Wear 376-377 (2017) 595–607

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Study of the erosive wear behaviour of cryogenically and tempered WC-CoCr coating deposited by HVOF

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ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form
3 December 2016
Accepted 22 December 2016

Keywords:
Thermal spray coatings
Solid particle erosion
Cermets
Cryogenic heat treatment
Electron microscopy

ABSTRACT

In this work the influence of deep cryogenic treatment followed by a double tempering at 150 °C on the erosive wear resistance of high velocity oxy-fuel (HVOF) WC-10Co-4Cr coating was evaluated. Cryogenically treated coatings exhibited a microstructural densification effect; more compact splats, lower porosity, and a clear redistribution of Co, enhancing its hardness with respect to that observed in the as-sprayed conditions. On the other hand, a reduction in fracture toughness was noticed. A dependence of the erosive wear mechanism was observed in regard to: 1) the erosive test parameters and; 2) the metallurgical conditions of the material. Cryogenically treated coatings displayed better erosive resistance at low impact angles such as 30° and both particle impact testing velocities i.e.100 m/s and 130 m/s. In contrast, at higher angles between 60° and 90° and 130 m/s, more material removal trough brittle mechanism was observed to occur in cryogenically treated coatings, reducing its erosive wear performance. At lower impact velocities (lower normalized load) this type of erosion was less evident suggesting the presence of a threshold velocity at which low fracture toughness coatings erode preferentially trough brittle mechanisms.

1. Introduction

Nowadays, cermet thermal sprayed coatings like WC-CoCr, are widely used as replacement of electrodeposited hard Cr coatings due to their high hardness and toughness. Because of their high and excellent wear resistance they have been extensively used; allowing a wide variety of applications such as: bushing pins, printing and corrugation rolls, ball valves, machine tools, fitting, hydraulic cylinders, rotating shafts, aircraft landing gear, etc [1]. Thermal spray techniques have demonstrated to be the more suitable and economically desired processes to deposit cermet coatings as the one mentioned above. Compared to other spraying technics, HVOF is one of the best depositing methods to produce coating with better properties of density, adhesion strength and microhardness. This due to the very high velocities reached during projection of fused powders. Also, the lower temperatures result in less decomposition of WC particles during spraying process [2]. It has been shown that coatings thermally sprayed by means of other spraying techniques such as plasma, a considerable decarburization of tungsten monocarbide (WC) to di-tungsten carbide (W_2C) occurs affecting the microstructure [3,4]. The erosion wear resistance of WC-CoCr coatings obtained by different methods has not been well-studied [2,5,6], whereas, in other similar composites, a considerable amount of scientific reports can be found for both; coatings [4,7,8] and sintered specimens [8,9].

The properties of these materials (WC-CoCr) are addressed by their phases, hard and brittle carbides, and the ductile binder (softer phase). Considering that cobalt is next to iron in the periodic table as part of VIIIB group, and by consequence its tendency to form similar phase in crystalline structures [10]. Some researchers have addressed their efforts on studying the effect of applying high temperature (between 250 and 1100 °C) [11] and deep cryogenic (~ −196 °C) heat treatments on the microstructure of WC-Co compounds as well as its influence on their erosive or abrasive wear performance [9,12]. Both, high and low temperature treatments demonstrated a considerable improvement of wear behaviour compared with the as-sprayed condition. Also, it was observed that the microstructure and hardness are not the only metallurgical characteristics affecting the wear resistance, stresses generated during layer by layer coating grow (impact velocity, and solid-state cooling of the splats) have also a considerable influence. Residual tensile and compressive stresses are two characteristics of as-sprayed coatings that depend on deposition parameters [13,14]. After heat treatment, the state of

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http://dx.doi.org/10.1016/j.wear.2016.12.061
0043-1648/

stresses change considerably, more compressive stresses are generated and are directly related to the densification process of the cobalt phase and to the formation of harder phases such as Co_3W_3C or Co_6W_6C [9,11,15]. Also, an improvement in the holding strength of the cobalt binder specifically after cryogenic treatments is considered. All these metallurgical features promoted a considerable increment of the erosive and sliding wear resistance in the composites.

Until now, the literature reviews reveal the contribution of cryogenic and temper heat treatments on the improvement of the wear properties of WC-Co cermets; either as-coating or sintered bulk. The information regarding the influence of the application of similar heat treatments on specific WC-CoCr compound and essentially evaluating its performance under erosive conditions at different abrasive particle impact conditions have not been studied widely; or the information available in the literature is limited. According to this, and considering that this material during the last few years has been positioned as one of the most used coatings in the industry against wear, a real need of generating technological and scientific knowledge has emerged. Accordingly to studies which involve the modification of metallurgical properties and its influence on increasing specific properties such as erosive wear resistance. This paper reports and analyses a deep cryogenic treatment followed by a multi tempering treatment of WC-CoCr HVOF sprayed coatings. It also describes the correlation between metallurgical conditions and erosive parameters.

2. Experimental procedure

2.1. Materials and coating deposition

Agglomerated and sintered WC-10Co-4Cr Praxair spherical powder with particle size ranging between ~20 and 45 μm was used as feedstock. Fig. 1 shows the morphology and microstructure of the powder, consisting of tungsten carbide grains embedded in a cobalt-chromium binder matrix. Austenitic 304 stainless steel plates (400 mm × 95 mm × 7 mm) were used as substrates and, prior to coating deposition they were grit-blasted up to a surface roughness of $R_a \approx 4.5$ μm and grease cleaned. The coatings were fabricated by the company SURESA using the HVOF (Jet-kote) spray process using their own deposition parameters. The thickness of the coatings was approximately 370 μm. The original steel sprayed plates were water jet sectioned obtaining samples of ~40 mm × 25 mm.

2.2. Heat treatments

After being cut, some of the specimens were subjected to a deep cryogenic treatment by introducing the specimens progressively into a chamber containing gaseous nitrogen which was generated from a deposit of liquid nitrogen. The temperature was continuously monitored by using a thermocouple placed directly on the specimens; a cooling rate of ~2.5 °C/min was used by controlling the immersion depth of the samples in respect to the liquid source of nitrogen until they reached a temperature of −193 °C, then, specimens were held for 24 h soaking time. Once the soaking stage was completed, samples were warmed up (~2.5 °C/min) to room temperature, this was possible by extracting progressively and monitoring the temperature of the samples during this stage. Finally, the samples were subjected to a double tempering; a conventional muffle was used to heat the samples, two cycles at 150 °C during 1 h each. Table 1 shows the identification of the applied heat treatments and relevant aspects of the coatings and particle erosion parameters.

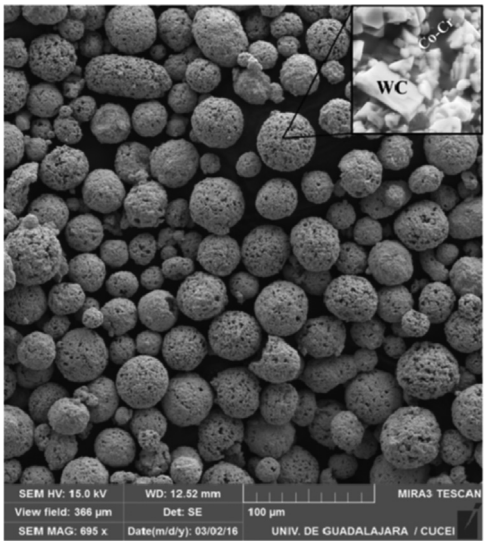

Fig. 1. Micrograph of WC-10Co4Cr feedstock powder.

Table 1
Samples identification and erosion test conditions.

Coating characteristics				Solid particle parameters	
Condition	**Identification**	**Porosity (%)**	**Thickness (μm)**	**Angle**	**Velocity (m/s)**
As-sprayed	AS	1.83	~370	30°, 60° and 90°	100 and 130
Heat treated	CR-T	1.49			

2.3. Coating characterization

The microstructure of specimens was examined using both optical (Olympus PME) and Field Emission Scanning Electron/FE-SEM (Tescan MIRA3 equipped with a Bruker EDS detector for chemical analysis) microscopes. Metallographic cross sections of as-sprayed (AS) and deep cryogenic double tempered (CR-T) specimens were prepared by grinding and polishing. Prior etching, porosity (Table 1) was determined from digital images and according to ASTM E-2109 [16]. Mirror polished specimens were etched with Murakami´s reagent; 2 g C6N6FeK4 (potassium ferrocyanide), 1 g NaOH, 10 mL distilled water for phase identification and in accordance to ASTM B657 [17]. X-ray diffraction was performed by means of an Empyream diffractometer using CuK_α radiation ($\lambda = 1.542$ Å) at an acceleration potential of 20 k. A Bragg-Brentano configuration with a 2θ diffraction angle range between 20° and 100° and with a scan speed of 1°/min, in order to identify the structure of powder feedstock and the present compounds in the coatings. From diffraction patterns the crystallite size of WC particles was calculated by applying the Williamson-Hall (W-H) [18] method, this equation represents a simplified integral breadth method where both size-induced and strain-induced broadening are deconvoluted by considering the peak width as a function of 2θ, Eq. (1):

$$\beta_{hkl} \cos\theta = \frac{k\lambda}{D} + 4\varepsilon \sin\theta \quad (1)$$

where D is the volume weighted crystallite size (nm), k is the shape factor (k=0.9), λ is the wavelength of the X-rays (λ=1.54056 Å for Cu Ka), θ is Bragg diffraction angle, β is the broadening of the diffraction peak measured at FWHM (in radians) and ε is the lattice strain.

Microhardness of samples was measured using a Future Tech