

Innovative Processing Technology of Chromium Carbide Coating to Apprise Performance of Piston Rings

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ABSTRACT

A chemical vapor deposition method for preparing high-quality chromium carbide coatings was developed. The resulting coatings exhibit high adhesion and increase wear resistance of the cylinder piston group components as compared to common coatings prepared by electrolytic chromium plating. The operation performance of the coatings was tested using scrapper piston of the Raba-Man diesel engine of Ikarus bus and compression and oil scrapper rings of the diesel engine 10D100. It was found that chromium coatings prepared by the method proposed are characterized by relatively low coefficient of friction and high corrosion resistance.

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INTRODUCTION

Since cylinder piston group (CPG) is a decisive component of the internal combustion engine improvement of their service life and efficiency is still urgent. The problem is often solved by application of chrome electroplating of the CPG components [1]. Owing to certain construction features of the oil scraper rings the galvanic chrome plating on their working edges is a complex problem. Moreover, galvanic chrome plating has certain disadvantages such as difficult burnishing, low heat stability, poor adhesion of oil on its surface, high internal stress, which leads to cracking and chipping, and large amounts of aqueous waste containing highly toxic Cr (VI) in the course of chrome electroplating [2,3,4,5].

Further improvement can be achieved by deposition of multilayer coating combining the useful properties of carbon and metal, e.g., advanced chromium carbide coatings (CCC) on the CPG components [6,7,8]. Such optimization of the coating structure can increase the resistance to abrasion, reduce friction and improve corrosion quality [9,10,11,12].

The studies conducted by authors allow revealing that the application of CCC to the piston rings using more technologically acceptable method of chemical vapor deposition (CVD) could significantly decrease the energy consumption of process. In our case, CVD procedure is adapted for preparing chromium coating from the gas phase.

This paper describes the results of extensive investigation on CVD coating deposition technique and the discovered properties of multilayer CCC on the CPG components.

EXPERIMENTAL

Method of preparing chromium coating from the gas phase is based on the thermal (pyrolytic) decomposition of appropriate chromium organometallic compound (OMC), such as BARCHOS chromium-organic liquid (see Russian TU - Technical Specification 6-01-1149-78). Technical specification is the official document, which determines technical characteristics of given commercial product. The possibility of using pyrolytic CCC (PCCC) to improve the friction wear resistance of the piston group (primarily, of the oil scraper and compression rings) has been consider for evaluation. To serve this goal the special pilot unit for rings coating by chrome was designed, the conditions for PCCC coating of the CPG components were selected and optimized, and pilot lots of the CPG components were produced and tested by application of special procedures [13]. The process is carried out in hermetically sealed system and the product of BARCHOS thermal degradation are collected and then used for preparing new portion of OMC, which excludes formation of hazardous wastes. As typical CPG component the scrapper piston rings 121 mm diameter used at the Raba-Man diesel engine of Ikarus bus and the compression and oil scrapper

rings 215 mm diameter utilized at the diesel engine 10D100 were selected for experimentation.

RESULTS AND DISCUSSION

In the course of studies the optimal parameters providing formation of the uniform shine coating on the rings were determined. Before coating deposition, the samples were degreased in an ultrasonic bath, rinsed and dried. The experimental conditions were as follows: temperature of the substrate in the heating zone $440 \pm 5^\circ\text{C}$, ultimate substrate temperature in the deposition zone $400 \pm 5^\circ\text{C}$, working pressure 15 ± 5 Pa, deposition time 20 - 30 min.

Using the above experimental parameters the samples with the PCCC thickness of 10-20 μm were prepared. The average growth rate of the coating did not exceed 0.50-0.65 $\mu\text{m}/\text{min}$. The surface was smooth. The coatings had the opaque mirror appearance with the separate light golden areas on the front surface of the rings. The photographs of the coated rings are shown in Fig. 1.

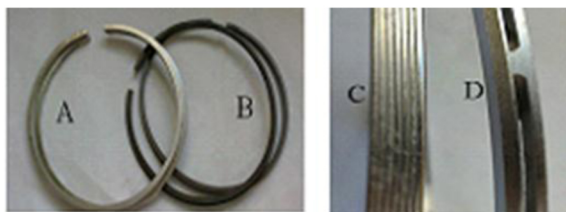


Figure 1. Compression and oil scraper rings 10D100 of the diesel engine before (A) and after (B) coating with PCCC; PCCC of the compression (C) and oil scraper (D) rings for diesel engines 10D100 piston rings

The chemical composition and microstructure of the coatings were studied by the electron - optical microscopy and electron probe microanalysis. The coatings prepared under the selected conditions were fine-crystalline and their metallographic slices (without etching) exhibit the horizontal-layered structure paralleled to the substrate. The typical microstructure and surface morphology of the PCCC coatings are shown in Fig. 2.

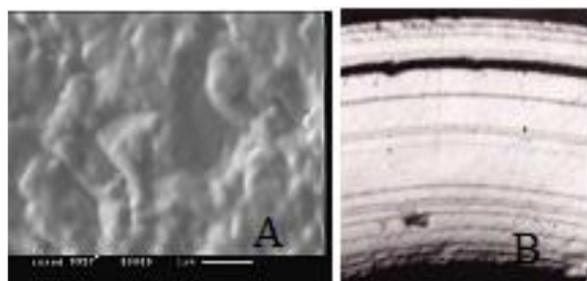


Figure 2. (A) SEM images of the surface morphology of the PCCC coating, (B) Cross-section micrographs of the coating (optical metallographic microscope MMP-4, x 500).

Visually, two types of layers are observed: white and gray/dark (Fig. 2). The light layers have the maximum thickness, whereas the dark layers are much thinner. The layer-by-layer analysis showed that chromium content comprised 95-96% and 92-94% in the white and dark layers, respectively. The content of carbon varied from nearly 5 to 6 - 8% in the same layers. PCCCs are the dispersed-crystallite compositions containing the particles of chromium carbide with dimensions of 10 - 80 nm and chromium metal, which are stabilized by carbonaceous impurities.

The results of the etching tests showed that the prepared PCCC (more than 10 μm thickness) are non-porous. The microhardness of the PCCC on the cast iron substrates was 16.5 ± 2 GPa; comparison of PCCCs with the other types of coatings is shown in Table 1. As seen, PCCC hardness is nearly the highest in a series of coatings analyzed. Comparable or higher micro hardness have only chromium nitride and C-Cr magnetron coating. But the process of this coating is difficult and expensive for mass production, therefore chromium nitride and C-Cr magnetron coating are currently used exclusively for small series production for competition engines and selected production engines [5, 10, 11, 12].

Table 1. Microhardness PCCC compared to other types of coatings [3, 4, 5, 6, 7, 14]

Type of coating	Microhardness, GPa
Chrome flame coating	3.2 – 11.2
Chrome plasma coating	5.0 – 11.8
Chrome plating	8.0 – 11.3
Ductile cast iron	3.0 – 8.2
Chromium nitride	17.2 – 18.0
C-Cr magnetron sputtering	14.0 – 24.0
PCCC	14.5 – 18.5

The averaged tribometrical results showed that under the same conditions the wear of the samples with PCCC is smaller by 3.5 - 4.0 times than that with galvanized chromium coating. At the same time, the wear resistance of the block joined with PCCC coated roller increases by 8-10 times as compared with those coated with galvanic chromium. Similar results were obtained earlier for the bearing interfaces. The wear intensity of the PCCC coated steel pairs was 5-10 times smaller than that for the galvanic chromium coatings [15].

The tests simulating the operating conditions, wear mechanism and the nature of interaction of the friction parts of the vehicle engines were carried out on the MTV-0 friction machine with a reciprocating motion using M14V2 diesel oil as a lubricant. The samples to be tested were prepared from the materials for cylinder sleeves, pistons and piston rings of the 10D100. The standard piston rings made of cast iron (purity grade surface $R_a = 1.5 - 1.25$ μm) were also used. The PCCC coated rings were tested in pairs with cylinder sleeves (purity grade surface 0.5 - 0.75 μm). The mechanical and performance properties of the oil scraper rings after their