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ARTICLE

Effects of Alloy Elements on the Mould Filling Capacity of Ti46Al8Nb Alloy

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Abstract: Embedded material shell was prepared using wax grid with 8×8 mesh. The effects of micro-alloy elements B, Y, Mn and Er on the mould filling capacity of Ti46Al8Nb melt were studied. The results show that the liquidity and mould filling property of Ti46Al8Nb melt are improved to some extent by B, Y, Mn and Er addition. 0.5%Y and 1.0%Mn addition have great improvement in the mould filling capacity of the alloy, which increase the filling ratio by 54.5% and 48.5%, respectively. The effect of 0.1%Er, 0.5%B and 1.0%B addition on the mould filling capacity of the alloy is not so remarkable, with the filling ratio increased by 3.0%, 4.5% and 5.3%, respectively.

Key words: micro-alloy elements; high Nb containing TiAl alloy; mould filling capacity

Titanium aluminides are regarded as new generation alloys owing to their low density and attractive high-temperature properties. They have great potential to replace the heavier nickel-base superalloys in aircraft turbine engine[1-5]. At present, titanium aluminide has been used in General Electric's GEnx gas turbine engine designed for the Boeing's 787 Dreamliner, and the mass reduction of single engine is about 90.8 kg[6]. However, the melt of TiAl based alloy has high viscosity and bad liquidity; in addition, it easily reacts with other substance at high temperature, which make TiAl based alloy hard to cast[7].

Mould filling capacity is one of the most important properties for alloy casting, which involves complicated fluid dynamics and physical chemistry processes. At present, researchers usually test the melt's filling property with wax grid. The filling ratio is determined by the filled grid after casting[8,9]. In this study, the effects of elements B, Y, Mn and Er on liquidity and mould filling property of Ti46Al8Nb (at%, all coponents are in atomic percent unless specified otherwise) were investigated in unvarying casting conditions.

1 Experiment

TiAl based alloys with nominal composition of Ti46Al8Nb and Ti46Al8Nb*X*(*X*=B, Y, Mn, Er) weighing 40 g (as seen in Fig.1) were used in this study. The alloys were prepared by vacuum arc melting furnace in argon atmosphere in a water-cooled copper hearth. The buttons were remelted three times to ensure chemical homogeneity. The content of micro-alloy element is shown in Table 1.

The samples for metallographic examination were cut from the core in the button ingots. The interested areas were analyzed using FEI Quanta 650 FEG scanning electron microscopy (SEM) and accessary energy dispersive spectroscopy (EDS) was used to confirm the particles formed in the alloys. Deep etch of the microstructure by a Kroll solution (80vol% H_2O+15vol%HNO_3+5vol%HF) for 10 min was applied to reveal the boride morphologies. Solidus and liquidus temperatures of Ti46Al8Nb based alloys were obtained by simulation in PROCAST software.

Wax grid of 22.8 mm×22.8 mm×0.8 mm in dimension with

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Fig.1 Button ingots

Table 1 Chemical composition of microalloy (at%)

Element	B	Y	Mn	Er
Content	0.5	0.2	1.0	0.1
	1.0	0.5	2.0	0.3

8×8 mesh (64 grids and 144 edges in total) were used to test the liquidity. The wax grid design is shown in Fig.2. The filling property can be characterized by filling ratio, which can be expressed by the formula:

$I=A/B\times 100\%$

Where, I-filling ratio, A-filled edges, B-total edges

The embedding materials were roasted, The roasting technology can be seen in Fig.3, and the mould prepared is shown in Fig.4. The experiments were carried out in a gravity titanium casting machine under the conditions of current 500 A, smelting time 45 s, and the shell preheated temperature of 200 ℃.

2 Results

The experimental results are shown in Fig.5. The filled edges in different alloys were statistically analyzed as seen in Table 2.

As seen in Fig.5, the additions of 0.2%Y, 0.5%Y, 1.0%Mn and 0.3%Er obviously increase the number of filled edges compared to that of the alloy Ti46Al8Nb. The statistical results shown in Table 2 indicate that trace elements B, Y, Mn and Er can produce a certain degree of improvement in filling properties of Ti46Al8Nb based alloy. Alloy with the addition of 0.5%Y shows the greatest increment in the number of filling edges (to 51), increased by 54.5%. With the additions of 1.0%Mn, 0.2%Y and 0.3% Er, the filling edges number increases to 49, 45.5 and 41.5 parallel to the filling ratios increased by 48.5%, 37.9% and 25.8%, respectively. Meanwhile, the effects of 0.1%Er, 0.5%B, 1.0%B and 2.0%Mn on the filling property seem to be weak, with the filling ratios only increased by 1.5%, 4.5%, 5.3% and 7.6%, respectively.

The micrographs of alloys containing different contents of B, Y, Mn, and Er are shown in Fig.6. It reveals that the dendrites and grain size are extremely refined in the alloys containing B, Er and Y compared to those in Ti46Al8Nb, and some particles are observed in these alloys; the addition of Mn achieves little refinement, but the dendrites are hardly to be observed.

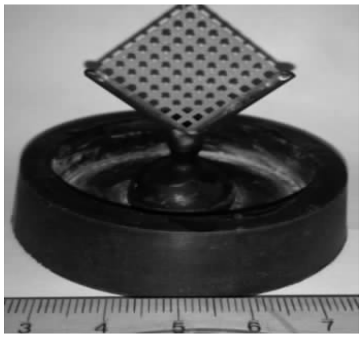

Fig.2 Wax pattern

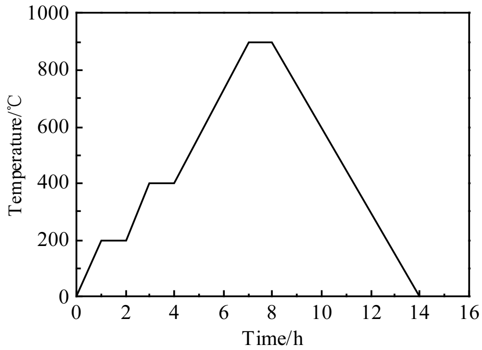

Fig.3 Roasting technology of mould shell

Fig.4 Mould shell

3 Discussion

Alloys filling property is greatly affected by viscosity which is closely related to many factors such as thermophysical properties, crystallization properties, and oxidation degree of the melt[10]. Generally speaking, the greater viscosity would cause the lower liquidity and thus the lower filling property as well[11]. The higher superheat is conducive to lower viscosity. Different additions result in different crystallization temperature intervals which will influence the liquidity. Wide- crystallization-temperature-range alloys would get to mushy

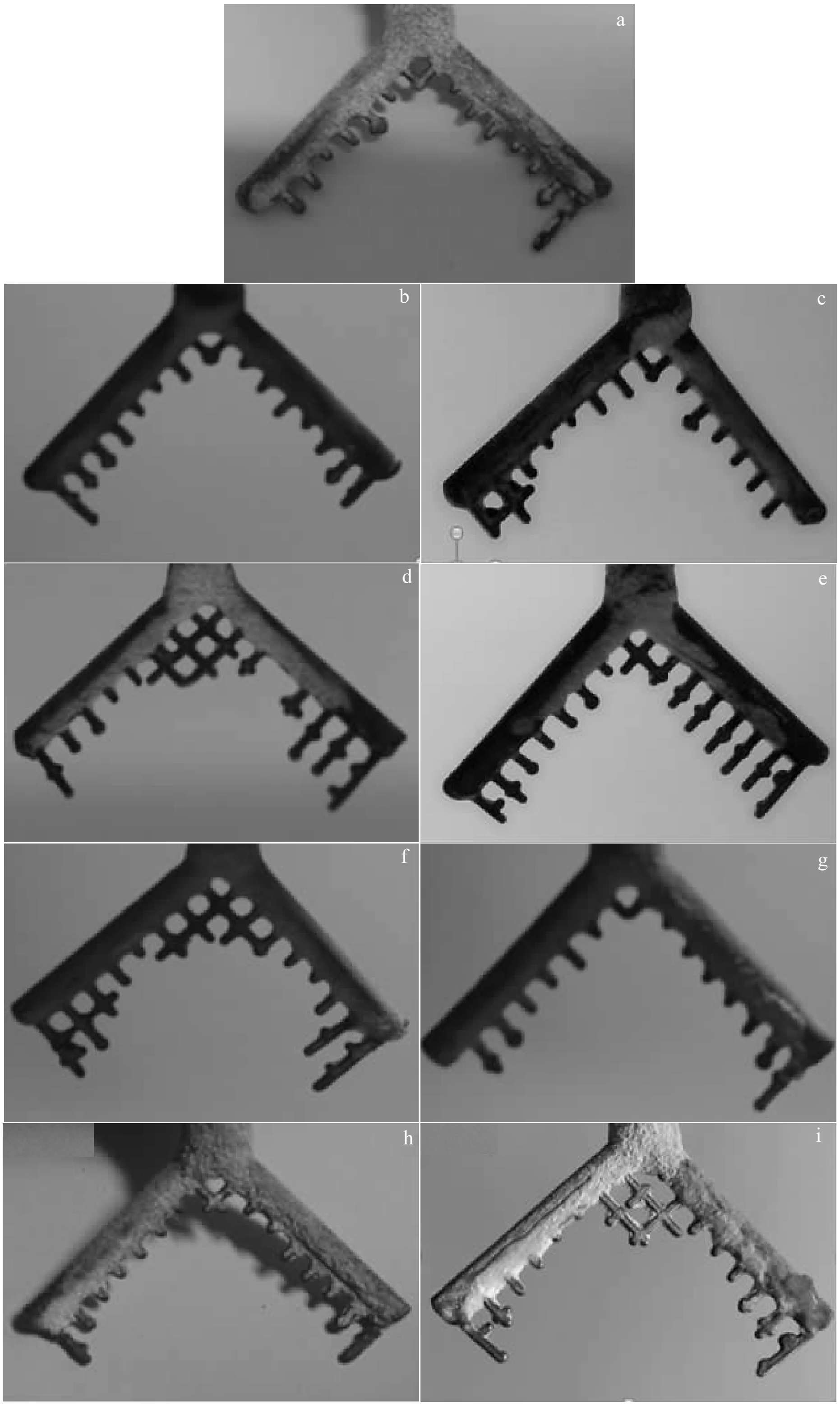

Fig.5 Results of mould filling tests for alloys with different element additions: (a) Ti46Al8Nb, (b) 0.5%B, (c) 1.0%B, (d) 0.2%Y, (e) 0.5%Y, (f) 1.0%Mn, (g) 2%Mn, (h) 0.1%Er, and (i) 0.3%Er

Table 2 Results of mould filling tests

Composition	Ti46Al8Nb	0.5%B	1.0%B	0.2%Y	0.5%Y	1.0%Mn	2.0%Mn	0.1%Er	0.3%Er
Number of filled edges	33.0	34.5	34.75	45.5	51.0	49.0	35.5	34.0	41.5
Filling ratio/%	22.9	24.0	24.1	31.6	35.4	34.0	24.7	23.6	28.8

solidification and cause much more developed dendrites than those in narrow-crystallization-temperature-range alloys. Some earlier studies[12,13] showed that refined dendrites and grain size are better for decreasing viscosity. Therefore narrow crystallization temperature range is better for liquidity.

Table 3 shows the solidus and liquidus temperatures of Ti46Al8Nb based alloys, which were simulated by PROCAST software. They were calculated based on a Ti-base alloy database, There might be some deviations from the actual temperatures; however, the results are still comparable considering that the calculations were undertook under uniform conditions.

It is obvious that the addition of B decreases the temperature difference (ΔT) between solidus and liquidus, which is consistent with the results of V. T. Witusiewicz et al[14]. Lower liquidus contributes to higher superheat and lower the viscosity. So the addition of 0.5%B and 1.0%B would increase the liquidity to some degree.

Some researchers have proved that B is the most efficient element in refining the microstructure of as-cast γ-TiAl[15]. With the addition of B, constitutional supercooling would arise beyond β phase solidification front and promote nucleation[16]. The dendrites and grain size will be refined so as to decrease the viscosity. In this experiment, needle-like and threadlike TiB_2 (e.g. the arrowed area in Fig.6c) are observed in the alloy matrix; the refined dendrites and grain size (shown in Fig.6b) which strongly reduce the viscosity are also observed. Furthermore, the process of TiB_2 precipitation and matrix solidification is similar to eutectic solidification[17], implying that TiB_2 and the matrix will block each other during solidification and increase the flow resistance. Thus the liquidity of the alloy with 0.5%B addition would not change too much. Early studies showed that there is a critical concentration (0.5at%~0.7at%) for grain refinement in a boron-added alloy, which is called "switch effect". Below the critical concentration, boron addition would not lead to grain refinement during solidification and there is no significant grain refinement with further increasing boron addition above the critical level[16], so the addition of 1%B would achieve little further refinement, leading to slight improvement in liquidity regardless of the further decrease in crystallization temperature interval.

In the case of alloys with Y, though solidus and liquidus change little, the addition of 0.2%Y and 0.5%Y both improve the filling property markedly, increasing the filling ratio by 37.9% and 54.5%, respectively. Researchers found that the element Y is able to improve the oxidation resistance of TiAl based alloys[18], which is indicative of that Y can reduce the oxidation film content on the surface of high temperature melt, thereby reducing the melt surface tension and improving the liquidity. Furthermore, the reaction between melt and mould shell material can be reduced by improving the oxidation resistance so as to increase the flow velocity beyond the boundary [19]. The solidification dendrites and grain size are refined in great degree by comparing Fig.6d and Fig.6a. With 0.5%Y, solidification dendrites and grain size are further refined as shown in Fig.6e, and the dendrites are virtually nonexistent. Particles (Y_2O_3 and Al_2Y) in the alloy are easily captured and distributed homogeneously in the matrix, and the resistance caused by them is much less than the improvement. Significant refinement of microstructure could greatly improve the liquidity of Ti46Al8Nb based alloys.

Table 3 Solidus and liquidus temperatures of Ti46Al8Nb based alloys with different additions (℃)

No.	Composition	Liquidus	Solidus	ΔT
1	Ti46Al8Nb	1499	1437	62
2	Ti46Al8Nb0.5B	1488	1429	59
3	Ti46Al8Nb1B	1476	1429	47
4	Ti46Al8Nb0.2Y	1499	1437	62
5	Ti46Al8Nb0.5Y	1501	1437	64
6	Ti46Al8Nb1Mn	1499	1437	62
7	Ti46Al8Nb2Mn	1499	1455	44
8	Ti46Al8Nb0.1Er	1499	1437	62
9	Ti46Al8Nb0.3Er	1502	1437	65

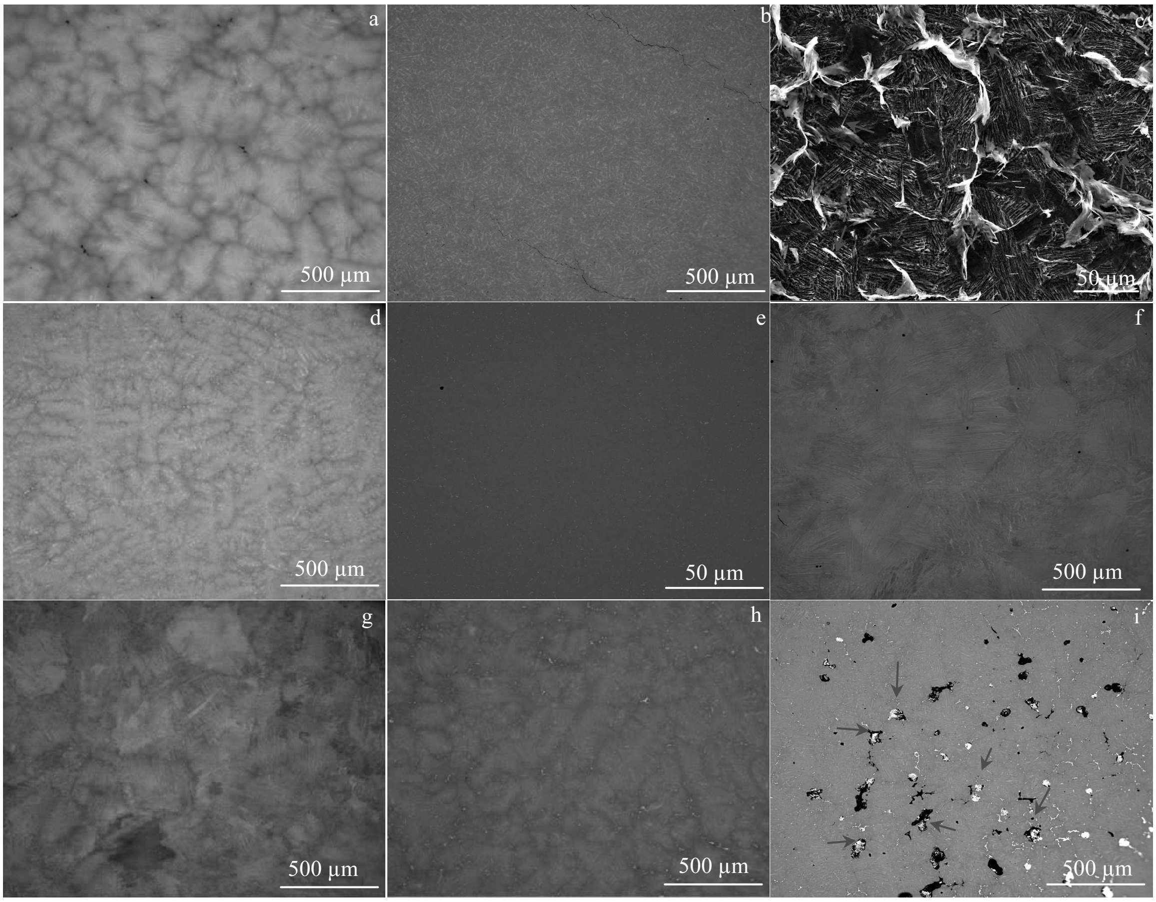

Fig.6 BSE micrographs of Ti46Al8Nb (a) and the alloys containing 0.5%B (b), 0.2%Y (d), 0.5%Y (e), 1.0%Mn (f), 2.0%Mn (g), 0.1%Er (h), 0.3%Er (i) and SE micrograph of the alloy with 0.5%B (c) obtained by deep etch

The addition of 1.0%Mn can significantly improve the liquidity while the addition of 2.0%Mn makes little change. In Fig.6f and 6g, there is hardly any dendrite in the matrix, which is reasonable for the improvement in liquidity. Based on Kainuma et al[20], Mn is β stabilizer element which equates to two times the effect of Nb. The addition of Mn could extend β phase field to higher Al direction and thus promote Ti46Al8Nb into β solidification instead of peritectic transformation which may cause columnar crystal and thus texture[21], and they are both harmful to liquidity. In Table 3, quite a liquidus and solidus temperature difference between Ti46Al8Nb and Ti46Al8Nb2Mn is exhibited, which reveals that the crystallization temperature interval becomes much narrower because of the addition of 2.0%Mn. It is expected that 2.0%Mn would greatly improve the liquidity. In contrary with the efficiency of 1.0%Mn, addition of 2.0%Mn shows slight improvement in liquidity, and it seems paradoxical considering the efficiency of Mn in promoting Ti46Al8Nb into β solidification. Maybe the addition of 2.0%Mn changes the latent heat, and more studies are needed to elucidate the Mn effect.

Er can rarely improve the filling property. In this case, Er_2O_3 particles are observed in both Ti46Al8Nb0.1Er and Ti46Al8Nb0.3Er alloys (as shown in Fig.6h and Fig.6i); meanwhile refined dendrites and grain size are also observed. Therefore the addition of rare earth element Er could increase the alloy liquidity by refining dendrites and grain size. In Fig.6i, many Er_2O_3 particles (e.g. the arrowed area) located in the shrinkage cavities are observed, and some Er_2O_3 particles are hardly to be engulfed but are pushed forward. This would cause great flow resistance during solidification. In consequence, additions of 0.1%Er and 0.3%Er reveal little improvement in the liquidity of Ti46Al8Nb alloy.

4 Conclusions

1) The addition of trace elements B, Y, Mn and Er could produce a certain degree of improvement in melt filling property of Ti46Al8Nb based alloy.

2) The addition of 0.2%Y, 0.5%Y and 1.0%Mn can signifi-

cantly improve the Ti46Al8Nb alloy in filling property. 0.5Y% and 1.0 Mn% addition increase the filling ratio by 54.5% and 48.5%, respectively. The effect of 0.10%Er, 0.5%B and 1.0%B addition on the mould filing capacity of the alloy is not remarkable with the filling ratio increased by 3.0%, 4.5% and 5.3%, respectively.

3) Oxide inclusions are great resistance to filling property in Ti46Al8Nb alloy, and refined dendrites and grain size is conducive to liquidity.

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合金元素对 Ti46Al8Nb 合金充型性能的影响

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摘　要：采用网状式样法制备包埋料型壳，对比研究了 B、Y、Mn 和 Er 等微合金元素对 Ti-46Al-8Nb 合金熔体铸造充型性能的影响。研究结果表明：添加微量元素 B、Y、Mn、Er 等均会对 Ti-46Al-8Nb 合金熔体铸造充型性能产生一定程度的改善作用。其中，0.5%Y 和 1%Mn 改善作用十分明显，其加入使充填率分别增加了 54.5%和 48.5%。0.1%Er、0.5%B 和 1.0%B 对该合金充型性能的改善作用较为一般，其加入使充填率分别增加了 3.0%、4.5%和 5.3%。

关键词：合金元素；高 Nb-TiAl；充型性能

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