Tribology International 102 (2016) 429–435

Contents lists available at ScienceDirect

Tribology International

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

Cavitation erosion of plasma-sprayed CoMoCrSi coatings

Yan Wang [a,*], Jiangwei Liu [a], Nan Kang [a], Geoffrey Darut [a], Thierry Poirier [b], Jorge Stella [c], Hanlin Liao [a], Marie-Pierre Planche [a]

[a] Université deBourgogne Franche-Comté, UTBM, LERMPS, Belfort, France
[b] Institut de Céramique Française, Limoges, France
[c] Universidad Simón Bolívar, Departamento de Ciencia de los Materiales, Caracas, Venezuela

ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form
24 May 2016
Accepted 10 June 2016
Available online 11 June 2016

Keywords:
Cavitation erosion
CoMoCrSi coating
Plasma spraying
Surface 3D profile

ABSTRACT

CoMoCrSi coatings were manufactured on a steel substrate by atmospheric plasma spraying (APS), followed by a three-hour heat treatment at a temperature of 800 °C and 1000 °C, respectively. Prior to the ultrasonic test of the cavitation erosion, coating cross-sections were observed by scanning electron microscopy (SEM) and analyzed by X-ray diffraction (XRD). 3D profiles were employed to investigate the erosion mechanism on both pristine and eroded surfaces. As a result, it is shown that the heat treatment can significantly reduce the mean erosion depth of the CoMoCrSi coatings and the cavitation damages mainly consist of the removal of the splashes with weak adhesion during plasma spray and the delamination of fragments from bubble collapses.

1. Introduction

Many components of mechanical systems working in liquid environments are involved in cavitation erosion. It is a kind of surface degradation caused by formation and collapse of bubbles in liquids that are subjected to frequent pressure changes. Bubbles appear in low pressure areas and implode in higher ones. When a bubble collapses just close to the solid surface of rotating components, an intensive shock wave is generated and consequently materials can suffer the effect produced by the dissipation of a large density of energy [1–4]. The repeated occurrence of this phenomenon leads to fatigue, plastic deformation and eventually mass loss of the material according to its mechanical properties. The removal of material under these conditions is called cavitation erosion. Many components of mechanical systems working in liquid environment are affected by this type of damage such as boat propellers hydro, turbines and pumps.

Generally, a hardfaced coating is applied by welding or thermal spraying to protect the basis metal against cavitation erosion. Wu [5] has demonstrated that HVOF sprayed WC–Co–Cr coating losses only 64% mass of that of stainless steel as exposed to cavitation erosion for 30 h for the contribution of presence of hard phase in the coating. Meanwhile, HVOF sprayed WC–10Co–4Cr [6] and ion-nitrided 34CrAlNi7 [7] steel are confirmed to show high resistances against cavitation erosion. In addition, Sreedhar [8] concluded that cavitation erosion resistance was improved by two different hard-facing deposits: Co-based Stellite6® alloy coatings and Ni-based Colmonoy5® coating. CoMoCrSi alloys, usually known as Tribology® family, is a cobalt alloy containing molybdenum, chromium and silicon. This group of materials exhibit an excellent resistance against corrosion, oxidation and abrasive wear [9,10] as well as mechanical strength [11]. The remarkable good coating properties observed in CoMoCrSi alloys result from the formation of hard precipitates (cobalt–molybdenum–silicon based intermetallic Laves phases) which are dispersed in a softer cobalt-based alloy matrix. However, coating resistance of these alloys against cavitation erosion has been to date insufficiently investigated.

This study deals with CoMoCrSi coatings manufacturing by atmospheric plasma spraying and their cavitation testing and characterization by means of microstructural and composition analysis. Cavitation erosion resistance of the coatings was examined by using a standard ultrasonic testing apparatus. In this context, erosion wear was evaluated and the damage mechanism induced by cavitation was discussed.

2. Experimental procedure

2.1. Materials and coating deposition

Commercial CoMoCrSi powder (Plasma-Technik AG, Switzerland) prepared by gas atomized was used as feedstock. Table 1 shows the nominal chemical composition of the powder. Coatings were manufactured on disk-shaped carbon steel (C22E) substrates of 25 mm in diameter. Chemical compositions of the substrates are illustrated in Table 2. The substrates were cleaned in an ultrasonic alcohol bath and

* Corresponding author.
E-mail address: wangyan140511@hotmail.com (Y. Wang).

http://dx.doi.org/10.1016/j.triboint.2016.06.014
0301-679X/

grit blasted with corundum particles just before the deposition in order to increase the adherence of the coatings.

The coatings were produced by means of an atmospheric plasma spraying process employing a Sulzer-Metco F4 plasma gun. An Ar–H_2 mixture was used as the plasma gas. Argon was also employed as carrier gas for the powder feed at a flow rate of 3.5 slpm. The spraying parameters are listed in Table 3. After spraying the as-sprayed coatings were heat treated for 3 h at temperatures of 800 °C and 1000 °C. The samples were cut and the resulting surfaces prepared in order to investigate the cross section morphology and hardness of the coatings.

2.2. Characterization

Size distribution of the powders was measured with a particle size analyzer through laser diffraction method (Mastersizer 2000, Malvern, England). Scanning electron microscopy in backscattering mode (JEOL, JSM-5800LV, Japan) was employed to characterize feedstocks, coating cross sections and its surface morphology after cavitation erosion tests. Elemental analysis of the coating was also carried out by energy dispersive spectrometry (EDS). The phase composition of the powder and the as-sprayed coating were examined employing X-ray diffraction (Bruker AXS D8 focus, Germany) with a cobalt anticathode ($\lambda = 1.78897$ Å) at 35 kV, 40 mA.

Vickers microhardness measurements of the as-sprayed coating were performed on the polished cross section with a Leitz microhardness tester with a load of 300 g applied during 15 s. Ten measurements were carried out to calculate the average value reported as the hardness value. Coating porosity was estimated by image analysis on polished cross sections by scanning electron microscopy and then analyzed by means of *Image J* software. Ten optical micrographs at magnification of 300 × at random places were used to estimate the average value. The 3D surface profile was analyzed with an Altisurf 500-ALTIMET surface profiler equipped with an optical sensor. Profiles were done after 0 and 114 min of cavitation to characterize the evolution of the surface damage.

Cavitation erosion tests were performed according to the ASTM G32 standard in distilled water at a temperature of 22 ± 1 °C. The tests were conducted under a frequency of 20 kHz and an amplitude of 45 μm respectively employing a sonotrode of 13 mm in diameter. The distance between the tip and testing specimen was 0.5 mm. The drawing of the vibratory device used for the cavitation erosion testing is illustrated in Fig. 1. The samples were polished to a roughness of 0.4 μm before testing and then ultrasonically cleaned in an alcohol bath for 10 min before testing. The mass loss of the tested specimens was measured by means of an analytical balance with a precision of 0.1 mg after 1, 4, 9, 24, 54 and 114 min cavitation erosion respectively. The mean depth of erosion (MDE) is obtained from the following equation:

$$\mathrm{MDE}(\mu\mathrm{m}) = \frac{\Delta w}{1000 \rho A} \quad (1)$$

where Δw is the mass loss in mg, A represents the exposed area in mm^2 and ρ is the density of the material in g/cm^3.

Table 1
chemical composition of the powder.

Element	Mo	Cr	Si	Co
Chemical composition (wt%)	28.5	17.5	3.4	Balance

Table 2
Chemical composition of C22E.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
(wt%)	0.17–0.24	≤ 0.40	0.40–0.70	≤ 0.030	≤ 0.035	≤ 0.40	≤ 0.10	≤ 0.40	bal.

3. Results and discussion

3.1. Characterization of the powder and coating

Fig. 2 illustrates the morphology and size distribution of the feedstock. It can be seen that the particles show a uniform spherical shape with few fine particles. The size distribution of the CoMoCrSi powders analyzed by laser scattering is ranged from 16.40 μm to 46.93 μm with an average size value of 30.18 μm. Fig. 3 (a) shows the cross section microstructure of the CoMoCrSi coating sprayed by APS. The coating exhibits a dense microstructure and an apparent good adherence to the substrate. No significant cracks were observed inside the coating or at the interface with the substrate and only few small pores can be observed in the coating

Table 3
Parameters of the APS process.

Parameters	value
Electric arc current (A)	620
Electric arc voltage (V)	60
Plasma gas (NL/min) Ar	35
Plasma gas (NL/min) H_2	10
Spraying velocity (mm/s)	300
Standoff distance (mm)	110

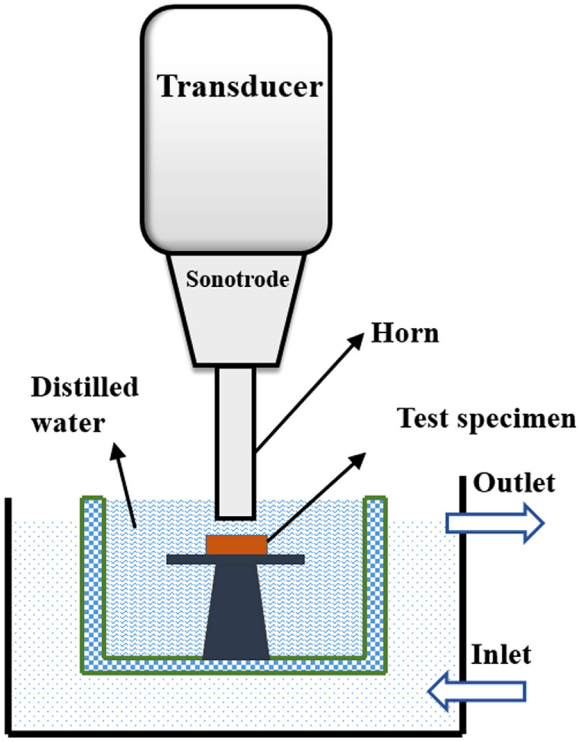

Fig. 1. Drawing of the cavitation erosion test device.