A New Method for the Production of Alloy Nanoparticles by Electrical Wire Explosion

Wonbaek Kim¹, Je-shin Park¹, Chang-yul Suh¹, Jae-chun Lee¹,
Junghwan Kim² and Yong-Jun Oh²

¹Minerals and Materials Processing Division, Korea Institute of Geoscience and Mineral Resources,
30 Gajeong-dong, Yuseong-gu, Daejeon 305-350, Korea

²Department of Advanced Materials Engineering, Hanbit National University,
San 16-1 Duckmyoung-dong, Yuseong-gu, Daejeon 305-719, Korea

The electrical wire explosion has been quite successful in the production of nanoparticles of various pure metals. However, the method failed to extend to the realm of alloys and intermetallics due in part to the unavailability of corresponding wires. In this paper, a new solution for this problem is suggested which utilizes electroplated wires instead. It is demonstrated that the explosion of Cu-plated Ni wire produce single phase CuNi alloy nanoparticles. The method is believed to have a potential to enable the synthesis of wide variety of alloy and intermetallic nanoparticles conveniently. [doi:10.2320/matertrans.MEP2007100]

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1. Introduction

The electrical wire explosion (EWE) has been considered as a practical method to produce nano-sized particles of pure metals.¹⁻⁴⁾ However, the method was not very successful to produce alloys and intermetallic compounds. Previously, two methods have been suggested to produce alloy nanoparticles. One is using pre-alloyed wires and the other is the simultaneous explosion of two or more wires. Explosion of alloy wires have been observed to produce nanoparticles of corresponding alloy. The method, however, has the obvious limitation relying on the availability of alloy or intermetallic wires. Thus, the method could be applied for alloy systems as Cu-Zn, Ni-Ti, Cu-Ni the wire of which are available in the market.⁵⁻⁷⁾ When wires of different metals are exploded simultaneously, mixtures of their metals and compounds are produced. Kotov⁸⁾ reported that the simultaneous explosion of Al and Fe wires produced their metals along with alloys of various composition. Here, we introduce a third method in which wires coated with different metals were exploded to yield alloy nanoparticles. We have chosen the CuNi system because it is a typical binary system of mutual solubility without intermetallic phases which might complicate the evaluation of the proposed method. The Cu/Ni couple was prepared by the electrodeposition of Cu on Ni wire.

2. Experimental Procedure

The wire for explosion was prepared by the electrodeposition of Cu on 0.2 mm ϕ Ni wire. The copper plating solution consisted of 0.78 mol/l of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and 0.3 mol/l of H_2SO_4 . The anode was pure Cu plate and electro deposition was conducted at constant voltage. To insure uniform thickness of the Cu layer, a motor-driven pulling system was made as shown in Fig. 1. Ni wire was pulled at controlled speed through the Cu plating bath in which the anode was located at the equal distance from the wire. The thickness of the deposit can be adjusted by the pulling speed

Fig. 1 Schematic of the continuous electroplating set up.

and applied voltage. After the deposition, the thickness of the wire was measured. The diameter of Cu-plated Ni (Ni-Cu) wire after deposition was 0.303 mm. Assuming a complete reaction between Cu deposit and Ni wire, the average composition of the Ni-Cu wire corresponds to 45.5 at% Ni.

The Ni-Cu wire was then loaded to the wire-explosion chamber. The explosion was conducted at argon pressure of 2 atm and a pulse voltage of 28 kV was applied to 8-cm long Ni-Cu wire. Each explosion was repeated every 2 sec. The on-time duration was 150 μs . The production rate was about 15 grams per hour. The produced particles were analyzed by Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and X-ray Diffraction (XRD) with Cu K_{α} radiation. The composition was measured by EDS attached in SEM and TEM.

3. Results and Discussion

Cu-Ni is the typical binary alloy of complete mutual solubility. Figure 2 shows the X-ray diffraction pattern of exploded particles. The pattern shows that they are solid solution as indexed by (111) (200) (220) peaks. Besides, NiO peaks are also seen. The lattice parameter calculated from the peaks was 3.5670 $\text{\AA}$ which corresponds to 47 at% Ni.⁹⁾ The average composition of particles measured by EDS in SEM was 53 at% Ni.

Figure 3 shows a TEM micrograph of CuNi nanoparticles. It shows that the particles are mostly spherical with some twins. The geometric mean diameter of the particles was 47.3 nm with geometric standard deviation of 1.48.

Fig. 2 X-ray diffraction pattern of the explosion products of Cu-plated Ni wire.

Fig. 3 TEM micrograph of CuNi alloy nanoparticles produced by electrical explosion of Cu-plated Ni wire.

The composition of individual nanoparticle was rather broad. Figure 4 shows the composition of 13 nanoparticles. It scatters between 40–60 at% Ni around the average value of 48.6 at% Ni. We could not find any relationship between the size and composition of the particle within the limited

Fig. 4 Composition of CuNi nanoparticles measured by EDS in TEM.

number of data. The average composition measured by either SEM or TEM was slightly higher in Ni content than the calculated value. One of the reason may be that the amount of Cu deposit is slightly less than calculated due to the surface roughness of Cu deposit.

The work is interesting since the suggested method obviously has a potential to enable the synthesis of variety of alloys and intermetallics conveniently. Moreover, the composition of the alloy might be controlled simply by the relative thickness of 2nd metal. It would be interesting to apply the method to a system where one of the metal has high vapor pressure as Cu-Zn. Obviously, more work should be conducted to elucidate the alloying mechanism of coated wire to produce alloys in more controlled manner.

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