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Synthesis and improved explosion behaviors of aluminum powders coated with nano-sized nickel film

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ABSTRACT

Nickel (Ni) materials with a thickness of a few hundred nm were homogeneously coated on the surfaces of aluminum (Al) powders by an electroless plating process. The Ni-coated Al powders show characteristic interfacial structures mixed of Ni, Al and O instead of densely packed Al oxide at the surface. The explosion test of the Ni-coated Al powders utilizing flame ignition showed that the powders had a 3.6 times enhanced pressurization rate of 405 kPa/ms compared to 111 kPa/ms of uncoated Al powders. It was found that this is due to a feasible diffusion of oxygen atoms into the Al powders through the thin and rough interfacial layers present at the Ni/Al interface. These results clearly indicate that nano-sized Ni film introduced instead of surface oxide acts as a very profitable layer to achieve efficient combustion behaviors by a rapid oxidation of Al powders.

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1. Introduction

Pure aluminum (Al) has attracted much attention regarding the use of energetic materials (EMs) due to its highly reactive oxidation behaviors and superior explosive properties when oxygen atoms are supplied from an external circumstance [1]. In general, EMs utilizing Al powders is applicable in military and civil applications, including solid propellants, missile fuel, water-welding materials, and air-bag systems [1,2]. However, in these applications, there is an important key issue to control surface-oxide of Al powders which is too dense to react with oxygen atoms. That is, since the natural oxide layers of Al powders become hard and closely packed as time or temperature increases, it is not easy to achieve further oxidation-reaction at low temperature [3].

Such surface oxides of Al powders should be minimized for more practical applications. Actually, it has been known that the surface oxides can be removed via melting by high temperature exceeding 2000 K or chemically dissolved in acidic or basic solvent [3,4]. However, as Al powders without an oxide layer are known to be very reactive and simultaneously unstable, surface-passivation treatments [5–9] are necessarily required to avoid the explosive phenomena abruptly generated by its oxidation.

Of various types of candidate materials for surface passivation, nickel (Ni) has been considered as one of the promising materials due to its wettability with Al and expected self-propagating heat synthetic (SHS) reaction during heating and combustion processes [8–12]. Many researchers have reported Ni-mixed or coated Al powders with a few mm in diameters created by physical vapor deposition such as sputtering [12]. Fundamental model experiments have been conducted to understand diffusion mechanism acting between Ni and Al [12,13]. These studies and developments have provided important information for utilizing Ni coating for energetic Al powders. However, there have been little detailed results and approaches to remove or decrease surface oxide when Ni layer is simultaneously coated. And the variation of the microstructures around the thin Ni shell used instead of surface oxide of Al powders has rarely been investigated for energetic applications.

Therefore, in this study, coating of Ni-film with homogeneous thickness on the surface of Al powders was carried out by using an electro-less plating method minimizing surface oxide [14]. The interfacial microstructures between Ni and Al were characterized and a combustion test of both Al and Ni-coated Al powders by using a flame ignition was performed to clarify the role of coated Ni thin film on the combustion process of Al powders.

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2. Experiment details

2.1. Materials and methods

The pure Al powders used in this study were synthesized by means of a gas-atomization method. They are spherical in shape with an average diameter of 25 μm . In order to synthesize Ni nanoshell onto the Al powder surface, an electroless plating process was utilized [14] in a pH-controlled chemical solution. The natural oxide layer present on the surface of the Al powders was removed using a NaOH solution based on a Pourbaix diagram showing the potential of the Al and H_2O system as a function of the pH. Nickel sulfate ($\text{Ni}(\text{SO}_4)_3$) salt was then added to the solution. Once the nickel salt is ionized in the solution, the ionized Ni is directly coated onto the pure Al surface, which peeled off surface oxide, due to the difference between the Ni and the Al in terms of the chemical reduction potential at temperature below 363 K. The synthesized Ni-coated Al powders in the solution were filtered onto filtration paper and dried in a vacuum at 10^{-2} torr for 12 h.

2.2. Characterization

The cross-sectional microstructure of the Ni-coated Al powders was characterized using scanning electronic microscopy (SEM, JEOL, JSM-5800). The heating rate was 5 Kmin^{-1} . For the Ni-coated

Al powders, the interfacial structure was investigated and an elemental analysis of the distribution of the Ni, Al and O atoms was conducted with energy-dispersive X-ray spectroscopy (EDS) using field emission transmission electron microscopy (FE-TEM, JEM-ARM200F). The phases of the Ni/Al powders and Al powders with a heat treatment were analyzed using an X-ray Diffractometer (XRD, D/Max-2500VL/PC, Rigaku International Co.).

The pressure cell test (PCT) of the Ni-coated Al and pure Al powders was conducted by means of the flame ignition method in the closed chamber system of an air atmosphere [16]. The flame was generated by the tip of a tungsten wire which was heated by a controlled DC current. The formed flame ignited both powder samples and the change in the pressure generated by the vigorous oxidation process was measured as a function of time in the closed chamber. In order to more clearly compare the capability of rapid oxidation behaviors, the concept of pressurization rate is introduced but also the same amount of Al in both powders is utilized [15]. The velocity of change in the pressure is converted into the pressurization rate (kPa/ms) which is calculated by Eq. (1) below.

$$\text{Pressurization rate} = \frac{P_{\text{max}} - P_i}{t_{\text{max}} - t_i} \quad (1)$$

Here, P_{max} is the maximum pressure, P_i is the pressure when the ignition process begins, t_{max} is the time until the pressure reaches its maximum value, and t_i is the ignition time or the ignition delay time.

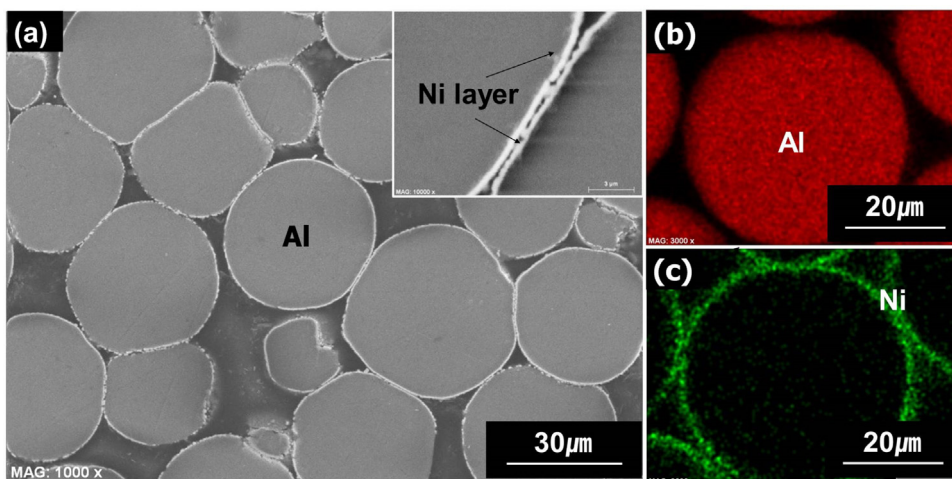


Fig. 1. (a) Cross-sectional SEM image of Ni-coated powders: the enlarged inset photo clearly shows the Ni-coated layer, and the EDS results show (b) the distribution of the Al phase, and of (c) the Ni phase.

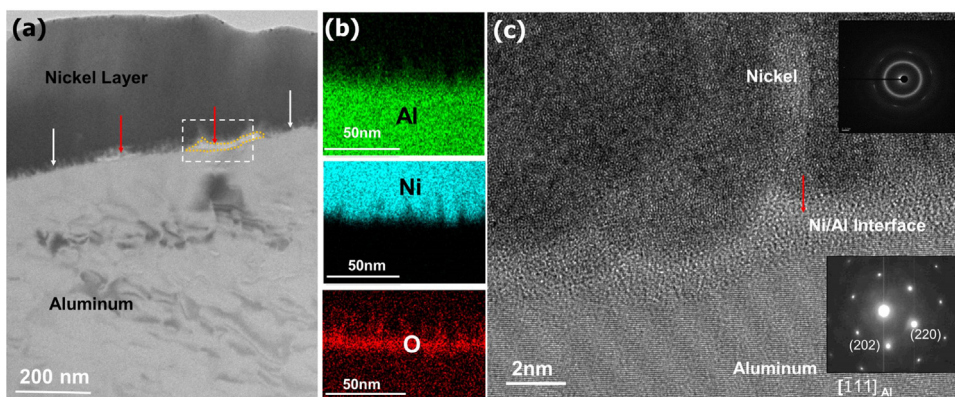


Fig. 2. (a) Cross-sectional TEM image of Ni-coated powders and (b) EDS results showing THE distributions of Al, Ni and O atoms, as indicated by the box with the white-dotted line, (c) a high resolution TEM image of Ni-coated Al powders with inset photos showing the SAED pattern of the Ni and Al phases. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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