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Investigation of the effect of nano-SiC on the hardness and wear resistance of Ni–SiC nanocomposite coatings

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Ni–SiC nanocomposite coating for the surface of automobile drive shaft based on 40Cr steel was obtained, its microstructure, hardness, wear resistance and corrosion resistance was analyzed, and the effect of the nano-SiC mass concentration on the hardness and wear resistance of Ni–SiC nanocomposite coatings was studied. The results show that the Ni–SiC nanocomposite coating consists mainly of Ni and SiC, and its average hardness is about 558.4 HV, which is 1.5 times of 40Cr steel. The increase of the content of nano SiC is beneficial for improving the hardness and the wear resistance. When the SiC particle size is 70 nm and the mass concentration is 14 g/L, the Ni–SiC nanocomposite coating has the highest hardness and the best wear resistance.
Keywords: Ni–SiC nanocomposite coating, automotive transmission shaft, wear resistance, corrosion resistance.

Получено нанокомпозитное покрытие Ni–SiC для поверхности приводного вала автомобиля на основе стали 40Cr, проанализированы его микроструктура, твердость, износостойкость и коррозионная стойкость, а также влияние массовой концентрации наночастиц SiC на твердость и износостойкость Ni–SiC нанокомпозитных покрытий. Результаты показывают, что нанокомпозитное покрытие Ni–SiC состоит в основном из Ni и SiC, и его средняя твердость составляет около 558,4 HV, что в 1,5 раза больше стали 40Cr. Увеличение содержания нано-SiC повышает твердость и износостойкость. Когда размер частиц SiC составляет 70 нм, а массовая концентрация составляет 14 г/л, нанокомпозитное покрытие Ni–SiC имеет самую высокую твердость и лучшую износостойкость.

Дослідження впливу нано-SiC на твердість і зносостійкість нанокомпозитних покриттів Ni–SiC. *Q.Wang, Muhammad Aqeel Ashraf*.

Отримано нанокомпозитне покриття Ni–SiC для поверхні приводного вала автомобіля на основі сталі 40Cr, проаналізовано його мікроструктуру, твердість, зносостійкість і корозійну стійкість, а також вплив масової концентрації наночастинок SiC на твердість і зносостійкість Ni–SiC нанокомпозитних покриттів. Результати показують, що нанокомпозитне покриття Ni–SiC складається в основному з Ni і SiC, і його середня твердість становить близько 558,4 HV, що в 1,5 рази більше сталі 40Cr. Збільшення вмісту нано-SiC підвищує твердість і зносостійкость. Коли розмір часток SiC становить 70 нм, а масова концентрація – 14 г/л, нанокомпозитне покриття Ni–SiC має найвищу твердість і кращу зносостійкість.

1. Introduction

Mechanical parts are required to operate reliably under varieties of working conditions, and the surface properties of mechanical parts have an important impact on their service life. Ni–SiC nanocomposite coating has the advantages of high hardness, corrosion resistance, wear resistance and high temperature oxidation resistance, and is widely used in internal combustion engine and automobile engine parts to improve the surface properties of the components [1].

As an important part of the automotive transmission system, the transmission shaft transmits the power of the engine to the wheels and drives the car. Automotive transmission bearings are subject to random characteristics of torque, and their surface performance will decrease with long-term use. Liu and others used Ni–SiC composite coatings obtained by pulse electrode position method to study the effects of SiC nanoparticles on the surface morphology, microstructure, microhardness, wear resistance and corrosion resistance of Ni–SiC composite coatings [2]. Li and others investigated the effects of nano-SiC particles on the structure and morphology of Ni–Co coatings. It was found that the addition of Co made the Ni coating grain finer, decreased the porosity and improved corrosion resistance [3]. Nazir and others analyzed the effects of direct current electrode position and pulse electrode position on the properties of the coating. It was found that use of the electrodeposition method led to sufficient improvement of the Ni–SiC nanocomposite coating [4]. Rizwan et al. prepared Ni-nano-SiC composite coating on the surface of Q235 steel by pulse electrode position. The effects of single process conditions on the micro hardness and wear resistance of Ni–SiC composite coatings were investigated by scanning electron microscopy (SEM), X-ray diffractometry (XRD), microhardness tester and friction and wear tester [5]. In [6] the effects of addition of silicon carbide particles on the micro hardness and wear resistance of the coating was studied. The test results have shown that the surface of the nanocomposite electroplated layer is smooth, and its microhardness and wear resistance are significantly improved compared with pure nickel plating [6].

In order to improve the anti-wear performance and corrosion resistance of automotive transmission shafts, Ni–SiC nanocomposite coatings were prepared on the surface of automotive transmission shafts based on 40Cr steel. The hardness, wear resistance and corrosion resistance of Ni–SiC nanocomposite coatings were investigated. And the effect of the mass concentration of nano-SiC on the hardness and wear resistance of Ni–SiC nanocomposite coating was investigated.

Table 1. Plating solution formula and electrode position process parameters

Formulation and process parameters	Value
$NiSO_4 \cdot 6H_2O$, $g \cdot L^{-1}$	300
$NiCl_2$, $g \cdot L^{-1}$	42
H_3BO_3, $g \cdot L^{-1}$	35
$C_{12}H_{25}NaO_4S$, $g \cdot L^{-1}$	0.1
Current density, $A \cdot dm^{-1}$	6.2
Bath temperature, °C	45
Nano SiC particle mass concentration, $g \cdot L^{-1}$	20
Magnetic stirring, $r \cdot min^{-1}$	350

2. Experimental

2.1 Substrate preparation

The base material was an automobile semi-axle steel (40Cr steel), and the sample size was 40.0×25.0×1.5 mm^3. The pretreatment process of 40Cr steel included grinding, polishing, degreasing, pickling, washing, and drying. The purpose of the pretreatment is to ensure that the surface of the 40Cr steel is free from cracks, deep scratches, and has no oil and oxide film. The base liquid is a watt-type nickel plating liquid, and its main components are: $NiSO_4Ni$ $SO_4 \cdot 6H_2O$ g/L, Ni Cl_2, H_3BO_3 30 g/L, $C_{12}H_{25}Na$ O_4S 0.1 g/L. Micro SiC (particle size 4 μm) and nano SiC (particle diameter 70 nm) were added to the base liquid. The mass concentration of micron SiC is 14 g/L. Stirring is sufficient to uniformly disperse the SiC particles in the base liquid.

2.2 Preparation of Ni–SiC nanocomposite coating

In this article, the composite electroplating method is used to prepare Ni–SiC nanocomposite coating (referred to as composite coating) on the surface of the substrate by electrode position [7–9]. The plating solution formulation and electrode position process parameters are shown in Table 1. The reagents used are analytically pure. The selected SiC particles have an average parti-

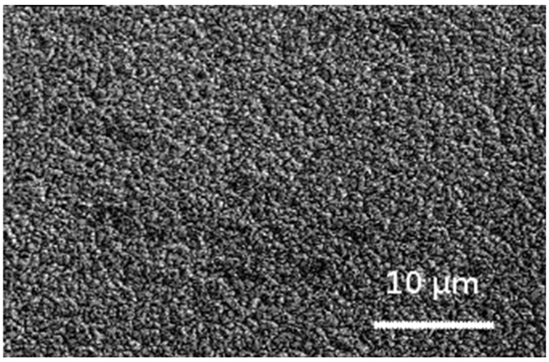

Fig. 1. Composite coating SEM.

cle size from 50 to 100 nm. The SiC particles are fully soaked with a small amount of deionized water containing a dispersing agent, then poured into the plating solution, and continuously stirred by a magnetic stirrer to uniformly disperse the SiC particles [10]. The experimental composite coating has a thickness of about 45 μm.

2.3 Performance test

The morphology of the composite coating was analyzed by JSM-6390A scanning electron microscope. The phase composition of the composite coating was analyzed by Bruker D8 Advance X-ray diffractometer (XRD). Tecnai G2 F30 Field Emission Transmission Electron Microscope (TEM) was used to analyze the microstructure of composite coatings. The hardness was measured using a XH-5L Vickers hardness tester with a load of 0.49 N for 10 s. Six points were taken on the surface of the composite coating for hardness measurement, and the average hardness was obtained.

The dry friction test was carried out using a MFT-4000 material surface property tester to test the wear resistance of the composite coating. The test load was 10 N and the rubbing time was 8 min. The corrosion resistance of the composite coating in 3.5 % NaCl solution and 1.5 % HCl solution was measured by static immersion etching. The experiment lasted for 140 h, and the samples were taken out every 20 h for cleaning and drying, and then weighed with an AR124CN type electronic balance to calculate the corrosion rate. Scanning electron microscopy was used to analyze the morphology of the composite coating after 140 h of soaking.

The hardness, anti-wear performance and corrosion resistance of the substrate were tested under the same conditions and the morphology of the substrate after 140 h soaking was analyzed.

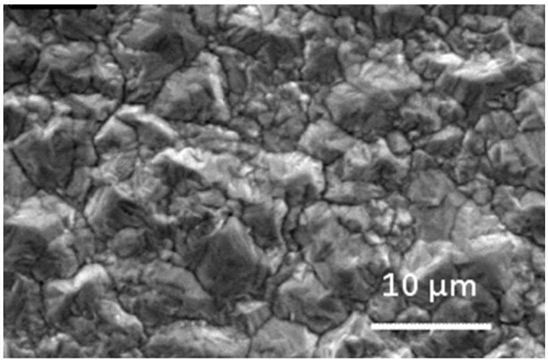

Fig. 2. Nickel plating SEM.

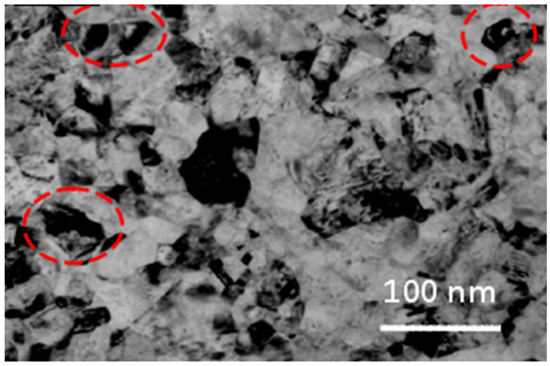

Fig. 3. Nanocomposite coating TEM.

3. Results and analysis

3.1 Microstructure of composite coating

Figure 1 and Figure 2 show the microstructure of Ni–SiC nanocomposite coating and nickel coating. It can be seen from Fig. 3 that the composite coating has fine crystal grains and compact structure, while the nickel plating layer has coarse crystal grains and the crystal grain size of few micrometers. Figure 3 is a TEM image of the composite coating. Nano SiC particles are uniformly dispersed between the nickel crystal grains. The dispersed nano-SiC particles effectively fill the intercrystalline pores and further evolve into catalytic nucleation sites, induce heterogeneous nucleation, and promote the formation and growth of new nucleus faster. At the same time, the coarsened growth of the formed crystal nuclei is hindered, so that the composite plating layer has fine crystal grains and compact structure.

3.2 Hardness of composite coating

Table 2 is a hardness table of the substrate and the Ni–SiC nanocomposite coating. As seen from Table 2, the hardness of the substrate ranges from 350 to 375 HV, and the average hardness is about

Table 2. Hardness of substrate and Ni–SiC nanocomposite coating

Material	Detection sampling point	Hardness, HV
Substrate	1	351
	2	362
	3	361
	4	368
	5	375
Composite coating	1	584
	2	562
	3	546
	4	552
	5	568

373.7 HV, while the hardness of the composite coating ranges from 545 to 580 HV, and the average hardness is about 558.4 HV. The composite coating has a higher average hardness than the substrate (in about 1.5 times). Although there is no direct correspondence between the hardness and wear resistance of the material, the higher hardness allows the material to have higher friction and wear resistance. Therefore, the higher hardness of the composite coating is beneficial to improve its wear resistance. Figure 4 shows the effect of the mass concentration of nano SiC on the hardness of the Ni-nano SiC composite coating. It can be seen from Fig. 5 that as the mass concentration of nano-SiC increases from 2 g/l to 20 g/L, the hardness of Ni-nano-SiC composite coating increases first and then decreases, the highest value is 5486 MPa, and the corresponding nano SiC has a mass concentration of 14 g/L.

When the mass concentration of nano-SiC is 2 g/L, the surface of the Ni-nano-SiC composite coating is loose and the grain size reaches the order of micrometers. When the mass concentration of nano-SiC is 14 g/L, the surface of the Ni-nano-SiC composite coating is dense, the grains are fine and uniform, and the size is reduced to the order of nanometers. It shows that the increase of nano SiC is beneficial to increase the density of the coating, improve its hardness and resistance to plastic deformation, then improve wear resistance. However, when the mass concentration of nano-SiC increases to 20 /L, the agglomerated nano-SiC reduce the density of the coating , which cause decrease of the hardness of Ni-nano-SiC composite coating .

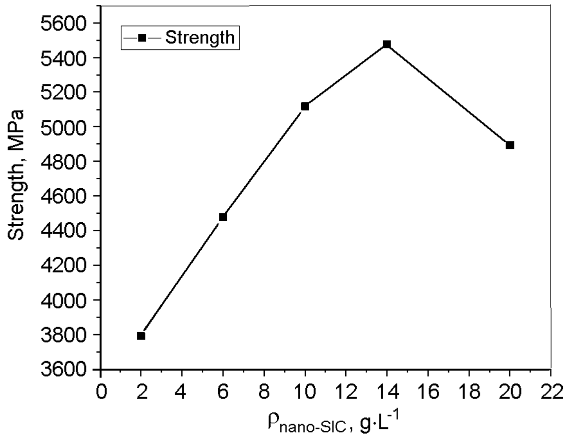

Fig. 4. Effect of nano SiC mass concentration on the hardness of composite coating.

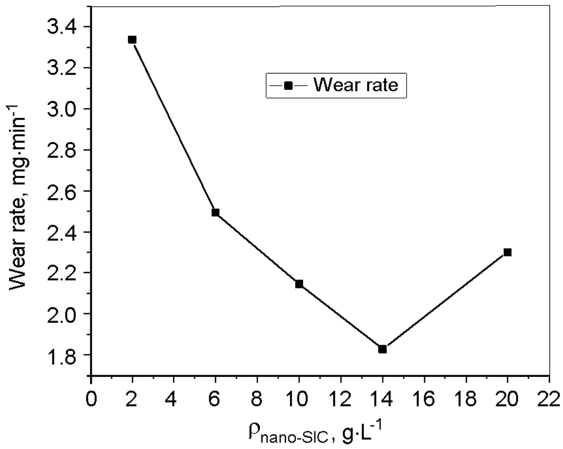

Fig. 5. Effect of mass concentration of nano SiC on wear rate of composite coating.

3.3 Wear resistance performance

Figure 5 shows the effect of the mass concentration of nano-SiC on the wear rate of Ni-nano-SiC composite coating, the wear time is 8 min. It can be seen from Fig. 7 that as the mass concentration of nano-SiC increases from 2 g/L to 20 g/L, the wear rate of Ni-nano-Si composite coating decreases first and then increases, the lowest is 1.82 mg/min, the mass concentration corresponding to nano SiC was 14 g/L.

3.4 Corrosion resistance

Figure 6 shows the corrosion rate of the substrate and the composite coating. Corrosion rate of the substrate and the composite coating gradually increases with the immersion time, while the corrosion rate of the composite coating is significantly lower than that of the substrate. After soaking for 140 h, the corrosion rate of the substrate is about 0.272 $\mu g \cdot mm^{-2} \cdot h^{-1}$, and the

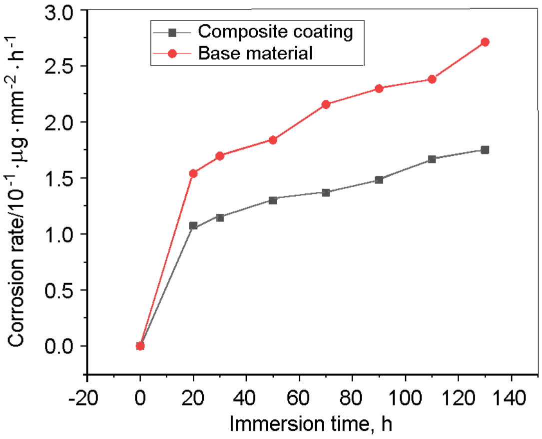

Fig. 6. Corrosion rate curve of substrate and composite coating.

corrosion rate of the composite coating is about 0.178 μg·mm^{-2}·h^{-1}. The corrosion rate is used as a reference index for evaluating the corrosion resistance of the material. As the corrosion rate of the composite coating is low, the corrosion resistance is expected to be high.

Figure 7, 8 is a surface topography image of the substrate and composite coating after 140 h of soaking. Soaking and etching leads to formation of corrosion pits on the surface of the substrate. After the immersion of the composite coating, the morphology is blurred, but it can be seen that the surface after immersion is still flat and there are no obvious corrosion pits.

In summary, the corrosion resistance of the composite coating is mainly attributed to the dispersion strengthening and fine grain strengthening of the nano-particles on the substrate coating. This effect increases the density of the coating, effectively hinders the adsorption of Cl in the etching solution and the corrosion caused by the penetration of the composite coating, thereby delaying the corrosion of the coating.

4. Conclusions

The influence of the nano-SiC on the hardness and wear resistance of Ni–SiC nanocomposite coatings was studied. The hardness of the composite coating ranges from 530 to 580 HV, and the average hardness is about 558.4 HV, which is 1.5 times of 40Cr steel. The plated stable friction factor (0.39), and the corrosion rate of the coating are significantly lower than for 40Cr steel. Ni–SiC nanocomposite coating can be used to improve the wear resistance and corrosion resistance of automotive transmission shafts based on 40Cr steel.

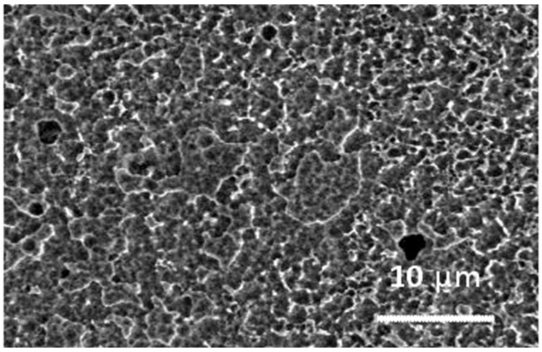

Fig. 7. Surface topography image after substrate immersion.

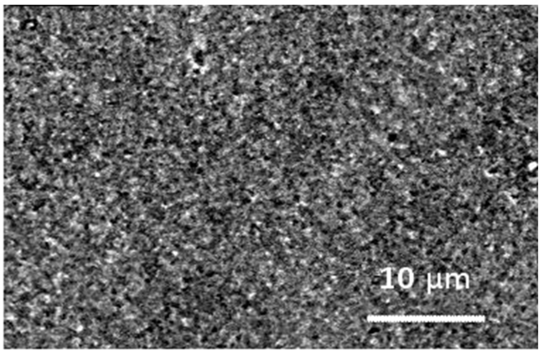

Fig. 8. Surface topography image after composite coating immersion

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