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Structure and morphology of Ti-Al composite powders treated by mechanical alloying

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Abstract: The evolution in microstructure and composition of the milled Ti-Al composite powder with different milling time were investigated. It shows that with the milling time increasing, the initial powder underwent a successive change in its morphology from a flattened shape (2 h) to a fine, equiaxed and uniform one (above 6 h). The milled Ti-Al composite powder was nanocrystalline with the average crystallite size of about 17 nm after milling for 8 h. The evolution mechanism of Ti-Al composite powder was elucidated. The Ti(Al) solid solution is formed through a gradual and progressive solution of Al into Ti lattice. By differential thermal analysis on the ignition temperature of the reaction between Ti and Al as a function of milling time, it indicates that mechanical milling of the powders significantly lowered the ignition temperature of the reaction by refining its Ti-Al composite structure.

Key words: TiAl; composite powder; mechanical milling

1 Introduction

TiAl-based alloys are important engineering materials with a great potential to replace nickel-based superalloys and titanium alloys applied in aerospace and automotive due to their high specific strength and stiffness, high strength retention at high temperature and high creep resistance at temperatures up to 800 °C [1−3]. At present, TiAl alloys have been gradually put into practical application such as exhaust valves, and the turbine superchargers used in automobile engine [4−5], and the turbine blades able to endure about 150 MPa stress at elevated temperatures [6]. However, the poor ductility at an ambient temperature and the low strength at an elevated temperature of TiAl alloy were significant limitations in broadening their practical application [7]. The ductility of TiAl intermetallic based alloys at room temperature can be improved by refining the microstructures of the alloys in terms of volume fraction of the α_2-Ti_3Al phase, and the structure and size of the lamellar colonies through heat treatment and composition modification [8]. It has also been demonstrated that an effective way of improving the formability and ductility of the material is refining near-gamma grains and/or the lamellar colonies [9−10].

Mechanical alloying (MA) at low temperature, as a non-equilibrium and solid-state powder processing technique, involves repeating, fracturing, cold-welding and re-welding of powder particles in a high-energy ball milling. Studies indicated that MA is capable of synthesizing a variety of equilibrium and non-equilibrium alloy phases, including supersaturated solid solutions, metastable crystalline phases, amorphous alloys and nanostructures [11]. MA is a feasible method for preparing in-situ particle reinforced composite powder [12−13]. Nevertheless, MA is a complex process and hence involves a large degree of uncertainty in obtaining desired phases and microstructures. Research efforts are still required so as to study the evolution of microstructure and property of the processed powder during ball milling.

2 Experimental

Ti powders (average particle size above 20 μm, 99.5% of molar fraction and Al powders 99.9% of molar fraction, average particle size about 25 μm) were used as experimentally raw materials. Powders above and stearic acid (1%, mass fraction) served as a process control agent were mixed homogenously by a planetary mill with stainless steel balls (6 and 10 mm in diameter) under argon (Ar) atmosphere. The milling time was 2, 4, 6 and 8 h at the speed of 400 r/min, respectively. The

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ratio of stainless steel ball to mixed powder was 20:1. The result of X-ray fluorescence spectroscopy shows that the contamination by Fe, Cr, and Mn from the milling tools was less than 0.2% (molar fraction) after 8 h milling.

Scanning electron microscopy (SEM, Hitachi S4000) was carried out to characterize the morphology of the milled powder. The structure of the as-milled powders was studied by X-ray diffraction (XRD) (Philips X-Pert system with Cu K_{α} radiation and a graphite monochromator). The sample holder was filled inside the glove box, covered with mylar film and put into a plastic box to protect the sample from atmospheric oxygen and moisture during transportation. The diffraction patterns were analyzed using the MDI Jade 5.0. Differential thermal analysis (DTA) was also conducted to study the transformation of reaction temperature during heating. The sample was placed in Al_2O_3 pans and heated to 800 °C at a rate of 20 °C/min in dynamic argon atmosphere.

3 Results and discussion

3.1 Microstructure characterization

The morphology and microstructure of the milled powders evolved for different milling time in the case of a high-energy ball milling (400 r/min) are illustrated in Figs. 1(a)−(d). The particle size distribution of powders becomes more homogeneous as ball milling was continued. The size of composite particles was smaller than 10 μm after 6 h ball milling. It was found that aluminum powders were refined first and emerged in irregular shapes and various sizes. However, titanium particles were mainly oval-shaped, as shown in Fig. 1(a). Figure 1(b) indicates the mixture particles became more equiaxed as high-energy ball milling proceeded. In the mean time, no deformation was observed yet. Cold welding and plastic deformation of the composite powder, essentially mixed by means of solid-state diffusion between titanium and aluminum atoms, were observed after milling for more than 6 h. The result above is also presented by Fig. 1(c) and Fig. 1(d), that is, only titanium particles enforced virtually by the insertion of the small aluminum particles were sufficiently plastically deformed and a layered structure and Ti-Al mixture were produced. The titanium particles which did not sink deeply enough within aluminum particles were little deformed and still presented a pure titanium core. Increasing the milling time to 8 h leads to flatten both

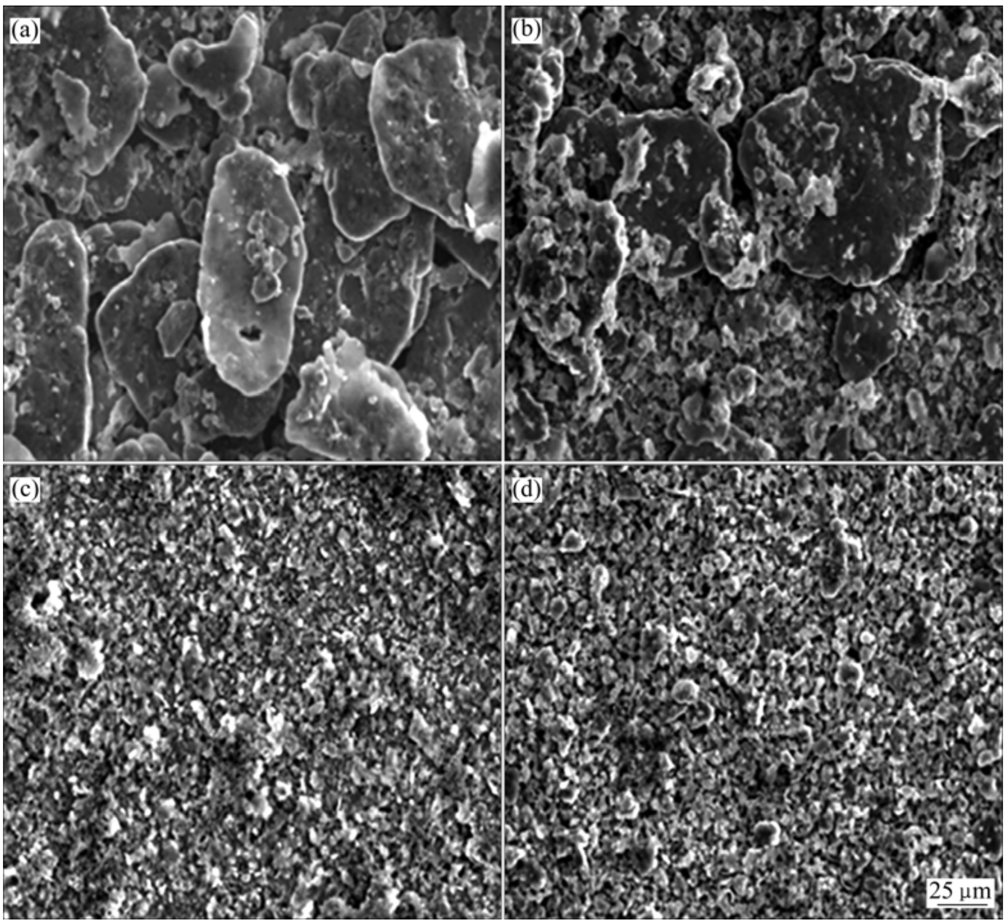

Fig. 1 SEM images of Ti-Al composite powders with different milling time: (a) 2 h; (b) 4 h; (c) 6 h; (d) 8 h