

CVD Technology for Preparing Wear-Resistive Chromium Carbide Coatings of Engine Components

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ABSTRACT

A chemical vapor deposition method for preparing high-quality wear-resistive chromium carbide coatings was developed. The large scale CVD installation was designed. The results of the industrial tests of the chromium carbide coatings of the cylinder piston group components and nozzles are presented. The resulting coatings exhibit excellent adhesion (more than 100 MPa), low coefficient of friction (0.04 - 0.06), high microhardness (12-14 and up to 20-24 GPa depending on the experimental conditions), and wear resistance from 3 to 10 times higher as compared to electroplated chrome. The coating process is environmentally friendly, it is characterized by high adaptability and relatively low cost.

CITATION: Bryskin, B., Kostylev, A., Pokrovskiy, Y., and Lumpov, A., "CVD Technology for Preparing Wear-Resistive Chromium Carbide Coatings of Engine Components," *SAE Int. J. Mater. Manf.* 7(3):2014, doi:10.4271/2014-01-1020.

INTRODUCTION

Various methods of surface treatment of components of the cylinder piston group (CPG) are used presently to increase the service life of the internal combustion engines and to improve their efficiency. Galvanic chrome plating of piston rings is the most common way to improve the engine performance [1]. However, this procedure 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) appearing at chrome electroplating.

Along with gradual improving the galvanic chrome plating technology, alternative procedures for preparing chromium and chromium nitride (CrN) coatings such as vacuum, flame, plasma, electric arc, etc., are also developed. Anti-friction coatings based on diamond-like carbon (DLC), metal containing diamond-like carbon (Me-DLC), and a number of similar composite materials are often used in industry [2, 3, 4, 5]. Deposition of multilayer coating combining the useful properties of carbon and metal can improve the coating characteristics. Such optimization of the coating structure can increase the abrasion resistance, reduce friction and improve corrosion quality [6, 7].

Our studies showed that the application of multilayer chromium carbide coatings to the piston rings prepared by more technologically acceptable procedure of chemical vapor deposition (CVD) could significantly decrease the energy

consumption of the coating process [8, 9]. In this paper we present the data on the behavior of chromium carbide coatings on the CPG components prepared by CVD coating deposition technique.

GENERAL INFORMATION ON CVD TECHNOLOGY

Chromium carbide coatings were prepared by CVD method, which is based on thermal decomposition of chromium organometallic compounds (OMC) from the gas phase. First, chromium OMC is evaporated at temperatures 200-260°C and then the vapor obtained is contacted with a substrate heated to 350-550°C, where the thermal decomposition of OMC vapors occurs. For this purpose, the special pilot unit for rings coating by chrome was designed, the conditions for CPG component coating were selected and optimized, and pilot lots of the CPG components were produced and tested by application of special procedures [10]. Metallic chromium and its carbides are deposited on the substrate surface as a compact uniform coating - pyrolytic chromium carbide coatings (PCCC).

PHYSICAL AND MECHANICAL PROPERTIES

PCCC are dispersed-crystallite compositions containing the particles of chromium carbide with dimensions of 10- 80 nm and chromium metal, which are stabilized by chromium oxides

impurities. The color of the prepared coatings changed from light yellow-silver or gold to a mirror-bright, which depends on the original finish treatment of the substrate surface.

The relief of the coating surface was a dome-shaped, smooth with some spheroidal globules (Fig. 1 a). 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. 1.

The internal microstructure is layered. Visually two types of layers are observed: white and gray/dark (Fig. 1 b). The light layers have the maximum thickness, whereas the dark layers are much thinner.

The layer-by-layer analysis showed that the chromium content in the layers comprised 95-96% in the white and 92-94% in the dark layers. Respectively, the content of carbon is varied from nearly 4-5 to 6 - 8% in the same layers.

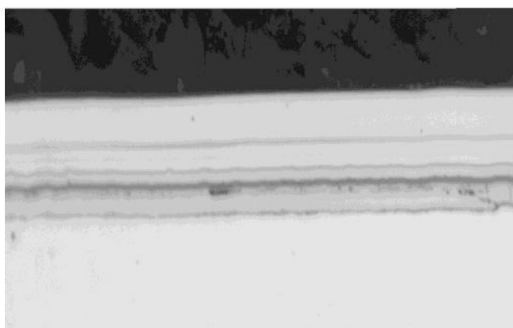


Figure 1. Cross-section micrographs of the coating: bottom light uniform layer - steel 301 with upper multilayer PCCC (optical metallographic microscope MMP-4, $\times 500$).

PCCC are often nonporous even at thicknesses of 4-5 μm and their corrosion resistance is close that of noble metals. Coatings exhibit high adhesion to most construction materials, around 100 MPa. PCCC microhardness varies from 12-14 to 20-25 GPa depending on the preparation conditions. In the conventional process coating is performed at temperatures below 400°C to preclude the release of the base metal. Under the above conditions, The microhardness of PCCC prepared under the above conditions was 16.5 ± 2 GPa; which is 2.5-3.0 times higher than the microhardness of hardened steel and chromium electroplating coatings.

The tribometric laboratory tests were performed on the certified friction machines by the roller-block and roller - roller schemes. The wear ratio was determined by weighing with an accuracy of 0.1 mg. The averaged results of the tests illustrated in Fig. 2 show that under the same conditions the wear of the samples (rollers) with PCCC is smaller by 3.5 - 4.0 times than that with galvanized chromium coating.

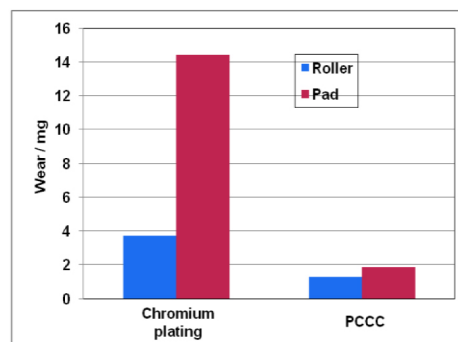


Figure 2. Average wear intensity of roller-block pair tested for 5 hours under 1 kN load on CMC-2 friction machine using MS-20 lubricating oil. Roller coatings: (left) 100- μm thick PCCC with 8.7 GPa microhardness; (right) 12- μm thick PCCC with 17 GPa microhardness; SCHhNMD cast iron block with 2.5 GPa microhardness. Temperature at contact point friction pairs reached 95 to 100 °C

At the same time, the wear resistance of the block joined with roller coated with PCCC increases by a factor of 8-10 as compared to the galvanic chromium coatings. Similar results were obtained earlier for the bearing interfaces. The wear intensity of the steel pairs with PCCC coating was 5-10 times smaller than that for the galvanic chromium coatings [11].

PCCC APPLICATION

As typical CPG component the scrapper piston rings 121 mm diameter used at the diesel engine and the compression and oil scrapper rings 215 mm diameter used at the diesel engine 10D100 were taken for our experiments.

The mechanical and performance properties of the oil scraper rings after their surface hardening with chromium carbide were tested in comparison with standard oil scraper rings with phosphate and galvanic chrome coating. It was found that PCCC increase the wear resistance of the oil scraper piston rings as compared to the rings coated with electroplated chromium by a factor of 3. The sliding friction coefficient of PCCC in pair with cast iron (preparation - grinding) was 0.04 - 0.06, which is significantly smaller than that of cast iron-cast iron pair (sliding friction coefficient 0.095) and of cast iron-cast iron with galvanic chromium coating (sliding friction coefficient ~ 0.07). Thus, as seen from experimental results, PCCCs showed higher (by several times) wear resistance than the common galvanic chromium coatings under the conditions close to the operating conditions of the piston rings. The full-scale tests in the engines of Ikarus buses demonstrated that in the case of PCCC coated rings the consumption of lubricant oil decreases by nearly 3 times despite their smaller thickness (20 μm and 100 μm for PCCC and galvanic chromium coatings, respectively) [12].

High tribotechnical properties of the coating are probably due to their layered structure (Fig. 2). This structural feature spherical surface morphology provides sufficient oil adhesion at relatively small height of the spherical globules on the surface. Given layered structure of the coating is characterized