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Original Research Paper

A study on the mechanochemical behavior of TiO_2–Al–Si system to produce Ti_5Si_3–Al_2O_3 nanocomposite

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ABSTRACT

In the present study Ti_5Si_3–Al_2O_3 nanocomposite was synthesized by a displacement reaction between Al and TiO_2 in ball milling of TiO_2, Al and Si powders. The effect of milling time and heat treatment temperatures were also investigated. The structural changes of powder particles during mechanical alloying were investigated by X-ray diffraction (XRD). Morphology and microstructure of powders were characterized by scanning electron microscopy (SEM). It was found that after 10 h of MA, the reaction between Al and TiO_2 initiated in a gradual mode and after about 45 h of milling, the reaction was successfully completed. The final product consisted of Ti_5Si_3 intermetallic compound with a crystallite size of 13 nm and amorphous Al_2O_3. Heat treatment of this structure at 1050 °C led to the crystallization of Al_2O_3 and ordering of Ti_5Si_3. The crystallite size of Ti_5Si_3 and Al_2O_3 after annealing at 1050 °C for 1 h remained in nanometer scale. So the final product appeared to be stable upon annealing.

1. Introduction

Intermetallic compounds have been the focus of significant research and development efforts during the last years. In fact, the high temperature structural application associated with aerospace and other industries has led to the growth of requests for high temperature structural materials. Refractory metal silicides of the 5:3 compounds like Ti_5Si_3, Zr_5Si_3 and Nb_5Si_3 have attracted much interest in few years as high temperature structural materials [1]. Among them monolithic Ti_5Si_3 has a mixture of covalent bonding, metallic bonding and ionic bonding which result in high temperature melting point (2403 K) and low density (4.32 g/cm^3) [2]. The high temperature strength, creep resistance, oxidation resistance and wear resistance of Ti_5Si_3 has cited this material as a good candidate for the above applications [3,4]. However, despite its attractive features, its application is limited by two major obstacles: unsuitable ductility and toughness at ambient temperature [5] and relatively poor oxidation resistance in temperatures above 850 °C [6]. It should be noted that the unsuitable ductility of this compound is related to low symmetry ($D8_8$) in crystal structure, and highly covalent bonding that increase the peierls stress. It has been shown that the synthesis of nanostructured materials has been successful in increasing ductility in some intermetallics [7,8]. On the other hand, for optimization of room temperature toughness and high temperature strength microstructural modifications are required. For these reasons it has been recognized that intermetallic matrix composites (IMCs) may be appropriate materials for structural applications, replacing in some cases intermetallics [9]. In the last few years a number of Ti_5Si_3 based composites have been synthesized by different investigators. Mitra [10] reported that alloying of Ti_5Si_3 with 8 wt.% Al formed uniformly dispersion Al_2O_3 in the matrix. Jianlin [11] reported the microstructural and mechanical properties of Ti_5Si_3–TiC nanocomposite using a reaction hot pressing process. Also Shon et al. [12] fabricated Ti_5Si_3–20vol.% ZrO_2 composite by reaction sintering. In all of these experiments, noticeable improvement in room temperature toughness was observed.

Several techniques such as self-propagating high temperature synthesis (SHS) [13], reactive hot press [11] and mechanical alloying (MA) [14] have also been used to produce a wide range of intermetallic matrix composites. Among these methods MA is well known for synthesis of compounds and nanocomposites using the mechanochemical reactions. The mechanosynthesis process has a number of advantages over the conventional material processing techniques. It enables the reduction of metal oxides and halides directly to pure metals or alloys. Furthermore, MA can enhance the kinetics of reactions and so the reactions could take place at room temperature [15]. It also causes microstructural refinements and suitable reinforcement distribution in the matrix.

It is reported that Al_2O_3 is a good reinforcement candidate in the IMCs. In fact desirable properties of alumina such as low density, high specific strength and high modulus can provide stiff ceramic inclusion introduced into an intermetallic matrix such as

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