

Influence of Aluminum Particle Size of Reaction Propagation of Al/CuO Nanothermite Layers on Copper Meshes

Wan-Lien Hsu , Sheng-Huai Su and Ming-Hsun Wu
Department of Mechanical Engineering, National Cheng Kung University
Tainan, Taiwan

Abstracts

Nanothermite (NT) not only eliminates the need for additional external energy but also combines the functions of fuel and oxidizer. It provides a mixture that enables rapid and controllable reaction rates, with the energy release being controlled by the composition and ratio of fuel and oxidizer. Compared to materials at the micron scale, NT exhibits higher combustion rates due to its increased specific surface area and volume, reducing the diffusion distance between fuel and oxidizer, decreasing ignition delay time, and enhancing reaction rates. As a result, NT finds widespread applications in various fields such as propulsion, explosives, pyrotechnics, microelectronics, and high-energy materials. Among them, NT materials like Al/CuO have garnered significant attention.

There are various methods for synthesizing NT, with physical mixing being the most basic approach, thoroughly and uniformly dispersing the fuel and oxidizer through simple ultrasonic oscillation. Other methods include self-assembly, vapor deposition, electrophoretic deposition (EPD), and gel combustion synthesis. We previously developed a method based on EPD that allows coating of NT on a copper mesh, as shown in Figure 1. Initially, an oxide layer is formed on the copper mesh through thermal oxidation. Then, the copper mesh is immersed in a suspension containing Al nanoparticles. Under the influence of an electric field, Al powder adheres between the copper oxide nanowires, forming an Al/CuO NT layer. By adjusting parameters such as voltage, current, suspension concentration, deposition time, and aluminum powder particle size, the combustion rate can be controlled.

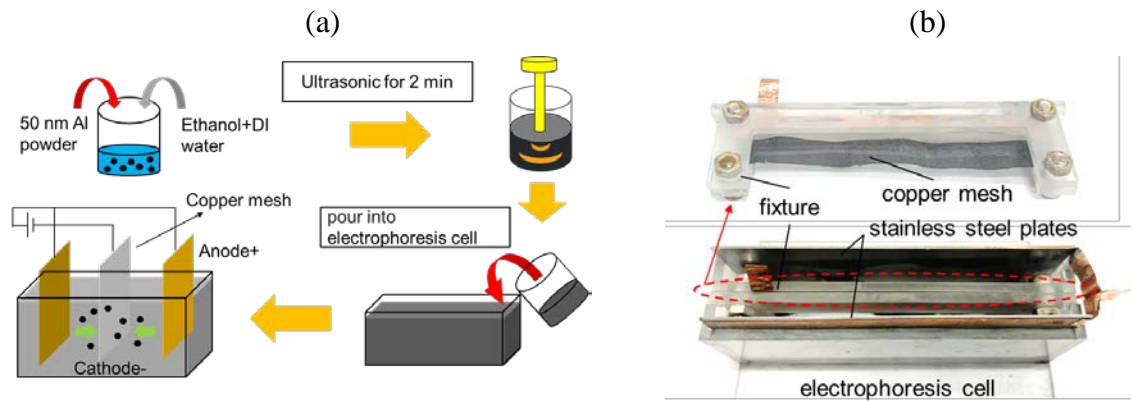


Figure 1: (a) schematic diagram of self-made electrophoretic deposition process, (b) apparatus for electrophoretic deposition.

Our research indicates that the combustion reaction of the Al/CuO NT layer deposited on the copper mesh exhibits unique characteristics influenced by the particle size of the aluminum. The NT layer with relatively small particle sizes (50 nm, 100 nm) demonstrates rapid and uniform self-sustained reaction propagation (as shown in Figures 2 and 3), leading to almost complete combustion of the copper mesh thermite within a relatively short time. On the other hand, the NT layer with larger particle size (500 nm) exhibits slower and non-uniform reaction propagation, resulting in partial combustion of the copper mesh thermite (as shown in Figure 4). The combustion rates for the three different particle sizes are summarized in Figure 5, with the 50 nm Al powder achieving a combustion rate of 22.1 cm/s, while the 500 nm Al powder only reaches 8.1 cm/s. Furthermore, thermal analysis reveals the generation of highly localized temperature in the Al/CuO NT layer deposited on the copper mesh, indicating its potential for localized heating applications.

In conclusion, this study provides valuable insights into the reaction propagation behavior of the Al/CuO NT layer deposited on the copper mesh. These findings are significant for the design and optimization of nanothermite-based systems to achieve controlled and efficient energy release, such as reactive materials in micro-scale combustion devices and microelectronics applications.

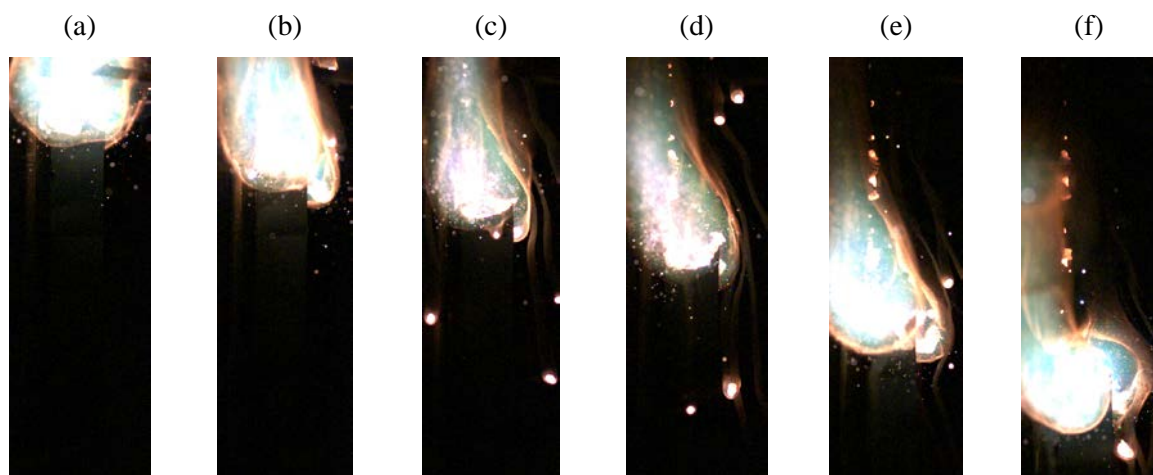


Figure 2 : Time sequence images of the combustion of 50 nm aluminum powder on a copper mesh (a)40 ms, (b)80 ms, (c)120 ms, (d)160 ms, (e)200 ms, and (f)240 ms.

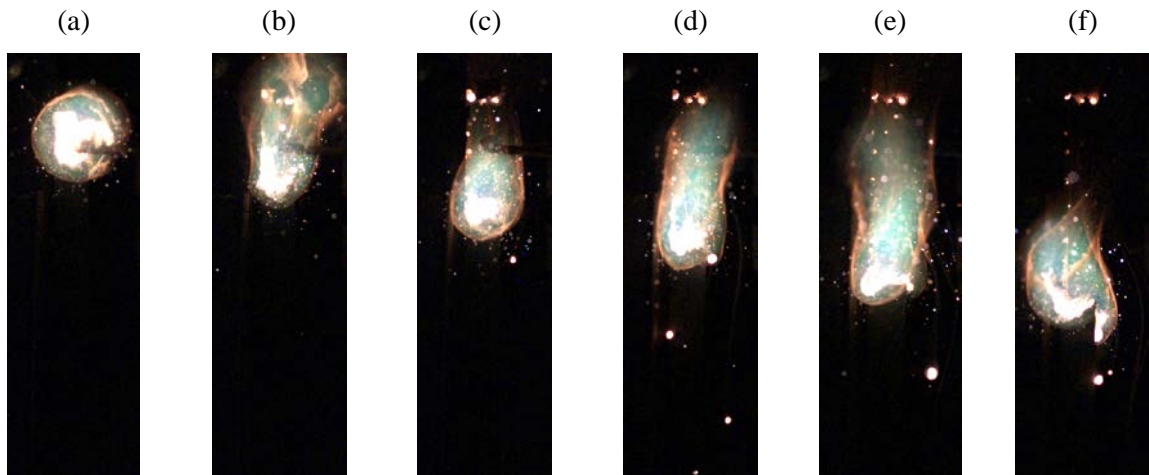


Figure 3 : Time sequence images of the combustion of 100 nm aluminum powder on a copper mesh (a)40 ms, (b)80 ms, (c)120 ms, (d)160 ms, (e)200 ms, and (f)240 ms.

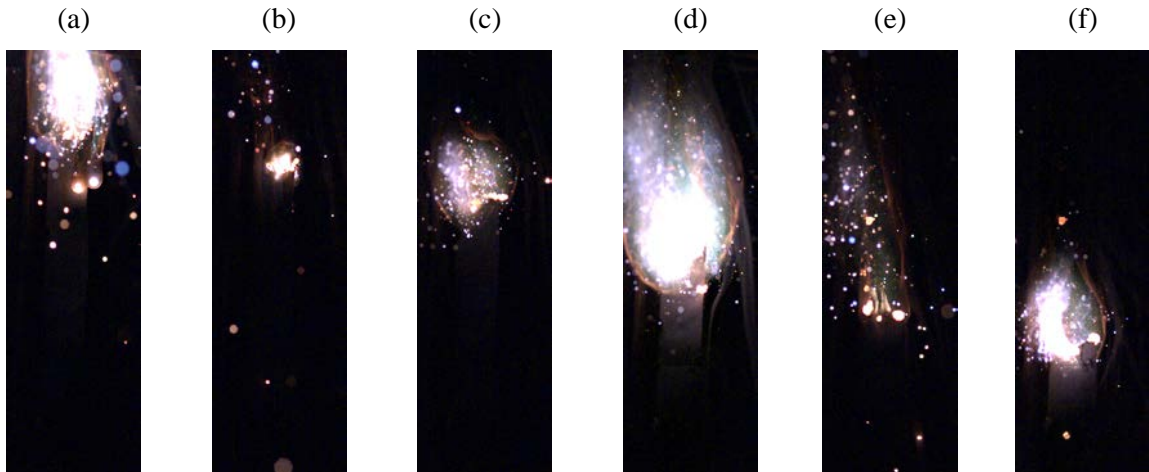


Figure 4 : Time sequence images of the combustion of 500 nm aluminum powder on a copper mesh (a)40 ms, (b)80 ms, (c)120 ms, (d)160 ms, (e)200 ms, and (f)240 ms.

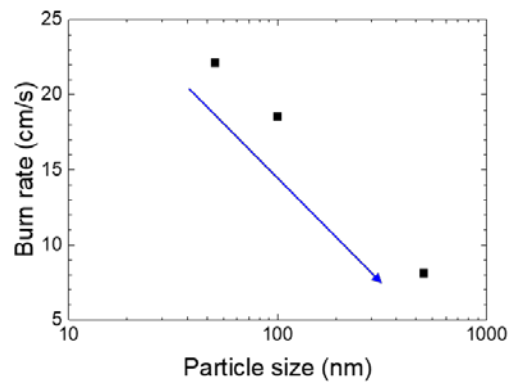


Figure 5 : The relationship between aluminum particle size and combustion rate.