

Effect of Electroless Nickel Plating on Properties of Iron Matrix Composites

Xuefei Lv^{a,*}, Ying Lv^b, Shukun Gan^c

^a College of Mechanical and Electrical Engineering, Jilin Institute of Chemical Technology, Jilin 132022, China

^b Key Laboratory of Measurement Instruments and Technology, Jilin Institute of Metrology and Research, Jilin 130103, China

^c College of Automotive Engineering, Jilin Institute of Chemical Technology, Jilin 132022, China
lxflxf_75@163.com

Iron matrix composites are a kind of high-performance, low-cost metal matrix composites. They are the most promising metal matrix composites. In order to overcome the problem of reinforced particles and molten iron not infiltrating, the application of electroless nickel plating can solve it successfully. Based on the principle of electroless nickel plating, this paper studies the erosion and wear resistance of iron matrix reinforced composite. The experimental results show that the electroless nickel plating on the surface of the reinforced particles can achieve better bonding with the iron matrix and improve the infiltration of the matrix. Different particle volume fractions and different particle sizes have a greater influence on the erosion wear resistance of iron matrix composites. The larger the volume fraction of particles, the greater the volume wear, and when the particle volume fraction is the same, the erosion wear of the iron matrix composites increases with particle size.

1. Introduction

Wear is one of the main forms of failure of mechanical parts, and there is a certain degree of wear between any two surfaces that touch or move with each other (Raval and Solanki, 2015). According to different mechanism of wear, common wear patterns include abrasive wear, erosion wear, fatigue wear, and corrosion wear, among which, erosion wear is the most common form of wear, it's the wear caused by the impacting of fluid or solid abrasive material on the material surface at a certain speed and angle, or the wear caused by the corrosive action of the fluid (Cheon et al., 2011; Zhao et al., 2017; Sudagar et al., 2012). There are many factors that affect erosion wear, including abrasive hardness, shape and size, fluid erosion speed, and erosion angle (Liu et al., 2017; Wu et al., 2009). Corrosion resistance and wear resistance of mechanical parts are very important under erosion wear conditions (Luo et al., 2013; Rajaguru et al., 2015).

The development of composite materials can give full play to the characteristics of various materials, make up for the limitations of material development, the composite materials can be designed so as to fully exert the superiority of the composition effect of composite materials and achieve the identity of materials and structures (Jagatheeshwaran et al., 2017). Metal matrix composites mean to paint the reinforcement material to the metal surface, making it has the properties of both the metal matrix and the reinforcement material at the same time, showing as higher specific strength, higher specific modulus, better wear resistance, and better corrosion resistance, etc. (Hopp and Vollmer, 2018; Zhong et al., 2014). Metal matrix composites are simple in production methods, low in production cost, and suitable for mass production, and can be industrialized. They have become widely used materials in aerospace, metallurgy, and chemical industries (Sajdha et al., 2011). Based on the principle of electroless nickel plating, this paper studies the erosion and wear resistance of iron matrix reinforced composites.

2. Preparation of surface nickel plating

2.1 Basic principle of electroless nickel plating

Metallic nickel can be precipitated in hypophosphite solution. High-phosphorus electroless nickel plating is a commonly used technique for electroless nickel plating. With the development of new processes and new technologies, pulsed, microwave, and laser electroless nickel plating techniques have gradually become more mature (Li et al., 2010; Das et al., 2015). The electroless nickel plating has extremely high hardness, wear resistance and corrosion resistance. The mature electroless nickel plating method uses sodium hypophosphite as a reducing agent. Using atomic hydrogen state theory, all chemical reactions take place on the surface of the metal composites, the specific reaction process is as follows:

Oxidation of reductant occurs at the anode:



Reduction of metal ions occurs at the cathode:



2.2 Plating process

Electroless nickel plating includes two chemical reactions: oxidation and reduction. If the pretreatment is not good, it will lead to poor adhesion of the plating layer on the surface of the metal composites. Before the nickel plating, the surface of the metal composites needs to be roughened, neutralized, sensitized activated and reduced in five steps, the selected electroless plating solution contains nickel salts, complexing agents, reducing agents and various additives, the nickel plating process generally uses glass nickel plating pool, with constant water bath heating (Medinaesquivel et al., 2012). Table 1 shows the effect of plating time on the plating thickness and plating rate. Figure 1 shows the relationship between plating thickness and plating time. It can be seen that as the plating time increases, the plating thickness increases more and more slowly, the thickness of the plating increased fastest in the first ten minutes, and the thickness of the plating tended to be gentle in about 60 minutes. Figure 2 shows the relationship between the plating rate and the plating time. The plating rate decreases with the increase of plating time, and finally approaches zero.

Table 1: Effect of plating time on plating thickness and plating rate

Plating time/min	Increased weight/g	Coating thickness/ μm	Plating speed/ $\mu\text{m}/\text{min}$
10	0.03856	1.508	0.1528
20	0.05237	2.037	0.0538
30	0.06520	2.439	0.0503
40	0.07104	2.780	0.0336
50	0.07641	2.969	0.0224
60	0.07874	3.0213	0.0156
70	0.08068	3.109	0.0081
80	0.08242	3.120	0.0031

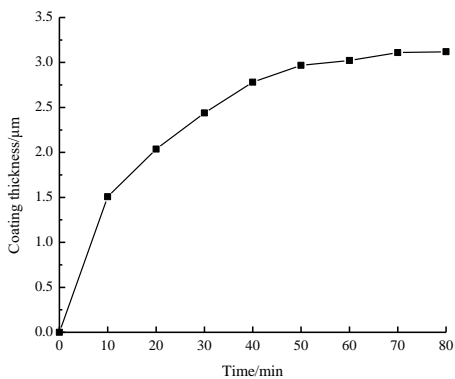


Figure 1: Relationship between plating thickness and plating time

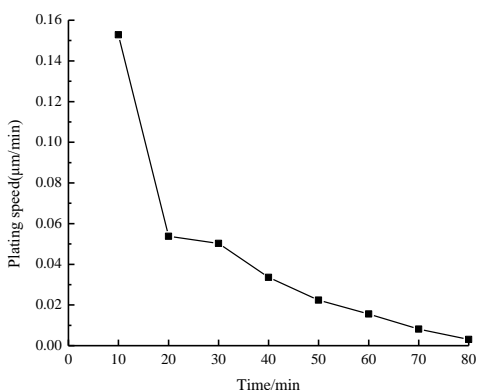


Figure 2: Relationship between plating rate and plating time

3. Preparation of iron matrix composites and microstructure and properties analysis

3.1 Preparation of iron matrix composites

In this experimental study, a vacuum negative pressure casting-infiltration process was applied to the preparation of iron matrix composites, which promoted the infiltration of high-temperature metal liquids into the composite layer and increased the infiltration depth. The role of vacuum was to generate internal and external pressures in the cavity and promote the matrix metal liquid to infiltrate into the composite layer, so as to increase the composite thickness, besides, vacuum can remove water vapor particles and avoid casting defects. In the preparation process of iron matrix composites, the casting temperature of the iron matrix metal liquid has an important influence on the composite layer, the higher the casting temperature, the better the bonding properties of the matrix interface. Figure 3 shows the process flow of negative pressure casting-infiltration. The selection of plastic mask is very important in the process of negative pressure casting-infiltration. The mask must have good formability and plasticity, and the range of heat softening temperature is large.

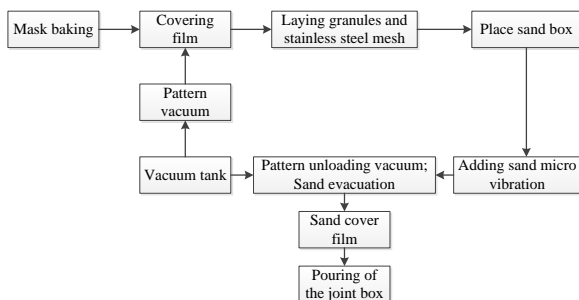


Figure 3: Process flow chart of negative pressure casting-infiltration preparation

3.2 Analysis of microstructure and properties of iron matrix composites

When the matrix is an iron matrix composite material, when the erosion wear test is performed, it can be found that the iron matrix material is susceptible to abrasive wear, that is, the support effect of the matrix will lose its effect, resulting in serious wear of the iron matrix composites, greatly reducing the wear resistance of the composite material. The reinforcement of composites with different particle sizes can significantly enhance the wear-resistance of iron matrix composites. The most widely used is alumina particles. The uniformity and properties of the particles play an important role in enhancing the contact properties between the particles and the matrix metal. In the case of nickel-plated composites, the composite layer is nickel-plated Al_2O_3 and high-chromium cast iron particles. Casting of the molten iron solution causes the high-chromium cast iron to melt and diffuse in the matrix.

4. Study of erosion and wear resistance of iron matrix composites

4.1 Experimental conditions and methods

Figure 4 shows the effect of erosion angle on the erosion wear of ductile materials and brittle materials. The erosion wear characteristics of the two materials are completely different. The erosion wear rate of brittle materials increases with the erosion angle. Under slurry erosion wear conditions, perform wear test on the electroless nickel plated iron matrix composites, the prepared slurry of the test is consisted of hard solid phase and weak alkaline solution, then evaluate the wear resistance of the composites under the interaction of corrosion and wear. Erosion wear test was performed using a wear tester with a high-speed rotating blade. The blade radius of the tester was 0.078 m, the spindle speed was 950 r/min, and the erosion angle was 90° . The high chromium cast iron wear resistant material was used as a control sample. The heat treatment curve of the high chromium cast iron is shown in Figure 5. The test uses 24h continuous erosion wear. The damage of the sample is the sum of the individual microscopic volume damage on the surface of the material. This paper takes the sample's unit area weight loss W as the indicator for measuring the erosion resistance of the sample:

$$W = \frac{W_1 - W_2}{T \cdot S} \quad (6)$$

Where: W_1 is the original weight of the sample; W_2 is the weight of the sample after erosion wear; T is the wear time; S is the area of the wear surface.

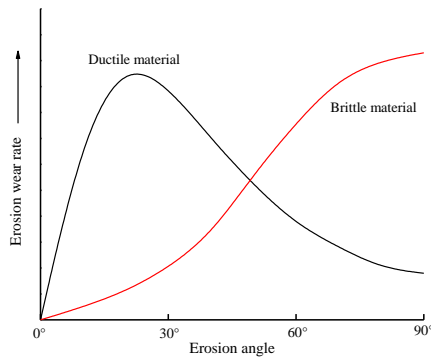


Figure 4: Effect of erosion angle on the erosion wear of ductile material and brittle material

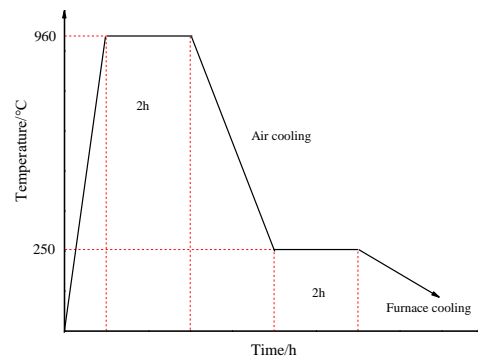


Figure 5: Heat treatment curve of high chromium cast iron

4.2 Experimental results and analysis

Table 2 shows the erosion wear test results of iron matrix composites with different particle volume fractions. The volume wear and relative wear resistance of the comparative sample and the composites can be clearly seen. Figure 6 shows the volume wear of iron matrix composites with different particle volume fractions, it can be seen that the larger the volume fraction of particles, the greater the volume wear, it's mainly because with the increase in particle volume fraction, the binding of particles and iron matrix becomes worse, when the volume fraction of particles is 19%, it is equal to the volume wear of high-chromium cast iron, showing better wear resistance. Table 3 shows the erosion wear test results of iron matrix composites with different particle sizes, and Figure 7 shows the erosion wear resistance of iron matrix composites with different particle sizes. It

can be seen that when the particle volume fractions are the same, the erosion wear of iron matrix composites increases with the particle size.

Table 2: Erosion wear test results of iron matrix composites with different particle fractions

Wear specimen	Volume wear ($\text{mm}^3/\text{m}^2\cdot\text{h}$)	Relative wear resistance
High chromium cast iron	62.10	1
Composite materials (Vc51%)	128.71	0.50
Composite materials (Vc36%)	93.82	0.68
Composite materials (Vc27%)	86.46	0.73
Composite materials (Vc19%)	63.20	0.9

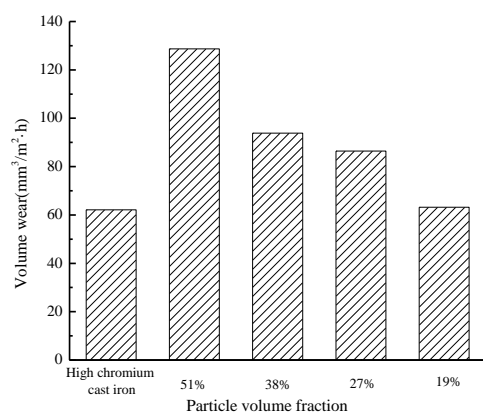


Figure 6: Volume wear of iron matrix composites with different particle volume fractions

Table 3: Erosion wear test results of iron matrix composites with different particle sizes

Particle size	Wear specimens	Volume wear ($\text{mm}^3/\text{m}^2\cdot\text{h}$)
20-40 mesh	Composite materials (Vc51%)	140.35
	Composite materials (Vc36%)	100.38
	Composite materials (Vc27%)	90.26
40-70 mesh	Composite materials (Vc51%)	129.45
	Composite materials (Vc36%)	94.35
	Composite materials (Vc27%)	87.94

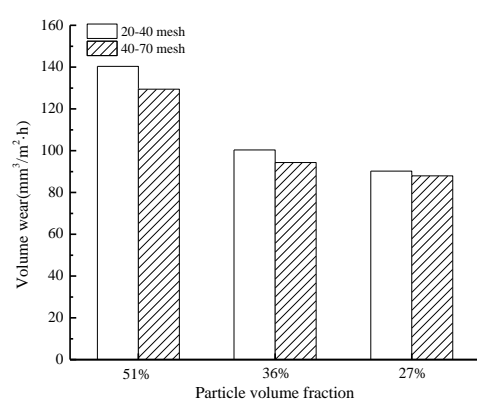


Figure 7: Erosion wear resistance of iron matrix composites with different particle sizes

5. Conclusion

In this paper, surface electroless nickel plating technology is used to improve the infiltration of molten iron between the reinforced particles, so as to obtain iron matrix composites with stronger erosion resistance, the specific conclusions are as follows:

(1) As the plating time increases, the plating thickness increases more and more slowly. The thickness of the plating layer increases fastest in the first ten minutes. The plating thickness tends to be gentle in about 60 minutes, and the plating rate decreases with the increase of plating time, and finally approaches zero.

(2) Reinforcement of composites with different particle sizes can significantly enhance the wear resistance of iron matrix composites. The uniformity and properties of the particles play an important role in enhancing the contact properties between the particles and the matrix metal.

(3) The larger the volume fraction of the particles, the greater the volume wear, the worse the binding of the particles and the iron matrix. When the volume fraction of the particles is 19%, it is equal to the volume wear of the high-chromium cast iron, showing better wear resistance. When the particle volume fraction is the same, the erosion wear of iron matrix composites increases with the particle size.

References

- Cheon S.Y., Park S.Y., Rhym Y.M., Kim D.H., Lee J.H., 2011, The effect of bath conditions on the electroless nickel plating on the porous carbon substrate, *Current Applied Physics*, 11(3), 790-793, DOI: 10.1016/j.cap.2010.11.076.
- Das S., Hendrix A., Stone D., Neithalath N., 2015, Flexural fracture response of a novel iron carbonate matrix – glass fiber composite and its comparison to portland cement-based composites, *Construction & Building Materials*, 93, 360-370, DOI: 10.1016/j.conbuildmat.2015.06.011.
- Hopp T., Vollmer C., 2018, Chemical composition and iron oxidation state of amorphous matrix silicates in the carbonaceous chondrite acfer 094, *Meteoritics & Planetary Science*, 53(2), 153-166, DOI: 10.1111/maps.12991.
- Jagatheeshwaran M.S., Elayaperumal A., Arulvel S., 2017, Impact of nano zinc oxide on the friction – wear property of electroless nickel-phosphorus sea shell composite coatings, *Materials Science & Engineering B*, 225, 160-172, DOI: 10.1016/j.mseb.2017.08.026.
- Li J., Zong B.Y., Wang Y.M., Zhuang W.B., 2010, Experiment and modeling of mechanical properties on iron matrix composites reinforced by different types of ceramic particles, *Materials Science & Engineering A*, 527(29–30), 7545-7551, DOI: 10.1016/j.msea.2010.08.029.
- Liu Y., Zhao W., Zhou T., Liu X., Wang X., 2017, Surface defect elimination in microgrooving of electroless nickel phosphide plating layer by brittleness enhancement, *International Journal of Advanced Manufacturing Technology* (7), 1327-1333, DOI: 10.1007/s00170-017-0940-7.
- Luo L.M., Lu Z.L., Tan X.Y., Ding X.Y., Huang L.M., Cheng J.G., 2013, A specific chemical activation pretreatment for electroless nickel plating on sic ceramic powders, *Powder Technology*, 249(11), 431-435, DOI: 10.1016/j.powtec.2013.08.039.
- Medinaesquivel R.A., Zambranoarjona M.A., Mendezgamboa J.A., Yanezlimon J.M., Ordenezmiranda J., Alvaradogil J.J., 2012, Thermal characterization of composites made up of magnetically aligned carbonyl iron particles in a polyester resin matrix, *Journal of Applied Physics*, 111(5), 2443, DOI: 10.1063/1.3691592.
- Rajaguru J., Duke M., Au C.K., 2015, Development of rapid tooling by rapid prototyping technology and electroless nickel plating for low-volume production of plastic parts, *International Journal of Advanced Manufacturing Technology*, 78(1-4), 31-40, DOI: 10.1007/s00170-014-6619-4.
- Raval M.C., Solanki C.S., 2015, Characterization of electroless nickel as a seed layer for silicon solar cell metallization, *Bulletin of Materials Science*, 38(1), 197-201, DOI: 10.1007/s12034-014-0828-1.
- Sajdha H.N., Kalsotra B.L., Kumar N., Kumar S., 2011, Synthesis and characterization of composites of mixed oxides of iron and neodymium in polymer matrix of aniline-formaldehyde, *Bulletin of Materials Science*, 34(4), 843-851, DOI: 10.1007/s12034-011-0204-3.
- Sudagar J., Lian J.S., Jiang Q., Jiang Z.H., Li G.Y., Elasezhian R., 2012, The performance of surfactant on the surface characteristics of electroless nickel coating on magnesium alloy, *Progress in Organic Coatings*, 74(4), 788-793, DOI: 10.1016/j.porgcoat.2011.10.022.
- Wu Z., Ge S., Zhang M., Li W., Tao K., 2009, Synthesis of nickel nanoparticles supported on metal oxides using electroless plating: controlling the dispersion and size of nickel nanoparticles, *Journal of Colloid & Interface Science*, 330(2), 359-366, DOI: 10.1016/j.jcis.2008.10.083.
- Zhao Y., Chen H., Yan Q., 2017, Enhanced phosphate removal during the simultaneous adsorption of phosphate and Ni^{2+} from electroless nickel wastewater by calcium silicate hydrate (CSH), *Environmental Technology & Innovation*, 8, 141-149, DOI: 10.1016/j.eti.2017.01.002.
- Zhong L., Ye F., Xu Y., Li J., 2014, Microstructure and abrasive wear characteristics of in situ vanadium carbide particulate-reinforced iron matrix composites, *Materials & Design*, 54(2), 564-569, DOI: 10.1016/j.matdes.2013.08.097.