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Investigating the impact of nano copper on the electrical conductivity of aluminum: A comprehensive study utilizing ANN, genetic algorithm, and fuzzy logic methods

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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 compare the predictive capabilities of Artificial Neural Networks (ANN), Genetic Algorithms (GA), and Fuzzy Logic (FL) methods in forecasting the electrical conductivity variations of Al based on these parameters.

Keywords: Electrical conductivity; GA method; ANN; Fuzzy Logic; Predictive model; Nano particle

1. Introduction

Aluminum is extensively used in electrical applications due to its fantastic conductivity-to-weight ratio, cost-effectiveness, self-isolated out layer, 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 [1-3]. Copper is renowned for its high electrical conductivity. Adding copper nanoparticles to aluminum can enhance its conductivity. Nano copper particles can fill the interstices within the aluminum matrix, creating a composite material with improved electrical pathways [4-7]. This study examines how different weight percentages and sizes of nano copper particles affect the electrical conductivity of aluminum at various temperatures [8-10].

There are various methods for predicting electrical conductivity of electrical wires such as: wave propagation, numerical analysis, genetic algorithm, artificial neural network, Fuzzy logic, mathematical modeling, and etc. Each method has its own advantage and its own side effects [11-13]. Although there are lots of different research about effectiveness of these methods, few research has been conducted to compare these methods with each other and which of these methods has better prediction especially when it comes to nano additives to enhance electrical conductivity of Aluminum wire. Therefore, in this paper a comprehensive study has been done to determine which of the GA, FL, and ANN has better prediction and is more precise in this case.

1.1. Predictive models

Three methods were selected in this study to predict the electrical conductivity of aluminum composites: Artificial Neural Networks (ANN), Genetic Algorithms (GA), and Fuzzy Logic (FL) [14]. A Comprehensive Study Utilizing ANN, Genetic Algorithm, and Fuzzy Logic Methods 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 [15-17]. In this extensive study, we explore the effects of varying weight

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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 compare the predictive capabilities of Artificial Neural Networks (ANN), Genetic Algorithms (GA), and Fuzzy Logic (FL) methods in forecasting the electrical conductivity variations of Al based on these parameters.

2. Experimental procedure

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%).

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.

2.1. Predictive Models

2.1.1. Artificial Neural Networks (ANN)

ANNs are computational models inspired by the human brain, consisting of interconnected nodes (neurons) that process input data and learn to predict outputs. ANNs are trained using a dataset of input parameters (weight percentage, particle size, and temperature) and corresponding electrical conductivity measurements. Once trained, the ANN can predict the electrical conductivity of new composite formulations.

Investigating the Impact of Nano Copper on the Electrical Conductivity of Aluminum.

2.1.2. Genetic Algorithms (GA)

GAs are optimization techniques inspired by natural selection and genetics. The GA process involves:

- Initialization: A population of potential solutions (composite formulations) is generated randomly.
- Selection: Solutions are evaluated based on their fitness, which, in this case, is the electrical conductivity of the composite.
- Crossover: Pairs of solutions are combined to create new offspring solutions, incorporating traits from both parents.
- Mutation: Random alterations are introduced to some solutions to maintain genetic diversity.
- Iteration: The process is repeated over several generations, with the best solutions carried forward to converge on an optimal solution.

Genetic algorithms (GAs) are a class of optimization techniques inspired by the principles of natural selection and genetics. GAs are particularly useful in prediction and optimizing complex processes and parameters, where traditional methods may fall short. By simulating the process of natural evolution, GAs iteratively to predict experimental results. In this study, GAs are used to predict and optimize the electrical conductivity of aluminum composites.

In this article a GA method is employed to predict electrical conductivity of Al based alloy reinforced by nano copper at different temperature and different nano particle size. Deeper knowledge about the specific material behavior, especially the electrical conductivity on temperature and different nano size range have to be carefully obtained prior to all forming experiments. Also the effect such as theoretically describing the forming behavior for simulation purposes. Right now this is a lack of understanding of constitutive equation for Aluminum bases alloys reinforced by nano copper when it comes to electrical conductivity especially at high temperatures. In this study the relationship of the electrical conductivity of these alloys to nano particle size and temperature was investigated by GA method based on constitutive model based on Zener – Holloman parameter. Genetic algorithm is presented that shows good agreement between experimental data and predicted data.

2.1.3. Fuzzy Logic (FL)

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. 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. Fuzzy logic is extremely useful for many people involved in research and development especially in electronic engineering.

FL is a computational approach that deals with reasoning that is approximate rather than fixed and exact. A Linguistic Variable has a name, a definition domain, a set of values and an interpretation. The name of the variable can be freely chosen, but it is wise to name it after the real variable it will represent. The definition domain has to be consistent with the universe where it will be used. The definition domain contains a set of Linguistic Terms, which represent the values that may take the Linguistic Variable at different states of intensity. Linguistic Terms are labelled fuzzy sets, usually with a trapezoidal or bell-shaped structure. (Triangles are, in this context, trapezes with the upper side reduced to one point). The cores of these fuzzy sets – (sets of elements with membership degree 1)- are ordered, and the supports (sets of elements with membership > 0)- overlap between Neighbors.

n 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 Fuzzy logic method was employed in the present study.

3. Results and Discussion

All these three predictive models were implicated in this study and were compered to each other as shown in figure 1. In order to compare which of these methos is the most accurate ones, the predicted results should be compare with the experimental data. Experimental data showed that artificial neural network is the most accurate method followed by Fuzzy logic method. Although Genetic algorithm method is able to predict electrical conductivity it seems that it is not as precise as ANN and FL. ANN accuracy comes from its training data that seems to be very well trained. Comparison between GA, ANN, and experimental data are shown in figure 2. It is quite clear that ANN data are completely aligned with experimental data and the mean average error is less than 0.95 % while the average error for GA is 4.55%.

Comparison between GA, FL, ANN, and experimental data considering 2% 30 nm cooper added to Al at various temperature are shown in figure 3. It is worthy that increasing temperature leads to more error creation.

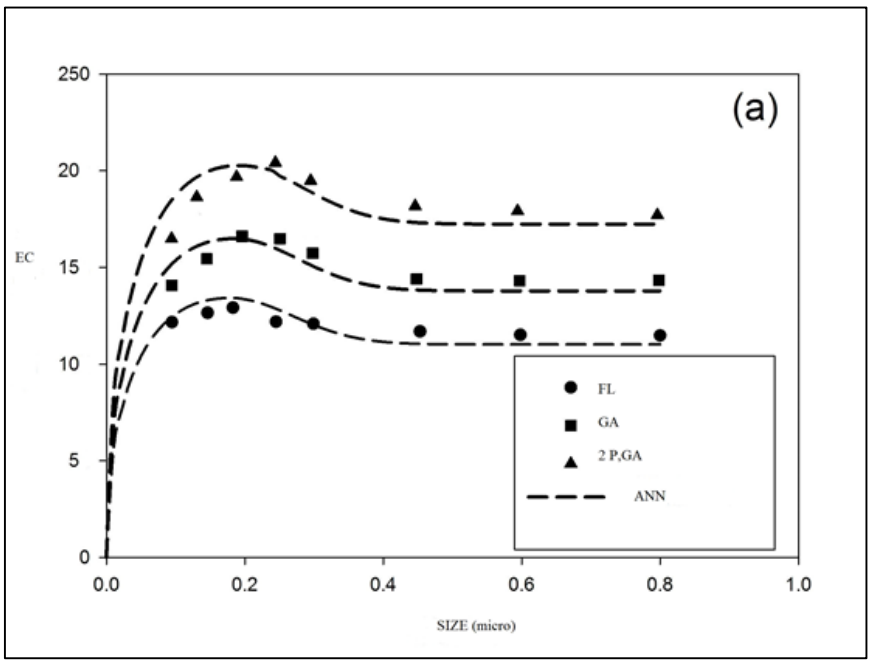

Figure 1 Comparison between all predictive models used in this study

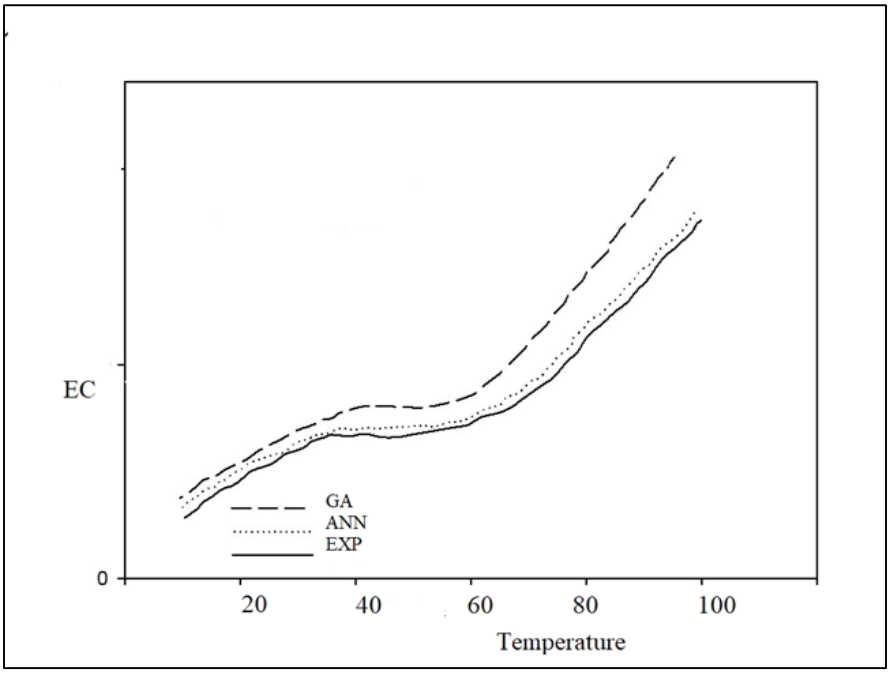

Figure 2 Comparison between GA, ANN, and experimental data

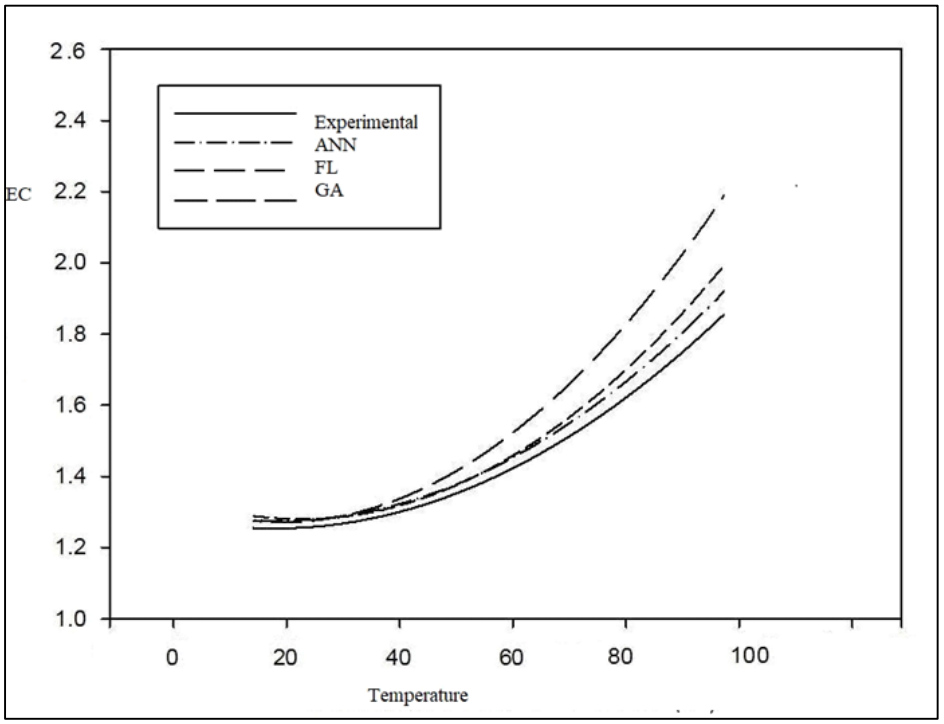

Figure 3 Comparison between GA, FL, ANN, and experimental data considering 2% 30 nm cooper added to Al at various temperature

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. Comparing ANN, GA, and FL methods reveals that artificial neural network is the most accurate method followed by Fuzzy logic method. The development of an ANN-based predictive model for electrical conductivity estimation in Al-Cu nanocomposites requires careful consideration of several key aspects. These include the selection of appropriate input features, the design of the network architecture (e.g., number of layers, neurons per layer, activation functions), the choice of training algorithm, and the evaluation metrics used to assess model performance.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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