WATER-COOLING CRUCIBLE VACUUM INDUCTION MELTING OF γ-TiAl BASED ALLOYS①

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ABSTRACT Water-cooling crucible vacuum induction melting is a good method for melting reactive alloys, the molten metal prepared has a homogenous composition, temperature and degree of superheating. The melting procedure of the γ-TiAl based alloys melted with water-cooling crucible vacuum induction melting furnace was studied and the results showed that the non-uniform composition in the skull determined by the forming processing of the skull and the evaporation of alloying elements with higher vapor pressure results in a composition difference between nominal and analyzing composition. There would be a sedimentation of large density alloying element in the molten metal because of density difference. The problem above mentioned can be solved by controlling the melting parameters and applying master alloy.

Key words γ-TiAl cold crucible induction melting skull

1 INTRODUCTION

The γ-TiAl based alloys as a new generation of high temperature structure material has been studied profoundly[1-3]. The components made of γ-TiAl based alloys have been produced by Germany, America and Japan[4-6]. For getting this kind of structural material, many processes could be selected, anyway, the melting technique is necessary and has an important effect on its properties[7-9]. The melting methods for titanium and titanium aluminides and such kind of reactive alloys include arc furnace, electron beam furnace, plasma furnace and induction skull melting and so on. Induction skull melting with a cold crucible originated from induction-slag melting technique and it combined the advantage of induction melting and cold crucible melting with no pollution resulted from the reaction between the aluminium vapored from the molten metal and the calcium fluoride. This method has many advantages, for instance, having homogenous composition and excellent high temperature property, the degree of superheating is controllable[10, 11]. In this paper the process of melting γ-TiAl based alloys by cold crucible vacuum induction melting furnace was studied.

2 EXPERIMENTAL PROCEDURE

The main melting equipment is a water-cooling copper crucible vacuum induction melting furnace shown as Fig. 1. The containment of the crucible was 1300 cm^3. The charges were sponge titanium, high pure aluminium, chromium and niobium; all the charges were mixtured together and compressed to a cylinder, then were put into crucible. Before the melting power being turned on, the chamber was evacuated and washed by argon. The melting parameters such as vacuum degree, melting power, temperature of molten metal and cooling water out from crucible were recorded automatically.

In the experiment, Ti-34Al and Ti-48Al-2Cr-2Nb (mole fraction) were melted, the molten metal were superheated and then casted in a permanent mold, a skull remained in cru-

① Project supported by the Science Foundation of National Education Committee of China for Outstanding Young Teachers
Recieved Mar. 31, 1997; accepted Jun. 16, 1997

cible after casting. The compositions of the wall and bottom of the skull and along the direction of axial and radial of the ingot was analyzed.

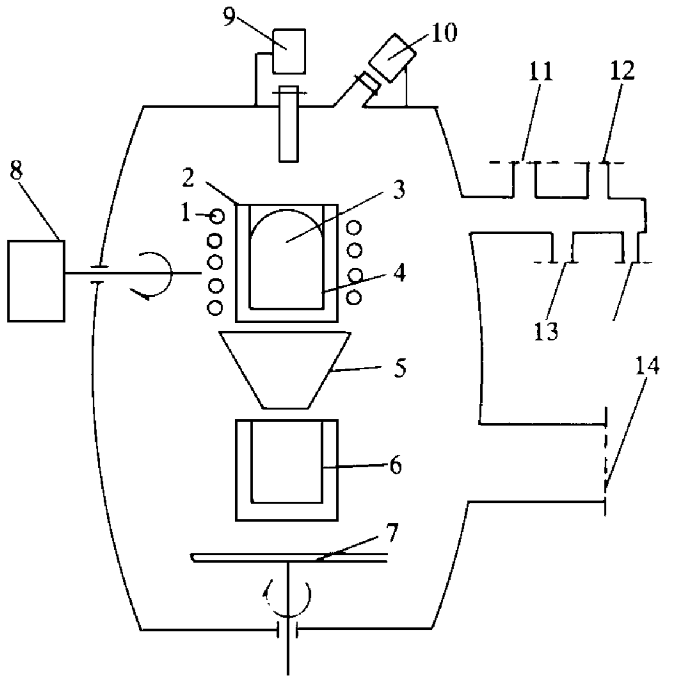

Fig. 1 A schematic diagram of water-cooling crucible vacuum melting furnace

1 —Induction coil; 2 —Water-cooling copper crucible; 3 —Molten metal; 4 —Skull; 5 —Running channel; 6 —Permanent mold; 7 —Centrifugal pouring dish; 8 —Tilting facility; 9 —Optical pyrometer; 10 —Pick-up camera; 11 —Inlet of inert gas; 12 —Inlet of air; 13 —Vacuum-meter interface; 14 —Attachment for connecting vacuum pump system

3 RESULTS AND DISCUSSION

3.1 The melting of Ti-34Al

The masses of the skull, ingot and runner are 0.658 kg, 2.440 kg and 0.428 kg, respectively, and the masses of the wall and bottom of the skull are 0.350 kg, a net 0.308 kg respectively. The aluminium content in ingot is illustrated in Fig. 2s, among different points in the ingot there exist a little difference that means the aluminium distribution is basically homogeneous in the molten metal but the terminal Al-content is lower than nominal Al-content; on the contrary, the aluminum contents of the wall and bottom of the skull are 31.03% Al and 34.66% Al, respectively, which means the aluminium content in the skull is not homogenous, i.e. in the wall of the skull the aluminium content is the highest and in the bottom of that the aluminium content is the lowest.

In spite of the above facts, it is necessary to assume that the molten metal composition is homogeneous, the wall and the bottom of the skull have the same composition, in order to calculate the mean composition of all sections as 33.00% Al, which is lower than the nominal composition.

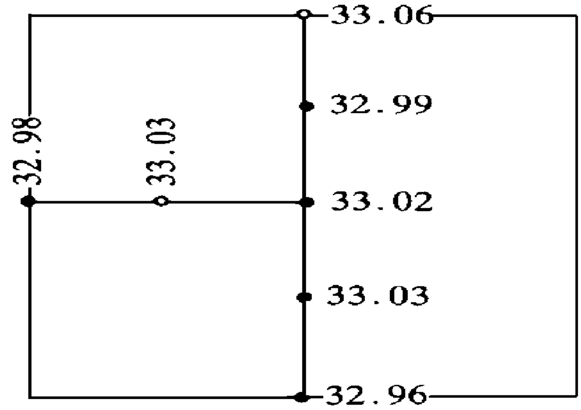

Fig. 2 Distribution of Al in ingot of Ti-34%Al

3.1.1 Skull formation process

Cold crucible method is a valid technology for melting reactive alloys. There is a skull formed from molten metal between crucible and molten metal. It is the skull protects the molten metal from pollution. The crucible used in induction melting is different from other ones used in VAR and EB furnace and so on. Not only the structure is different but also there is a stirring effect.

When the charge is compact ingot, the melting process of the charge is easier. In this experiment the charge are sponge titanium and pieces of aluminium. In an induction condition, titanium is easy to be heated up than aluminium. The difference of the theoretical melting point between titanium and aluminium is 1000 ℃, but the actual temperature difference between titanium and aluminium during induction heating is not larger than 1 000 ℃ due to the high heat conductivity, so the aluminium melted firstly.

According to the simulation of fluid field of the molten metal during induction melting[12], the melted aluminium will flow toward the crucible wall and be solidified, then the inner charge be melted. The formation process of the skull is a dynamic equilibrium, as the melting power increasing, the thickness of the skull decreased and the skull scaled off from crucible under pushing force of electromagnetic field and remelted. The remelted molten metal was pushed to the wall of the crucible under the weight of the molten metal and solidified again. This processing recycled with increase of melting power. The pushing force increased with the increase of melting power and the molten metal can not contact the wall near the slits of the crucible and kept the slits on the skull as shown in Fig. 3(a).

3.1.2 Variation of composition

Chemical analysis showed that the aluminium content of the ingot is lower than the nominal value. There are two possible reasons, one is that the distribution of aluminium in the skull is not homogeneous, as above mentioned, the average content of aluminium in the skull is higher than that resulted from a lower aluminium content in the molten metal, the other is the evaporation of alloying element with higher vapor pressure.

3.2 The melting of Ti-48Al-2Cr-2Nb

3.2.1 Melting from pure element

All the alloying elements weighted according to the nominal composition of Ti-48Al-2Cr-2Nb were put into the crucible and melted after evacuating and washing the melting chamber. The molten metal was casted into a permanent mold after superheating. There are many particles with tips and rectangular pieces on the bottom of the skull, which are Cr and Nb confirmed by chemical analysis. Only small part of the Cr and Nb soluted in the molten metal.

It is known from the experiment of melting TiAl alloy and Ti-6Al-4V alloy when the alloy containing aluminium under vacuum was melted, the vacuum degree and the temperature of the molten metal should not be too higher to minimize the evaporating aluminium. So a small melting power was adopted in this experiment, at which the TiAl binary alloy can be melted.

In the mixture of Ti-Al-Cr-Nb, the reaction between titanium and aluminium reduced the melting point of titanium, and the melting point of Ti-48% Al (mole fraction) is only about 1450 ℃. So the titanium in the mixture dissolved below the titanium melting point. But at this temperature Cr and Nb could not dissolve in the TiAl molten metal. They did not react with titanium just as aluminium did. The dissolution depended on diffusion which needs a longer time to get balance.

As the melting power increased, the temperature of the molten metal increased and the dissolvability of Cr and Nb increased, but the viscosity of the molten metal decreased with increasing the temperature of the molten metal. So the Cr and Nb with a higher density moved toward the bottom, the Cr and Nb is more difficult to be dissolved when they attached to the bottom where is the coldest section of the crucible. Then the ingot and skull was remelted and a larger

Fig. 3 Morphology of skull of Ti-34%Al
(a) —Wall; (b) —Bottom

melting power and a long superheating time was used, after casting, there were particles of Cr and Nb also, but the size had been minimized. At the same time, much aluminium vaporized from the molten metal and polluted the melting chamber.

3.2.2 Melting from master alloy

From the above experiments it can be seen that Cr and Nb can be dissolved in TiAl molten metal by increasing the melting power and superheating time, but the evaporation of aluminium increased due to higher temperature and longer superheating time of the molten metal.

According to the binary phase diagram of Ti-Cr and Ti-Nb, the melting point decreased in the order of Nb and Cr and Ti. Ti-Cr and Ti-Nb can dissolve each other over the liquidus and no compounds difficultly melted will form. When Cr content lower than 50% (mole fraction), the liquidus decreased with the increase of Cr content, but the liquidus of Ti-Nb increased abruptly with the increase of Nb content. If the mixture of Ti, Cr and Nb being induction melted, the melting power and superheating time can be increased to accelerate the dissolution of Cr and Nb in the molten metal and there do not exist a serious evaporation.

Table 1 Composition of Ti-48Al-2Cr-2Nb melted (%)

Element	Nominal content	Measured content
Al	33.34	33.40
Cr	2.68	2.87
Nb	4.78	4.74
Ti	balance	balance

Based on the analyses above, preparing the master alloy of Ti-Cr-Nb is a possible method to solve the problem of the evaporation of aluminium. The master alloy should contain minimum Nb and maximum Ti to lower its melting point, so the composition was designed to be Ti-3.85Cr-3.85Nb (mole fraction). Only adding some alluminium into the master alloy the Ti-48Al-2Cr-2Nb can be obtained.

4 CONCLUSIONS

(1) The composition of the molten metal melted by the induction furnace is homogeneous.

(2) The composition of the skull getting from melting pure elements is not homogeneous which makes it difficult to fulfilling the nominal composition.

(3) The evaporation of aluminium in the TiAl molten metal melted under vacuum is a major factor for the composition variation.

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(Edited by Huang Jinsong)