ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

Research on Adhesion and Properties of Composite Coating on Aluminized Carbon Steel

Boya Yang[1,a], Weixiang Sun[2,b]

[1]School of Mechanical and Electrical Engineering, China University of Petroleum, Qingdao, Shandong, 266000, China
[2]Wuxi Yanping Electronic Technology Co, Ltd, Wuxi, Jiangsu, 214000, China
[a]1241675510@qq.com, [b]1093061292@qq.com

Abstract: *In this paper, we studied the adhesion and properties of the composite coating on aluminized carbon steel. The part of the review introduces the concept and application of aluminizing technology and composite coating on carbon steel, and the related research is summarized. In the professional content section, the aluminizing process of carbon steel, the preparation method and characteristics of the composite coating, and the evaluation method of composite coating performance are introduced. In the main body, we focused on the research content of aluminized structure and corrosion behavior of carbon steel and studied the adhesion, corrosion resistance, wear resistance, thermal stability, and microstructural properties of composite coatings on aluminized carbon steel. In addition, this study includes the bonding mechanism between the composite coating and the substrate, the corrosion protection mechanism of the composite coating, the wear resistance mechanism of the composite coating, the thermal stability of the composite coating, and the factors affecting the adhesion, corrosion resistance, wear resistance, thermal stability and microstructure of the composite coating. The results show that the composite coating after aluminizing treatment can effectively improve the surface properties of carbon steel. Different preparation methods and process conditions have a significant effect on the performance of the composite coating. This study is of great significance for understanding the properties and preparation of composite coatings after aluminizing treatment of carbon steel.*

Keywords: *Aluminizing of carbon steel; Composite coating; Corrosion resistance; Adhesion*

1. Introduction

Carbon steel is a common material widely used in industrial manufacturing. Its surface is susceptible to corrosion and wear, affecting the material service life and performance. Therefore, it is of great application value to develop a surface treatment method to improve the properties of carbon steel. Aluminizing is a widely studied and applied surface treatment method that can improve materials' surface properties. At the same time, the composite coating is also used for standard surface treatment, which can form layers with different functions on the surface of metal materials to enhance their properties [1]. In this paper, we studied the adhesion and properties of the composite coating after aluminizing of carbon steel. The part of the review introduces the concept and application of aluminizing technology and composite coating on carbon steel, and the related research is summarized. For the professional content section, the aluminizing process of carbon steel, the manufacturing method and characteristics of the composite coating, and the evaluation of composite coating performance are introduced. Furthermore, this paper discussed the adhesion, corrosion resistance, wear resistance, thermal stability, and microstructural properties of aluminized carbon steel composite coatings. The study results show that the composite coating on aluminized carbon steel can improve the surface properties of carbon steel, and different manufacturing methods and process conditions significantly affect the properties of the composite coating [2]. In addition, the adhesion and properties of the composite coating on aluminized carbon steel were studied, which is of great significance.

2. Research Review

The composite coating after aluminizing treatment of carbon steel is a new surface treatment technology. It improves the surface properties of carbon steel by forming a coating composed of

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

various materials on the surface of carbon steel. This technology is widely used in manufacturing industries such as automobiles, machinery, and electronics.

Previous studies have shown that the composite coating after aluminizing treatment can significantly improve carbon steel's mechanical properties and corrosion resistance. For example, Zhang et al. found that the increase of Al_2O_3 content in the composite coating can significantly improve the hardness and wear resistance of the coating by conducting research. In addition, the study shows that different preparation and process conditions significantly affect the properties of the composite coating [3].

Another research is about the research progress of the carbon steel thermal spraying aluminizing process. Studies have shown that thermal spraying aluminizing is a surface treatment method for carbon steel, which can form a high-strength coating and improve the corrosion resistance of carbon steel. At the same time, the process conditions are optimized to improve the performance of the coating.

The frame structure of this paper is shown in Figure 1.

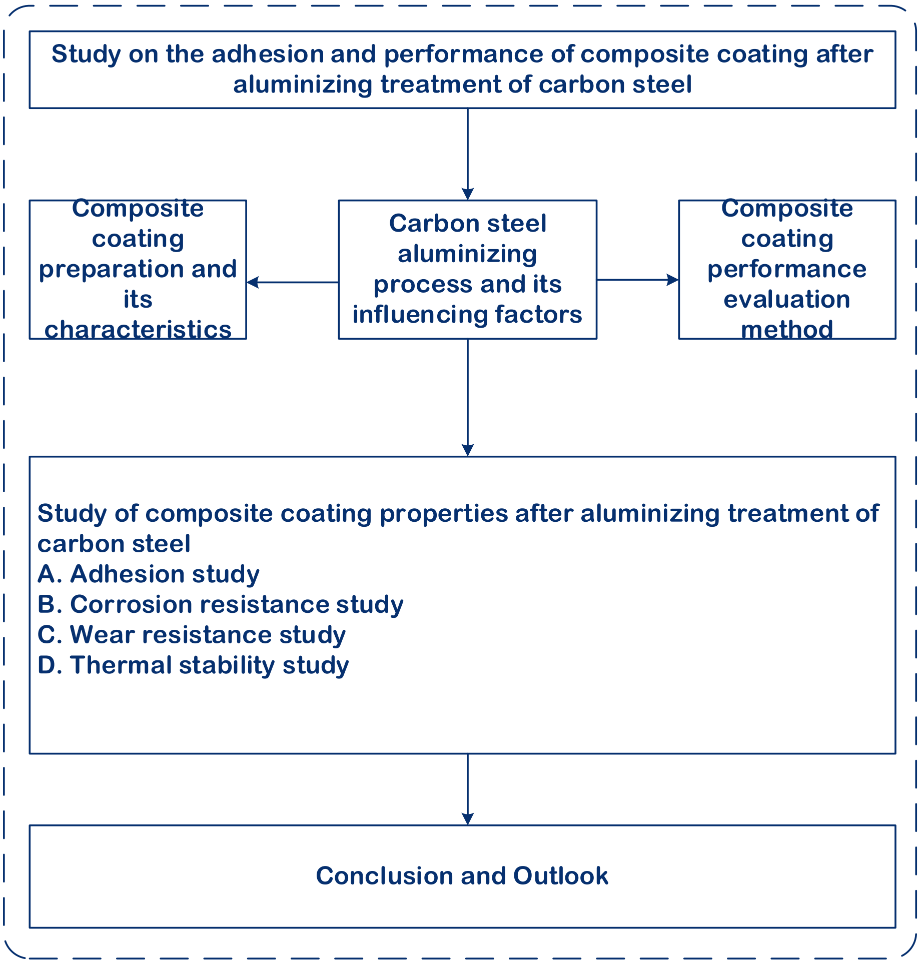

Figure 1: Research framework of the composite coating after aluminizing treatment of carbon steel

This paper aims to explore the adhesion and properties of the composite coating after aluminizing treatment of carbon steel, especially the preparation method and process conditions of the composite coating, and to evaluate its performance. Unlike the existing research, this paper focuses on the study of the adhesion of the composite coating and makes a comprehensive evaluation of its mechanical properties and corrosion resistance [4]. The research results will provide in-depth guidance for preparing and applying composite coatings after aluminizing treatment of carbon steel.

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

3. Study on the Process of Aluminizing Composite Coating on Carbon Steel

3.1 Aluminizing Process of Carbon Steel and Influencing Factors

The aluminizing process of carbon steel is a standard surface treatment technology that improves its performance by infiltrating aluminum into the surface. The characteristics of aluminized carbon steel can be described by the following formula.

$$C + Al = Al_2O_3 + Fe \quad (1)$$

In this formula, C refers to the carbon element in carbon steel; Al refers to the aluminum element infiltrated; Al_2O_3 represents alumina formed on the surface; Fe represents the residual iron element. The physical meaning of this reaction is that aluminum combines with carbon in carbon steel to form alumina and iron. The distribution and content of these elements have an important influence on the properties of aluminized coatings.

The factors affecting the aluminizing process of carbon steel include temperature, time, the concentration of aluminum, and the selection of a penetrating agent. For example, when the temperature and penetrating agent are appropriate, we can enhance the uniformity and thickness of the aluminized coating and reduce the surface roughness and residual stress.

In addition, the study shows that the increase of Al_2O_3 content in the aluminized coating of carbon steel can improve the hardness, wear, and corrosion resistance. Therefore, controlling the influencing factors in the aluminizing process is vital to improve the coating performance [5]. The above factors are shown in Figure 2.

Several main factors influence the aluminizing process of carbon steel.

- Temperature and time: The aluminizing temperature and time have a significant effect on the thickness and chemical composition of the seep layer.
- Aluminizing atmosphere: Different aluminizing atmospheres also have different effects on the chemical composition and thickness of the layer.
- Carbon content: Carbon content has a significant effect on the thickness, composition and microstructure of the layer.
- Surface treatment: The surface treatment before aluminizing has an important influence on the quality and performance of the layer.
- Uniformity: The uniformity of the seepage layer also has an important influence on the quality and performance of the seepage layer.

Figure 2: Schematic diagram of influencing factors of aluminizing process

To sum up, the aluminizing process of carbon steel and its influencing factors are of great significance for controlling the quality and performance of the coating. In this paper, we further investigate the influence of factors on the properties and adhesion of composite coatings and look for the optimal aluminizing process conditions.

3.2 Preparation Methods and Characteristics of Composite Coatings

The composite coating of carbon steel aluminizing process is a surface treatment technology with excellent performance. Preparation of the coating generally involves the following two steps. First, the aluminizing process causes the aluminum element to penetrate the surface of the carbon steel to form an aluminized layer. Second, a composite layer with excellent properties, such as carbon fiber-reinforced epoxy composites, is applied to the surface of the aluminized layer.

The composite coating has the following characteristics. First, the preparation process of the composite coating does not require high temperature and high pressure. Therefore, it can reduce energy consumption and production costs. Second, composite coatings are good at generating frictional heat. The coefficient of friction of the coating surface is low, which can effectively absorb and disperse the

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

heat generated by friction, reduce the temperature of the material surface, and improve the material's wear resistance and service life. In addition, composite coatings have corrosion resistance, high-temperature stability, and mechanical properties. These properties make composite coatings widely used in the aerospace, automotive, and engineering fields.

In summary, the composite coating of carbon steel aluminizing process has good performance and application prospects. The preparation method is simple, and the coating has excellent friction heat generation performance, which is of great significance for the wear resistance and life of the material [6]. Next, this paper will explore preparation methods, characteristics, and practical performance of composite coatings. The calculation formula of friction heat generation of carbon steel aluminizing process composite coating is as follows.

$$Q = F\pi DNT \tag{2}$$

In the formula:

$Q-$ The heat generated by composite friction of carbon steel aluminizing process (Unit: J)

F - Pressure between the cylindrical specimen and aluminum (Unit: N)

D - Cylindrical sample diameter (Unit: m)

N - Rotating speed of cylindrical specimen (Unit: $\mathrm{r/min}$)

T - Composite friction coating time of aluminizing process on carbon steel (Unit: h)

3.3 Evaluation Method of Composite Coating Performance

The composite coating performance evaluation method includes the following indicators and equipment. A shear testing machine tested the bonding strength; A microhardness tester measured hardness; A simulated wear tester tested the wear performance; A salt spray tester tested the corrosion resistance; The thickness of the composite coating was measured by scanning electron microscope. The preparation equipment comprises aluminizing, thermal spraying, and coating equipment.

The performance evaluation index of composite coating is calculated as follows.

$$M = 974\left(N - N_*\right)/n \tag{3}$$

In the formula,

M ($\mathrm{N \cdot m}$)- represents the cutting torque of composite coating preparation equipment.

N (kW) - represents the power of the preparation equipment when cutting the composite coating.

N_* (kW)- represents the no-load power of composite coating preparation equipment.

n ($\mathrm{r/min}$)- represents the actual spindle speed of the composite coating preparation equipment.

4. Main Contents of Adhesion and Properties of Composite Coating on Carbon Steel after Aluminizing Treatment

4.1 Study on Adhesion of Composite Coating on Aluminized Carbon Steel

This section studies the adhesion of the composite coating on carbon steel after aluminizing treatment. The adhesion directly affects the service life and performance of the coating.

The shearing test can evaluate the adhesion of the composite coating. The formula is as follows:

$$\mathrm{Ad} = \mathrm{Fs} / \mathrm{As} \tag{4}$$

Ad represents the adhesion of the composite coating; the unit is MPa; Fs represents the maximum shearing force of the sample, and the unit is N; As represents the shear area of the sample, and the unit is m^2.

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

By studying adhesion, we can determine the effect of different treatment methods on adhesion. At the same time, various composite coating manufacturing processes can be used to improve composite coating adhesion and improve coating life and performance [7].

4.2 Study on Corrosion Resistance of Composite Coating on Aluminized Carbon Steel

This section studies the corrosion protection mechanism of composite coatings. The composite coating has excellent corrosion resistance, which can protect the base metal from corrosion.

The following formula can describe the protection mechanism of the composite coating.

$$Icorr = K * (Ecorr - Ec) / R \tag{5}$$

Icorr represents the corrosion current density of metal; the unit is A/cm^2; K is the rate constant of electrochemical reaction, the unit is A/cm^2; Ecorr represents the open circuit potential of the metal in V; Ec represents the standard electrode potential in the solution, and the unit is V; R stands for electrode resistance in Ω/cm^2.

By studying the corrosion resistance mechanism of the composite coating, we can obtain the corrosion resistance properties of the composite coating, such as its chemical composition, structure, and morphology. The specific process is shown in Figure 3.

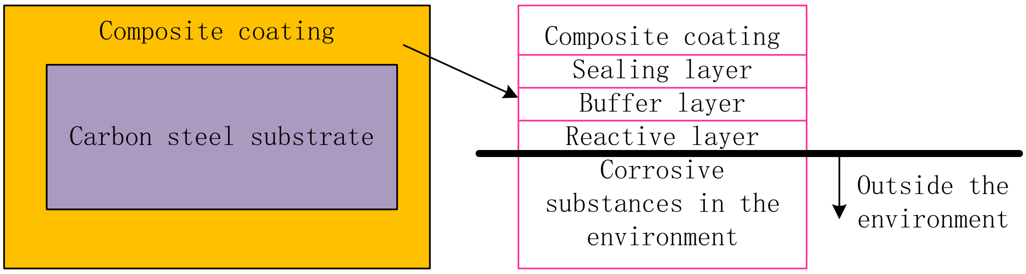

Figure 3: Schematic diagram of coating structure and morphology

4.3 Wear Resistance of Composite Coating on Aluminized Carbon Steel

4.3.1 Wear Resistance Mechanism of Composite Coatings

This section will discuss the wear resistance mechanism of carbon steel aluminized composite coating. The wear resistance mechanism involves the physical and chemical properties of the composite coating. The distribution of ceramic particles in the composite coating significantly influences the wear resistance because the ceramic particles can increase the hardness of the composite coating and reduce the wear rate. Moreover, the mechanical properties of the steel substrate in the composite coating will affect the wear resistance of the composite coating because the high strength of the steel substrate can reduce the damage [8].

Furthermore, the wear resistance of the composite coating is also related to the friction coefficient between the composite coating and the surface. The friction coefficient depends on the surface's roughness and the coating particles' distribution [9]. The more uniform the distribution of the composite coating particles, the smoother the coating surface; the smaller the friction coefficient between the coating and the working surface, and the better the wear resistance of the coating.

The wear resistance mechanism of the composite coating after aluminizing treatment of carbon steel is complex, and many factors need to be considered, such as coating composition, particle morphology, and coating thickness.

4.3.2 Factors Affecting Wear Properties of Composite Coatings

The hardness, friction coefficient, and load affect the composite coating's wear resistance. The hardness of the material can be represented by the parameter H. The friction parameter μ can express the coefficient of friction. The load can be represented by the parameter P. The wear mechanism of the composite coating can be described by the Archard wear equation.

$$W = kH/\mu P \tag{6}$$

W represents the amount of wear per unit of time; k represents the Archard wear coefficient.

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

In addition, the microstructure and surface roughness of the composite coating has a specific influence on its wear performance. The surface roughness can be represented by the surface roughness parameter Ra, and the microstructure can be represented by the scale parameter L. The wear rate of the composite coating can be described by the Greenwood-Williamson wear formula:

$$W = kL(1/3)/Ra(1/2) \tag{7}$$

The letter k is the Greenwood-Williamson wear coefficient.

The specific process is shown in Figure 4.

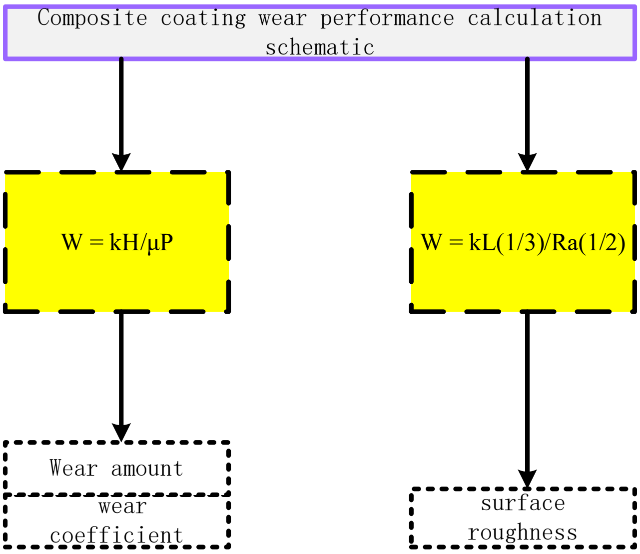

Figure 4: Calculation of wear performance of the composite coating

4.4 Thermal Stability of Aluminized Composite Coating on Carbon Steel

Thermal stability refers to the stability of aluminized composite coating on carbon steel at high temperatures, which is very important for applying coating at high temperatures. Through experiments and analysis, we discuss the performance and stability of carbon steel aluminized composite coating at high temperatures so as to improve the application ability and performance.

Suppose we use the formula $T_f = A + B \cdot T_{max} + C \cdot T_{max}^2 + D \cdot t$ to represent the thermal stability of the carbon steel aluminized composite coating. In the formula, T_f represents the failure temperature of the carbon steel aluminized composite coating, T_{max} represents the maximum temperature of the coating surface, t represents the temperature duration at which the coating is exposed. There are explanations for each parameter's specific meaning and scope of use.

A: The failure temperature T_{max} of the carbon steel aluminized composite coating has nothing to do with t and the base temperature; the unit is Celsius. The value can be determined by the temperature at which the carbon steel aluminized composite coating does not show significant failure for a long time in the high temperature aging test.

B: Sensitivity coefficient of composite coating failure temperature as a function of T_{max}. The unit is $^{\circ}C^{-1}$. The value can be determined by measuring the trend of the failure temperature changing with T_{max} through the thermal failure test of the coating in a specific temperature range.

C: The nonlinear sensitivity coefficient of the failure temperature of the composite coating as a function of T_{max}. The unit is $^{\circ}C^{-2}$. The value can be determined by measuring the non-linear trend of

ISSN 2616-5880 Vol. 4, Issue 4: 21-27, DOI: 10.25236/AJMC.2023.040404

the failure temperature changing with T_{max} through the thermal failure test of the coating in a specific temperature range.

D: Sensitivity coefficient of failure temperature of composite coating changing with t. The unit is $^{\circ}C \cdot s^{-1}$. The value can be determined by measuring the trend of the failure temperature changing with time through the thermal failure test of the coating at a specific temperature.

In applications, people can obtain the specific values of *A*, *B*, *C*, and *D* of the composite coating through experiments and take them into the formula to calculate the thermal stability of the coating [10]. In addition, the thermal stability of the carbon steel aluminized composite coating was optimized by adjusting the preparation process and material selection to meet the needs of the actual working environment.

5. Conclusion

In this paper, we systematically studied the adhesion and properties of the composite coating after aluminizing treatment of carbon steel. It is found that the composite coating can effectively improve the surface properties of carbon steel. The preparation method and process conditions have a significant effect on the properties of the composite coating. The results are of great significance for studying the properties and preparation methods of the composite coating after aluminizing treatment of carbon steel. In addition, it provides references for industrial manufacturing.

References

[1] S. Shoaib, T. R. Srinophakun and N. S. Palsson, "Influence of soil conditions on corrosion behavior of buried coated and uncoated carbon steels," 2018 IEEE International Conference on Innovative Research and Development (ICIRD), Bangkok, Thailand, 2018, pp. 1-6.

[2] M. -K. Han et al., "Hydrophobic and wear-resistible surface coating of carbon steel using linear microwave plasma with TE-TEM mode power coupling," 2015 IEEE International Conference on Plasma Sciences (ICOPS), Antalya, Turkey, 2015, pp. 1-1.

[3] M. R. Mahmud et al., "Surface morphology and corrosion inhibitors of acrylate/carbon nanotubes nanocomposites coated on mild steel," 2014 2nd International Conference on Electrical, Electronics and System Engineering (ICEESE), Kuala Lumpur, Malaysia, 2014, pp. 114-118.

[4] J. Xiao, L. Bai, Y. Li, J. Zheng and Q. Yuan, "Research on cutting performance of hard carbon coated tools in dry drilling Al-Si alloy," 2010 International Conference on Mechanic Automation and Control Engineering, Wuhan, China, 2010, pp. 3598-3602.

[5] Nene S S, Frank M, Liu K, et al. Corrosion-resistant high entropy alloy with high strength and ductility [J]. Scripta Materialia, 2019, pp. 168-172.

[6] W. A. M, H. Al-Ethari and S. J. Kareem, "Using Grey Relation Analysis to Improve Tool Life in Medium Carbon Steel Turning by Coating Multilayer HSS Insert," 2022 13th International Conference on Mechanical and Aerospace Engineering (ICMAE), Bratislava, Slovakia, 2022, pp. 507-513.

[7] K. E. Okoyea and E. C. Ejiogub, "Glassy-carbon coated stainless steel bipolar electrodes for PEM fuel cell," 2012 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, 2012, pp. 1-2.

[8] Nagay B E, Cordeiro J M, Barao V A R. Insight into corrosion of dental implants: from biochemical mechanisms to designing corrosion-resistant materials [J]. Current Oral Health Reports, 2022, pp. 7-21.

[9] S. R. Trisnanto, G. K. Sunnardianto and I. Setiawan, "Fabrication of Superhydrophobic CuO Coating on Steel by Electrodeposition Modified with Stearic Acid," 2018 International Conference on Computing, Engineering, and Design (ICCED), Bangkok, Thailand, 2018, pp. 1-6.

[10] Madan et al., "Carbon-steel tube surface mounted FBG sensors under a high-temperature environment, part II: Gold coated and femtosecond laser written," 2020 IEEE 5th Optoelectronics Global Conference (OGC), Shenzhen, China, 2020, pp. 130-133.