Conference Proceedings Paper

Resistance to Cavitation Erosion and Sliding Wear of MCrAlY and NiCrMo Metallic Coatings

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Abstract: Bulk cobalt- and nickel-based metallic materials exhibit superior resistance to cavitation erosion and sliding wear. Thus, thermally deposited High Velocity Oxygen Fuel (HVOF) coatings seem promising for increasing the wear resistance of the bulk metal substrate. However, the effect of chemical composition on the cavitation erosion and sliding wear resistance of M(Co,Ni)CrAlY and NiCrMo coatings has not yet been exhaustively studied. In this study, High Velocity Oxygen Fuel (HVOF) coatings such as CoNiCrAlY, NiCoCrAlY, and NiCrMoFeCo were deposited on AISI 310 (X15CrNi25-20) steel coupons. The microstructure, hardness, phase composition (X-ray diffraction, XRD) and surface morphology of the as-sprayed coatings were examined. Cavitation erosion tests were conducted using the vibratory method in accordance with the ASTM G32 standard. Sliding wear was examined with the use of a ball-on-disc tribometer, and friction coefficients were measured. The mechanism of wear was identified with the scanning electron microscope equipped with an energy dispersive spectroscopy (SEM-EDS) method. In comparison to the NiCrMoFeCo coating, the CoNiCrAlY and NiCoCrAlY coatings have a lower wear resistance.

Keywords: HVOF, thermal spraying, metallic coatings, sliding wear, cavitation erosion, MCrAlY

1. Introduction

Bulk cobalt- and nickel-based metal alloys have superior resistance to both cavitation erosion and sliding [1–5]. Moreover, Co-, Ni- or even Fe-based overlay deposits are considered highly resistant to abrasion and erosion [1,2,6]. Thus, HVOF thermal spraying seems to be the next step in increasing the wear resistance of bulk metal substrates. Various cermet coatings systems have been investigated in relation to sliding, abrasive or erosion wear [7–12]. It is known that thermally sprayed coatings increase the wear resistance of machine and equipment components and make it possible to prevent or reduce various damage processes. Abrasive damage, erosion by solid particles and corrosion are the most frequently described damage processes in literature [13–16]. Despite the fact that the HVOF method is widely used for metallic or cermet coating deposition [7,9,15,17–20], the anti-wear properties of HVOF coatings are still being investigated. New studies on the abrasive wear of thermally deposited coatings are published, and even though these issues seem to be quite well-known there are relatively few scientific reports combining both sliding and cavitation testing of HVOF metallic coatings. The effect of alloying composition on the cavitation erosion and sliding wear resistance of Ni-based coatings deposited by the HVOF method has not been exhaustively investigated. In comparison to other thermal spraying processes, e.g., plasma spraying or flame spraying, HVOF-deposited coatings exhibit low porosity and homogeneous structure. This is mainly due to the low process temperature and the high speed of the particles being sprayed [14,21,22]. It is well known that the homogeneous structure of the material has a positive effect on its resistance to cavitation erosion [23,24]. Furthermore, the investigation into wear resistance is an up-to-date problem from the point of view of both scientific and engineering practice [8,9,20,25,26]. In this paper, the sliding and cavitation erosion wear resistance of NiCrMoFeCo, CoNiCrAlY and NiCoCrAlY coatings is investigated.

2. Experimental

The nominal chemical compositions of powders used for deposition of HVOF coatings are given in Table 1. The substrate was AISI 310 (X15CrNi25-20) with the thickness ranging from 180 to 200 μm and the initial roughness of deposited coatings, Ra, ranging between 4 and 6 μm. The coatings were examined on their top surfaces using a SEM microscope. Phase composition was estimated by the XRD method. Hardness was measured on the metallographic cross-sections with a nano-hardness tester (Anton Paar CSM Instruments) having a load of 500 mN.

Table 1. Nominal chemical composition of feedstock powders.

Chemical Element, wt %	Specimen Code		
	A	B	C
	CoNiCrAlY	NiCoCrAlY	NiCrMoFeCo
Ni	32	Balanced	Balanced
Co	Balanced	22	0.5
Cr	21	17	21.5
Al	8	12.5	-
Y	0.5	0.5	-
Mo	-	-	8.5
Fe	-	-	3

Sliding wear tests were performed by the ball-on-disc method with a tribotester from CSM Instruments, Switzerland, in compliance with the procedure described in [27,28]. The counter-ball was made of 100Cr6 steel; the applied load was 15 [N] and the sliding distance was set equal to 200 [m]. The mass loss of the samples was estimated with an accuracy of 0.01 mg. Wear traces were first examined with the Dektak 150 contact profilometer (Veeco Instruments, USA) for calculating volume loss. After that, they were also examined with the use of a scanning electron microscope (SEM).

Cavitation erosion tests were conducted using a vibratory rig operating under the conditions given in the ASTM G32 standard [29] and described in previous papers [8,30]. The stationary specimen test method and distilled water were used. The samples were weighed in specified time intervals with an accuracy of 0.01 mg. The worn areas were analyzed with the SEM microscope.

3. Results

3.1. Coating Characterization

The surface morphology of the coatings is presented in Figure 1 and Figure 2. The top-view of the coatings indicates their lamellar microstructure and the presence of unmelted powder particles, porosity and oxides that are typical of thermally sprayed coatings [14,31,32]. According to the XRD analysis results, the coatings A and B form a γ solid solution with the structure of fcc and phases β-(Co,Ni)Al and Cr_3Ni. This is in agreement with the data reported in the literature [14,19]. The hardness ranges from 4.7 to 5.8 GPa, which is comparable with the literature data [19,33].

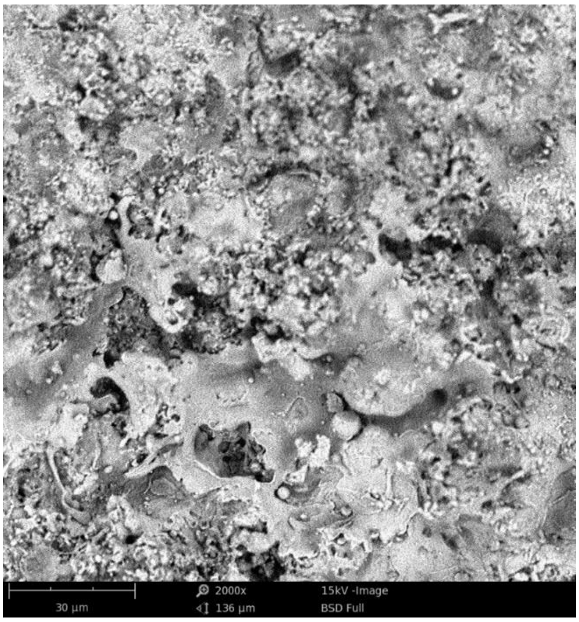

Figure 1. Surface morphology of coating A, SEM.

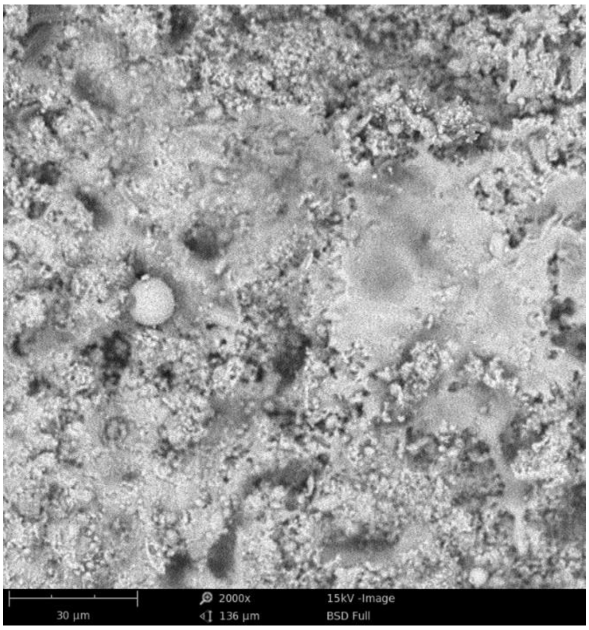

Figure 2. Surface morphology of coating C, SEM.

3.2. Sliding Wear Results

Sliding wear results are given in Figure 3-5 and in Table 3. The results clearly demonstrate that coating A has undergone the highest wear while coating C is the most resistant to wear. The friction coefficients are in agreement with the mass loss data, as shown in Figure 3. At the initial stage of the wear process, the top surface peaks of the coatings are cut out or smashed, and, subsequently, a great amount of debris occurs in the wear trace. The wear results are complementary with the surface roughness measurements of the coatings. Also, it can be observed that the wear of the C (nickel-based) coating is much lower.

Figure 4 shows the wear traces of M(Ni,Co)CrAlY coatings and Figure 5 shows the wear trace of the Ni-based coating. All wear traces show the presence of oxides (primary oxides or material oxides due to wear). Also, it can be observed that the wear mechanism relies on smearing the coating material and, especially in the case of coating C, on low-cyclic fatigue resulting in the delamination of the coating material. The material removal is a result of cyclic compression and smearing of the HVOF-deposited material. Moreover, the observed delamination is in agreement with the splat dimensions indicating splat-induced detachment. Wear debris also plays an important role due to its smearing through the wear trace and cyclic deformation leading to a fatigue detachment of the coating material.

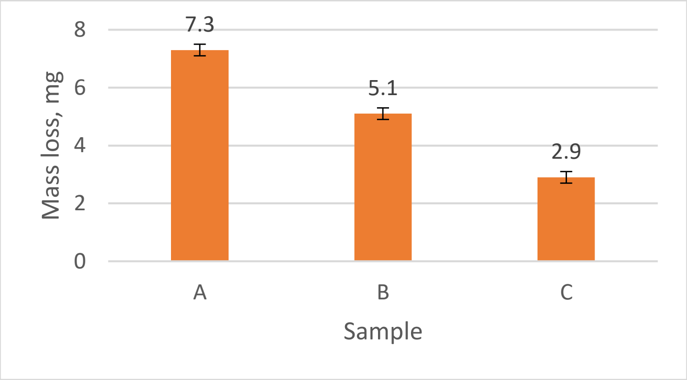

Figure 3. Sliding wear results.

Table 3. Friction coefficients of the tested coatings.

Coating code	Friction Coefficient	
	Average	**SD**
A	0.97	0.07
B	0.64	0.05
C	0.57	0.04

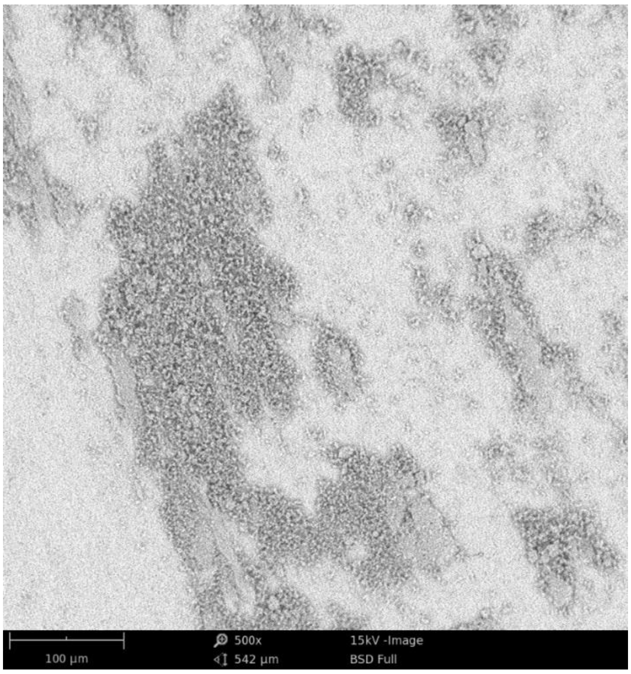

Figure 4. Wear trace of coating A, SEM.

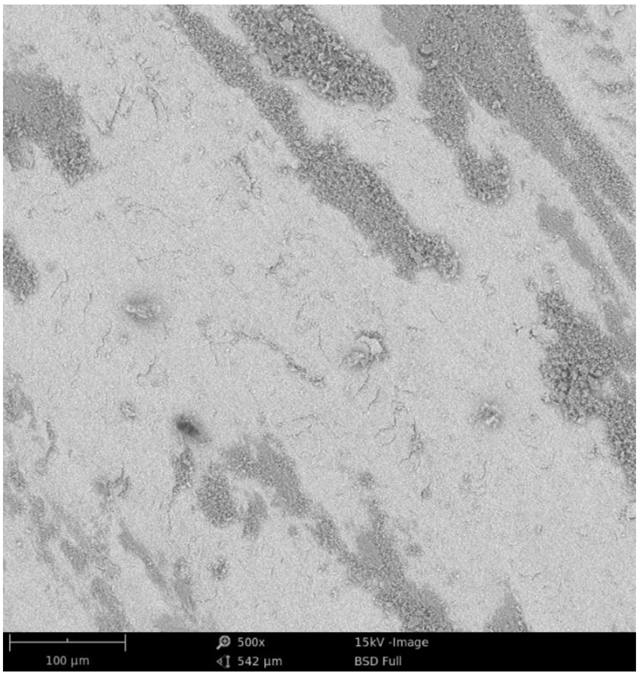

Figure 5. Wear trace of coating C, SEM.

3.3. Cavitation Erosion

Cavitation erosion curves of the HVOF coatings are given in Figure 6. It can be observed that in comparison to M(Ni,Co)CrAlY, the C (nickel-based) coating exhibits a higher resistance to cavitation. The material loss of the coatings A and B is comparable, and it is twice higher than that of coating C. The wear mechanism in the M(Ni,Co)CrAlY-type coatings is similar and it consist in the detachment of loose splats and cracking induced by non-uniformities (unmelted particles, oxides and lamellae borders). Material erosion is followed by plastic deformation of the coating material. Figure 7 and Figure 8 show the cavitation-eroded surfaces of the coatings B and C. A comparison of the SEM images reveals the presence of plastic strains. Moreover, it can be observed that in the case of coating B the material is removed in massive chunks, while the C coating exhibits a much compact morphology and lower surface roughness, which increases its wear resistance. In contrast to coating C, the coatings A and B have an Ni-Co-based matrix. It seems that the deformability of nickel leads to an increased wear resistance of coating C.

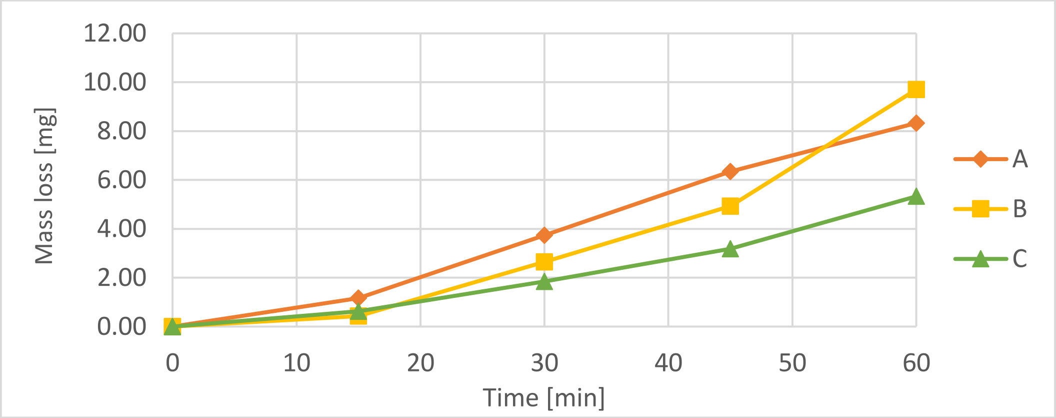

Figure 6. Cavitation erosion curves of HVOF coatings.

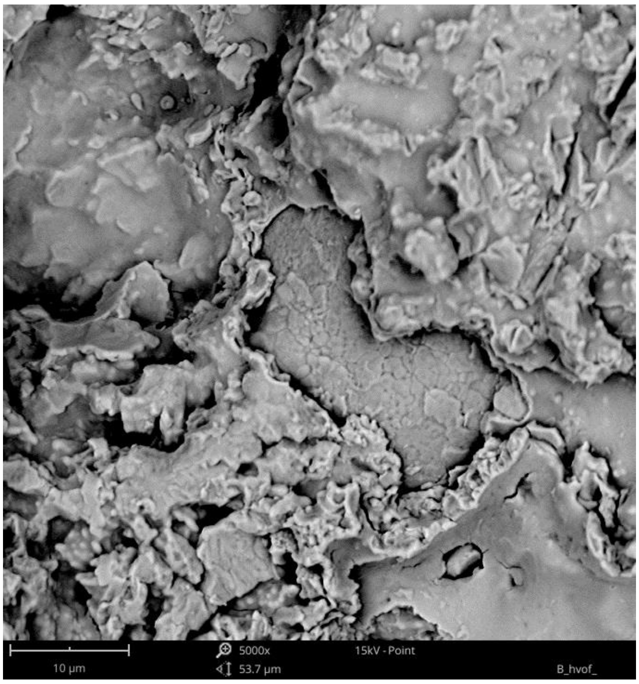

Figure 7. Cavitation-eroded surface of coating B, SEM.

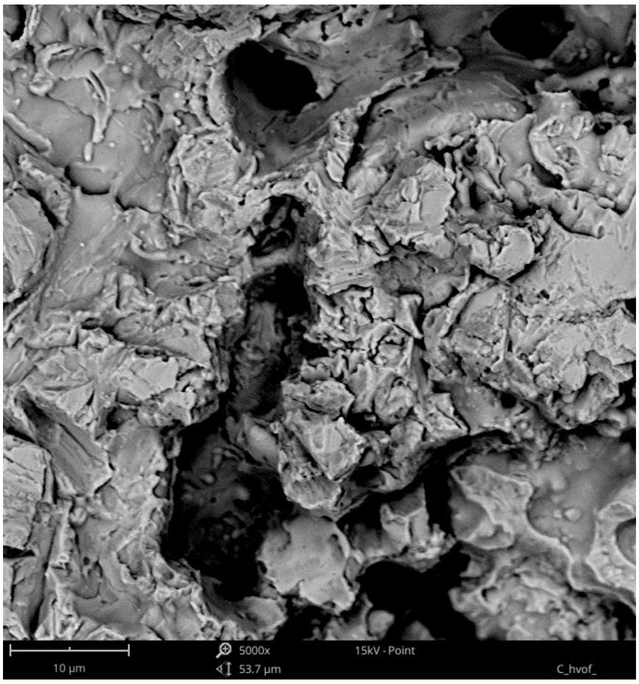

Figure 8. Cavitation-eroded surface of coating C, SEM.

4. Conclusions

The results of the study lead to the following conclusions:

- the sliding wear resistance increases with increasing the nickel content as follows: NiCrMoFeCo < NiCoCrAlY < CoNiCrAlY;
- the friction coefficient increases with increasing the Co content as follows: NiCrMoFeCo < NiCoCrAlY < CoNiCrAlY;
- the resistance to cavitation erosion of the M(Co,Ni)CrAlY coatings is almost two times lower than that of the NiCrMoFeCo deposit;

- a combination of adhesive, oxidation and low-cyclic fatigue is the dominant sliding wear mechanism;
- cavitation erosion damage is induced by plastic deformation of the coating material; it is initiated at the non-uniform areas (unmelted particles, oxides and lamellae borders) and results in the removal of the HVOF deposited material.

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