

Influence of process variables on the qualities of detonation gun sprayed WC–Co coatings

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Abstract

Detonation gun (D-gun) spraying is one of the most promising thermal spray technology for high quality wear resistant coatings. Of all the ceramic materials that can be D-gun-sprayed, WC is the most widely established and these coatings have already gained industrial acceptance for diverse applications. The use of D-gun-sprayed WC–Co coating as protection against aggressive environment requires a precise knowledge of the influence of spraying process parameters on the coating characteristics and properties (porosity, adherence, roughness, hardness, etc.). In this article, experimental results are presented in terms of the structure, including surface roughness, XRD patterns and porosity, as well as adhesion strength, hardness, and fracture toughness of D-gun-sprayed WC–Co coatings as a function of spraying distance from nozzle exit to substrate and ratio of $O_2:C_2H_2$. It is found that both the spraying parameters influence structure and properties of D-gun-sprayed WC–Co coatings. The decarburization of WC–Co powders during the spraying is little even when the highest oxygen–fuel ratio was employed. When the higher oxygen–fuel ratio was employed, hardness and adhesion increase, while, porosity and fracture toughness decrease, which can be attributed to the higher temperature and velocity feed powders obtained from the detonation wave. On the other hand, denser microstructure, higher adhesion strength and higher hardness appear when the coating was deposited at spraying distance of 110–20 mm, while fracture toughness is a little lower, which may come from the best compromise of decreasing velocity and lagging of heat transfer process for the particles to obtain a good molten state.

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1. Introduction

Carbide coatings are sometimes preferred for tribological applications [1]. The carbide coatings are also being considered as a viable replacement for hard chrome plating in abrasion, sliding and erosion applications owing to the strict environmental regulations [2]. This kind of coating is consisted of hard phase of carbide and tough matrix phase of metal [3]. Among various carbides, tungsten carbide is most preferred, which can be used at temperatures up to 500 °C.

The carbide coating has been coated by air plasma spray (APS) or high velocity coating processes [4]. Although the APS coatings are considered to be cheaper, considerable decarburization of tungsten monocarbide (WC) to di-tungsten carbide

(W_2C), as well as metallic tungsten occur [5,6]. The presence of oxygen in APS was found to promote the nucleation of oxy-carbides in considerable amount, which is undesirable for wear resistance. Furthermore, higher porosity and lower hardness are major disadvantages in the APS coatings for some of the tribological applications. The high velocity processes, such as high velocity oxy-fuel (HVOF) and detonation gun (D-gun) spraying processes, minimize decomposition of the carbide phase due to lower heat enthalpy and shorter duration involved in the coating processes. In addition, higher particle velocity during deposition provides resulting coatings several advantages, such as lower porosity, higher bond strength and hardness.

Among these three processes, the detonation process offers highest velocity (800–1200 m s^{−1}) for the sprayed powders that are unattainable by the plasma and HVOF conditions [7–9]. The high active energy makes the powder closely conjoint the surface, and form a layer with high strength, high hardness and good wear resistance [10–12]. This technology has been widely

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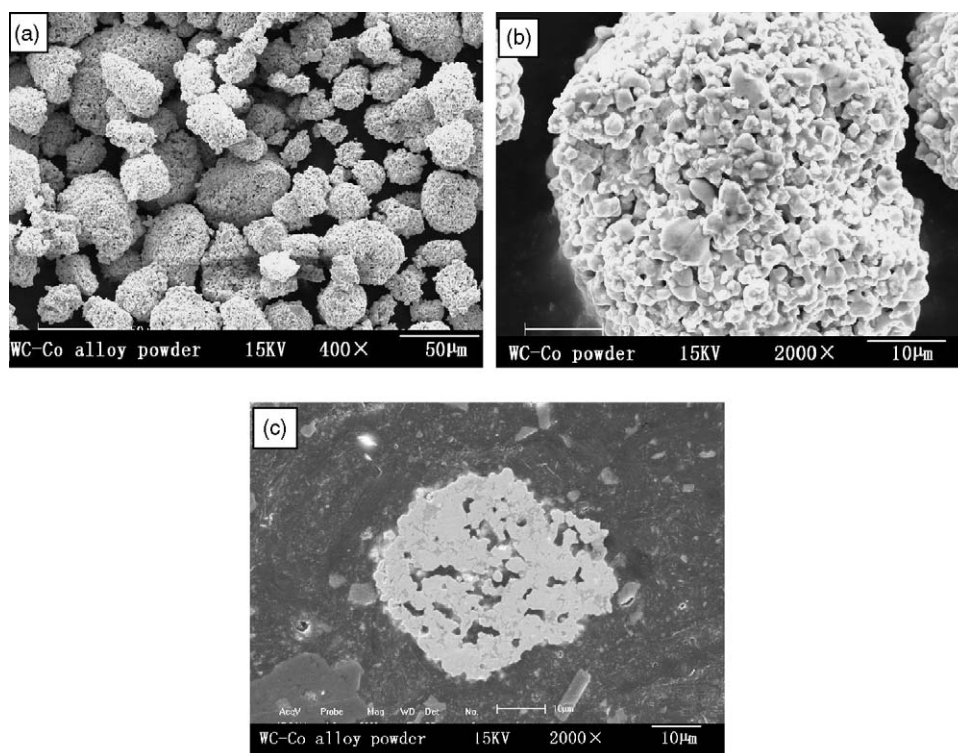


Fig. 1. Morphologies of WC–12 wt.% Co alloy powder structure. (a) Low resolution view, (b) high resolution view, and (c) cross-section view.

used in many fields, such as aviation, space flight, petroleum, metallurgy, and machinery industry [13–15]. The D-gun spraying process consists of following stages [13]: A portion of a flammable gas mixture – composed of oxygen and acetylene, for example – is fed through a mixer into a tubular barrel closed at one end. Simultaneously, powder is injected through a feeder. Then an explosion is triggered by a sparkplug. The resulting combustion of the gas mixture leads to a detonation effect and formation of a high-pressure ultrasonic wave that propagates the hot gas stream and accelerates the powder particles. The collision of the powders with the substrate forms a highly dense coating with strong adhesion. It is considered that the ability to change the properties of the detonation wave and resulting coatings over a broad range is an important advantage of D-gun spraying technology [16].

This work aims at investigating the effects of deposition conditions, such as spraying distance from nozzle exit to substrate, and ratio of $O_2:C_2H_2$, on the structure including XRD pattern, surface roughness and porosity, as well as properties including adhesion strength, Vickers hardness and fracture toughness of D-gun-sprayed WC–Co coatings. Furthermore, reasons for these effects are discussed.

2. Experimental details

2.1. Preparation of WC–Co coatings

A commercial WC–Co alloy powder (JK112, Shanghai Stellite Co. Ltd., China) with a nominal composition of 88 wt.% WC and 12 wt.% Co was employed in this work. The WC–Co

powder with size in range of 15–60 μm and an average 30 μm was formed by aggregating small grains (1–5 μm) in which the carbide and cobalt were combined together due to chemical reaction, which is shown in Fig. 1.

A Russian D-gun spraying system ('ob'-type) was employed to deposit WC–Co coatings in this work. This system is consisted of a 1.25 m long stainless steel detonation tube, an electrical spark located at the closed end of the tube, and a powder feeder with distance of 0.5 m to the nozzle exit. Acetylene was employed as fuel gas, while nitrogen as carrier gas to introduce the sprayed powders into the gun, as well as cleaning gas. The stainless steel substrates with thickness of 5 mm were sand-blasted by using compressed air to obtain a good adhesion for the resulting coating with the substrate. The thickness range of as-sprayed coatings was 250–300 μm . The employed D-gun spraying parameters, such as the oxygen–fuel ratio, spraying distance, diameter of spot and powder flow rate, are included in Table 1. In this work, experiments were performed, where the spraying parameters were controlled as accurately as possible with a special focus on the spraying distance from the nozzle exit to substrate and oxygen–fuel ratio. Rich C_2H_2 atmospheres were employed in all sample deposition.

2.2. Characterization of WC–Co coatings

The crystalline structures of WC–Co powder and resulting coatings were investigated by using a Rigaku (Japan) X-ray diffractometer operating with Cu $K\alpha$ ($\lambda = 0.154056$ nm) radiation. The analyzed range of the diffraction angle 2θ was between 20° and 85° by a step width of 0.02° . The surface roughness of as-sprayed WC–Co coatings were measured as Ra with a Form

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