Calculation of Volatilization Behavior of Alloying Elements During Electron Beam Melting of Near-A Titanium Alloy

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Abstract: In this paper, near-α titanium alloy were prepared by electron beam melting. The composition and volatilization behavior of alloying elements were studied. The results show that the mass loss rate of the alloy increases with the increase of melting power. After melting, the mass fractions of Al and Sn decreased, while the mass fractions of other elements increased. The melt was simplified into Ti-Al-Sn ternary alloy model to study the volatilization behavior. The activity coefficient and activity of alloying elements could be predicted by Miedema model. The theoretical volatilization rate of other elements was very small, and the volatilization loss was basically negligible. The volatilization rate of Al and Sn elements is calculated by introducing the activity coefficient compensation factor.

Keywords:near-α titanium alloy, Electron beam cold hearth melting,Volatilization of element

1 Introduction

Titanium alloy has excellent comprehensive properties such as high specific strength, high specific stiffness and high temperature resistance, and the application demand in aerospace is increasing day by day [1,2]. In industrial production, the traditional smelting method of titanium alloy is difficult to fundamentally eliminate the most serious metallurgical defects in high and low density inclusion of titanium alloy. However, the introduction of Electron beam cold hearth melting (EBCHM) technology be a good solution to the above problems. However, in the process of electron beam melting, the alloying elements will be volatilized.

The volatilization behavior of alloying elements during electron beam melting of near α type titanium alloys was studied in this work, which can provide theoretical guidance for element control during electron beam melting of near α type high temperature titanium alloys.

2 Experimental procedure

The measured composition of the raw material in this experiment is Ti-5.88Al-3.87Sn-3.32Zr-1Mo-0.37Si-0.39Nb-0.32Ta-1.11W. The electron beam melting furnace model SEBM-60A is used for melting, and the melting parameters are: 6kW/10min(1), 8kW/10min(2), 15kW/5min(3) and 20kW/5min(4). The mass of the alloy before and after the experiment was measured by an electronic balance(ACS-D Ⅱ) with a precision of 0.1g, and the composition of the alloy was analyzed by inductively coupled plasma atomic emission spectrometry(ICAPPRO X ICP-OES Duo).

3 Result and discussion

Component analysis

After the experiment, the test results of alloy composition are shown in Table 1. After electron beam melting, the mass fraction of aluminum and tin decreases, while the mass fraction of other elements increases. The mass loss rate of experimental raw materials is shown in Table 2. It can be seen that the mass loss rate increases with the increase of melting power. The reason is that at a given scanning speed, the volatilization loss depends on the line energy, and as the line energy increases, the volatilization loss also increases.

Table1. Chemical Composition Test Results of Raw Materials after experiment (mass fraction/%)

Al	Sn	Zr	Mo	Si	Nb	Ta	W	Ti
3.62	3.28	3.47	1.08	0.42	0.41	0.34	1.18	Bal.
2.58	2.84	3.67	1.13	0.45	0.43	0.36	1.23	Bal.
3.11	3.06	3.6	1.11	0.45	0.42	0.34	1.2	Bal.
2.3	2.83	3.65	1.13	0.44	0.44	0.36	1.24	Bal.

Table2. Mass loss and mass loss rate alloys experiment

Power	Raw material quality	Quality after melting	Mass loss	Mass loss rate
6kW	165g	158g	7g	4.2%
8kW	162g	147g	15g	9.2%
15kW	160g	145g	15g	9.4%
20kW	160g	141g	19g	11.9%

Volatilization behavior of element

According to literature [3], the saturated vapor pressure of pure elements depends on temperature and can be calculated by the Clausius-Capeyron equation:

$$\lg P_i^0 = \frac{A}{T} + B\lg T + CT + D \quad (1)$$

The volatilization behavior of alloying elements is mainly affected by the interfacial volatilization process.

According to Langmuir equation, the volatilization loss of alloying element i during electron beam refining can be expressed as:

$$\Delta m_i = S \cdot texp\left(\frac{\bar{G}_i^{ex}}{RT}\right) \times \chi_i \times P_i^0 \times \sqrt{\frac{M_i}{2\pi RT}} \quad (2)$$

According to the actual volatilizing loss of Ti element during electron beam melting, the average surface temperature of molten pool under different melting power can be calculated by equation (2) as 1669.4K, 174.4k, 1792.9k and K1807.9K, respectively.The main volatile elements in near-α titanium alloy are Ti, Al and Sn. The solution system can be simplified as a Ti-Al-Sn ternary alloy model to study the volatilization behavior of alloying elements in the alloy. In addition, Zr, Mo, Si, Nb, Ta, and W are relatively low in content, so the solution is first regarded as a dilute solution of these elements when calculating the activity coefficient, which is considered to be 1. According to Miedema model, the activity coefficient and volatilization rate of elements at different temperatures are shown in Fig 1((b) (c)).It can be seen from the figure that the activity coefficient and volatilization rate of elements increase with the increase of temperature.The theoretical volatilization rates of Zr, Mo, Si, Nb, Ta, and W are very small, so the volatilization losses in electron beam melting are basically negligible.Since Al and Sn have a large saturated vapor pressure, their activity coefficient and activity have a great influence on the theoretical volatilization rate, resulting in inaccurate calculation of volatilization loss of Al and Sn through Langmuir equation. It is necessary to introduce the activity coefficient compensation factor ω to optimize the volatilization rate of Al and Sn. After optimization, the theoretical volatilization rate can be expressed as:

$$V_i = \chi_i \times \gamma_i \times \omega_i \times P_i^0 \times \sqrt{\frac{M_i}{2\pi RT}} \quad (3)$$

The approximate value of the activity coefficient compensation factor of Al and Sn in this experiment is 0.0035 and 1.26. The volatilization rate of Al and Sn after optimization and the theoretical volatilization rate are shown in Fig 1(d). It can be seen from the figure that the theoretical volatilization rate of Ti, Al and Sn in the electron beam melting process is in good agreement with the actual volatilization rate.

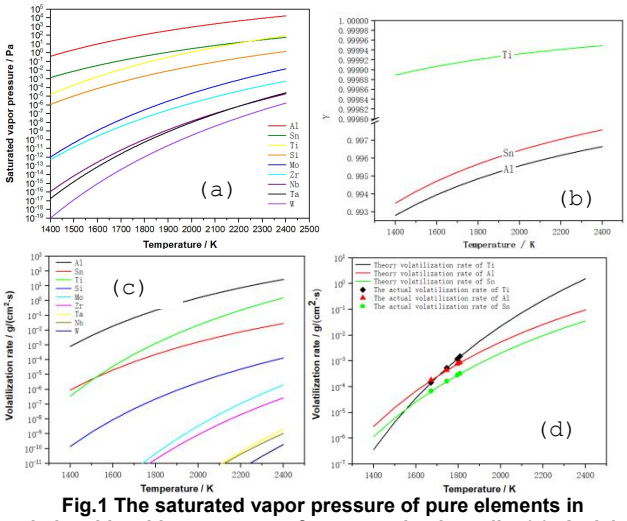

Fig.1 The saturated vapor pressure of pure elements in relationship with temperature for near-α titanium alloy(a); Activity coefficient(b) and volatilization rate(c) of each element at different temperatures;Actual mass loss and theoretical mass loss of volatile elements(d)

4 Conclusion

It is reasonable to simplify the alloy into Ti-Al-Sn ternary system and use Miedema model to calculate the activity coefficients and volatilization rates of Ti, Al and Sn. When calculating the volatilization rate of Al and Sn, it is necessary to introduce the activity coefficient compensation factor to optimize the theoretical volatilization rate.

5 Acknowledgments

The Acknowledgment section is an optional section that uses and “body” text style (10 pt., Times New Roman).

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