

EVAPORATION BEHAVIOR OF COMPONENTS IN Ti-15-3 MELT DURING ISM PROCESS^①

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ABSTRACT Based on Kohler's ternary solution model and Miedema model for calculating the heats of formation $-\Delta H_{ij}$ of binary systems, the activity coefficients in Ti-15-3 melt have been calculated. Taking advantage of the activity coefficients and the corrected Langmuir Equation, the evaporation losses of components in Ti-15-3 melt during ISM process have been studied. The calculated results prove Ilchner's statement of existing a critical vacuum degree (about 1.33 Pa) during melting process under the vacuum condition. When the vacuum degree in the vacuum chamber surpasses this value, the evaporation of components takes on a state of free evaporation. Finally, the calculated results are compared with the experimental data, which testifies the reliability of the models for calculating activity coefficients and evaporation losses.

Key words Ti-15-3 alloy evaporation loss ISM process

1 INTRODUCTION

Metastable β titanium alloys are now finding progressively more applications, especially owing to their good forming properties^[1]. Ti-15V-3Cr-3Al-3Sn (Ti-15-3), a typical metastable β titanium alloy, was developed to answer the need for a titanium alloy sheet metal in aerospace application^[2].

Although ISM process, an advanced process for melting high reactivity alloys, may avoid the pollution of refractory and guarantee the homogeneity of alloy composition, there exist two problems: one is the difficult control to the skull constituents, the other is the evaporation losses of components during melting process. By now, little research has been focused on these two problems. Because of the addition of a great amount of alloying elements in metastable β alloys, it is difficult to obtain alloy melt with qualified nominal composition, and for Ti-15V-3Cr-3Al-3Sn (Ti-15-3), it is without exception. Because of the addition of these elements such as Al, Cr and Sn with high vapor pressure, their e-

vaporation losses can not be ignored. This paper is aimed at studying the second problem during ISM process of Ti-15-3.

2 CALCULATION MODEL

Because of the existence of residual gas (including metal vapor, inert gas and air molecule), the diffusion of the evaporating atoms can be impeded. According to Langmuir theory^[3], the real evaporation rate could be corrected as^[4]

$$N_{m,i} = -K_L \varepsilon (p_i^e - p_i^s) \sqrt{M_i / T_{ms}} \quad (1)$$

$$p_i^e = \gamma_i x_i p_i^0$$

where $N_{m,i}$ —Evaporation rate of component i , $\text{g} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$; K_L —Langmuir constant, $K_L = 0.05833$; ε —Condense constant, for metals $\varepsilon = 1$; T_{ms} —Temperature in the evaporating interface, K; p_i^e —Saturated vapor pressure of component i at temperature T_{ms} , Pa; M_i —Atomic mass of component i ; p_i^s —Partial pressure of component i in the effective space, Pa; γ_i —Activity coefficient of component i ; x_i —Mole fraction of component i in alloy melt; p_i^0 —

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Saturated vapor-pressure of pure component i , Pa

When we use Eq. (1) to predict the evaporation losses of components, the only one problem is the definition of γ_i and p_i^s .

2.1 Calculation of γ_i

Based on Kohler Equation^[5] and Miedema model^[6] for calculating the heats of formation — ΔH_{ij} of binary systems, the integral formula for calculating the activity coefficients of ternary systems has been established^[7]. Because of the little concentration of Al, Cr and Sn in the Ti-15-3 melt, we can divide Ti-15-3 into three ternary systems, namely Ti-16V-3Al, Ti-16V-3Cr and Ti-16V-3Sn, to calculate the activity coefficients in Ti-15-3 melt. The calculated results are shown in Fig. 1 and Fig. 2.

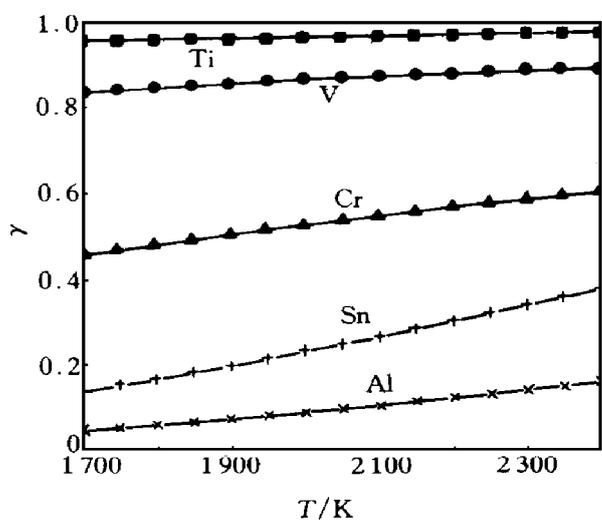


Fig. 1 Relation curves of activity coefficient (γ) vs temperature (T) in Ti-15-3 melt

2.2 Theoretical model for p_i^s

Fig. 3 shows the theoretical model for defining p_i^s , for which there exist four hypotheses:

(1) Within a very short time-step, mole number of atoms evaporating into the vacuum chamber equals that of the pumped-out gases (including inert gas, air and metal vapor) from the effect space (V_{eff}), in other words, p_{out} is a constant value;

(2) Within a very short time-step ($t \rightarrow t +$

dt), the proportion of element i in the pumped-out gases is in direct proportion to its mole fraction at t moment in the vacuum chamber;

(3) The metal vapor is thought as ideal gas, namely it satisfies the state equation:

$$pV = nRT;$$

(4) In the effective space, the metal vapor doesn't condense.

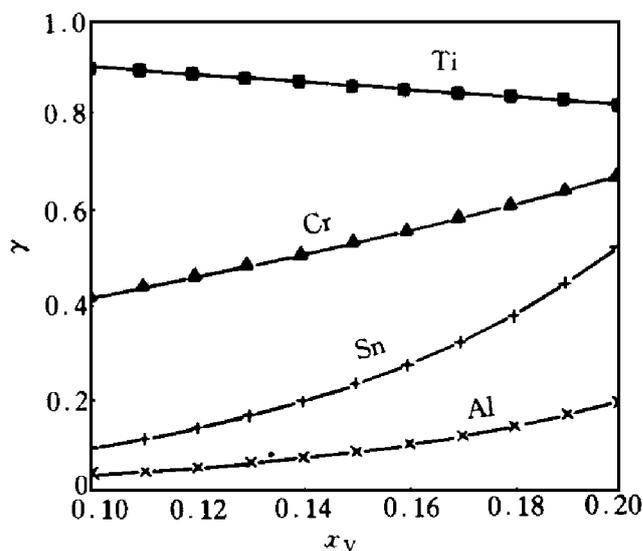


Fig. 2 Effect of concentration of V (x_v) on activity coefficients (γ) in Ti-15-3 melt ($T = 2000 \text{ K}$)

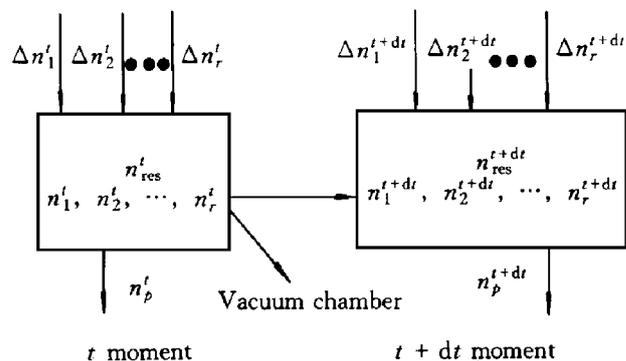


Fig. 3 Sketch for estimating partial pressure (p_i^s)

In Fig. 3, Δn_i^t indicates the mole number of component i evaporating into the effective space within dt ($t \rightarrow t + dt$); Δn_i^{t+dt} indicates the mole number of component i evaporating into the effective space within $t + dt \rightarrow t + 2dt$; n_{res}^t is the mole number of the residual gases in the effective space at t moment, including inert gas

and air; n_{res}^{t+dt} is the mole number of the residual gases at $t + dt$ moment; n_i^t and n_i^{t+dt} indicate mole fractions of component i at t moment and $t + dt$ moment, respectively. Through a series of strict deduction, we can get the partial pressure (p_i^{t+dt}) of component i at the $t + dt$ moment as follows:

$$p_i^{t+dt} = \frac{RT' (n_i^t M_i + N_{m,i}^t S \cdot dt)}{V_{eff} M_i} - \frac{R^2 T'^2 n_i^t (\sum_{i=1}^r \frac{N_{m,i}^t S \cdot dt}{M_i})}{p_{out} V_{eff}^2} \quad (2)$$

where S —Area of evaporation interface; T' —Temperature in the effective space, generally 310K; R —Gas constant; M_i —Atomic mass of component i .

Combining Eq. (2) with the corrected Langmuir Equation (Eq. (1)) and exerting iterative computation on Eq. (1) by means of computer, we can calculate the evaporation rate at arbitrary moment, temperature, concentration and so much as the outer pressure. During the computing process, the following initial and boundary conditions must be complied with:

- (1) at $t = 0$, $n_i^t = 0 (i = 1 \sim r)$;
- (2) when $N_{m,i} = 0.000000$, the computation process will be finished;
- (3) the whole melting time, namely the computed time is 600 s.

3 CALCULATED RESULTS AND DISCUSSION

Firstly, the influence of melting temperature (T) on evaporation rate has been studied. Due to the same influence regularity of melting temperature on the evaporation rates of Al, Cr and Sn, so we figure out only the relation curves of the evaporation rate of Al— $N_{m,Al}$ vs time at various temperature in Fig. 4 when p_{out} equals 1.33 Pa. It is obvious that, with the rise of T , N_m increases continually. Despite the change of T , N_m quickly decreases from the maximum to a constant value within a much short time (about 40s). The reason of this phenomenon is that: at the moment of initial 40s, the residual gases (including inert gas and air) have been pumped

away completely, consequently, within the following time, the metal atoms evaporating out are pumped away completely, too; and at the same time the partial pressure (p_i^t) keeps a constant value.

Secondly, the influence of outer-pressure (p_{out}) on evaporation rate has been studied, too, which is shown in Figs. 5~ 7, respectively. From these three figures, it can be found easily that: when p_{out} surpasses the so-called critical vacuum degree—1.33 Pa, N_m has a great increase and almost comes up to the maximum

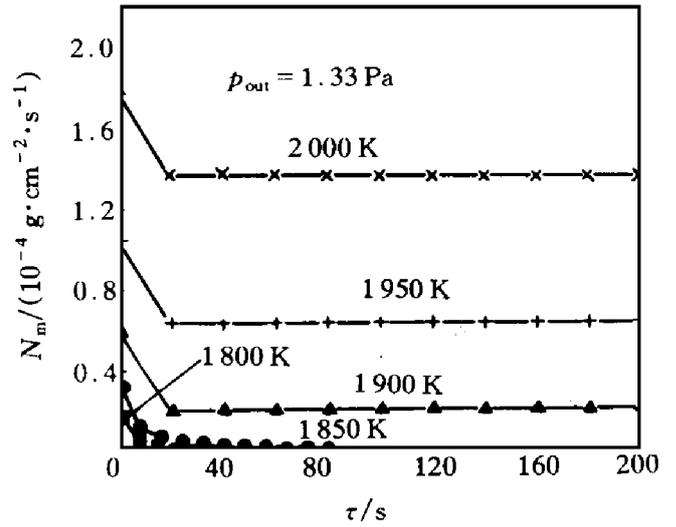


Fig. 4 Al's relation curves of evaporation rate (N_m) vs holding time (τ) at various T

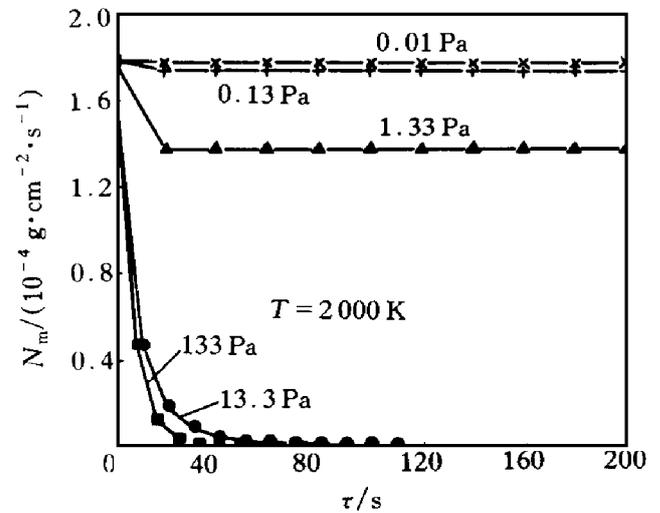


Fig. 5 Al's relation curves of evaporation rate (N_m) vs holding time (τ) at various p_{out}

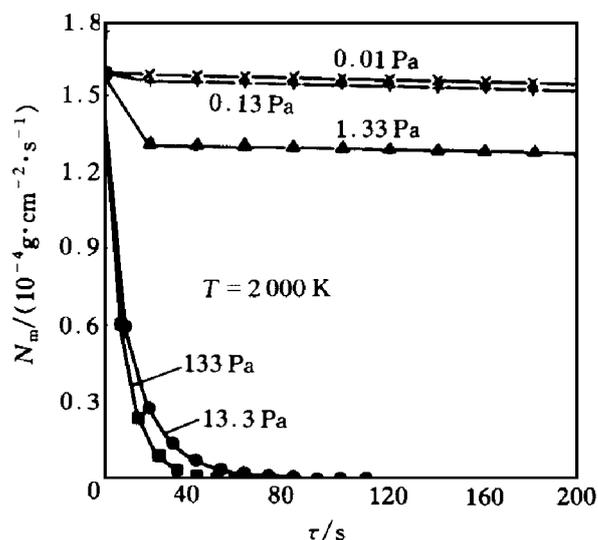


Fig. 6 Cr's relation curves of evaporation rate (N_m) vs holding time (τ) at various p_{out}

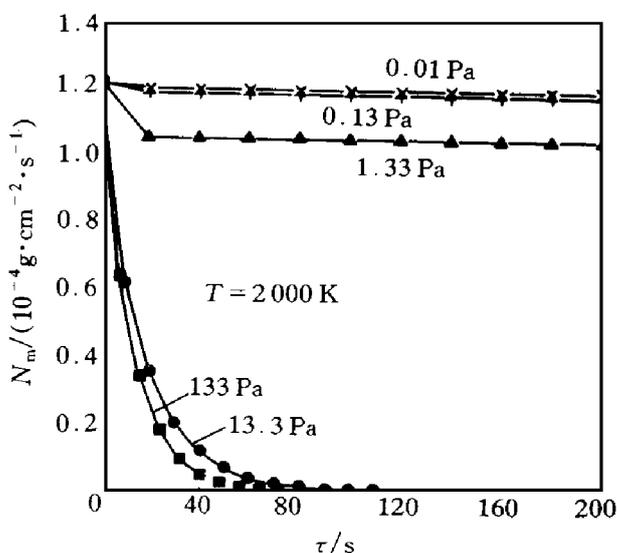


Fig. 7 Sn's relation curves of evaporation rate (N_m) vs holding time (τ) at various p_{out}

evaporation rate. In other words, at this time, the diffusion of metal atoms in the residual gases will not be one of the restrictive links of metal evaporation. This calculated result is in accordance with that of Ilschner's research^[8].

Finally, the calculated results have been compared with the experimental results. Two melting practices had been carried out and the process conditions are: W (melting power) = 320 kW; $T = 2000$ K; $p_{out} = 1.33$ Pa. Composition analysis is also conducted to the ingot and skull. The analysis results are shown in Table 1. In Fig. 8, three curves indicate the relationship between evaporation losses and holding time, from which we can find that: when the holding time of T \bar{r} -15-3 melt reaches 600 s, the evaporation losses of Al, Cr and Sn are 9, 8.6 and 7 g, respectively. Compared with the data in Table 1, these calculated results reflect the real situation in the main, only with the exception of Cr, but the error is so little that it can be ignored. From

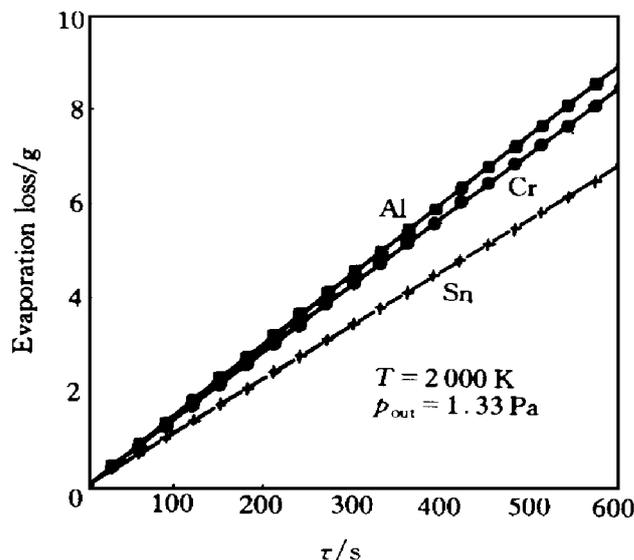


Fig. 8 Relation curves of evaporation losses vs holding time (τ) of various elements

Table 1 Composition analysis of ingot and skull

Melting number	Furnace Charge/g	Mass/g		$\varphi(\text{Al})/\%$		$\varphi(\text{Cr})/\%$		$\varphi(\text{Sn})/\%$		Evaporation loss/g		
		Ingot	Skull	Ingot	Skull	Ingot	Skull	Ingot	Skull	Al	Cr	Sn
Number one	5 000	3 900	1 075	2.85	2.87	2.74	2.89	2.89	2.79	8	12	9
Number two	5 000	3 920	1 050	2.84	2.82	2.78	2.89	2.86	2.80	10	11	8
Average values	5 000	3 910	1 063	2.83		2.78		2.85		9	11.5	8.5

the above contrast, we can come into a conclusion that the model for calculating activity coefficients of components and the model for estimating partial pressure in this article are reliable.

4 CONCLUSIONS

(1) With the rise of melting temperature (T), the evaporation rates of all elements increase continually and within a very short holding time (about 40s) of Tř 15-3 melt, the evaporation rate decreases from the maximum value to a constant value.

(2) During the vacuum melting process, there exists a critical vacuum degree (about 1.33 Pa). When the vacuum degree in the vacuum chamber surpasses the critical value, the evaporation rate has a great increase and almost comes up to the maximum value. In other words, the diffusion of metal atoms in the residual gases has not been one of the restrictive links of metal evaporation.

(3) Under the condition of $T = 2\,000\text{ K}$,

$p_{\text{out}} = 1.33\text{ Pa}$ and holding time $\tau = 600\text{ s}$, the evaporation losses of Al, Cr and Sn are 9, 8.6 and 7 g, respectively. These results reflect the real situation in the main and also prove the reliability of the model for calculating activity coefficients of components and the model for estimating partial pressure.

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