PRACE INSTYTUTU ODLEWNICTWA
TRANSACTIONS OF FOUNDRY RESEARCH INSTITUTE

Volume LVII Year 2017 Number 4

Electrolyte coatings of chromium with nanodiamonds on sintered steels

Nelly Gidikova[1], Radoslav Valov[1], Vladimir Petkov[1], Elmas Salamci[2], Zeynep Bilgili[2], Rahmi Unal[2]

[1]Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre "Acad. Angel Balevski" at Bulgarian Academy of Sciences, 67 Shipchenski prohod, 1574 Sofia, Bulgaria

[2]Gazi University, Faculty of Engineering, 06570 Maltepe, Eti Mah. Yukselis Sk. No. 5, Ankara, Turkey

E-mail: radoslav.valov@gmail.com

Received: 23.10.2017. Accepted in revised form: 29.12.2017.

DOI: 10.7356/iod.2017.34

Abstract

Sintered ferrous components were coated with electrochemical chromium coatings modified with nanodiamond particles. The nanodiamond particles were produced by detonation synthesis with an average grain size 8 nm. The objective of this study was to determine the tribological properties and the corrosion resistance of sintered iron samples coated with an electrochemically deposited chromium layer modified with nanodiamond particles. The thickness of the obtained composite coatings was more than 25 µm. The microstructure and microhardness were determined by metallographic methods. The mechanical and chemical properties of the samples were compared to uncoated samples prepared from the same iron powder. The microhardness was 5 times higher, the wear resistance increased 6 times and the corrosion resistance in 0.1 M NaCl solution was 10 times higher.

Keywords: *sintered products, chromium coating, wear resistance, corrosion resistance*

1. Introduction

Powder metallurgy is a high precision method with the capability of producing parts with near net shape and complex form with high dimensional tolerance. However, some problems may arise during the application of sintered parts because of their surface porosity [1]. Porous items show less resistance in a corrosive environment and also a decrease in mechanical properties [1,2]. To overcome these problems coatings are applied. The electrochemical chromium coatings have a wide practical application. They increase the hardness and the wear resistance of the substrate material and possess increased corrosion resistance. The modification of the chromium galvanic coatings with nanodiamond particles (NDPs) additionally increases these chemical and mechanical properties. The research of the influence of the nanodiamond particles on the characteristics and properties of the modified chromium layer in the published studies refer to coatings on dense materials [3–6]. The main goal of this study was to investigate the influence of the NDPs on microhardness, wear resistance and corrosion resistance of electrolytic chromium coatings applied on sintered iron products.

2. Experimental

The objective of this study was to apply composite chromium coating modified with nanodiamond particles on sintered iron products and to study the mechanical and chemical properties of the coating.

The electrochemical chrome plating was carried out on sintered samples prepared from iron powders produced by the company Höganäs AB Distaloy AB2 (DAB2) and Distaloy AB5 (DAB5) with chemical compositions shown in Table 1.

Table 1. Chemical composition of the pre-alloyed iron based powders

Iron powder	Components, wt. %					
	C	Cu	Ni	Mo	MnS	balance, Fe
Distaloy AB2	0.2	1.5	1.7	0.5	0.5	95.6
Distaloy AB5	0.5	1.5	1.7	0.5	0.5	95.3

The samples were prepared by cold uniaxial pressing at pressures 420, 550 and 700 MPa and sintered at 1120°C for 30 minutes in a reducing environment. The heating rate was 15°C/min and the cooling rate was 20°C/min. The total sintering cycle was 150 min. The dimensions of the sintered compacts were 12.7 × 31.7 × 10 mm.

The chromium was deposited on the surface of the sintered compacts by an electrolytic process with the traditional acidic electrolyte containing CrO_3 – 220 g/l and H_2SO_4 – 2.2 g/l. The parameters of the electrolytic process were: current density – 45 A/dm^2; process duration – 45 min and temperature of the electrolyte – 50°C. The diamond nanoparticles were added to the electrolyte as an aqueous suspension. Their concentration in the electrolyte was 25 g/l. The nanodiamond particles were produced by detonation synthesis [7].

The microstructure of the coatings was studied by light microscopy and scanning electron microscopy. The microhardness HV tests were carried out according to Vickers standard at least 10 points. The applied load was 0.5 N. The wear resistance was tested by pin-on-plate method. The corrosion resistance was studied in 0.1 M NaCl solution.

3. Results and discussion

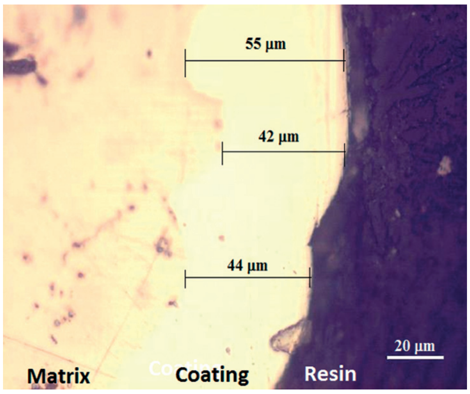
Microhardness increases with increasing the pressure and respectively with the sintered density (Table 2). The increase in microhardness of the coated sintered compacts compared to the uncoated ones is 4−5 times higher than for samples prepared from both DAB2 and DAB5 powders.

Table 2. Microhardness of samples uncoated and coated with chromium modified with ND

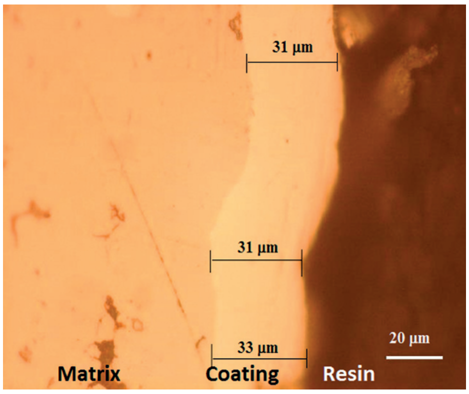
Samples	Compaction pressure, MPa	Sintered density, g/cm³	Microhardness of uncoated samples, MPa	Microhardness of coated samples, MPa
DAB2	420	7.164	2166	10 653
	550	7.196	2401	9 937
	700	7.220	2450	11 456
DAB5	420	7.104	2744	10 868
	550	7.108	2842	10 721
	700	7.111	2940	10 898

Microstructures of the coated cross section with chromium samples obtained from DAB2 and DAB5 powders are shown in Figure 1. The coating adheres tightly to the surface and follows the topography of the sintered product. The average measured thickness of chromium coating modified with nanodiamonds for DAB2 samples is 47 µm (Fig. 1A) and for DAB5 is 32 µm (Fig. 1B). The coatings of the two samples, DAB2 and DAB5, are prepared in the same galvanic conditions with the same concentration of nanodiamonds in the electrolyte (25 g/l) nevertheless the difference in their thickness is almost 50%. This effect can be attributed only to the composition of the matrix material. DAB2 contains 0.2% carbon and DAB5 contains 0.5% carbon.

The morphology of the surface of coated compact, prepared from DAB2 – compacting pressure 420 MPa, was observed by scanning electron microscopy (Fig. 2). The chromium coating cannot fill all the pores of the matrix material, which leads to pores and unevenness of the deposited layer.



A)



B)

Fig. 1. Microstructure of chromium coating deposited on the surface of steel compacts: A) DAB2, compacting pressure – 420 MPa, B) DAB5, compacting pressure – 420 MPa

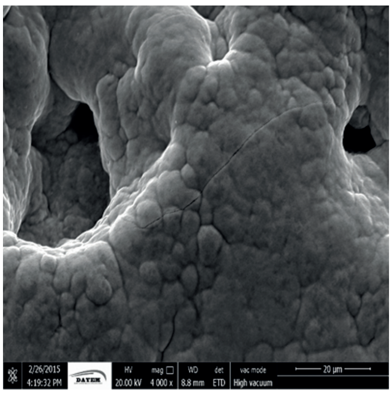


Fig. 2. Morphology of the chromium coating surface of coated sample (DAB2 – 420 MPS) observed by SEM

The surface porosity of coated and uncoated samples of both powders and at different compacting pressures is shown in Table 3. The surface porosity of coated samples prepared of DAB2 powder is decreased by 25−30%, while the change in the surface porosity for DAB5 samples is insignificant.

Table 3. Surface porosity of coated and uncoated samples

Sample code with compacting pressure	Surface porosity of uncoated samples, %	Surface porosity of coated samples, %
DAB2, 420 MPa	10.17	8.16
DAB2, 550 MPa	9.78	7.00
DAB2, 700 MPa	9.36	7.58
DAB5, 420 MPa	10.74	10.80
DAB5, 550 MPa	10.44	10.24
DAB5, 700 MPa	10.29	10.87

The wear resistance was determined from the loss of mass after 300, 500 and 600 cycles, which corresponds to a sliding distance of 45, 75 and 90 m. The wear resistance of samples prepared from both powders at compacting pressure 550 MPa is shown in Figure 3. It was found that coated steel compacts prepared from powder Distaloy AB2 (DAB2) perform better (approximately 5 times) compared to those prepared from Distaloy AB5 (DAB5). A similar effect as with the difference in the coating thickness is exhibited most probably due to the different composition of the substrate material.

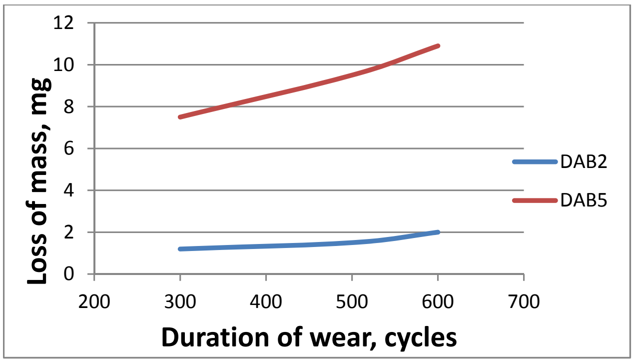


Fig. 3. The loss of mass during wear test

The corrosion resistance study of coated and uncoated samples was performed in 0.1 M NaCl solution. It was determined by polarization resistance test. The volt – ampere characteristics are shown in Figure 4. The corrosion current of the coated (green line) and uncoated (black line) samples can be compared. The corrosion current of the uncoated samples is much greater than that for the coated samples. This is evidence that the chromium coating modified with nanodiamonds applied on the surface increases significantly the corrosion resistance of the sintered ferrous parts.

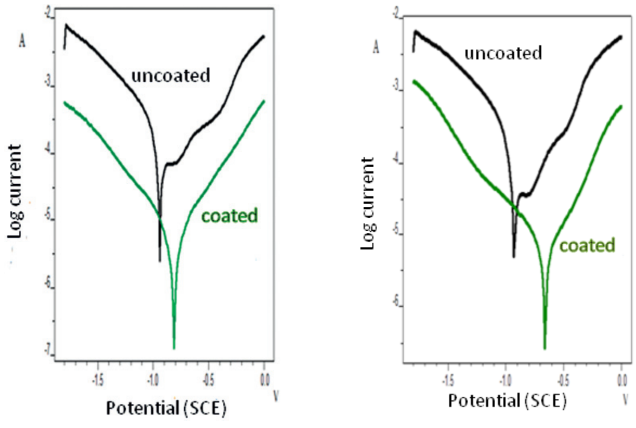


Fig. 4. Polarization resistance curves in 0.1 M NaCl solution of coated and uncoated samples prepared of DAB2 (A) and DAB5 (B)

The rate of corrosion and the efficiency of the coating are presented in Table 4. The samples were prepared at 550 MPa compaction pressure. The corrosion environment is 0.1 M solution of NaCl. The increase in corrosion resistance of coated samples prepared from DAB5 equals 505% compared to uncoated ones. A similar increase for samples of DAB2 equals 1030%.

Table 4. Corrosion rate and coating efficiency of coated and uncoated samples prepared from DAB2 and DAB5 powders

Sample	Corrosion environment	Corrosion rate, mm/year	Efficiency of the coating, %	Increase of the corrosion resistance, %
DAB2 uncoated	0.1 M NaCl	1.249	–	–
DAB2 coated	0.1 M NaCl	0.121	90	1030
DAB5 uncoated	0.1 M NaCl	1.057	–	–
DAB5 coated	0.1 M NaCl	0.209	80	505

The newly obtained product of sintered items and composite chromium coating undoubtedly has much higher performance values than conventional uncoated sintered iron powder samples. The influence of the composition of the substrate material on the properties of the coatings should be studied in greater detail.

4. Conclusions

1. A new product, consisting of composite coating of chromium modified with nanodiamonds, applied on a sintered iron substrate material, was fabricated. It was found that the deposited coating is smooth, dense and tightly bonded to the substrate material.

2. The measured average microhardness of the coating is 4−5 times higher than the average microhardness of the uncoated samples.

3. The corrosion resistance of the composite chromium coating modified with nanodiamonds deposited on sintered iron samples is up to 10 times greater than that of the uncoated samples.

4. The composite coating gives new possibilities for technical applications of the sintered products.

Acknowledgements

The financial support of the Fund “Scientific Researches” at the Ministry of Education and Science, Contract No. DN 07/8/15.12.2016 is gratefully acknowledged.

References

1. Etaat M., M. Emamy, M. Ghambari, E. Fadaei. 2009. “Surface treatment and nickel plating of iron powder metallurgy parts for corrosion protection”. *Materials and Design* 30 (9) : 3560−3565.

2. Leisner P., R.C. Leu, P. Møller. 1997. “Electroplating of porous PM compacts”. *Powder Metallurgy* 40 (3) : 207−210.

3. Dolmatov V., T. Fujimura, G. Barkat, E. Orlova. 2003. “Preparation of wear-resistant chromium coatings using different types of nanodiamonds”. *Powder Metallurgy and Metal Ceramics* 42 (11−12) : 587−591.

4. Mandich N.V., J.K. Dennis. 2001. “Codeposition of nanodiamonds with chromium”. *Metal Finishing* 99 (6) : 117−119.

5. Isakov V.P., A.I. Lyamkin, D.N. Nikitin, A.S. Shalimova, A.V. Solntsev. 2010. “Structure and properties of chromium-nanodiamond composite electrochemical coatings”. *Protection of Metals and Physical Chemistry of Surfaces* 46 (5) : 578−581.

6. Gidikova N., A. Ciaś, V. Petkov, M. Madej, M. Sułowski, R. Valov. 2014. “Wear resistant chromium coatings modified with diamond nanoparticles”. *Archives of Metallurgy and Materials* 59 (4) : 1513−1516.

7. Krueger A. 2008. “The structure and reactivity of nanoscale diamonds”. *Journal of Materials Chemistry* 18 (13) : 1485−1492.