Effect of Y$_2$O$_3$ on physical and mechanical properties of TiAl-based alloys

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Abstract. Ti-45Al-5Nb alloy powders were used as the matrix, and added different contents of Y$_2$O$_3$. The TiAl-based alloys with excellent mechanical properties were prepared by vacuum hot pressing sintering technology. Analysed the effect about Y$_2$O$_3$ on the properties of the alloys. The results show that trace amounts of Y$_2$O$_3$ can effectively improve the physical and mechanical properties and refine the grain size of the alloys. When 0.25% Y$_2$O$_3$, the TiAl alloy exhibits excellent hardness, density, flexural strength and fracture toughness. TiAl-based alloys are mainly composed of brittle fracture.

1. Introduction
TiAl-based alloys have high specific strength, low density, good corrosion resistance and good mechanical properties such as creep resistance under high temperature conditions. They are considered as the most promising new generation of high temperature resistant materials. They have a wide range of applications in the aerospace, automotive industry and other fields [1-5]. However, the TiAl-based alloy itself has poor room temperature plasticity, thermal deformation ability and oxidation resistance at high temperature, those severely restricts their application. Therefore, it is important to study and improve these properties of TiAl alloys.

Added small rare earth elements in the TiAl alloys easily forms fine, dispersed intermetallic compounds, which have good thermal stability and strengthen the grain boundaries and grains. At the same time, rare earth can improve the wettability of the matrix and the reinforcement, and improve the properties of the intermetallic compound-based composite. Y$_2$O$_3$ are a kind of rare earth oxide which are insoluble in water and alkali. They can refine the strength and plasticity of alloy grain refining alloy, and the thermodynamic characteristics of Y$_2$O$_3$ are the most stable [6-7].

In this paper, the matrixes are Ti-45Al-5Nb, added a small amount of Y$_2$O$_3$ to prepare new TiAl-based alloys. To analyzed the effects of different contents of Y$_2$O$_3$ on the properties of the alloys.

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2. Experimental methods

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2.1. Preparation of new TiAl based alloys

The Ti-45Al-5Nb matrix was prepared by adding Ti powder, Al powder and Nb powder in molar mass fraction, adding (0%, 0.25%, 0.5%, 0.75%) Y$_2$O$_3$, and preparing new TiAl-based alloy material by powder metallurgy vacuum hot pressing sintering technology. Preparation process parameters are shown in Table 1.

| Temperature(°C) | Pressure(Mpa) | Insulation holding time(min) |
|----------------|---------------|------------------------------|
| 1200           | 30            | 30                           |

2.2. TiAl alloy density tests

Using the Archimedes drainage method to measure density of alloys, and alloys are polished and cleaned before the test. Each sample is measured 5 times and averaged as the final result. The calculation formula is as shown in 1:

$$\rho=M/V=M_1\times\rho_w/M_1-M_2$$ (1)

$\rho$—alloy density (g/cm$^3$),
$\rho_w$—the density of water (g/cm$^3$),
$M_1$—the mass of the sample not suspended in water (g),
$M_2$—The mass of the sample suspended in water (g).

2.3. TiAl alloy hardness tests

Using a digital microhardness tester HXD-1000TMSC to measured hardness of the alloys. The TiAl-based alloy samples were coarsely ground, finely ground, and polished to improve the surface quality before the test. The pressure was set to 1000 N and maintained for 15s. Randomly taken 10 points on each sample, and the average value was taken as the final hardness value.

2.4. TiAl alloy bending strength tests

Cutting TiAl alloys into strip samples of 40.0 mm × 4.0 mm × 3.0 mm, and subjected to a three-point bending test, which is schematically shown in Fig. 1. Test conditions: span of 30 mm, loading rate of 0.5 mm / min. The bending resistance formula is as shown in 2:

$$\sigma=3PL/2bh^2$$ (2)

$P$—maximum load (N),
$L$—the span of the fulcrum (mm),
$B$—the width of the sample (mm),
$H$—the height of the sample (mm).
Each set of samples was tested 3 times, and the average value was taken as the final bending strength of the sample.

2.5. TiAl alloy fracture toughness tests
Cutting TiAl alloys into strip samples of 40.0 mm × 4.0 mm × 3.0 mm, and a V-shaped port was cut on one side thereof to a depth of 1 mm. The fracture toughness test of the metal material was carried out according to the regulations. As shown in Fig. 2. Test conditions: span of 30 mm, loading rate of 0.5 mm / min. Its formula is shown as 3:

\[
K_{IC} = \frac{3PL(10a)^{1/2}}{200bh^2[1.93-3.07\times(a/h)+(a/h)^2-25.07\times(a/h)^3+25.08(a/h)^4]}
\]  

\(K_{IC}\)—fracture toughness (MPa·m\(^{1/2}\)),
\(A\)—cut depth (mm),
\(B\)—sample width (mm),
\(P\)—the maximum load (N),
\(H\)—sample height (mm),
\(L\)—span (mm).

Each set of samples was tested 3 times, and the average value was taken as the final fracture toughness of the sample.
3. Experimental results and analysis

3.1. Physical properties analysis of new TiAl based alloys

Fig. 4 shown the densities and hardness of the four TiAl based alloys.

Figure 3. Physical properties of the new TiAl based alloys

Figure 3 is the physical properties change curve about the new TiAl-based alloys. With the increase of Y2O3 content the density and hardness of the TiAl-based alloys are increase first and then decrease. When 0.25% Y2O3, the density of the alloy is the largest, that meaning the TiAl-based alloy has the highest density. When alloy added 0.5%Y2O3, the hardness is the highest, about 535HV. The hardness of the alloy is about 530 HV at 0.25% Y2O3. When the content of Y2O3 in the alloys is 0.25% and 5%, the hardness values of the alloys are basically similar. Therefore, when the content of Y2O3 in the TiAl-based alloy is 0.25%, the overall physical properties are excellent.

3.2. Analysis of mechanical properties of TiAl based alloys

Figure 4. Mechanical properties of TiAl based alloy

Figure 4 is the mechanical properties change curve about the new TiAl-based alloys. With the increase of Y2O3 content the fracture toughness and flexural strength of the TiAl-based alloys are increase first
and then decrease. When the content of Y$_2$O$_3$ is 0.25%, the mechanical properties of the TiAl-based alloy are the most excellent. With the increase of Y$_2$O$_3$ content, the flexural strength of the alloys is 470 MPa, 506 MPa, 490 MPa, 484 MPa, the fracture toughness is 12MPa m$^{1/2}$, 14MPa m$^{1/2}$, 13.1 MPa m$^{1/2}$, 12.4MPa m$^{1/2}$. It shows that a small amount of Y$_2$O$_3$ can effectively improve the mechanical properties of the alloy.

3.3. Fracture analysis of TiAl based alloys
Combination with the above three-point bending fracture tests to analyze the fracture morphology of the alloys. Figure 5(a) shows the TiAl fracture morphology at 0% Y$_2$O$_3$. Figure 5(b) shows the TiAl fracture morphology at 0.25% Y$_2$O$_3$. Figure 5(c) shows the TiAl-based fracture morphology at 0% Y$_2$O$_3$. Figure 5(d) shows the TiAl fracture morphology at 0.75% Y$_2$O$_3$.

![Fracture morphology of the new TiAl based alloys](image)

**Figure 5.** Fracture morphology of the new TiAl based alloys

It can be seen from Figure 5 that the four new TiAl-based alloys are brittle fractures, and the fracture morphologies are flat without dimples. It was further observed that the fracture cleavage morphology appeared in the fracture, so the TiAl-based alloys was transgranular brittle fracture.

Compared with Figure 5 (b) (c) (d), it can be seen that a small amount of Y$_2$O$_3$ can effectively refine the microscopic crystal grains, thereby improving the overall performance of the alloy. In Figure 5 (b), the alloy fracture shows an obvious pattern of river shape, which is a typical transgranular cleavage fracture. When 0.25% Y$_2$O$_3$, the alloy has good mechanical properties and physical properties, which is consistent with the above test results. In Figure 5 (d), when 0.75% Y$_2$O$_3$, there is a certain crack in the fracture of TiAl-based alloy, which has a certain influence on the mechanical properties of the alloy. It indicates that the microstructure of the alloy is prone to some defects when the excess Y$_2$O$_3$ are added.
4. Conclusion

TiAl alloys were prepared by vacuum hot pressing sintering technology. Analyzed the effects of different contents of Y$_2$O$_3$ on the properties of TiAl-based alloys:

It is found that with the increase of Y$_2$O$_3$ content of the new TiAl-based alloys, the mechanical properties are increase first and then decrease, when 0.25% Y$_2$O$_3$, the mechanical properties and physical properties of the new TiAl-based alloys are excellent.

Observed the microstructures about TiAl alloys with different content of Y$_2$O$_3$. It was found that the addition of trace amounts of Y$_2$O$_3$ can effectively refine grains and improve the overall performances of the alloys. It was found that when 0.25%, the alloy showed obvious pattern flow, and it is transgranular cleavage fracture.

Acknowledgments

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