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Fabrication and characterization of reactive Ni–Ti–C powder by mechanical alloying

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ABSTRACT

Reactive powder was prepared by mechanical alloying of a mixture of Ni, Ti and C elemental powders using a high energy planetary ball mill. Two MA methods were investigated and the effect of these routes together with the milling intensity was studies. Powders were characterized using X-ray diffractometery (XRD) and scanning electron microscopy (SEM). The thermal stability of reactive powders was investigated by differential scanning calorimetery (DSC). Results show that, by the selection of appropriate conditions, a metastable Ni–Ti–C powder with the nominal composition Ni–32 wt.%Ti–8 wt.%C could be obtained. This metastable powder was capable of in situ synthesis of Ni–TiC composite during exposure to high temperatures and can be applied in reactive sintering methods.

1. Introduction

TiC possesses a series of excellent properties such as high melting temperature (3200 °C), high hardness (3200 HV), low density (4.95 g cm^{-3}), high mechanical stiffness, high young modulus, good corrosion and erosion resistance [1]. On this account different metallic matrix coatings reinforced with TiC hard particles have been widely investigated. As one of the most promising materials, Ni matrix composites are well known for their various properties such as an excellent thermal stability and excellent corrosion and wear resistance [2]. The addition of TiC particles to the nickel matrix can remarkably improve the properties of the alloy and consequently the TiC-reinforced Ni-based composites are potential materials with high wear resistance for many practical applications [3,4].

TiC particles are commonly incorporated into the Ni matrix via casting or powder metallurgical processes. The main problems of these methods are agglomeration and inhomogeneous distribution of TiC particles in the matrix. In order to overcome these limitations in situ processes have recently received much attention because of their interesting characteristics [5]. By the in situ formation of metal matrix composites (MMCs), a more homogenous microstructure can be achieved. Moreover, the reinforcements made by in situ reactions show a clean interface between reinforcing particles and the matrix and small size of particles resulting in better mechanical properties [6–8]. For an in situ process to take place, an exothermic reaction is needed to form the reinforcement. It is also essential for the reinforcement to be thermodynamically stable in the matrix. Among all the in situ reinforcements for Nickel, WC, TiB_2, and TiC have been most widely used [9].

A variety of processing techniques have been developed for in situ production of MMCs during the past decade. Traditionally, in situ MMCs such as Ni–TiC composites have been produced by several processing routes such as self-propagating high temperature synthesis (SHS), various casting techniques, i.e., reactive squeeze casting, reactive hot pressing (RHP) and mechanical alloying (MA) [10,11]. MA is a solid state powder processing method which involves repeated cold welding and fracture of particles as a result of the high energy ball-sample collisions. It is shown that by this process some reactions, which are difficult to occur under conventional conditions, can be induced [12]. MA technique has been extensively used to fabricate in situ ceramic particle reinforced MMCs [13,14].

The formation of the TiC phase, i.e. the Ti + C = TiC reaction, is thermodynamically advantageous due to $\Delta G_{298} = -180.84$ kJ mol^{-1} [15], and its diffusion kinetics can be accelerated by the formation of point defects, dislocations and the fine lamellar structure induced by MA [5]. In situ formation of TiC during MA has been investigated in a few researches [16,17]. The reactive consolidation of Ni–Ti–C powder to synthesize Ni–TiC during HVOF thermal spraying has been also reported in a previous study [18].

It has been shown previously that in a system like Al–Ti–B a high Al content in the initial mixture reduced the direct contact of Ti and B elements during MA by lengthening the diffusion distance and as a result prevented the reaction between Ti and B in the mixture. In order to overcome this problem, a double step

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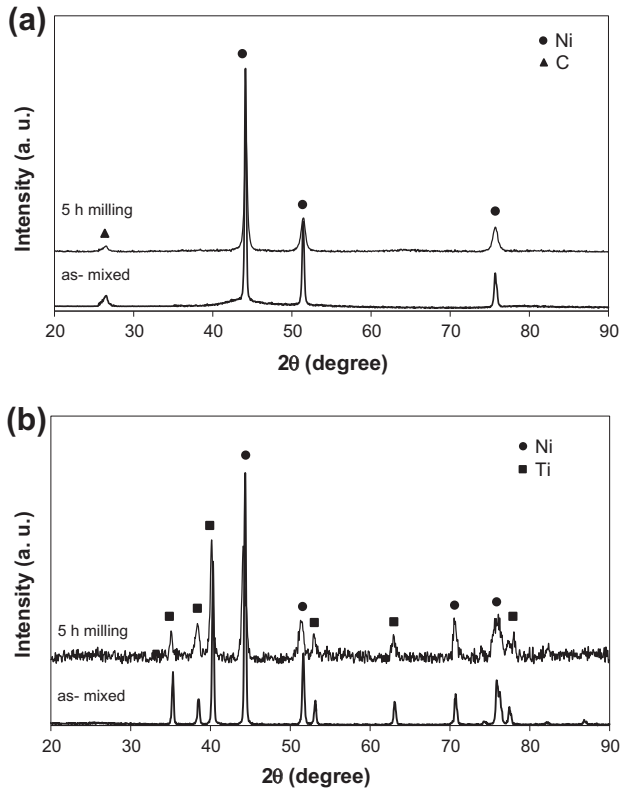

Fig. 1. XRD patterns of powder mixtures after 5 h of MA in the first step of 400 rpm double step approach, (a) Ni–C, and (b) Ni–Ti.

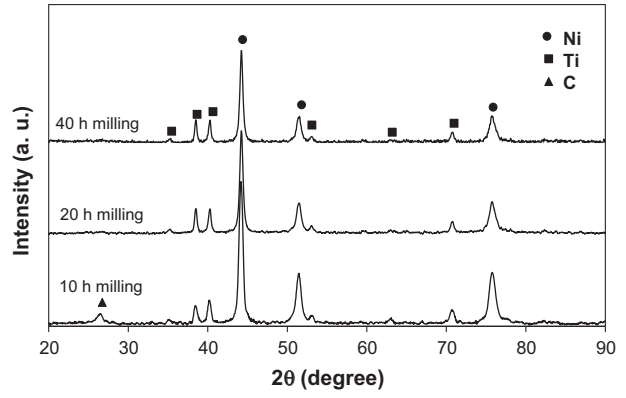

Fig. 2. XRD patterns of the powder after different times of MA at the second stage of 400 rpm double stage MA (mentioned times are total MA times).

MA was proposed [19]. In the present study single and double step routes have been applied to obtain reactive Ni–Ti–C powder by MA (in which TiC did not form) and the effect of these routes on the microstructure of resultant powders has been investigated. Fabrication of reactive powder by MA process shortens the powder processing time and can be considered as a more economic alternative to produce in situ nanocomposite. This reactive powder can be consolidated by high temperature processes to fabricate in situ Ni–TiC composite.

2. Materials and methods

Commercially available Ni (Merck, 99%, <20 μm), Ti (Sigma–Aldrich, 99.9%, 40–60 μm), and C (Merck, 99%, <50 μm) powders were used as starting materials. Stoichiometric ratio of Ni–40 wt.%TiC was considered for the preparation of powder mixtures. Powder mixtures were milled by a planetary ball mill similar to Pulverisette 5 Fritsch, made by Sepahan equipment company, Iran. The ball to powder weight ratio was chosen to be 10:1 and the diameter of the chromium steel balls was 15 mm. The hardened chromium steel vial was evacuated and filled with pure

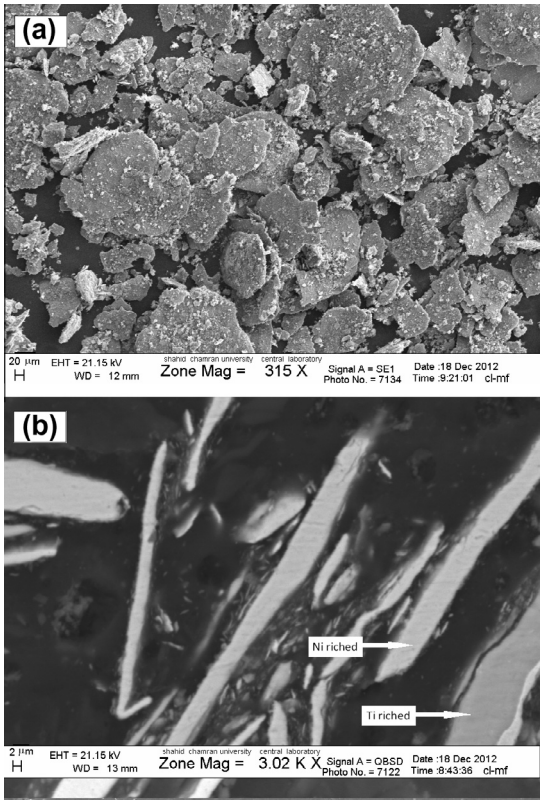

Fig. 3. SEM micrographs of the powder obtained from double step mechanical alloying with 400 rpm after a total MA time of 40 h, (a) morphology and (b) cross-section of the powder.

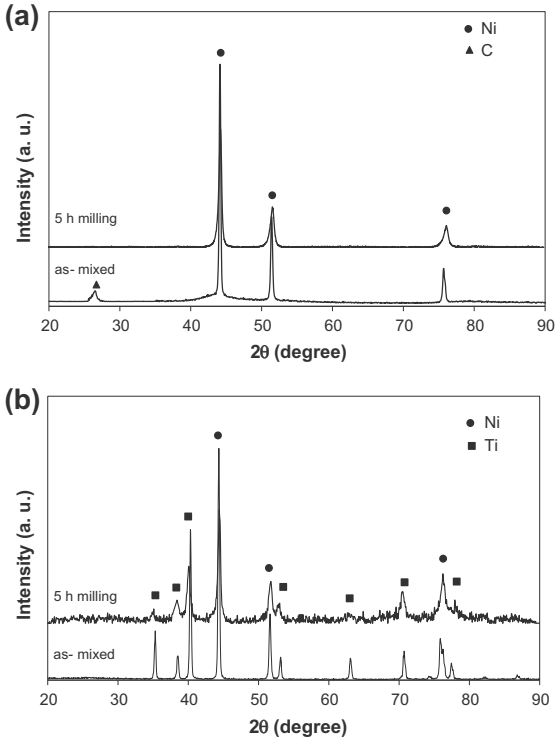

Fig. 4. XRD patterns of powder mixtures after 5 h of MA in the first step of 600 rpm double step approach, (a) Ni–C, and (b) Ni–Ti.