocompatibility[1−2], has always enjoyed the reputation of "space metal" and "ocean metal", and has been widely used in aerospace, automotive and biomedical fields [3−4].

Ti-3Al-2.5V is a titanium alloy material mainly used to make aviation and high-end civil pipes. This alloy is a near-α-type titanium alloy. Its strength is 20%-50% higher than pure titanium at room temperature and high temperature. The welding performance and cold forming performance are better than TC4 alloy. Because there are very few β phases at room temperature, heat treatment and aging methods cannot be used to strengthen, and the strengthening method is mainly through cold working deformation. Ti-3Al-2.5V alloy was originally developed as a material for welded pipes and seamless pipes. Later, this alloy was also used in other structures, but the application of pipes is still dominant. Now practically all commercial airliners have Ti-3Al-2.5V hydraulic systems, and this alloy is increasingly used in chemical equipment. The chemical equipment made of it can withstand higher operating temperatures, improve efficiency, and significantly reduce environmental impact, especially its good corrosion resistance in seawater, making it gradually applied to seawater cooling systems and subsea oil extraction. [5]

The conventional ingot metallurgical process for preparing titanium alloy includes multiple vacuum consumable smelting, billet forging, multi-fire processing deformation and other multi-pass processes. The process flow is long, the energy consumption of smelting and high-temperature forging is large, and the equipment investment is amazing, making the cost of ingot metallurgy Ti-3Al-2.5V alloy is generally higher. Powder metallurgy has the advantages of low raw material cost, short process flow, low energy consumption, and small equipment investment. It can significantly reduce material costs [6-10]. For some parts with complex shapes, the use of powder metallurgy can reduce costs by 50% ~70%, is one of the potential technologies for preparing low-cost titanium alloys. At present, there is no report on the preparation of Ti-3Al-2.5V alloy by powder metallurgy. In this paper, TiH2 powder, Al-V alloy
powder and V powder are used as raw materials to prepare powder metallurgy Ti-3Al-2.5V alloy bars by pressing-vacuum sintering process, and the microstructure and mechanical properties of the alloy are studied.

2. Experiment

2.1. Raw material powder
The raw material powders used in this study are elemental TiH2 powder, V powder and 60Al-40V alloy powder. The LECO 836 system was used to analyze the impurity element content of the powder, and the results are listed in Table 1. It can be seen from the table that the main impurity element of the raw material powder is O, and the O content of TiH2 powder is relatively high, with a mass fraction of 0.345%. Fig 1. Shows the particle size distribution of the raw material powder. It can be seen from the figure that the average particle size of TiH2 powder and the average particle size of Al-alloy powder meet the requirements. The SEM morphology of the powder is shown in Fig 2.

The three powders all present irregular shapes without obvious agglomeration. Powders with different particle sizes and different morphologies are expected to increase the compaction and sintering density of the alloy, and have a positive effect on improving the structure and mechanical properties of the material.

Table 1. The impurity content of raw material powders (mass fraction, %).

| Raw powders       | O     | N     | H (ppm) |
|-------------------|-------|-------|---------|
| TiH2 powders (≤45)| 0.345 | 0.296 | 3498    |
| TiH2 powders (≤88)| 0.287 | 0.319 | 3590    |
| 60Al-40V powders  | 0.182 | 0.103 | 177     |

Figure 1. Particle size distribution of the raw powders.
2.2. Preparation of powder metallurgy Ti-3Al-2.5V alloy

Prepare a certain quality of raw material powder, weigh TiH2 powder, Al-V powder and V powder according to the nominal composition of Ti-3Al-2.5V alloy (mass fraction, the same below), mix them evenly on the V-type mixer, and mix time for 5 h, protect with argon. The powder mixture is compacted at room temperature through a 600mpa mold, and the pressure holding time is 1 min. For this reason, 25g of each sample is used to make a rectangular (length 65mm, width 10mm, height 11.25mm) green compact, which is convenient for further processing and tensile test. The compact is vacuum sintered, the vacuum degree is <1*10^{-3} Pa, the sintering temperature is 1150℃, 1250℃, the holding time is 4h and 8h, and it is cooled with the furnace.

2.3. Performance testing

The density of the powder metallurgy Ti-3Al-2.5V alloy was measured by Archimedes drainage method. Three samples were taken from each state for measurement, and the surface oxide layer was removed by sanding before the test. The LECO 836 system is used to analyze the alloy's impurity elements (oxygen, nitrogen, hydrogen) content. Scanning electron microscope (SEM, Vega 3 TESCAN) and optical microscope (Leika Zeiss) were used to observe the microstructure and tensile fracture morphology of the alloy. In order to clean the fracture, use an ultrasonic cleaner before observation. Prepare tensile specimens in accordance with the national standard GB/T228-2002. The gauge length of the specimen (diameter×length) is 5 mm×25mm, take 3 specimens from each state, and conduct a tensile test on a universal tensile machine.

3. Results and discussion

3.1. Microstructure

Fig 3 shows the microstructure of Ti-3Al-2.5V alloy, and Table 2 lists the density and oxygen content of the alloy. As can be seen from Figure 5, the increasing of the sintering temperature and of the processing time leads to a reduction of the porosity, which is primary isolated and spherical, in agreement with the relative density data. From Fig 3, it can be also seen that α grains and α + β lamellae are the micro-constituents of the samples because they were slowly cooled from above the β-transus. Furthermore, it seems that these phase grows with the temperature and the lamellae get bigger, with this behaviour being more pronounced for a longer time. It is remarkable that the microstructures of both specimens are homogeneous, as proved by EDS analysis, and no undissolved alloying element particles are present. It can be seen from Table 2 that the powder metallurgy Ti-3Al-2.5V alloy has a higher density, with an average density of 98.14%, and the average oxygen content of the alloy is 0.33%, which has little change compared with the oxygen content of the raw material powder.
Figure 3. SEM images of the powder metallurgy Ti-3Al-2.5V alloy. (a) 45μm, 1150℃, 4h; (b) 45μm, 1250℃, 4h; (c) 45μm, 1250℃, 8h; (d) 88μm, 1150℃, 4h; (e) 88μm, 1250℃, 4h; (f) 88μm, 1250℃, 8h.

Table 2. Density and oxygen content of the powder metallurgy Ti-3Al-2.5V alloys.

| Ti-3Al-2.5V alloy samples | Density/ (g·cm⁻³) | Relative density/% | Porosity/% | w(O)% |
|---------------------------|--------------------|--------------------|------------|-------|
| 45μm, 1150℃, 4h           | 4.389              | 98.2               | 1.8        | 0.260 |
| 88μm, 1150℃, 4h           | 4.369              | 97.75              | 2.25       | 0.307 |
| 45μm, 1250℃, 4h           | 4.398              | 98.39              | 1.61       | 0.337 |
| 88μm, 1250℃, 4h           | 4.382              | 98.03              | 1.97       | 0.257 |
| 45μm, 1250℃, 8h           | 4.379              | 97.98              | 2.02       | 0.342 |
| 88μm, 1250℃, 8h           | 4.402              | 98.5               | 1.5        | 0.385 |

3.2. Mechanical properties
Fig 4 shows the true tensile stress-true strain curve of the powder metallurgy Ti-3Al-2.5V alloy. The tensile properties are listed in Table 3. It can be seen from Table 3 that the powder metallurgy Ti-3Al-2.5V alloy has good mechanical properties, and the data of tensile strength, yield strength and elongation are good, and the strength reaches the level of forged Ti-3Al-2.5V alloy.

Fig 5 shows the tensile fracture morphology of the powder metallurgy Ti-3Al-2.5V alloy. It can be seen from the figure that there is no obvious necking at the fracture, the surface of the fracture is rough, there are a few dimples, and obvious residual pores can be observed at the fracture. In the stretching process, residual pores cause stress concentration, so cracks are easy to initiate in the pores and quickly
connect the pores to release the stress, resulting in rapid fracture of the material. The internal pores of the material can be eliminated by other means to improve its density and plasticity.

| Sample | Tensile strength/MPa | Yield strength/MPa | Elongation/% |
|--------|----------------------|--------------------|--------------|
| 45μm,1150℃,4h | 851.78 | 840.83 | 18.70 |
| 88μm,1150℃,4h | 820.05 | 809.87 | 17.05 |
| 45μm,1250℃,4h | 874.87 | 858.40 | 20.80 |
| 88μm,1250℃,4h | 885.61 | 878.64 | 9.9 |
| 45μm,1250℃,8h | 912.41 | 897.12 | 14.9 |
| 88μm,1250℃,8h | 917.89 | 908.05 | 8.75 |

Figure 4. Stress-strain curves of the PM Ti-3Al-2.5V alloy

Figure 5. Fracture morphologies of the PM Ti-3Al-2.5V alloy. (a) 200X; (b) 500X
4. Conclusion

1) In this work, using a mixture of TiH$_2$ and Al-V master alloy powders, a uniform Ti-3Al-2.5V alloy with acceptable impurity content was produced by pressing and sintering BEPM.

2) The effects of different time-temperature sintering parameters on the microstructure are analyzed in detail, including residual porosity, grain size and mechanical properties. Experiments have proved that the microstructure produced by sintering at 1250°C for 4 h shows the best balance of strength/ductility.

3) To strike a balance between strength (UTS 868±49MPa) and ductility (extension 18.0±2.0%), it is expected to consider the practical application of Ti-3Al-2.5V alloy manufactured by the significantly cost-effective BEPM method.

Reference

[1] Lutjering G, Williams J C. Titanium[M]. Springer: Berlin Heidelberg, 2007: 234–236.
[2] Leyens C, Peters M. Chapter 13. Titanium Alloys for Aerospace Applications[M]// Titanium and Titanium Alloys: Fundamentals and Applications. Wiley-VCH Verlag GmbH & Co. KGaA, 2005: 419–427.
[3] Boyer R R. An overview on the use of titanium in the aerospace industry[J]. Materials Science & Engineering A, 1996, 213(1/2): 103–114.
[4] Boyer R R, Briggs R D. The use of β titanium alloys in the aerospace industry[J]. Journal of Materials Engineering and Performance, 2005, 14(6): 681–685.
[5] Effect of heat treatment system on the structure and properties of Ti-3Al-2.5V titanium alloy strip, Meng Chen, Na Liu, Xixing Yue.
[6] Froes F H. How to market titanium: Lower the cost[J]. JOM, 2004, 56(2): 39–39.
[7] Froes F H. The titanium image: Facing the realities of life[J]. JOM, 2000, 52(5): 12–12.
[8] Myers J R, Bomberger H B, Froes F H. Corrosion behavior and use of titanium and its alloys[J]. JOM, 1984, 36(10): 50–60.
[9] Hayes F H, Bomberger H B, FROES F H, et al. Advances in titanium extraction metallurgy[J]. JOM, 1984, 36(6): 70–76.
[10] Sachdev A K, Kulkarni K, Fang Z Z, et al. Titanium for automotive applications: Challenges and opportunities in materials and processing[J]. JOM, 2012, 64(5): 553–565.