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Pressure un-assisted reactive powder processing of high-density aluminide composites

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Abstract

The combustion synthesis of aluminide intermetallic composites has been extensively studied during the past three decades. A major problem in the combustion synthesis of intermetallic composites has been poor density and poor homogeneity of the final product. This has resulted in the need for the application of pressure to densify the product in addition to high temperature heat treatments to homogenize it. This paper discusses a new strategy for elemental green compact design that promotes considerably improved densities of combustion synthesized nickel aluminide–titanium carbide composites (at 20 vol.% TiC loading) without the application of external pressures. The paper covers ball milling studies, compaction behavior and the effect of elemental powder/green compact microstructural design on the porosity, phase content, microstructure and hardness of the combustion synthesized product. Product porosities as low as 1.4% have been produced using this new design compared to 25% using conventional means of powder processing prior to combustion synthesis, this has also contributed to a greater than five times improvement in hardness of the resulting product.

Keywords: Combustion synthesis; Intermetallic composites; Nickel aluminide; Titanium carbide; Ball milling

1. Introduction

Combustion synthesis is a low-energy process that has been used to produce intermetallics, ceramics and composites from powder compacts at relatively low processing temperatures and in very short processing times [1,2]. In the combustion synthesis of nickel aluminides under the thermal explosion mode of ignition, the powder compact is uniformly heated to a temperature above the ignition temperature (~640 °C). Following ignition, the compact reacts throughout its volume converting the nickel (Ni) and aluminum (Al) into the desired nickel aluminide intermetallic depending on initial composition. The reaction is exothermic so the compact is raised to very high temperatures that can sometimes equal/exceed the melting point of the intermetallic being formed. Products are usually porous, this has lead one of the authors to apply bulk deformation processes (extrusion/forging) simultaneously while the specimen is hot to generate consolidated materials [3,4]. One of the prerequisites for successful reactive processing using combustion synthesis is that molten aluminum (the low melting point phase) should be able to efficiently spread throughout the compact, and effectively surround the nickel particles. The process has also been termed reactive transient liquid phase sintering [5]. The addition of ceramic reinforcements (e.g. titanium carbide (TiC)) to the 3Ni + Al mixture has a number of detrimental effects [6]. First, the spreading of Al will be restricted by the presence of TiC. Second, TiC will act as a heat sink and thus the maximum attainable temperature achieved during the reaction (i.e. the combustion temperature) will be reduced. Both of these effects will lead to an increase in product porosity and in-homogeneity with an increase in volume fraction of TiC reinforcement. Recently, Yeh et al. reported a decrease in product density with increase in TiC content for combustion synthesized NiAl–TiC composites [7]. The detrimental effect that ceramic reinforcements have on the product porosity and homogeneity has lead a number of researchers to simply apply pressure during or immediately after the reaction, in order to generate high-density products and also use high temperatures to homogenizes the microstructure when reinforcing the intermetallic with a ceramic phase [8–11]. In this paper we introduce

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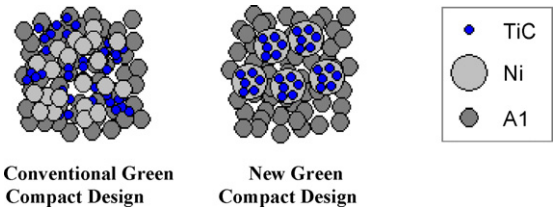

Fig. 1. Conventional and proposed microstructural designs of composite green compact prior to combustion synthesis.

a new microstructural design of the green compact that basically removes the ceramic reinforcement from the path of molten Al to allow more efficient spreading, resulting in high product densities without the need for an externally applied pressure. Fig. 1 is a schematic of the new and conventional compact design. The TiC is embedded in the high temperature phase (Ni) through the process of ball milling, which can also have the effect of introducing lattice defects that can improve diffusion characteristics during the reaction. The effect of this new design on the Vickers hardness of the final product is also discussed.

2. Experimental procedures

Commercially pure Ni (5–10 μm), Al (8–11 μm), and TiC (2 μm) powders (Atlantic Equipment Engineers, NJ, USA), were used as the starting materials (all particle sizes are manufacturer quoted values). Micrographs of the powders are shown in Fig. 2.

The composition of the powder mixture was chosen to give a final product of Ni_3Al with 20 vol.% TiC after complete conversion.

The Ni and TiC powders were first rotator mixed for 1.5 h then ball-milled for 10 h (interrupted runs) in a SPEX 8000 mixer under an argon atmosphere. WC-Co balls were used as the milling media. The ball-to-powder weight ratio used was 4:1. This process was conducted to embed/disperse the TiC into the nickel powders. The milled Ni–TiC composite powders were then gently rotator mixed for 1.5 h with the remaining Al making up the balance. The elemental powders at this stage are referred to as composition A. Prior to ball milling, all powders were vacuum degassed at 120 °C for 10 h. This is important so as not to trap/embed any moisture or low-boiling point impurities with the TiC or Ni into the new composite particles, which would evaporate and expand during the reaction and cause unwanted porosity. Green specimens used or the combustion synthesis experiments were produced by pressing the powders in a die with diameter of 8 mm, and height ~3 mm (to a relative density of 70–75%). The specimens were then combustion synthesized in a tube furnace under argon atmosphere by heating at 10 °C/min to a temperature of 700 °C and dwelling for 15 min followed by cooling. For comparison Ni, Al and TiC were rotator-mixed for 1.5 h compacted and combustion synthesized under exactly the same

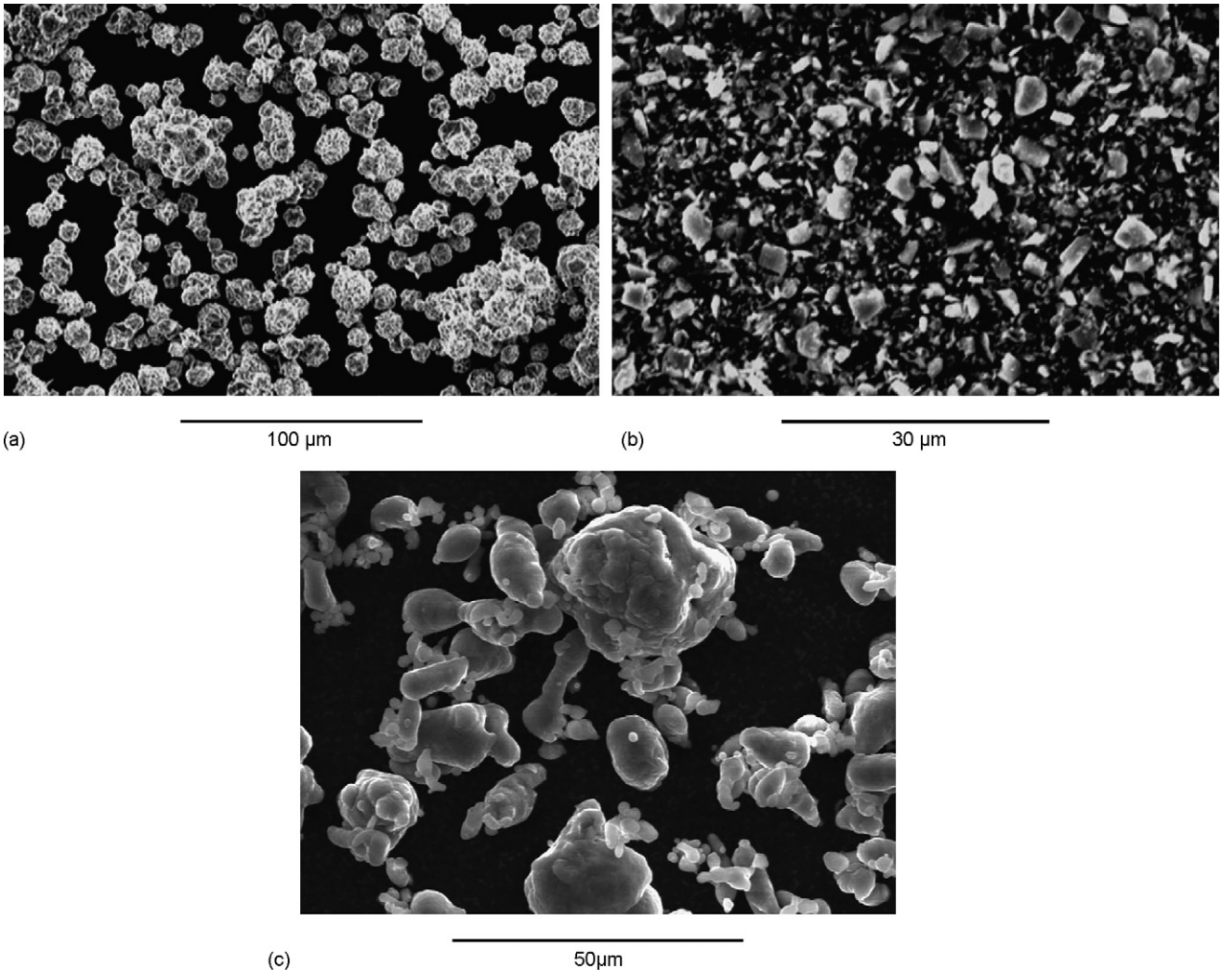

Fig. 2. (a) SEM image of initial Ni powders. (b) SEM image of initial TiC powders. (c) SEM image of initial Al powders.