Preparation of nano-Al powder with wire electric explosion

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Abstract. Nano-Al powder was prepared by wire electric explosion of different diameter aluminium wires. The results show that nano-Al powder particles appear spherical and agglomerate together, the surface was covered by Al$_2$O$_3$ layer. The particle size of nano-Al powder obey normal distribution and the average particle size increases with the increasing of wire diameter.

1. Introduction
Many preparation method of nano metal powder developed rapidly in the past decades that makes the diameter of the metal particles reach nano size, which present special effects and characteristics [1-4]. Generally speaking, the preparation methods of nano metal powders mainly include physical and chemical methods. Physical methods include high-energy ball milling, vapor-phase condensation based on different vapor technologies. Chemical methods include chemical vapor deposition, reduction of salts in aqueous solutions, sol-gel and hydrothermal techniques [5-8].

The wire electric explosion method was applying high DC voltage to the ends of metal wire in certain gas medium. Under the influence of high voltage and large current, the metal wire will explode and gasify immediately. During this process, the explosive products continuously collide with the surrounding low-temperature inert gas and then lose their energy, eventually deposit together to form metal powder [9-12]. The electrical explosion process is affected by many factors, including wire material, diameter, length, voltage, and so on. These factors have an impact on the morphology, particle size distribution, and agglomeration state of the nano metal powder [13, 14].

Nano-Al powder has shown good performance in many fields such as energetic materials and catalyst [15-17]. Due to the low production cost and controllable product properties, wire electric explosion method has become one of the most widely used nanotechnology methods. Therefore, it is of great value to concern on the preparation of nano-Al powders by wire electric explosion.

In this paper, the preparation of nano-Al powder was investigated, effect of aluminum wires diameter on nano-Al powder particles appearance was dicussed. We hope the work presented interesting result for researcher who works on nano materials.

2. Experiment
In this paper, nano-Al powder was prepared by wire electric explosion method. The mass fraction of aluminum wire was 99.99\%, and table 1 showed the specific experimental parameters. The prepared nano-Al powder was passivated in the air for 72h, the products were characterized by electron microscopy, X-ray diffraction.
Table 1. Experiment parameters’.

| Experimental parameters        | Values          |
|-------------------------------|-----------------|
| Wire diameter                 | 0.20, 0.30, 0.40, 0.50 mm |
| Operating Voltage             | 30 KV           |
| Gas type                      | Argon           |
| Pressure in the operating volume | 2.0 MPa        |

The prepared nano-particles were examined using a JEM-2100 transmission electron microscope (TEM), The TEM images were processed to obtain particle size distributions and average size for selected powders. An Analytical X’Pert PRO diffractometer was used for x-ray diffraction (XRD) to determine phase compositions of the prepared materials.

3. Results and discussion

Figure 1. Morphology of nano-aluminum powder prepared by different wire diameters

Fig. 1 was the TEM images and particle size distribution diagrams of nano-Al powder prepared from aluminum wires with different diameters. As the pictures show that the nano-Al powder is spherical and on the state of agglomeration.
Figure 2. Average size of nano particles prepared by different wire diameters.

Fig.2 was the average size of nanoparticles prepared by aluminum wires with different diameters. According to the particle size statistics, it is found that as the diameter of the aluminum wire increases, the average particle size of the nano-aluminum powder increases.

For the experiment, the voltage is kept at 30KV, that means the $E_{\text{input}}$ (input energy) is constant, increasing of the diameter of the wire will lead to both increasing in the wire mass and the $E_{\text{sub}}$ (the sublimation energy of the aluminum wire), then the value of $K$ will increase.

$$K = \frac{E_{\text{input}}}{E_{\text{sub}}}$$  \hspace{1cm} (1)

$K$ is overheating coefficient.
As the $K$ value increases, the content of metal steam generated during the electric explosion process is reduced, the content of metal droplets is increased, which ultimately resulted in an increase in average particle size.

Figure 3. XRD pattern of nano-Al powder.
Fig.3 was XRD pattern of the nano-Al powder after passivation. As can be seen that the passivation product consists of two phases, Al and Al2O3. The appearance of Al2O3 is because the nano-Al powder prepared by electric explosion method is in a high-energy state, which is extremely prone to oxidation reactions. In order to facilitate storage and use, passivation treatment is required. When the 72-hour passivation process is complete, a 3-6 nm thick oxide layer is formed on the surface, which we can see from Fig.4.

4. Conclusion
By controlling the diameter of the aluminium wire of the electric explosion method, the average particle diameter and particle size distribution of the nano-Al powder was investigated. The increasing of the diameter of the aluminium wire will cause the average particle diameter of the nano-Al powder to increase. Through the passivation treatment in the air, an Al2O3 oxide layer with a thickness of 3-6 nm is formed on the surface of the nano-Al powder. The existence of the oxide layer enables the nano-Al powder to be safely stored and transported.

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