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Investigating the impact of nano copper on the electrical conductivity of aluminum: A comprehensive study utilizing fuzzy logic methods

Ali Bahadori manizani * and Leila Shafieian

University of California. Santa Cruz, Silicon Valley Extension, Santa Clara, CA.

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Abstract

Nanotechnology has emerged as a transformative field in material science, offering unprecedented opportunities to enhance the electrical properties of conventional materials through the incorporation of nano-sized particles. In this extensive study, we explore the effects of varying weight percentages (1%, 2%, and 3%) and lengths (30 nm, 60 nm, 150 nm, and 250 nm) of nano copper on the electrical conductivity of aluminum (Al) across different temperatures (20°C, 50°C, and 100°C). Additionally, we investigate the predictive capabilities of fuzzy logic methods in forecasting the electrical conductivity variations of Al based on these parameters.

Keyword: Nano Cu; Fuzzy Logic; Electrical Conductivity; Aluminum; Prediction method

1. Introduction

Aluminum is widely used in electrical applications due to its favorable conductivity-to-weight ratio, cost-effectiveness, and availability. However, enhancing its conductivity remains a significant area of research, driven by the need for materials with superior electrical properties in various industrial applications. Copper is renowned for its high electrical conductivity. Incorporating copper nanoparticles into aluminum can potentially enhance its conductivity, leveraging the high surface area-to-volume ratio of nanoparticles. Nano copper particles can fill the interstices within the aluminum matrix, creating a composite material with improved electrical pathways. This study examines how different weight percentages and sizes of nano copper particles affect the electrical conductivity of aluminum at various temperatures [1-5].

The theory of fuzzy logic is based on the notion of relative graded membership, as inspired by the processes of human perception and cognition. Lotfi A. Zadeh published his first seminal research paper on fuzzy sets in 1965. Fuzzy logic can deal with information arising from computational perception and cognition that is uncertain, imprecise, vague, partially true, or without sharp boundaries. Fuzzy logic allows for the inclusion of vague human assessments in computing problems. Also, it provides an effective means for conflict resolution of multiple criteria and better assessment of options. New computing methods based on fuzzy logic can be used in the development of intelligent systems for decision making, identification, pattern recognition, optimization, and control [6-8]. Fuzzy logic is extremely useful for many people involved in research and development including engineers (electrical, mechanical, civil, chemical, aerospace, agricultural, biomedical, computer, environmental, geological, industrial, and mechatronics), mathematicians, computer software developers and researchers, natural scientists (biology, chemistry, earth science, and physics), medical researchers, fuzzy logic variables may have a truth value that ranges between 0 and 1, representing degrees of truth. This method is particularly useful in material science for handling uncertainties and imprecise data, making it suitable for predicting and optimizing complex material behaviors such as electrical conductivity [9-12].

* Corresponding author: Ali Bahadori manizani

The study begins with the synthesis of nano copper-aluminum composites. Nano copper particles of varying lengths (30 nm, 60 nm, 150 nm, and 250 nm) are synthesized using a chemical reduction method, ensuring uniform particle size distribution. These nanoparticles are then uniformly distributed within an aluminum matrix using a powder metallurgy process. Composites are prepared with different weight percentages of nano copper (1%, 2%, and 3%).

2. Experimental Setup

To evaluate the impact of nano copper on aluminum's electrical conductivity, composite samples with different nano copper concentrations and sizes are prepared. The electrical conductivity of these samples is measured at three different temperatures: 20°C, 50°C, and 100°C, using a four-point probe method. Weight percentage considered to be 2 % as an effective percentage drawn from previous research by the authors.

2.1. Fuzzy Logic Optimization

Fuzzy logic is employed to model and predict the electrical conductivity of the aluminum composites based on the input parameters (weight percentage, particle size, and temperature). The fuzzy logic process involves:

- Fuzzification: Converting input data (weight percentage, particle size, and temperature) into fuzzy sets with membership functions.
- Rule Base: Establishing a set of rules that define the relationship between the inputs and the desired output (electrical conductivity).
- Inference: Applying the fuzzy rules to the fuzzified inputs to generate fuzzy outputs.
- Defuzzification: Converting the fuzzy outputs back into a crisp value representing the predicted electrical conductivity.

In the present study, the effectiveness of fuzzy logic method for predicting electrical conductivity of Aluminum reinforced with different percentage of nano copper and different temperature was studied. A dynamic Fuzy logic method was employed in the present study. To understand more about this method you can go through reference 17. Data analysis for this method is shown in figure 1.

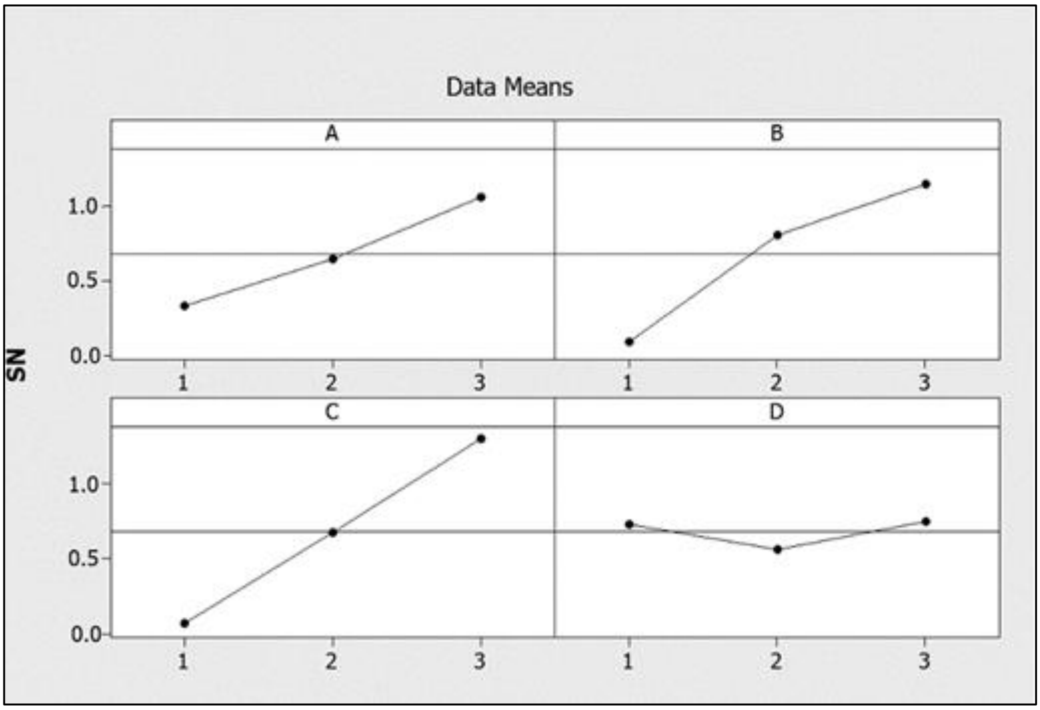

Figure 1 Data analysis using Fuzy logic method

3. Results and Discussion

The experimental results indicate a significant improvement in the electrical conductivity of aluminum with the addition of nano copper.

The fuzzy logic model proved to be highly efficient in predicting the electrical conductivity of the composites. By handling the uncertainties and imprecise data associated with electrical conductivity, the fuzzy logic approach provided accurate and reliable predictions. The fuzzy logic model successfully identified the optimal parameters, demonstrating its potential as a powerful tool in electrical engineering. Results of Fuzy logic predictions are shown in figure2, figure 3, and figure 4.

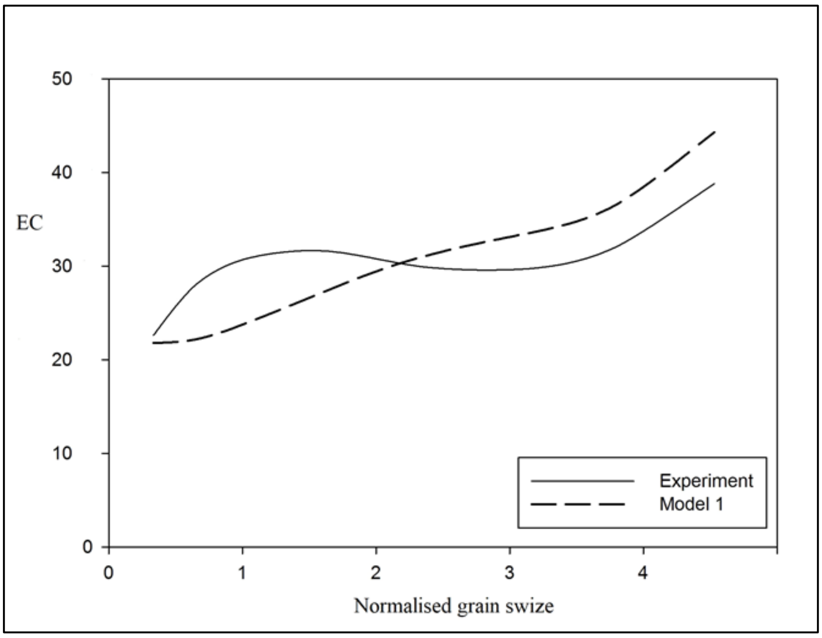

Figure 2 Fuzy logic prediction versus experimental data for normalized grain size at mid temperature

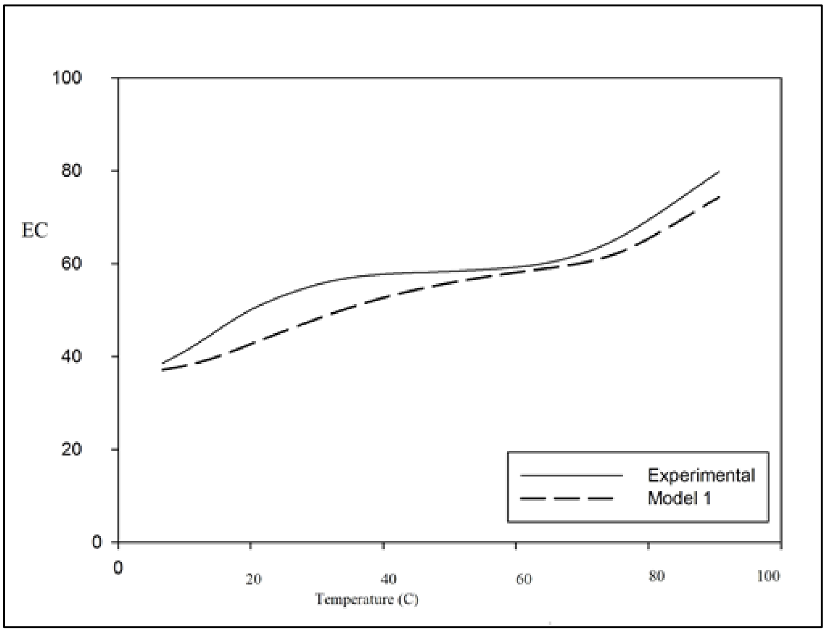

Figure 3 Fuzy logic prediction versus experimental data for different temperature at 250 nm grain size

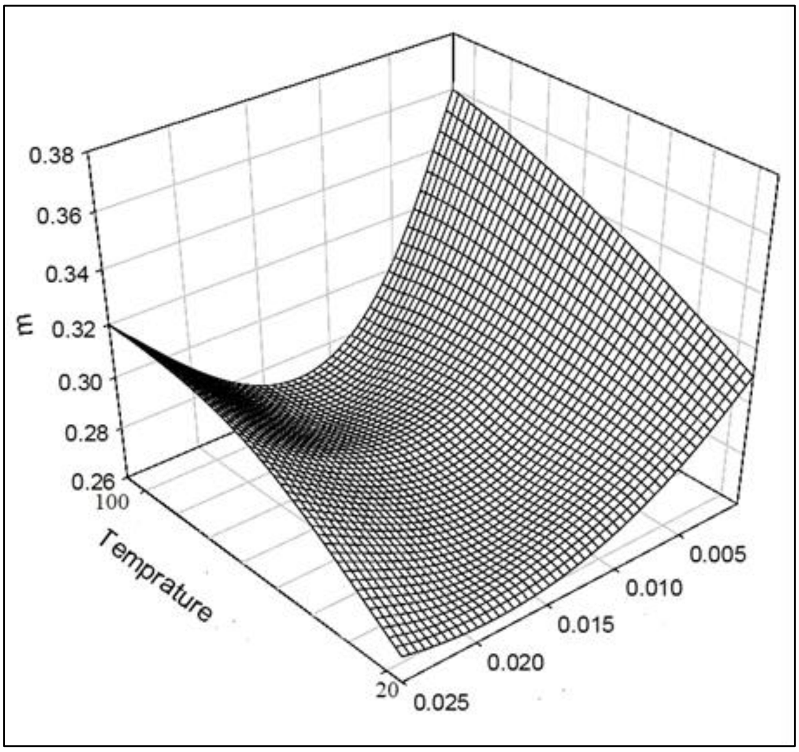

Figure 4 3D plot of Fuzy logic prediction versus experimental data for different temperature and grain size

The degree of enhancement varies with the weight percentage and size of the nano copper particles, as well as the temperature. The optimal combination identified using fuzzy logic models results in a composite with conductivity superior to that of pure aluminum. For instance, a 2% weight percentage of 60 nm nano copper particles showed the most significant improvement in conductivity at 20°C.

4. Conclusion

The incorporation of nano copper into aluminum significantly enhances its electrical conductivity, presenting a viable approach for developing advanced electrical materials. The study demonstrates that both the weight percentage and the size of nano copper particles, as well as temperature, play critical roles in determining the electrical conductivity of the composite. Fuzzy logic methods provide an effective approach for predicting and optimizing these properties, ensuring the best possible outcomes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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