Ceramics International xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Short communication

Effects of Ta_2O_5 on mechanical properties and elements diffusion of Ti/Al_2O_3 composites prepared via hot pressing sintering

Hanqing Xu[a], Liu Zhang[a], Zhi Wang[a,*], Junyan Wu[a,*], Fan Yang[b]

[a] School of Material Science and Engineering, University of Jinan, Jinan 250022, China
[b] ShanDong Guangxin Engineering Testing Group Co.,Ltd,, Jinan 250022, China

ARTICLE INFO

Keywords:
Ti/Al_2O_3
Ta_2O_5
Mechanical properties
Elements diffusion
Hot pressing sintering

ABSTRACT

Homogeneous Ti/Al_2O_3 composites with different volume percentages of Ta_2O_5 addition were prepared at different temperatures via hot pressing sintering. Laminated Ti/Al_2O_3 composites with different volume percentages of Ta_2O_5 added were prepared. The effects of Ta_2O_5 on the composition, microstructure, mechanical properties and elements diffusion of the composites were characterized and investigated. Ta_2O_5 inhibited the production of TiAl and Ti_3Al by forming solid solution with Ti or new reaction product of Al. This solid solution melted and filled the void of Al_2O_3 phase to increase the density of Ti/Al_2O_3 composites at high temperature. Mechanical properties had also been improved by this phenomenon. Because Al element couldn't diffuse in Ta or react with it, Al couldn't diffuse through the Ta-enriched area at the interface of Ti and Al_2O_3.

1. Introduction

With the progress of science and technology, a single material of ceramic or metal can't meet the demand in some fields [1]. Therefore, cermets are worked out to solve the problem for they may exhibit the excellent performances of both a ceramic, such as high hardness, high temperature resistance and wear resistance, and those of a metal, such as the well toughness and plasticity [2]. Cermets are composed by ceramic phase and metal (alloy) phase in which ceramic hard phase is defined as matrix and metal (alloy) is design to be the binder phase [3]. So far, oxide-based [4,5], nitride-based [6,7], carbide-based [8,9], boride-based [10] and silicide-based [11] cermets have been researched and used as high temperature bearings, cutting tools, sealing rings and components of aero-engines [12–14].

In order to improve the mechanical properties of Al_2O_3, some metals, such as Al, Cu and Ni, are chosen to fabricate Al_2O_3 based cermets by the preparation techniques of gas pressure assisted infiltration, gas pressure assisted infiltration and high-pressure torsion [15,16]. Although the mechanical properties of the cermets have been improved to some extent, the new problems appeared. Firstly, because of the low melting point of Cu and Al, traditional sintering methods, such as hot pressed sintering or pressureless sintering, can't be used to prepare the composites. When the samples are heated at the sintering temperature of alumina (It may be more than 1300 °C), the metals will melt. Secondly, the above preparation methods are too complicated. They are not suitable to be used to prepare the products with irregular shapes in industrial production.

Ti/Al_2O_3 composites, which can be prepared by traditional sintering methods, are proposed by some researchers to solve the above problems. In Ti/Al_2O_3 composite, the brittle Ti-Al intermetallic compounds of TiAl and Ti_3Al generated in the sintering process would reduce mechanical properties of the cermet [17]. It was because that when applied by an external force, the brittle phases might fracture in the samples easily. Researchers tried to mitigate the negative impact of the brittle reaction products by adding some additives, such as Ni [18], NiCr [19], CeO_2, Y_2O_3 and Pr_6O_{11} [20]. These additives obviously decreased the content of TiAl and Ti_3Al by reacting with Ti or Al_2O_3. And some of them, such as CeO_2 and Y_2O_3, could generate eutectic phase to accelerate the sintering and reduce the sintering temperature of Ti/Al_2O_3 cermets [21,22].

In the previous studies, rare-earth oxides were used to promote the sintering of Ti/Al_2O_3 composites and inhibit the production of Ti-Al intermetallic compounds for they were the sintering additives of Al_2O_3. However, we noted that Ti was not easy to be well sintered in the experiment. In the present study, homogeneous and laminated Ti/Al_2O_3 composites with different volume percentages of Ta_2O_5 are prepared by vacuum hot pressing sintering. Homogeneous samples are used to research the effects of Ta_2O_5 on the microstructure, mechanical properties and sintering process of Ti/Al_2O_3 composites. Laminated samples are used to study the element diffusion in the interface of Ti and Al_2O_3 by the influence of Ta_2O_5. Samples are analyzed by X-ray diffraction analysis (XRD), scanning electron

* Corresponding authors.
E-mail addresses: wangzhi@ujn.edu.cn (Z. Wang), wujy8509@163.com (J. Wu).

http://dx.doi.org/10.1016/j.ceramint.2017.03.003
Received 19 February 2017; Received in revised form 28 February 2017; Accepted 1 March 2017

Table 1
The different volume percentages of Ta_2O_5 for each composition.

Sample	Al_2O_3 (vol%)	Ti (vol%)	Ta_2O_5 (vol%)
C0	60	40	0
C1	59	40	1
C2	58	40	2
C3	57	40	3
C4	55	40	5
C5	53	40	7
C6	50	40	10

microscopy (SEM), energy dispersive spectrometer (EDS) and electron probe X-ray microanalysis (EPMA). We are trying to find a material to be the additive of Ti or both of Ti and Al_2O_3 which can promote the sintering Ti/Al_2O_3 composites at relatively low temperatures and pressures.

2. Materials and experimental methods

Powders of α-Al_2O_3 (average particle size: 1.5 μm, purity: 99.8%), Ti (average particle size: 2 μm, purity: 99.9%) and Ta_2O_5 (average particle size: 0.8 μm, purity: 99.8%) were used as the starting materials. In this study, two kinds of samples, including seven kinds of homogeneous composites (used to analyze the composition, microstructure and mechanical properties of Ti/Al_2O_3 composites) and two kinds of laminated composites(used to analyze the diffusion of different elements of Ti/Al_2O_3 composites), were prepared. Table 1 presented the different volume ratio of Al_2O_3, Ti and Ta_2O_5 of homogeneous composites. The mixed powders were ball milled in alcohol at a speed of 150 rpm for 4 h with Al_2O_3 balls and dried at 60 °C. Every proportion of the mixture was sintered at different temperatures (1300 °C, 1350 °C, 1400 °C and 1450 °C) under an applied pressure of 30 MPa for 1.5 h via hot pressing sintering, respectively. Samples were taken out when they were cooled naturally to room temperature and processed into bars with a size of 3 mm×4 mm ×35 mm. The structure of laminated Ti/Al_2O_3 composites and the content of Al_2O_3, Ti and Ta_2O_5 were shown in Fig. 1. As mentioned above, the mixed powders of Al_2O_3 and Ta_2O_5 were ball milled and dried. The mixed powders and pure Ti powder were pressed into sheets in a 45 mm diameter steel mold under an uniaxial pressure of 30 MPa, respectively. Laminated Ti/Al_2O_3 composites were sintered at 1450 °C under 30 MPa for 1.5 h via hot pressing sintering.

Phase compositions were recorded by X-ray diffraction (XRD, D8 Advance, Bruker Corporation) with Cu Kα (λ¼1.5406 Å) radiation at a scanning rate of 5°/min with a range from 10° to 80°. Microstructures of the samples were observed under scanning electron microscope (SEM, S4800, Hitachi) along with energy dispersive spectra analysis (EDS). Element distributions of laminated Ti/Al_2O_3 composites were evaluated by electron probe X-ray microanalysis (EPMA, EPMA-1600, Shimadzu). Relative density of the prepared composites was measured by Archimedes immersion method in distilled water. The theoretical density of the samples was calculated with respect to the volume percentage and the density of Ti, Al_2O_3 and Ta_2O_5. Micro hardness was tested by a Vickers micro-hardness tester (HV-1000IS, SIOMM). The flexural strength and fracture toughness were measured by an electromechanical universal testing machine (CMT5504, MTS systems).

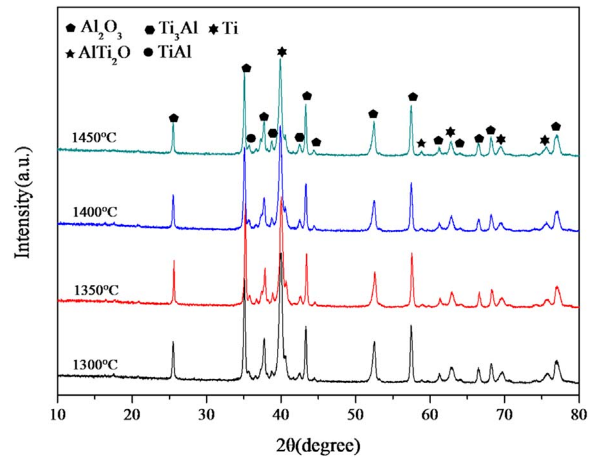

Fig. 2. XRD patterns of blank samples sintered at different temperatures.

3. Results and discussion

3.1. Phase composition

Fig. 2 shows the XRD patterns of the samples without Ta_2O_5 addition at different temperatures. The brittle phases of TiAl and Ti_3Al can be detected in all of the samples without Ta_2O_5 addition. According to others' conclusion, generating TiAl and Ti_3Al by interfacial reaction is the main interface bonding type of Ti and Al_2O_3 in Ti/Al_2O_3 composites [23]. The diffraction peaks of TiAl or Ti_3Al in these samples have no significant differences. It illustrates that the degrees of interfacial reaction are similar in the four samples. In other words, the contents of TiAl or Ti_3Al are similar in them. In this case, sintering temperature is not the critical factor affecting the interfacial reaction of Ti and Al_2O_3 in blank samples.

XRD analysis results of the samples with different volume percentages of Ta_2O_5 prepared at 1400 °C are shown in Fig. 3(a). Compared with the blank sample, diffraction peaks of TiAl and Ti_3Al show a gradual weakening trend with the addition of Ta_2O_5 from 1 vol% to 3 vol%. When the content of Ta_2O_5 reaches 5 vol%, TiAl and Ti_3Al are difficult to be detected. With the further addition, when the content Ta_2O_5 goes up to 10%, some new phases, such as $AlTa_2$ and TiO_2 can be noticed. From the magnified view (Fig. 3(b)) of the peaks of Ti at about 40° in Fig. 3(a), it is can be observed that the diffraction peak of Ti is

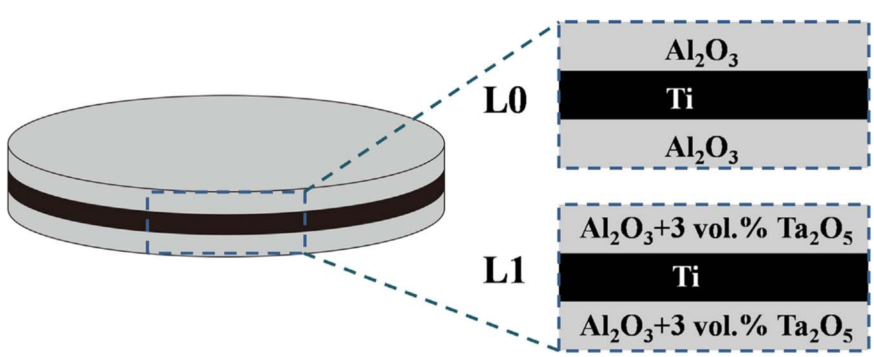

Fig. 1. Structure of laminated Ti/Al_2O_3 composites and the compositions of each samples.