Abrasive wear resistance of HVOF thermal sprayed WC-CrC-Ni coatings

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1. Introduction

Nowadays, there is a growing need to reduce or control wear in order to extend the lifetime of engineering components, to preserve material resources, to save energy and to improve safety [1]. Every year, the cost of losses due to wear represents a significant percentage of the gross national product (GNP) of each country. On the other hand, wear is desirable in some surface finishing processes, such as polishing and grinding.

One of the most attractive methods used to minimize wear is the application of surface treatments [2]. Among a large number of surface treatments developed, thermal spraying is one of the most widely used technologies to improve the wear behaviour of different engineering components [3].

Thermal spraying methods, especially high velocity oxy fuel (HVOF) spray, provide excellent wear resistant coatings for different industries, such as aviation, automotive, energy and metal processing. Tungsten carbide and chromium carbide-based coatings are often used for applications such as gas turbine, steam turbine, aero engine to improve the abrasive and erosive wear resistance. Also, carbide coatings are considered a viable alternative to hard chrome plating due to environmental regulations [4-6].

Since wear is not a material property, but depends on the tribological system, the development of optimized coatings requires knowledge regarding the stress conditions (wear mechanism, load etc) [7]. Therefore, the aim of this study was to develop optimized wear protective coatings for engineering components subject to dry abrasive wear.

2. Experimental procedure

2.1. Materials

30 µm size WOKA 7504 powder from Sulzer Metco, Switzerland was used. The approximate chemical composition, particle dimension and density of the WOKA 7504 powder is presented in Table 1.

WOKA 7504 powder is formed of spherical particles and is obtained by sintering. It has a uniform distribution of 43% chromium carbide and 37% tungsten carbide The SEM micrograph of the spray powder is given in Figure 1.

The material used as a substrate in the present work was an austenitic stainless steel, AISI 304L, according to SR EN 10088-1:2005, with a thickness of 4 mm. The chemical composition, according to the quality certificate, is presented in Table 2.

Table 1. Chemical composition and particle distribution.

Chemical composition [%]					
W	Cr	Ni	Co	C	Fe
Balance	38.5-43.5	10-13	2.9-4.1	7.7-8.5	<0.5

Particle dimension, distribution and density			
Dimension (max.)	Dimension (min.)	Primary carbide appearance	Density [g/cm^3]
30 µm	10 µm	Rough	3.1 – 3.8

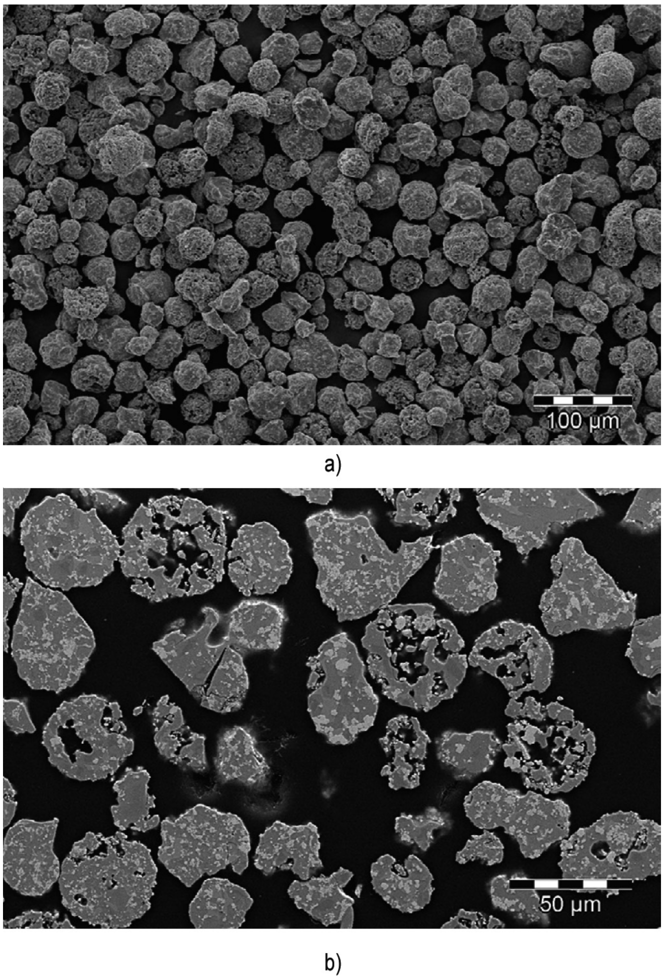

Figure 1. SEM micrograph of WOKA 7504 powder: a) Powder morphology; b) Microstructure [9].

2.2. High Velocity Oxy Fuel (HVOF) depositions

Sulzer Metco HVOF equipment and a robot arm were used for the deposition of WOKA 7504 powder. The coating deposition was carried out inside an acoustic chamber because the HVOF coating process produces very loud noise. The HVOF deposition parameters are presented in Table 3. Before the deposition, the samples were sandblasted and degreased with alcohol. The deposition was realized immediately in order to avoid the formation of a thick oxide layer on the samples surface which could influence the coatings quality. For this experimental study, one, two, four and six layers were deposited.

Table 2. Chemical composition of AISI 304 L steel.

Chemical composition, [wt.%]	According to	
	ASTM	Quality certificate
$C_{max.}$	0.03	0.03
Cr	18-20	19
Ni	8.0-12.0	11
$Mn_{max.}$	2.0	2,0
$P_{max.}$	0.045	-
$Si_{max.}$	1.0	1.0
$S_{max.}$	0.03	-
Fe	balance	balance

Table 3. HVOF deposition parameters.

Spraying parameters	
Spray distance	225 mm
Spray angle	90^o
Powder feed rate	60 g/min
Oxygen flow rate	185 l/min
Fuel (Propane) flow rate	68 l/min
Gun travel speed	75 mm/s

2.3. Coating characterization

The microstructure of the base material and of the coatings was investigated by means of optical microscopy using a MeF2 microscope. Cross sectioned specimens were grounded, polished and etched using a B10 immersion reagent. Microhardness measurements were performed on the cross-section of the base material and HVOF coatings. The measurements were realized using a Zwick 3212 equipment, under a 1000 g load and a loading time of 10 seconds. Each hardness value represents the average value of five measurements. The coatings thickness was measured according to ISO 1463:2003 and the average results of 26 measurements for each sample are presented in Table 4.

Table 4. Coatings thickness.

Sample	Coating thickness, [µm]
M1 (1 layer deposited)	112
M2 (2 layers deposited)	219
M4 (4 layers deposited)	415
M6 (6 layers deposited)	620

The wear behaviour of the HVOF coatings was determined by Taber Abraser tests corresponding to ASTM F1978. The tests were carried out at ambient temperature of 25° C and humidity of 30 - 65 %, applying the maximum load of 1000 g per abrasive wheel, using the Taber Rotary Abraser Model 5135 equipment (Figure 2). Prior to testing, the samples were exposed in 3% NaCl solution for 72 hours.

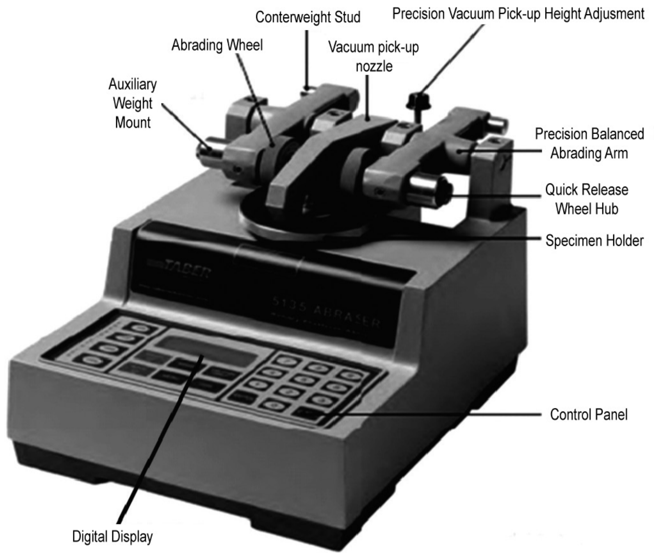

Figure 2. Taber Rotary Abraser equipment.

The coatings were tested 30.000 cycles. All coatings were tested with polished surfaces state exclusively. In order to perform the tests, all the specimens were grinded to a thickness of 6.35 mm and a centre hole of 6.35 mm. The specimens were cleaned in order to be free from grit, grease, fingerprints or other contaminants. Prior to abrasive wear testing, the samples were conditioned for 24 hours in the test atmosphere.

3. Results and discussion

3.1. Microstructure

The microstructure was found to be normal for 304L stainless steel, as it can be observed from Figure 3, and consists in a

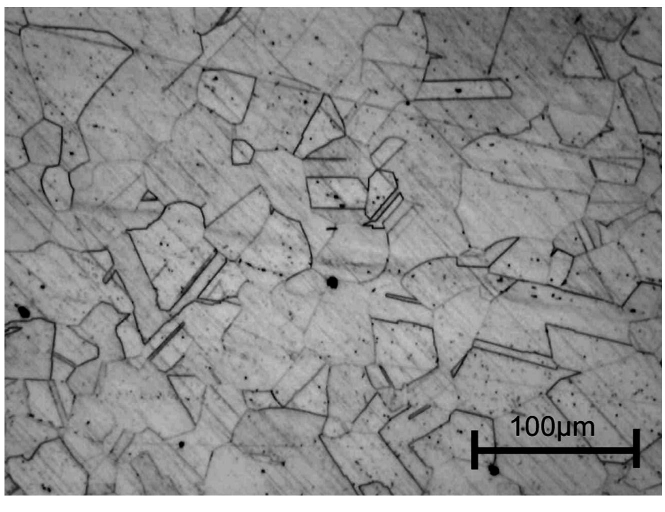

Figure 3. Microstructure of the base material.

homogeneous austenite structure with annealing twins. The microstructure of the HVOF coatings is presented in Figure 4 a,

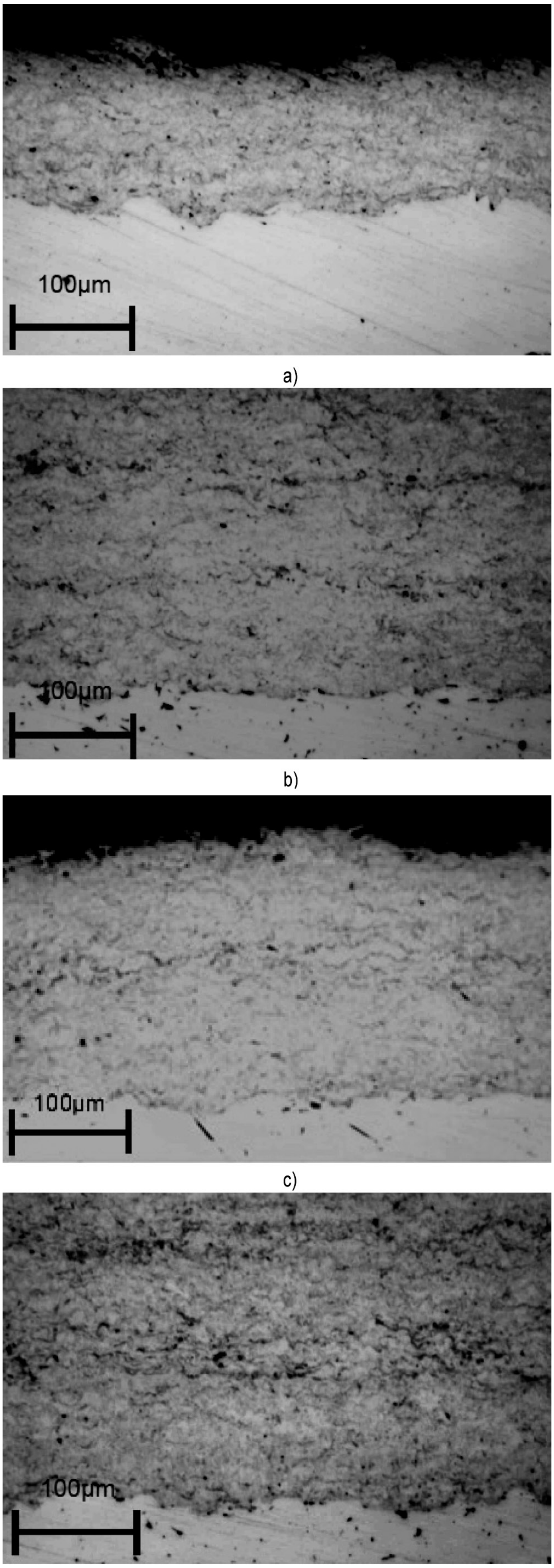

Figure 4. The microstructure of HVOF coatings
a – one deposited coating; b-two deposited coating; c-four deposited coatings; d-six deposited coatings.

b, c, d and is composed of W and Cr carbides. Also, it is noted that the coatings show a good homogeneity.

3.2. Hardness

The results of hardness tests are presented in Table 4. For comparison, the hardness of the base material was also determined and ranges between 186 and 216 HV0.1. The hardness values show that there is a substantial increase in hardness after the HVOF deposition.

Table 4. Hardness results.

Sample	Hardness HV1
M1 (1 layer deposited)	1003
M2 (2 layers deposited)	1099
M4 (4 layers deposited)	1151
M6 (6 layers deposited)	990

3.3. Dry abrasive wear

In order to evaluate the abrasive wear resistance of the specimens the depth wear method was used. The depth was determined using a mechanical comparator. The measurements were performed in four points (A, B, C, D) on un-abraded samples, recording the depths. After the tests, the measurements were repeated in the same points and were calculated the differences in each point between the depths before and after the abrasive wear tests. In order to compensate for depth differences around the specimen wear path, an average depth value was calculated for each point. The results of the abrasive wear tests are presented in Table 5.

Table 5. Abrasive wear results.

Sample	Wear volume [mm^3]	Worn mass [g]	Wear rate [g/h]
M0 (base material)	738	5.76	0.83
M1 (1 layer deposited)	150	1.17	0.16
M2 (2 layersdeposited)	58	0.45	0.06
M4 (4 layersdeposited)	79.	0.61	0.09
M6 (6 layersdeposited)	73	0.57	0.08

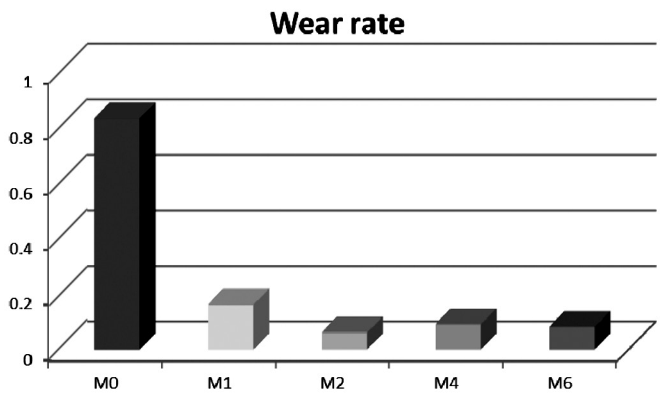

Figure 5. The variation of the wear rate.

Figure 5 presents the variation of the wear rate as a function of the deposited layers.

4. Conclusions

The experiments performed lead to the following conclusions:

- The structure of the base material consists of a homogeneous austenite structure with annealing twins and W and Cr carbides for the HVOF coatings;
- The hardness of HVOF coatings increased up to a value of 1151 HV1 due to the presence of Cr and W carbides phases in the structure. Compared with the hardness values of base material, it can be observed an increase of about 6 times;
- HVOF coatings possess superior dry abrasive wear resistance, compared to the base material, due to a higher hardness;
- The lowest wear rate, of 0.06 grams/h, was obtained for the samples with two layers deposited.

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