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Effect of roughness on the wear behavior of HVOF coatings dry sliding against a friction material

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ABSTRACT

WC-CoCr coatings on cast iron discs were prepared with different surface roughness and submitted to dry sliding wear tests against a commercial friction material using a pin-on-disc configuration. The effect of roughness on the friction and wear of the tribological system was evaluated. The pin wear rate increases with the coating roughness and becomes very high for an arithmetic average roughness, R_a, in excess of 1 µm. In contrast, the friction coefficient was found to increase as roughness decreased. The discs wear was anyway negligible. The experimental results were explained considering the characteristics of the friction layer that forms during sliding at the interface of the mating bodies in dependence of the initial roughness of the coatings. It is shown that the friction layer plays an important role in determining the relative contribution of the abrasive and adhesive interactions and, thereby, the resulting friction and wear behavior of the tribological system.

1. Introduction

Recent investigations have shown that the wear fragments produced by the braking systems greatly contribute to the overall emission of particulate matter (PM) in the environment [1–3]. Therefore, a number of investigations have been aimed at understanding the wear mechanisms in the braking pad-disc system to develop guidelines for reducing the emissions [4–7]. The brake pads are usually made of a friction material that typically contains a large number of different constituents, including metallic fibers and powder, minerals, ceramic particles, solid lubricants and a phenolic resin that after curing binds all the ingredients together [8,9]. The disc is usually made of a pearlitic cast iron, although other materials, like stainless steel, Al alloys, composite systems are used for specific applications. Since wear of the cast iron disc contributes by approximately 50% to the whole system wear, important efforts have been initiated to reduce such a contribution. In a previous paper, promising results were obtained using conventional heat-treatments of the cast iron disc [10]. It was demonstrated that wear rates of both disc and adopted friction materials in pin-on-disc wear tests were reduced by almost one order of magnitude.

WC-Co-based coatings obtained by thermal spray are widely used in mechanical applications where a high resistance to sliding wear is required [11–13]. In particular, high velocity oxy-fuel (HVOF) thermal spraying is regarded as one of the best methods for depositing conventional WC-Co feedstock powders [14,15], in view of the good combination of higher deposition rate and lower temperature with respect to plasma deposition. These conditions determine a lower porosity and, therefore, a better wear resistance of the coatings [13–15]. The HVOF WC-Co-based coatings in the as-sprayed condition normally display a hardness in the range 1100–1200 HV, and a surface average roughness, R_a, around 5 µm, depending on the powder particles size and morphology and on the specific spraying parameters [16–21]. Depending on the application, the coatings can be submitted to subsequent grinding in order to reduce the roughness, typically down to 0.1–1 µm range. In the proper conditions, the dry sliding specific wear rates of HVOF WC-Co coatings against steel or a counterface of the same type are approximately in the range 10^{-15} (or less)–10^{-14} m^2/N, i.e., typical of very mild wear [12,22]. For these systems, the identified wear mechanisms were: coating delamination, fracture of the carbides, cracking in the metallic phase with following disruption of the carbide-binder interfaces, micro-cutting, extrusion of the binder phase [23]. With regard to the coating microstructure, a quite important role is played by the metal content, and the size and quality of the WC particles [24–28]. In addition, the final properties can be tuned also by changing the type of carbides (using, for example, Cr_3C_2, VC, or mixtures [29–31]), and the type of metallic binder (such as Cr, Ni, or different metals together [11,13,32]).

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Table 1
Surface finish of the coated discs.

Surface finish	Final roughness R_a (μm)	Profile skewness R_{sk}
As sprayed	5	0.05
Diamond disc (220 grit) – 30 s	1	-1.65
Diamond disc (220 grit) – 2 min.	0.1	-2.27
Diamond disc (220 grit) – 2 min.	0.04	-5.94
Diamond disc (1200 grit) – 5 min.		
Cloth + 9 μm diamond paste – 15 min.		
Cloth + 6 μm diamond paste – 15 min.		
Cloth + 3 μm diamond paste – 15 min.		

As concerns brake systems, to the authors' knowledge, thermal coatings have been investigated so far mainly in case of train brake discs, where the contact temperature can be very high because of the large frictional heating [33]. In the present paper, the results of an exploratory research aimed at obtaining starting information on the feasibility of thermal spray coatings in the pad-disc braking system for the automotive market are reported, with particular reference to the reduction of PM emissions. The investigation was carried out using a laboratory pin-on-disc testing device, and the tests are thus not meant to reproduce real braking conditions for which specific equipment, like dyno-tests and bench test apparatuses, are available and are going to be considered at a subsequent step. The present are expected to provide preliminary information on the acting wear mechanisms, with particular emphasis to the characteristics of the friction layer, which typically forms at the pin (pad)-disc interface during sliding [34–37]. The pins and discs where machined from commercial brake pads and discs respectively. Each disc was successively coated with a commercial WC-based layer, by an industrial apparatus, using well established operating conditions. Since the hardness of the friction material is typically much lower than that of the cermet coating, a specific attention has been paid to the role of the coating surface roughness. With this in mind, in the present research the coating roughness was reduced to three different levels in addition to the as-sprayed condition. The resulting wear behavior of the tribological coupling has been evaluated and explained making specific reference to the acting wear mechanisms and the corresponding characteristics of the friction layer building up between the pin-disc mating surface during the tests.

2. Experimental procedure

The discs for the pin-on-disc (PoD) testing had a diameter of 63 mm and were machined from a commercial cast iron disc with a pearlitic microstructure. Successively they were coated on both sides by using an industrial HVOF system and employing a commercial WC-CoCr powder (Amperit 558.074), containing 86 wt%. WC particles (with a size in the range 1–10 μm) embedded in a matrix constituted by 10 wt%. of Co and 4 wt%. of Cr. The feedstock composite powder was produced by agglomeration and sintering and had spherical grains with an average size in the range 15–45 μm. The spray parameters were optimized in previous researches, and were quite typical for this kind of coating [38,39]. The kerosene and oxygen flow rates, and the spray distance were around 24 L/h, 950 L/min and 380 mm respectively. All substrates were pre-heated using the plasma torch with the same parameters and robot program as during the deposition.

As expected, the surface average roughness, R_a, in the as-sprayed condition was quite high, approximately 5 μm, as measured with a stylus profilometer. Different grinding and polishing procedures were thus adopted to obtain discs with a surface roughness varying in a wide range: from 5 μm down to 0.04 μm. Such procedures, carried out using an automatic polishing machine, are described in Table 1, together with the relevant R_a-values. The coatings were observed in a FEI TMP-XL30 scanning electron microscope (SEM) to reveal the main characteristics of the cross section as well as of the surface topography. Information on the phase composition of the coating was also obtained by means of X-ray diffraction (XRD) measurements (Cu-kα radiation), carried out using IPD3000 apparatus manufactured by Ital structures and equipped with an Inel CPS 120 detector. An evaluation of the present phases was carried out by means of a full-profile Rietveld approach using the Maud software [40,41]. Microhardness measurements were made on the cross-sections using a Vickers indenter under a load of 300 g.

Dry sliding tests were carried out using a Eyre/Biceri PoD testing rig. Each cylindrical pin with a flat end contacting the disc

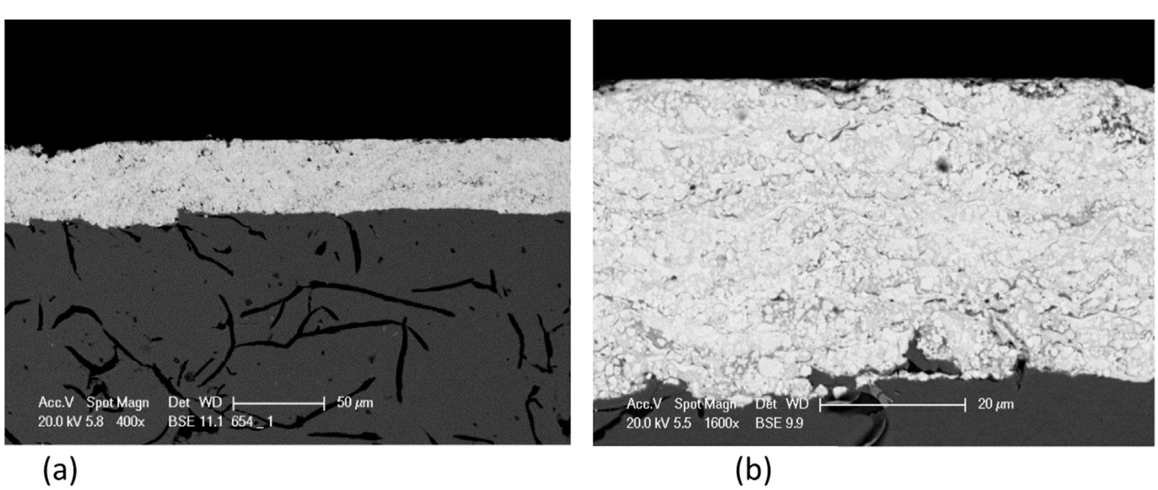

Fig. 1. Example of cross section of a cast iron disc coated with a WC-CoCr layer. (a) Low magnification; (b) high magnification.