Design of Neural Network Model and its Application to Coating Performance Prediction

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Abstract. 316L stainless steel has excellent mechanical properties and good corrosion resistance. It is used as a medical implant material, but it is susceptible to pitting corrosion to precipitate harmful ions and lead to the failure of the material. To solve the above problems, the surface modification method is used to solve it, and it is now widely accepted. Among them, magnetron sputtering technology has been widely used because of its advantages such as good adhesion and other advantages. The parameters of the RF magnetron sputtering process have a great influence on the performance of the coating, and the influence of each parameter has a non-linear mapping ability. The artificial neural network is used to build a model to predict the performance of the coating. It is highly targeted and practical. The establishment of artificial neural network is a prediction model from sputtering process parameters to coating performance, which can save pre-research time and improve work efficiency. The establishment of artificial neural network uses the strong nonlinear mapping ability of artificial neural network, combined with the measured value of Hf-based coating performance to establish a model to predict the effect of Hf-based coating sputtering process parameters on the performance of the coating. The simulation results indicate the prediction The error between the value and the measured value meets the BP network design requirements ≤0.3.

Keywords: Hf-based Coating, Magnetron Sputtering Technology, BP Neural Networks, Mechanical Properties, Corrosion Resistance, Performance Forecasting

1. Introduction

The artificial neural network processes data units based on the working mode of the biological brain,
so that it has the ability to summarize, summarize and search for the underlying rules of known data \[1\]. The realization of the approximation of arbitrary functions through directed topological connection is essentially a learning process rather than traditional code writing, and thus has strong nonlinear mapping capabilities and practicality.

At present, the most extensive technology is the application of magnetron sputtering in the field of metal materials. The density of its coating is high and it has a good film-based binding force. In the actual coating preparation process, the performance of the coating is affected by the experimental parameters. In this paper, with the help of the nonlinear mapping ability of the artificial neural network, the performance parameters of the Hf-based coating are used as the original values to establish a model to predict the influence of the sputtering process parameters of the Hf-based coating on the mechanical properties and corrosion resistance of the coating.

The research and development of new materials requires a lot of manpower, material resources and time. The application of artificial neural networks in the field of materials can solve this problem. The network model prediction is based on the previous research, and this has an accurate prediction of the performance of research and development of new materials, which will help save scientific research funds and basic research time \[2-7\].

2. Experimental Methods

2.1. Structure of BP networks

The structure of the BP network affects the model performance of the BP network. Among them, the strength of the prediction performance of the BP network is controlled by the number of hidden layers. If the number of hidden layers is larger, the prediction accuracy will be higher, but this will reduce the network learning efficiency and convergence. This paper uses the network structure shown in Figure 1 to predict the effect of magnetron sputtering process on the performance of Hf-based coatings. Among them, 5 neurons are used for the input layer, and 4 neurons are used for the output layer. The number of hidden layer nodes is determined by the adaptive method\[8\] combined with the self-training of the model, and the number of nodes obtained is 18.

![Figure 1. Model of BP neural network of inert coatings.](image)

2.2. Normalization of sample data

The BP network needs to select teacher samples to train the designed network when performing calculations. Because the input of the model differs too much, it will cause the model to fail to converge during training. Therefore, in order to improve the convergence, we need to normalize the input and output after selecting the teacher samples and before performing network learning. In this
paper, the normalization formula (1-1) is used to normalize the data to the interval (0,1), so as to ensure that each data occupies the same position in the network learning process, reducing the difficulty of network training. The normalized formula is:

\[ X' = 0.1 + (0.9 - 0.1) \times \frac{(X - X_{\text{min}})}{(X_{\text{max}} - X_{\text{min}})} \quad (1-1) \]

\( X' \), \( X_{\text{max}} \) and \( X_{\text{min}} \) are the normalized results, the maximum and minimum values at the input.

In this paper, the network simulation results are treated by using formula (1-2):

\[ X = (X' - 0.1) \times \frac{(X_{\text{max}} - X_{\text{min}})}{(0.9 - 0.1)} + X_{\text{min}} \quad (1-2) \]

\( X \) is the value of \( X' \) inverse normalization treatment.

3. Design of Artificial Neural Network

Based on the Hf-based coating, a back propagation algorithm is used to predict the corrosion resistance and mechanical properties of the coating. The network training function uses the \text{trainlm()} function. The \text{logsig()} function is used as the transfer function between the input layer and the output layer \((0,1)\), and the \text{purelin()} function is used as the transfer function between the hidden layer and the output layer.

In this paper, 40 sets of data obtained from the previous experiment are selected as input data and normalized to perform artificial neural network training, and 8 sets of data are used to detect the reliability of the established network. Part of the input data is listed in Table 1.

**Table 1.** The data for training BP neural network.

| No | Vacuum 
\(10^{-4}\text{Pa}\) | Pressure (Pa) | Power (W) | Ts (°C) | Bias voltage(V) | H/E (GPa) | H²/E² | \(E_{\text{coor}}\) | \(I_{\text{coor}}\) (μA/cm²) |
|----|----------------|---------------|-----------|--------|-----------------|-----------|------|----------------|----------------|
| (1) | 1.1            | 0.35          | 120       | 25     | 0               | 0.0519    | 0.0282 | -156          | 1.79E⁻⁶        |
| (2) | 1.9            | 0.35          | 120       | 25     | -100            | 0.0568    | 0.0535 | -191          | 7.62E⁻⁷        |
| (3) | 0.95           | 0.35          | 120       | 25     | -150            | 0.0657    | 0.0734 | -134          | 1.47E⁻⁷        |

It can be seen from Figure 7 that after 1000 cycles of training, the error of the designed artificial neural network model is 1.19E-30 and it approaches 0 indefinitely. Therefore, the artificial neural network designed in this chapter meets the requirements.
3.1. BP Network Predicted Hf-Base Coatings

The model of Figure 1 is used to predict the mechanical properties and corrosion resistance of Hf-based coatings. The error between the predicted value and the measured value of the performance of Hf-based coatings prepared under different process conditions is shown in Table 2. It can be seen intuitively from Table 2 that the error between the predicted results and the measured data is stable, which meets the requirements of the experimental design.

Table 2. The error between the forecast results and measured value of coating.

| No | Vacuum $(10^{-4}$Pa) | Pressure (Pa) | Power (W) | Ts $(^\circ$C) | Bias voltage(V) | Error |
|----|----------------------|---------------|-----------|--------------|----------------|-------|
| (1) | 1.1 | 0.35 | 120 | 25 | 0 | 0.11 |
| (3) | 0.95 | 0.35 | 120 | 25 | -150 | 0.15 |
| (4) | 1.1 | 0.35 | 120 | 25 | -200 | 0.17 |

The above simulation results indicate that the BP neural network can be used to complete the prediction from the input process parameters to the output mechanical properties and corrosion resistance, which meets the experimental design requirements.

4. Conclusion

Using the artificial neural network toolkit in Matlab software to predict the mechanical properties and corrosion resistance of the coatings measured in this paper, the results are as follows:

Use the BP network to establish the prediction model of the prepared coating from the sputtering process parameters to the mechanical properties and corrosion resistance, and evaluate the predicted performance of the designed model, and optimize the structure of the model to improve the network
Simulation efficiency

The artificial neural network module in Matlab software is used to successfully establish a coating prediction model. There is a certain error between the predicted value and the measured value, but both meet the experimental design requirements ≤0.3.

Acknowledgments

1. Ningxia science and technology key research and development project (2018BEE03029);
2. Ningxia natural science foundation (2019AAC03272);
3. Ningxia higher school scientific research project (NGY2018-250);
4. Yinchuan University of Energy talent introduction fund project (2018-KY-R-01)

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