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Improving the wear resistance of HVOF sprayed WC-Co coatings by adding submicron-sized WC particles at the splats' interfaces

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ABSTRACT

In this paper, the submicron-sized WC particles (~300 nm) with the content of 3 wt.% and 5 wt.% are incorporated into high velocity oxy-fuel (HVOF) sprayed WC-Co coatings with the aim of improving properties of the coatings. XRD analyses suggest a small amount of decarburization of the incorporated WC phase after the composite coating deposition. The SEM microstructure showed even distribution of WC particles at the interfaces of WC-Co splats, indicating significantly enhanced wear resistance of the coatings with the wear rate as much as $\sim 10^{-7}$ $mm^3/N \cdot m$. The content of submicron-sized WC particles plays an important role in determining the wear performances of the coatings. The increment of submicron-sized WC particles causes a decrease in wear rate from 6.09×10^{-7} $mm^3/N \cdot m$ to 5.15×10^{-7} $mm^3/N \cdot m$. Also, the Vickers microhardness of the coatings enhances as the increasing of WC particle ratio (reaches 1365 HV with the content of the WC particles of 5 wt.%). The wear failure analysis gives further insight into the mechanism of the property enhancement. The change of stress state and crack initiation at splats' interfaces act as the predominant mechanism, which is caused by the presence of submicron-sized WC particles at splats' interfaces.

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1. Introduction

Thermal sprayed WC-based cermet coatings, such as WC-Co and WC-Co-Cr coatings, have been investigated extensively for high wear and severe corrosion applications [1–4]. Considering the long term functional service, more and more attention is paid on the further enhancement of the mechanical properties of the WC-Co coatings. Among the processing approaches, high velocity oxy-fuel spraying (HVOF) is one of the best methods for depositing the WC-Co coatings with superior mechanical performances and little decarburization of WC [5–7]. Tribological performances of HVOF WC-Co coatings have been investigated systematically under a series of testing environments, such as erosion [8,9], erosion–corrosion [10,11], sliding wear [2,10] and abrasive wear [9,12]. It is clear that dense microstructure and well retained WC phase in the coatings are essentially required, apart from other important considerations such as residual stresses [12], WC grain size [13], content of binder phase [14] and diffusion of hard phase to binder [6,14]. Nanostructure WC-Co coatings are reported to exhibit significantly enhanced performances in both sliding and abrasive wear, and show substantially higher hardness than the coatings with conventional structure [2,8,14]. It is believed that the decrease of the WC grain sizes benefits the properties of the coatings [9,13,14], while this effect is influenced by other variables such as hardening [15] and ductility [16] of the Co-rich binder phase. Higher metallic Co binder content contributes to higher ductility and fracture toughness of the WC-Co coatings, and also results in less cracking during rolling contact test [17]. The diverse wear behaviors of the WC-Co coatings have been well explained in terms of the differences in powder characteristics in particular the WC grain sizes, the extent of reaction and decarburization during spraying, and the evolution of the microstructure during coating formation stage [16,18]. To further improve the hardness and wear resistance of the WC-Co coating, incorporating other materials into WC-Co to form composite structure offers exciting opportunities. Mixing WC-Co powders with various particle sizes or adding other materials into WC-Co are evidenced effective in enhancing the wear resistance of the resultant coatings [4,8,19,20]. Recent work on functionally graded structure of WC-Co with other materials such as stainless steel [21] and NiAl [22] shows promising wear damage tolerance. However, the techniques attempted must be in accordance with the wear failure mechanism of the coatings. In general, the weakest zone of the WC-Co coatings during wear-related services is the interfaces between the splats [4,18]. Even though cross-sectioning characterization by focused ion beam of the first-layer WC-Co splats shows intrusion of large WC particles into substrate, causing enhanced adhesion of the coatings [23], to the authors' best knowledge, there is no experimental evidence yet that shows invasion of the micron-sized WC grains in the WC-Co splats. In this regard, strengthening the interface between WC-Co splats may open a new window for enhancing the wear resistance of the overall coatings.

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As an anisotropic inhomogeneous material, the mechanical behavior of composite coating is very complex. It is a function of the synergistic properties of the second phase, matrix, second phase/matrix interfacial bond. It also relates to the geometric properties such as particle size distribution, and content in the matrix. Profound theoretical work has been proposed in the research field of bulk composite materials. However, the theories are not suitable for the thermal sprayed composite coatings due to their special characteristics, such as limited bond area between splats, porous structural feature and unpredictable phases that originated during coating deposition. Attempts have been made on composite coatings and some mechanisms have been proposed [24,25]. However, the knowledge about the enhancing mechanism triggered by addition of small particles at the splats' interfaces is still lacking. In this study, submicron-sized irregular WC particles are incorporated into the HVOF sprayed WC-Co coatings through their even distribution at the splats' interface. Microstructure characterization and property evaluation are conducted and the relationship between the composite structure and properties is also elucidated.

2. Experimental setup

2.1. Powder and coating preparation

The commercial agglomerated and sintered WC-12 wt.%Co powders (H.C. Starck, Germany) with the size range of 45 ± 15 μm were used in this study (Fig. 1a). The spherical powder particles contain micron-sized WC grains of 1–10 μm, which are embedded in the cobalt binder phase. Prior to coating deposition, the submicron-sized WC particles with the size of ~300 nm (Fig. 1b) were mechanically blended with the WC-12Co powders by ball milling process (Fig. 1c, d). Closer examination of the composite powder particles shows presence of the submicron sized WC particles on the WC-Co particle (Fig. 1d). Most of the WC particles have already firmly bound with the WC-Co particles. Others remain as individual particles (Fig. 1c). The WC particles consist of sole WC phase (Fig. 2a). Phase analyses of the WC-12Co powders revealed presence of WC and cubic elemental Co (Fig. 2b). Coating deposition was conducted using the DJ-2700 HVOF system (Sulzer Metco, USA), which utilized propane as the fuel gas. The HVOF spray parameters are listed in Table 1. 304 stainless steel plates with the dimension of 26 mm × 18 mm × 2 mm were used as the substrates, which were Al_2O_3 grit-blasted and subsequently cleaned by sonication in acetone for 5 min before the spraying.

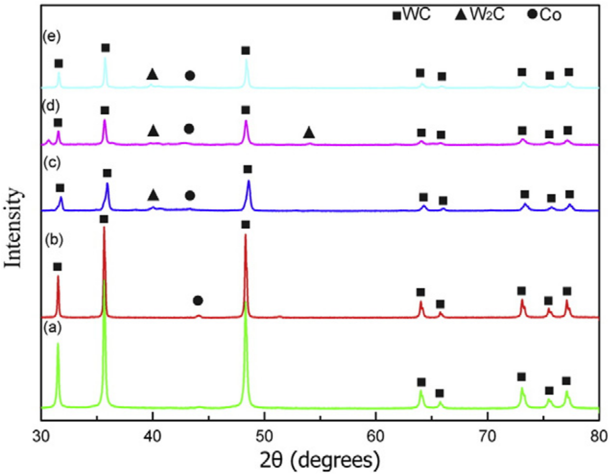

Fig. 2. XRD patterns of (a) the submicron-sized WC powders, (b) the WC-Co powders, and (c-e) HVOF sprayed WC-Co coatings with different contents of the submicron-sized WC (c: 0%, d: 3 wt.%, and e: 5 wt.%).

2.2. Coatings characterization

Phases of the coating samples were detected by X-ray diffraction (XRD, Bruker AXS, Germany) with a scanning rate of 0.1°/s using monochromatic Cu-Kα radiation operated at 40 kV. Microstructural features of the powders and coatings were characterized by using field emission scanning electron microscope (FESEM, FEI Quanta FEG250,

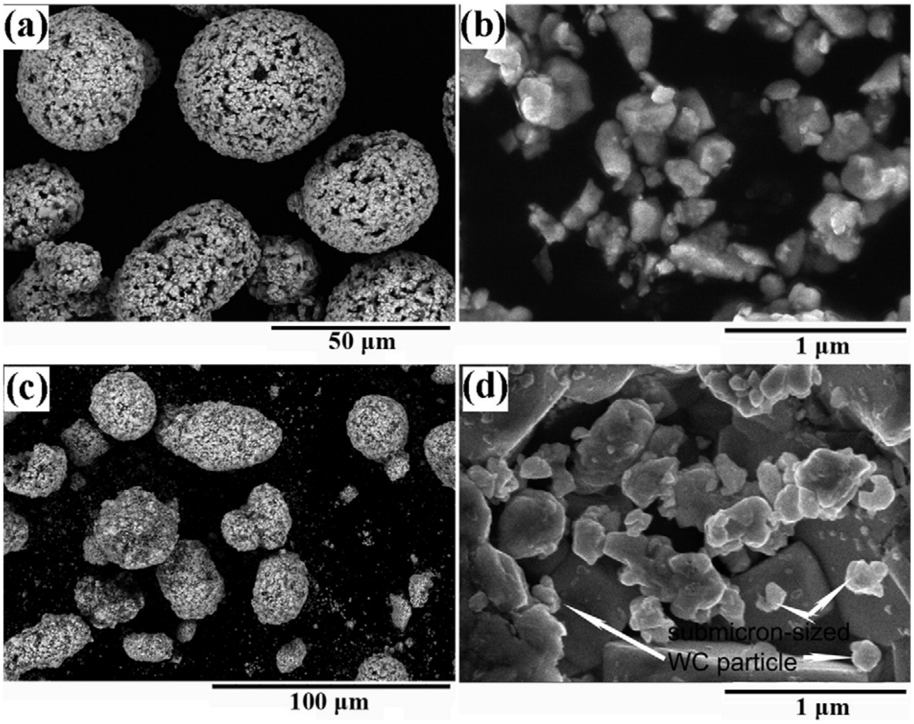

Fig. 1. FESEM images of the WC-12Co powders (45 ± 15 μm) (a), submicron-sized WC (~300 nm) (b), and the mechanically blended WC-Co/5wt.%WC powders (c), closer observation of the composite powder shows attachment of the submicron-sized WC particles on WC-Co particle (d).

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