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DETONATION SPRAYED COATINGS Al_2O_3-TiO_2 AND WC/Co ON ADI INVESTMENT CASTINGS

POWŁOKI Al_2O_3-TiO_2 ORAZ WC/Co NATRYSKIWANE DETONACYJNIE NA ODLEWY PRECYZYJNE Z ŻELIWA ADI

Austempered Ductile Iron ADI posses many mechanical properties thanks them became competitive for many ferrous and nonferrous materials, for example for steels and aluminium alloys. These properties are somewhat limited in a couple of areas. One of them is instability of mechanical properties of ADI in high temperature caused by the separating processes over 400°C in this material. The research shown in this article proposes the detonation gun spraying method which could solve this problem.

This article shows the technology of acquiring coatings Al_2O_3-TiO_2 and WC/Co detonation sprayed on the base made of austempered ductile iron EN-GJS-800-8 grade. Produced material was the subject of measuring light and electron microscopy. Research results show that sprayed coatings may have thickness form few to several hundreds of micrometers, micro hardness of Al_2O_3-TiO_2 coating can have values up to 900HV0,1 and for coatings WC/Co up to 1400HV0,1. This article shows also results of the abrasive wear tests. It was found that surface layer of the austempered ductile iron was hardened as a result of spraying process. This article also presents the results of the coating morphology tests, performed in the zone of connection between coating and base.

Keywords: Detonation gun spraying, Austempered Ductile Iron, TRIP effect, Metastable austenite, Investment castings

Żeliwo sferoidalne ausferrytyczne ADI posiada wiele właściwości mechanicznych, dzięki którym stało się konkurencyjne dla wielu materiałów żelaznych i nieżelaznych, np. stali i stopów aluminium. Bardzo dobre właściwości mechaniczne żeliwa ADI są jednak ograniczone w pewnych zakresach. Wadą żeliwa ADI jest niestabilność jego właściwości mechanicznych spowodowane zachodzeniem procesów wydzieleniowych powyżej 400°C. Uniemożliwia to eksploatację tego materiału w podwyższonych temperaturach. Niniejsza praca proponuję metodę natryskiwania detonacyjnego jako rozwiązanie tego problemu.

W artykule przedstawiono technologię otrzymywania powłok Al_2O_3-TiO_2 i WC/Co natryskiwanych detonacyjnie na podłoże z żeliwa sferoidalnego ausferrytycznego gatunku EN-GJS-800-8. Powłoki natryskiwane detonacyjnie charakteryzują się wysoką odpornością na zużycie i wysoką temperaturę, odpornością na korozję, wysoką twardością, małą porowatością oraz dużą adhezją i kohezją. Wytworzony materiał poddano badaniom mikroskopii świetlnej i elektronowej. W wyniku badań stwierdzono, że nałożone powłoki w zależności od warunków procesu mogą mieć grubość od kilku do kilkuset mikrometrów, mikrotwardość dla powłoki tlenkowej do 900HV0,l oraz dla powłoki węglikowej do 1400HV0,1. Przedstawiono również wyniki badań odporności na zużycie przez tarcie. Stwierdzono umocnienie warstwy wierzchniej żeliwa sferoidalnego ausferrytycznego wywołanego procesem natryskiwania. Przedstawiono wyniki badań morfologii powłoki, strefy połączenia powłoka-podłoże.

1. Introduction

Austempered Ductile Iron (ADI) is a constructional material, classified according to standard PN-EN 1564 and ASTM A897 [1,2]. Its great mechanical properties, competing with those of steel [3], are somewhat limited in a couple of areas. Especially interesting problem with ADI is instability of mechanical properties in high temperature. Over 400°C, in this material, the separating processes which worse its properties, are proceeding. These separation processes make the usage of ADI element impossible. The destruction of the desired microstructure in high temperature makes it impossible to improve wear resistance and corrosion resistance through classical processes of surface treatment, which are usually realized above 400°C. The research shown in this article proposes a technological method which could fulfill our needs. This method is detonation spraying.

Detonation sprayed coatings are characterized with high wear resistance and resistance to high temperature, good corrosion resistance, high hardness, small porosity, high adhesion and cohesion. These layers can enrich

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surface of important elements of machine parts and tools not only manufactured through machining, but also manufactured as precision castings, in which the surface is destined for exploatation directly after casting. The energy from the explosive combustion of the gaseous mixture is used for detonation spraying. This energy is used to heat up particles of powdered coating material and to give them specific kinetic energy. Accelerated particles collide at high velocity with element's surface forming a layer strongly bounded with the base.

This article shows the research results of the Al_2O_3-TiO_2 and WC/Co coatings detonation sprayed on the austempered ductile iron castings, grade EN-GJS-800-8 grade.

Bounding of particles with the base in the detonation spraying method can be described as follows [4]:

1. First, as a result of plastic deformation of the particles in touch with the base and next incoming particles with those already placed and deformed on the base the physical connection is created.
2. Next, the connected surfaces activate themselves. Activation is the function of temperature, pressure, which depends on the terminal velocity and the mass of the particle, and sometimes their interaction.
3. The following stage is the volume influence of the materials through the contact surfaces and generating the strong connection.

Acquiring of the strong connection between coating and base is possible thanks to generation of chemical connection between the atoms of both materials at the phase boundary. Chemical bonds between the saturated base atoms must be destroyed and they must connect with the free bounds of the particle atoms [5]. Adhesion is generated also through the mechanical connection of the coating with rough surface of the base, [6], while the higher the roughness is, the higher is the resistance of the connection.

2. Methods of research

Investment castings from the austempered ductile iron were acquired as a result of melting metal in medium-frequency induction furnace, with the load capacity of 500kg with spheroidizing NiCuMg17, the Sandwich method. The samples were casted in the shape of "stairs" (fig.1a). The specimens were made in the ceramic forms air-cooled after the casting process. The castings (which chemical constitution, measured by means of emissivity spectrometer with spark induction Foundry Master S/N, is shown in table 1) were next sand blast cleaned and after cutting off the gatting system the microstructures were examined (Fig. 1b). The castings were made in the Polish Foundry Research Institute in Krakow in the Iron Alloys Department. The heat treatment were austenitizing (T=900°C, t=2h) and austempering in fluidized bed (T=370°C, t=1h).

TABLE 1

Chemical composition of the austempered ductile iron grade EN-GJS-800-8, [% wt.]

C	Si	Mn	P	S	Cr
3,40	2,80	0,28	0,035	0,015	0,04
Ni	Mg	Cu	Mo	Fe	
0,02	0,055	0,72	0,27	92,46	

TABLE 2

Physical properties of the powders used for creation of layers and theoretical mechanical properties for coatings created from these powders

Powder type	Al_2O_3 – TiO_2	WC/Co
Powder's chemical constitution [% wt.]	82% Al_2O_3 18% TiO_2	88% WC 12% Co
Granulation [μm]	22÷56	22÷56
Density [g/cm^3]	3÷4	14,2
Hardness HV0,3	1080	1150
Coating's porosity [%]	0,5	0,5
Minimal adhesion between coating and layer [MPa]	60	30
Maximum work temperature [°C]	1400	560

The specimens were analyzed on the image analyzer NIS-Elements BR 3.0 connected with optical microscope Nicon Eclipse LV-150. The analysis results show that in the specimen form ADI, which had oxides layer, the average amount of modular graphite at 1mm^2 is about 390, and in the one which had the carbides layer it was about 353.

Specimens for coating were prepared in the form of plates 15×50×1,5mm and rollers ø8×21mm, which were both cut out from the cast. Before coating, the base surface was cleaned with the abrasive blasting with the use of aloxite. Coatings from powders: Al_2O_3-TiO_2 and WC/Co, with granulation 25÷56μm, was detonation sprayed with the use of different frequencies of the device: 4Hz for spraying the carbides coating, 2Hz for the oxides coating [7]. Table 2 shows the physical properties of the coating powders and theoretical mechanical properties for coatings created from these powders [8].

a)

b)

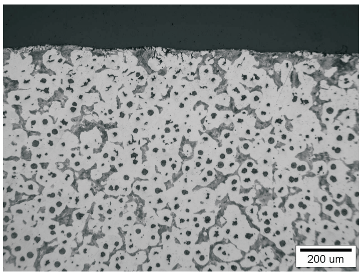

Fig. 1. Investment cast in the form of "stairs" (a) and ferrito-perlite microstructure of the ductile cast iron in the tested casting before the heat treatment (b)

Metallographic measurements and thickness measurements of the detonation coatings were performed on the optical microscope Eclipse LV-150, while the scanning electron microscope measurements of the coating and the area of connection between coating and base were made on microscope HITACHI S-3500N with attachment EDS (with ThermoNORAN software).

The hardness penetration patterns for metallographic specimens were made on the hardness tester produced by Zwick company with the load of 100g. The abrasive wear test with the method "3 rollers-cone" [9] was made on ø8mm rollers with the load of 200 and 400MPa on the tester I-47-K-54 in the Institute of Precision Mechanics. The samples of ADI without coating were also subjects to these tests.

3. Research results and discussion

Metallographic research have shown, that average thickness of the sprayed oxides coating is about 126,9μm, and carbides coating 54,6μm. Figure 2 shows in the left column the structure of Al_2O_3-TiO_2 coating (Fig. 2a,c,e,g), while the right column shows the structure of WC/Co coating (Fig. 2b,d,f,h). In both cases the coatings have lamellar structure. Small porosity of both coatings is visible. The lighter areas of the oxides layer, placed along the edge of the coating and shown at Fig. 2a,c,e, testify for existence of titanium oxide in the coating. Figures 2e,f,g,h show the strongly deformated base material, as the result of high velocity collision between the powder particles and the base material. The effect of material deformation, which occurred in these cases, which result was transformation of the metastable austenite into martensite, was described with more details in the articles [10, 11].

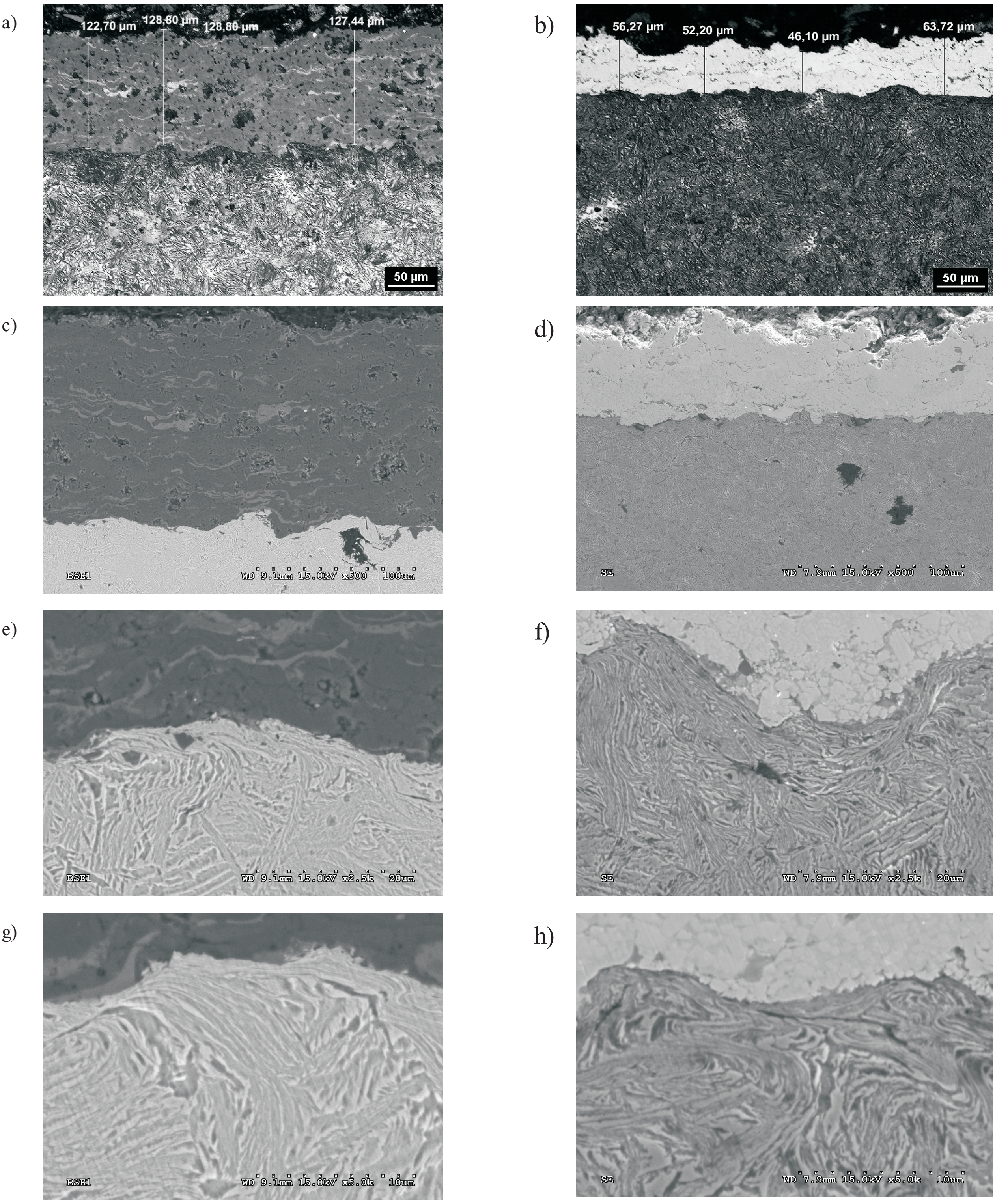

Fig. 2. Microstructure of the coatings Al_2O_3-TiO_2 (2a,c) and WC/Co (2b,d) ADI cast iron and connection Al_2O_3-TiO_2 – ADI (2e,g) and WC/Co – ADI (2f,h)

Figures 3 and 4 describe the mass transport, which occurred from the coatings to base. Figure 3 shows the decreasing concentration of oxygen, aluminium, carbon, at the connection of coating Al_2O_3-TiO_2 – ADI and increasing concentration of iron and carbon at this connection. Figure 4 shows the decreasing concentration of carbon and wolfram and increasing concentration of iron at the connection WC/Co – ADI. Tests of the connections between detonation coatings and the base are especially significant, because adhesion between the coating and base depends on the chemical composition and morphology of the connections area. The following research works will be devoted to the testing of connections between the coatings and the base.

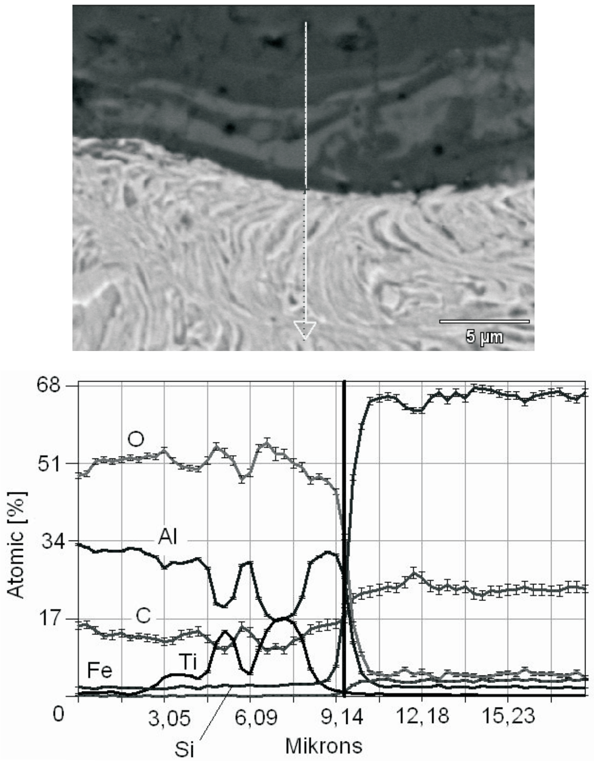

Fig. 3. Transport of mass from coating Al_2O_3-TiO_2 to the base

The results of hardness measurements are shown in the form of diagrams at Figure 5. Analysis of the diagrams shows that carbide coatings characterize themselves with higher hardness than oxides layer. Also, there was acquired higher hardness of the ADI cast iron surface layer, on which the carbon coating was sprayed (about 700HV0,1), in comparison with surface layer under oxide coating (about 500HV0,1). It maybe the result of higher consolidation of the base, for which higher frequency of powder spraying was used.

The results of abrasive wear tests of the ADI cast iron and tests of coatings on the ADI base are shown at Figure 6a,b. The results show that carbide coating has higher wear resistance than the oxide coating. The coating Al_2O_3-TiO_2 spalled after 90 minutes of testing under the load of pressure 200MPa, and after 20 minutes of testing after the load of pressure 400MPa. Figure 7 shows the pictures of spalled oxides layer after wear tests. ADI cast iron spalled after 40 minutes under the load of pressure 400MPa.

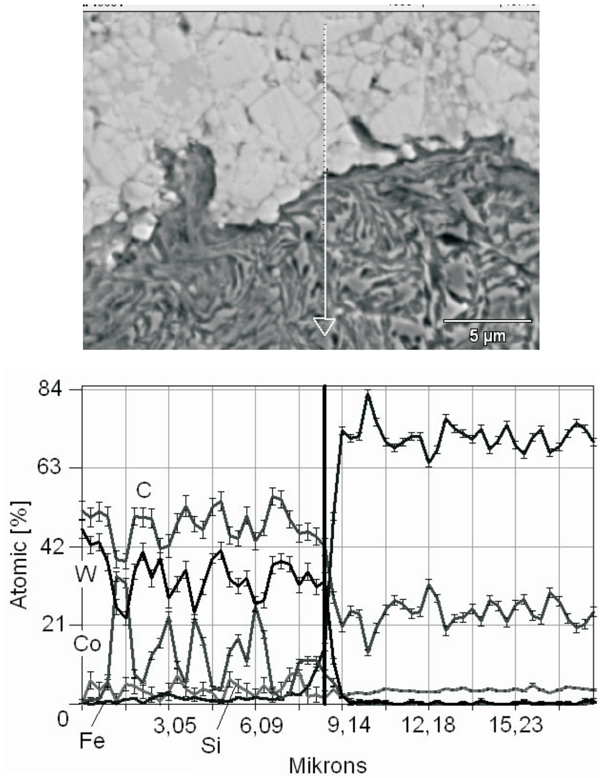

Fig. 4. Transport of mass from coating WC/Co to the base

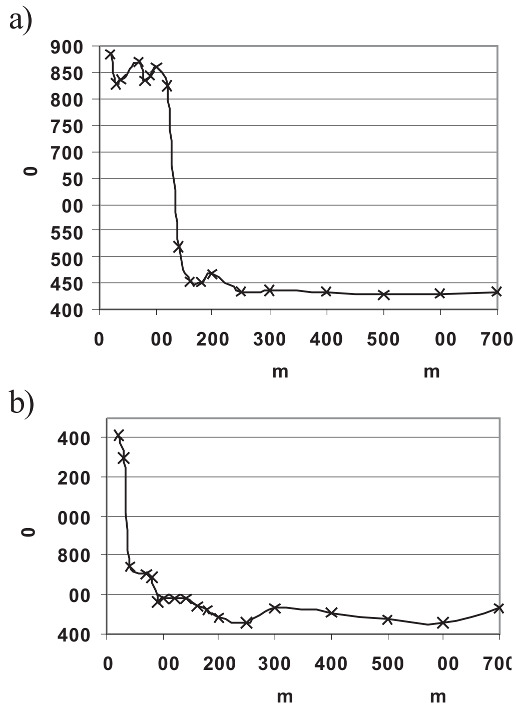

Fig. 5. Hardness penetration pattern of the coatings on the ADI base: a) Al_2O_3-TiO_2, b)WC/Co

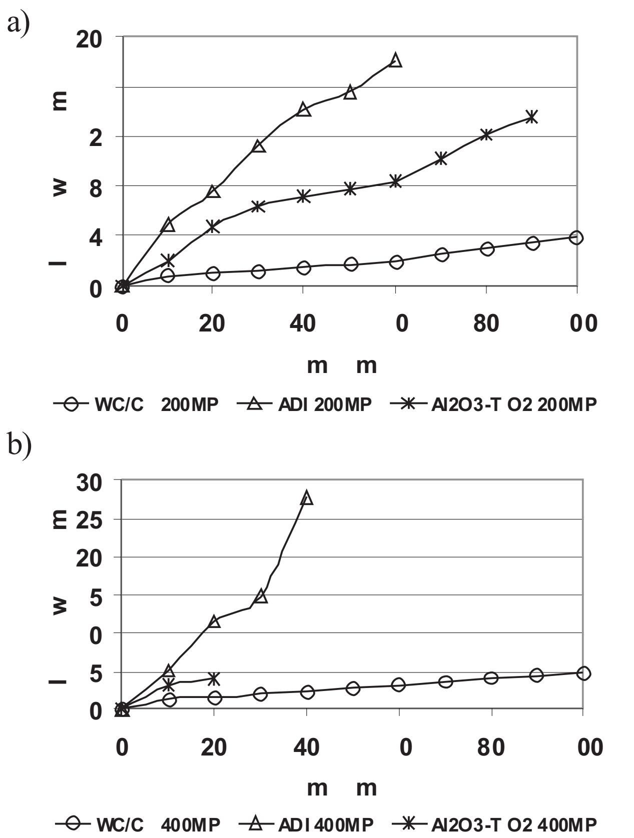

Fig. 6. Wear of coatings in function of time under the load: a) 200MPa, b) 400MPa

Fig. 7. Rupture of the coating Al_2O_3-TiO_2

4. Conclusions

On the base of research results the following conclusions can be drawn:

1. The coatings Al_2O_3-TiO_2 or WC/Co can be detonation sprayed on the ADI investment castings with the thickness from few to several hundred micrometers with hardness about 900HV0,1 and 1400HV0,1 (respectively).
2. Powders WC/Co sprayed on the ADI base have caused the effect of TRIP in the base material, which means the transformation of the metastable austenite into martensite as an effect of inducting stresses in the base material through the sprayed powder. This effect is visible as increased hardness in the surface layer of the base material ranging up to 700μm inside ADI base.
3. The coatings WC/Co sprayed on the ADI base show high friction wear resistance.
4. During the spraying process of the coatings Al_2O_3-TiO_2 type, applying technological parameters with which the powder particles have several times lower energy than in case of other coatings, the effect of lesser consolidation of the ADI base is observed. This effect doesn't help the adhesion between coating and base, and therefore can lead to spallating of the coating in case of high unit pressures, which can take place during the frction wear tests.

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