Study of Interfacial Reaction between TiAl Alloys and Four Ceramic Molds

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Abstract: With the aid of SEM and DTA, the microstructures at metal side of interface between Ti48Al2Cr2Nb alloy and Y_2O_3, ZrO_2 (Y_2O_3 stabilized), ZrO_2 (MgO stabilized), and Zircon sand were investigated, respectively. The initial reaction temperatures were measured for Ti48Al2Cr2Nb alloy and Y_2O_3, ZrO_2 (Y_2O_3 stabilized), ZrO_2 (MgO stabilized), respectively. The results show that the microstructure is the coarsest with rosettes-like shape after Ti48Al2Cr2Nb alloy reacts with Zircon sand, and even the smallest with granular-like shape after Ti48Al2Cr2Nb alloy reacts with Y_2O_3. The order of the initial reaction temperatures between Ti48Al2Cr2Nb alloy and four oxide ceramic materials is non-reaction at 1500, 1400, 1380, and 820 ℃, respectively.

Key words: DTA; interfacial reaction; ceramic; TiAl alloy

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TiAl based alloys are potential high-temperature structural materials and find a wide range of applications such as aeronautical, aerospace, marine, and automotive industries, owing to their low density, high specific strength, excellent corrosion and creep resistance, and appropriate high temperature properties[1~3]. A lot of manufacturing processes have been successfully developed for utilization of these alloys[4~8]. Among these processes, investment casting is the optimal process because of its low cost, mass-production and high efficiency, in which the most extensive use is oxide ceramic mold. But molten titanium alloys will react with the ceramic mold to form casting defects such as α contaminated layer in the metal near the surface[9,10] and gas porosity[11~13], resulting in the deterioration of castings mechanical properties. Therefore, the main problem of the investment casting is how to increase reaction temperature and control the chemical reaction between titanium alloy melt and molding materials.

In this paper, with the aid of scanning electron microscope (SEM) and Differential Thermal Analysis (DTA), the initial reaction temperature and microstructure at metal side of interface between Ti48Al2Cr2Nb alloy and Y_2O_3, ZrO_2 (Y_2O_3 stabilized), ZrO_2 (MgO stabilized), and Zircon sand were researched, respectively.

1 Experimental

The four types of ceramic powders for the tests were Y_2O_3, yttria partially stabilized ZrO_2 [ZrO_2 (Y_2O_3 stabilized)], magnesia partially stabilized ZrO_2 [ZrO_2 (MgO stabilized)], and Zircon sand. First, the ceramic powders were pressed into U-type crucibles with Φ10 mm×5 mm in inner diameter and Φ20 mm×10 mm in outer diameter at 60 t universal material testing machine. Then the U-type crucibles were sintered at 1600 ℃ for 2 h in the SXK-8-16 high-temperature vacuum electric resistance furnace. Four rectangular Ti48Al2Cr2Nb alloy samples with 5 mm in height and 8 mm in length were prepared and placed in the four U-type ceramics crucibles, respectively to be heated in the furnace. The heating temperature was 1520 ℃, and the heating rate was 20 ℃/min. Ti48Al2Cr2Nb alloy samples were allowed to solidify and cooled to room temperature in the U-type crucible in order to simulate the worst practical situation with respect to the interaction between metal and crucible. Ti48Al2Cr2Nb alloy samples for characterization were separated from the ceramic crucibles. The interface of Ti48Al2Cr2Nb alloy and ceramic crucible was observed using SEM.

The above four ceramic powders were mixed

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individually with Ti48Al2Cr2Nb powder in certain ratio, and pressed into precast blocks with 20 mm in diameter and 10 mm in height. The precast blocks were machined into DTA cylindrical samples with 3 mm in diameter and 6 mm in height. The DTA test was carried out in thermal analyzer. The heating rate was 10 ℃/min.

2 Results and Discussion

2.1 Microstructures

Fig.1 shows the SEM micrographs of Ti48Al2Cr2Nb alloy at the interface after interaction. As shown in Fig. 1a, the microstructures after interaction between Ti48Al2Cr2Nb alloy melt and Zircon sand are composed of the granular structure merged together and the rosette -like structure formed by granular growing. It indicates that the chemical reactions take place preferentially at these zones meeting the conditions of composition and energy fluctuations. In Fig.1b, the reaction product between Ti48Al2Cr2Nb alloy melt and ZrO_2 (MgO stabilized) is nearly globular granular with about 5 μm in diameter. Although some nearly globular granulars reach 20 μm in diameter due to non-uniform chemical reaction at interface, the microstructures in Fig.1b are more uniform and finer compared to those in Fig.1a. In Fig.1c and 1d, the microstructures after interaction between Ti48Al2Cr2Nb and Y_2O_3, and ZrO_2 (Y_2O_3 stabilized) are formed by accumulating of fine and uniform granular. But the granular in Fig.1c is coarser than that in Fig.1d, and some grains have merged together in dark zone. From the above four systems, it can be noted that the interaction product is the coarsest and the chemical reaction is also the most intensive for the Ti48Al2Cr2N-Zircon sand system, but for the Ti48Al2Cr2N-Y_2O_3 system, the interaction product is the finest with about 1 μm in diameter.

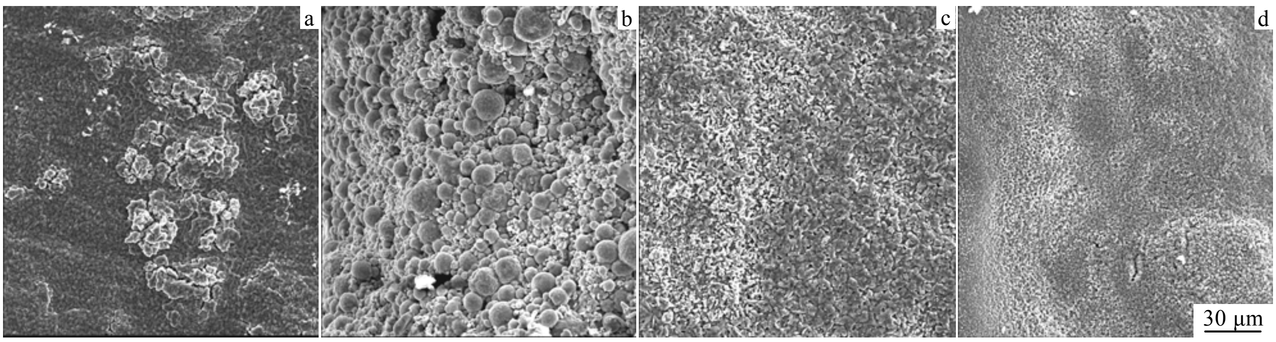

Fig.1 SEM morphology of Ti48Al2Cr2Nb-ceamics reaction interface: (a) Ti48Al2Cr2Nb/Zircon sand, (b) Ti48Al2Cr2Nb/ZrO_2 (MgO stabilized), (c) Ti48Al2Cr2Nb/ZrO_2 (Y_2O_3 stabilized), and (d) Ti48Al2Cr2Nb/Y_2O_3

2.2 DTA curves

The extent of chemical reaction can be measured by means of reaction heating effect between Ti48Al2Cr2Nb alloys and ceramic materials, that is to say, the more intensive the chemical reaction, the more the exothermal quantity. In previous studies, the sessile drop was the most extensive method used to investigate the micro-structure, the phase composition and the element distribution at metal side of interface after interaction between metal and ceramic materials. However, because the contact area between Ti48Al2Cr2Nb alloy and ceramic substrate is too small to measure exactly reaction heat, the interfacial reaction process can not be obtained truly.

In this paper, by means of DTA, the reaction heat between Ti48Al2Cr2Nb alloys and molding materials is measured through mixing uniformly alloy powder with ceramic powder. As both alloy and molding materials are the powder mixes, the contact area increases greatly, resulting in more complete chemical reaction and higher reaction heat. Thus, the reaction kinetics process between Ti48Al2Cr2Nb alloys and four ceramic materials can be obtained exactly, such as the initial temperature.

Fig.2 presents the DTA curves between Ti48Al2Cr2Nb alloys and four oxide ceramic materials. As shown in Fig.2a, there is a high exothermic peak at 890 ℃ from 800 ℃ to 1100 ℃. This is because Zircon sand contains a lot of SiO_2, which is instabile against Ti48Al2Cr2Nb at high temperature. Ti in Ti48Al2Cr2Nb alloy can be reduced into TiO or TiO_2 by SiO_2 so as to intensify the interfacial reaction. Some small irregular endothermic and exothermic peaks occurring before 500 ℃ appear due to the decomposition and volatilization of organic substance in Ti48Al2Cr2Nb/Zircon sand system.

From Fig.2b, it can be seen that in Ti48Al2Cr2Nb/ZrO_2 (MgO stabilized) system, there is an exothermic reaction at 1380 ℃. This is because in vacuum, when MgO contacts with Ti48Al2Cr2Nb alloy melt, it partially decomposes into element Mg and active O. The element Mg enters the furnace chamber in the form of gas, which provides a favorable condition for metal elements of Ti48Al2Cr2Nb alloy melt combining with active O. Meanwhile, the above combination in turn accelerates the decomposition process of MgO. Compared to Fig.2a, the initial reaction temperature elevates 600 ℃, and the area of exothermic peak reduces obviously. This indicates that ZrO_2 (MgO stabilized) is more stable than Zircon sand against Ti48Al2Cr2Nb alloy melt.

In Fig.2c, the DTA curve shows that the stability of ZrO_2 (Y_2O_3 stabilized) against Ti48Al2Cr2Nb alloy is also better at high temperature. Only after 1400 ℃, the DTA curve rises rapidly. This indicates that the chemical reaction between Ti and ZrO_2 takes place and an exothermic peak appears. However, the exothermic peak is unable to be measured because the maximum operation temperature of the thermal analyzer is 1500 ℃. Compared to Fig.2b, the initial reaction temperature in Fig.2c increases by about 70 ℃. This is reason that compared to MgO, the stability of Y_2O_3 at high temperature against ZrO_2 is better, resulting in increasing the initial reaction temperature between Ti and ZrO_2.

Fig.2d shows the DTA curve of Ti48Al2Cr2Nb/Y_2O_3 system. It can be seen that the change of the curve is flat without endothermic or exothermic peak. This indicates that compared to the above three molding materials, thermodynamic stability of Y_2O_3 against Ti48Al2Cr2Nb alloy is the best at high temperature. But in the process of practical pouring, Y_2O_3 reacts with Ti48Al2Cr2Nb alloy due to the high activity of Ti.

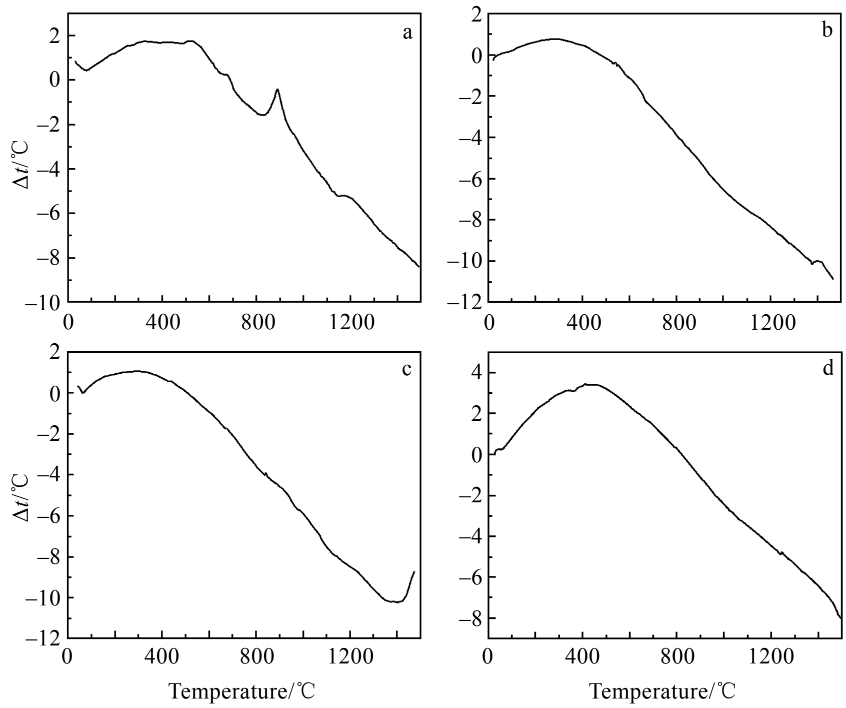

Fig.2 DTA curves of Ti48Al2Cr2Nb/ceramics system: (a) Ti48Al2Cr2Nb/Zircon sand, (b) Ti48Al2Cr2Nb/ZrO_2 (MgO stabilized), (c) Ti48Al2Cr2Nb/ZrO_2 (Y_2O_3 stabilized), and (d) Ti48Al2Cr2Nb/Y_2O_3

In summary, the initial reaction temperatures for Zircon sand, ZrO_2(MgO stabilized), ZrO_2(Y_2O_3 stabilized), Y_2O_3 against Ti48Al2Cr2Nb alloy increase sequentially. This is in agreement with the thermodynamic stability of the above four molding materials and the microstructures at metal side of interface between Ti48Al2Cr2Nb alloy and four molding materials at 1500 ℃. The higher the initial reaction temperature, the finer the microstructure at the metal side of the interface. For the four molding materials, the initial reaction temperature of the Zircon sand/Ti48Al2Cr2Nb system is the lowest. Zircon sand will react intensively with Ti at 890 ℃, which is unsuited to be used as molding material. The initial reaction temperature of other three ceramic materials against Ti48Al2Cr2Nb alloys are greater than 1380 ℃, and their thermodynamic stability at the high temperature is better. They are all able to be used as molding materials. Although the high-temperature stability of Y_2O_3 is the best among them, it is expensive. Therefore, the ratio of performance to cost for ZrO_2 (Y_2O_3 stabilized) is the highest.

Compared to the practical pouring process, the heating rate of DTA tests is slower, and the heating time is longer so that the initial reaction temperatures are measured under the near reaction equilibrium condition. Therefore, the initial reaction temperatures measured in this paper can be used to practical production.

3 Conclusions

1) The initial reaction temperature between Ti48Al2Cr2Nb alloy and Y_2O_3, ZrO_2 (Y_2O_3 stabilized), ZrO_2 (MgO stabilized), and Zircon sand is non-reaction at 1500, 1400, 1380, and 820 ℃, respectively.

2) The reactions between Ti48Al2Cr2Nb alloys and Y_2O_3, ZrO_2(Y_2O_3 stabilized) take place, resulting in forming the structures with finer and uniform granular. The microstructure of the reactants of Ti48Al2Cr2Nb alloy with ZrO_2 (MgO stabilized) presents non-uniform globular, with 5~20 μm in particle size. The interfacial reaction between Ti48Al2Cr2Nb alloy and Zircon sand is the most intensive, and the reaction products possess coarse rosette structures.

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钛铝基合金与 4 种陶瓷界面反应的研究

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摘 要：借助 SEM 和差热分析(DTA)，研究了 Ti48Al2Cr2Nb 合金与 Y_2O_3、ZrO_2(Y_2O_3稳定)、ZrO_2(MgO 稳定)和锆英砂 4 种陶瓷耐火材料界面反应后金属侧的显微组织，并测定了 Ti48Al2Cr2Nb 合金与 Y_2O_3、ZrO_2(Y_2O_3稳定)、ZrO_2(MgO 稳定)和锆英砂 4 种陶瓷耐火材料的初始反应温度。结果表明，Ti48Al2Cr2Nb 合金与锆英砂反应后的显微组织最粗大，为菊花状，而与 Y_2O_3 反应产物最细小均匀，为颗粒状；4 种陶瓷材料对 Ti48Al2Cr2Nb 合金的初始反应温度依次为：1500，1400，1380 和 820 ℃。

关键词：差热分析；界面反应；陶瓷；钛铝基合金

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