Surface & Coatings Technology 206 (2012) 2233–2241

Contents lists available at SciVerse ScienceDirect

Surface & Coatings Technology

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

The parameters optimization and abrasion wear mechanism of liquid fuel HVOF sprayed bimodal WC–12Co coating

Qun Wang [a,*], Zhenhua Chen [a], Luoxing Li [a], Guibing Yang [b]

[a] College of Materials Science and Engineering, Hunan University, Changsha, Hunan 410082, PR China
[b] Ganzhou Zhangyuan Tungsten New Materials Co., Ltd, Ganzhou ,Jiangxi 341300, PR China

ARTICLE INFO

Article history:
Received 23 June 2011
Accepted in revised form 29 September 2011
Available online 8 October 2011

Keywords:
HVOF
Processing optimization
Bimodal
WC–Co

ABSTRACT

In this work, the spray parameters of the bimodal WC–12Co powder are optimized by Taguchi experiment program by using liquid fuel JP-8000 HVOF spray system with mass flow meter controlling the flux of the medium. The phase composition, microstructure, hardness, porosities, fracture toughness, per-pass deposited thickness and the abrasive wear mechanism of the coatings have been studied in detail. The results indicate that the varying of the spraying parameters shows little effect on the phase composition of the WC–12Co coatings but great influence on their other performance such as hardness, porosity, fracture toughness and the per-pass thickness of coatings. High hardness of the coatings usually means low porosity, low fracture toughness, low per-pass thickness and high wear resistance for the HVOF WC–12Co coatings. The bimodal coating deposited under the optimal spray parameter exhibits excellent performance, which can be attributed to its small mean free path of the cobalt binder resulting from the bimodal distribution of WC particles. As last, three groups of spray parameters, named as economic, moderate and high level spray parameters, are suggested according to the results of Taguchi experiment program and the applied situation of the coated parts as well as their preparation cost.

1. Introduction

High velocity oxy-fuel (HVOF) thermal spraying WC/Co coatings have been used widely in many fields which subjected to severe abrasive wear, such as metallurgy, energy sources, construction industry as a result of their excellent abrasive wear resistance [1,2]. Recently, a new class of HVOF thermal spray feedstock powder consisted of aggregate of hard ceramic particles that are mixed with nano- and micro- sized WC particles has been suggested, which is called bimodal (or multimodal) powder, many researchers reported that spraying this WC/Co powder by using HVOF spray process not only provided enhanced wear properties but also reduced cost, compared with the nanostructured powders [2–4]. Besides powder, the properties of HVOF sprayed WC/Co coatings also strongly depend on the HVOF spraying equipment and spray parameters adopted [5]. In order to obtain qualified coating with reasonable cost, the optimization of the spray parameters is necessary. Many optimizations have been done on those HVOF spraying system such as DJ2700 and JK3500 using C_3H_6 or C_3H_8 as fuel [5–7], but little for the JP-5000/8000 sprayed system using kerosene as fuel. Lovelock [8] have carried an unsuccessful experiment in optimizing the spray parameters using JP-5000 sprayed system, because little difference appeared among these coatings deposited by different HVOF sprayed parameters, which probably resulted from inaccurate medium flow (medium flow is controlled by general flow meter but not the mass general flow meter for JP-5000 HVOF system)for Taguchi experimental program. As for the bimodal WC/Co powder, the spray parameters optimization by using liquid fuel JP5000/8000 HVOF equipment has not been reported.

The HVOF coating processes are optimized by Taguchi method which is well known for the good reappearance of experiments concerned only with the main effects of design parameters [5]. In this work, the coating properties, such as microstructure, hardness, porosity and fracture toughness of bimodal WC–12Co coatings prepared by optimal coating process (OCP) have been investigated. In particular, the cost and performance of WC–12Co coatings are evaluated in detail. All the coatings are deposited by the JP-8000 HVOF spray system with PLC-based closed-loop mass flow controls, which can provide precise flux of every medium.

2. Experiment

2.1. Materials

A new bimodal WC–12Co powder (ZYT103D produced by Ganzhou Zhangyuan Tungsten New Materials Co., Ltd, China; mass percent: C = 5.31%, Co = 11.92%, W = 82.66%, O = 0.074%, Fe = 0.036%) was coated on the low carbon steel substrate by JP-8000 HVOF equipment.

* Corresponding author.
E-mail address: wangqun72@163.com (Q. Wang).

0257-8972/$ – see front matter
doi:10.1016/j.surfcoat.2011.09.071

The bimodal powder was synthesized by mixing the coarse (2.5 μm) with the fine (0.2 μm) WC particles, the ratio of the coarse to the fine WC particles was 7:3. The powder mixture was spray-dried and agglomerated, and then sintered into sprayable particles in the range of 5–45 μm. Fig. 1 shows the low magnification image of the spray particles and a high magnification image of a single particle marked by rectangle in Fig. 1a.

The spray powder exhibit good spherical shape (see Fig. 1) and the single spray particle is composed of cobalt binder, coarse and fine WC grains as well as many pores on the surface of the WC–12Co particles. The good spherical shape of the spray particles contributes to powder feeding and pores on the surface of particles can made the spray particle heated homogenously in the plume during spraying.

2.2. Preparation of HVOF coatings

Prior to spraying process, rectangular (200 × 57 × 5 mm^3) samples are degreased and grit blasted with 60 meshes Al_2O_3. About 0.35 mm thick WC–12Co was coated on substrates by using JP-8000 HVOF system (Praxair) and kerosene is used as fuel. WC–12Co coatings are prepared by nine different parameters designed by Taguchi experimental program based on three levels of four parameters: kerosene flux (No. 3 aviation kerosene), oxygen flux, powder feed rate and spray distance as shown in Table 1.

According to the operating experience and the suggestion spray parameters provided by the JP-8000 HVOF manufacturer, the other spray parameters out of the Taguchi program have been set as follows: spray gun speed in the horizontal direction is 500 mm/s and the step in the vertical direction is 5 mm. The powder carrier gas is nitrogen and the flux is 10.8 L/min. The spraying angle is 90° and the temperature of substrate during spraying is kept below 150 °C with compressed air cooling.

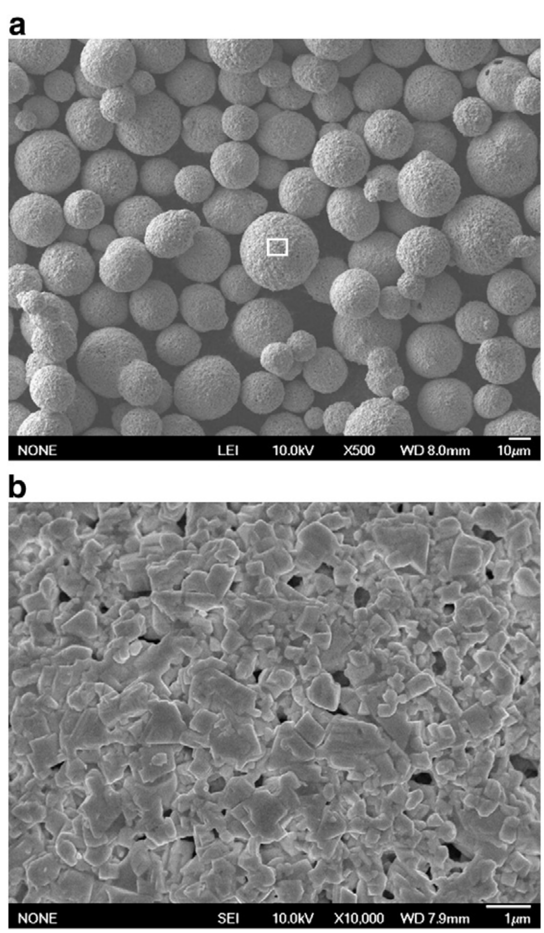

Fig. 1. Micrographs of bimodal WC–12Co powder (a) low magnification, and (b) high magnification.

Table 1
Chamber pressure of nine WC–12Co coatings prepared by Taguchi program and the OCP.

Process	Kerosene flux (L/min)	Oxygen flux (L/min)	Feed rate (g/min)	Spray distance (mm)	Chamber pressure (MPa)	Coating code
1	0.38	850	60	326	0.653	SF1
2	0.38	920	75	353	0.696	SF2
3	0.38	990	90	380	0.737	SF3
4	0.41	850	75	380	0.682	SF4
5	0.41	920	90	326	0.717	SF5
6	0.41	990	60	353	0.762	SF6
7	0.44	850	90	353	0.698	SF7
8	0.44	920	60	380	0.739	SF8
9	0.44	990	75	326	0.782	SF9
OCP	0.44	990	60	326	0.782	SF10

2.3. Characterization

X-ray diffraction (XRD) analysis of the powder and coatings is carried out using a Rigaku D/max-2550 diffraction meter with Cu-Ka radiation. Scanning electron microscopy (SEM) of the cross section of the coating is obtained using a FEI-Quanta200 or JSM6701 with EDS system. Porosity measurement is performed on the transverse section of the coating with a Zeiss 401MAT microscope fitted with image analyzer. Ten readings are recorded and the average was reported. Hardness measurements are also done on the transverse section of the coating with a Vickers indenter at the load of 0.3 kg, 1 kg and 5 kg, respectively, and a dwell time of 10s using a HV-5 Vickers hardness tester. An average of ten readings is reported. Cracks parallel to substrate will appear on the cross-sectional of the HVOF coating which can be measured, and the fracture toughness of coatings is calculated by using the length of indention and cracks measured according to Evans and Wilshaw equation [9]. The per-pass thickness of coating is obtained by using the total thickness of coating at room temperature divided by total spray passes.

2.4. Abrasion wear tests

The coated specimens with a dimension of 57 × 25 × (~5.35) mm are tested using the well known wet sand rubber wheel abrasion tester [2]. Steel wheel covered by vulcanized rubber whose Shore hardness is 72 and turn against the test specimen under the load of 100 N. The rotation speed of the rubber wheel was 240 rpm. The tribological pair are submerged in a mixture of 20–40 mesh quartz sand and fresh water, the weight of quartz sand is 1.5 kg and the weight of water is 1 kg, the abrasive slurry used were not recycled. The coating mass loss is measured at every 3000 rounds; the total duration of the test is 9500 rounds. The first 500 rounds are just to accommodate the system and it is not taken into account in the wear measurements. All the samples before and after the test were measured by ultrasonic cleaning for 5 min in acetone,and then dried by a stream of hot air. The weight loss of the samples is measured using a FA1004 electric balance with accuracy of 0.1 mg. The mass loss obtained is normalized with the coating density to obtain the volume wear loss.

The abrasive wear mechanism is speculated by the final worn surface of HVOF WC/Co coating in the previous studies [2,6,10]. In order to systematically study the wear process, a visualization approach is employed by means of studying the same spot on the wear track with high resolution named as microscopic observation in situ [11]. In order to locate the same position in the electron microscope, several indentations using a Vickers indenter were made with a 0.5 kg load