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ScienceDirect
Applied Surface Science 254 (2008) 2269–2275
applied surface science
www.elsevier.com/locate/apsusc

The influence of process parameters on deposition characteristics of a soft/hard composite coating in kinetic spray process

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Received 18 August 2007; accepted 5 September 2007
Available online 12 September 2007

Abstract

In kinetic spray processes, the non-uniformity of resultant composite coatings is generally caused by the difference in critical velocity and deposition efficiency between the components of a mixed feedstock. In the present paper, the effects of process parameters, such as feed rate, spray distance, and particle velocity, on the compositional variation between the mixed feedstock and resultant composite coating have been investigated. The results showed that the high diamond fraction in the coating can be achieved using a low feed rate, intermediate spray distance, and high impact particle velocity. The possibility of impact between hard brittle diamond particles is the main factor affecting the diamond fraction in the coating. Although the deposition efficiency, diamond fraction, and bond strength of the coating increase with particle velocity, a slight decrease of cohesive strength between diamond particle and bronze base was also observed.

PACS : 62.20.Fe; 81.15.Rs; 83.80.Ab; 87.15.By

Keywords: Kinetic spraying; Soft/hard composite; Process parameters; Deposition efficiency; Bond strength

1. Introduction

Kinetic spraying (or cold gas dynamic spraying) is a newly emergent technique to deposit coatings onto a substrate by high velocity impact without heat input [1–3]. Other than the conventional thermal spray methods, the successful coating of the substrate in kinetic spray processes depends mainly on the kinetic energy of incident particles rather than on the combination of thermal energy and kinetic energy [1,3]. Because of the advantages of solid state deposition and high deposition efficiency at low temperatures, the deposition of oxygen-sensitive materials by kinetic spray processes is significantly attractive. During the last decade, this process has developed quickly and a wide range of pure metals, alloys, polymers, composites, and metallic glasses have been deposited successfully [4–17].

Despite the fact that the bonding mechanism is not precisely known, it is widely accepted that the adhesion of coatings to the substrate in kinetic spray processes derives from the plastic deformation of both particles and substrates upon impact [3,6]. Numerous studies show that a critical velocity, one over which the particle can be deposited onto the substrate successfully, depends mainly on plastic deformability, which itself relies on the physical properties and states of the impact couple (power and substrate) [6,7,18]. Therefore, it is extremely difficult to control the composition of the composite coatings because of the significant difference in the critical velocity of each component of the initial powder in a kinetic spray process. That is, the fraction of each component in the coating is always quite different from that in the original mixture powder. This is due to the different deposition efficiency of those components resulting from their different critical velocities and deformability upon impact. Fortunately, the deposition efficiency of each component of a given powder can be optimized through process parameters (such as spray distance, feed rate, process gas parameters, among others) in relation to their physical

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2007.09.017

Table 1
Kinetic spraying parameters for coating

Feed rate (g/min)	Spray distance (mm)	Process gas pressure (MPa)		Constants
11	30	N_2	2.1	Process gas temperature: 500 °C.
16	50		2.9	Gun travel rate: 0.01 m/s
22	70	He	2.5	

properties, such as density and deformability. Thus, it is possible to deposit a uniform composite coating with only a slight difference in the composition of components from that of an initial feedstock.

In the present paper, composite coatings composed of ductile bronze and brittle diamond that are employed in grinding wheel applications were deposited onto Al6061 substrate successfully through a kinetic spraying process. Brittle diamond hardly deforms upon kinetic spray impact onto the substrate; it can be embedded only in the substrate and a pre-deposited ductile bronze layer. Furthermore, it is worth noting that fracture or erosion of diamond particles can occur, which decreases diamond fraction in the resultant coating if the impact occurs between brittle particles. Hence, optimizing the process parameters may be the only way to increase the fraction of diamonds in coatings by reducing the probability of impact between the brittle particles and optimizing the relative deposition efficiency of the two components (bronze and diamond) in the kinetic spray process.

2. Experimental procedure

2.1. Spraying system

A commercially available kinetic spraying system (CGT3000, Germany) was employed in this study. The equipment and coating process are described in detail elsewhere [1,3,4]. A de Laval-type nozzle with a rounded exit was used. The diameter of the throat and the diameter ratio of the exit to the throat were 8.5 and 3.15 mm, respectively. Nitrogen and helium were used as the process gases to achieve different particle velocities. The feed rate, spray distance, and process gas pressure were utilized as the main variables. The process gas temperature was fixed at 500 °C. The detailed process parameters are given in Table 1.

The mean particle sizes in the bronze and diamond powders were 20 and 5 μm, respectively. The micrographs of the feedstock are shown in Fig. 1. The diamond particles are angular in shape, which is beneficial to particle acceleration and embedding in a plastic bronze layer or Al6061 substrate during deposition. The composite powder was mixed mechanically in a ratio of 80% bronze to 20% diamond (volume fraction) and was used as the feedstock. An Al6061 alloy was used as the substrate, which was polished as smooth as a metal mirror ($R_a < 1.5$) before deposition.

2.2. Analysis

An OSEIR SprayWatch system, shown schematically in Fig. 2, was used to measure the bronze particle velocity. This system uses a fast-shutter CCD camera with a high power pulsed laser diode (HiWatch) to illuminate the particles. The dimensions of the effectual measured region were 20 mm × 20 mm × 1 mm. The center of the measured region was 30 mm in front of the nozzle exit along the axial direction. Particle velocity was calculated based on the laser emission frequency and the particle flying distance, which was measured from the images taken by the CCD camera. For each process condition, the number of measured flying particles was more than 300. It is worth noting that the measurement of diamond particle velocity has not been performed because of its high cost. However, it seems feasible to ignore the independent effect of diamond particle velocity on its deformation and resultant deposition behavior upon impact. Also, the effect of the velocity of a diamond particle on its inlay into the pre-deposited bronze base is negligible in this case. The effect of

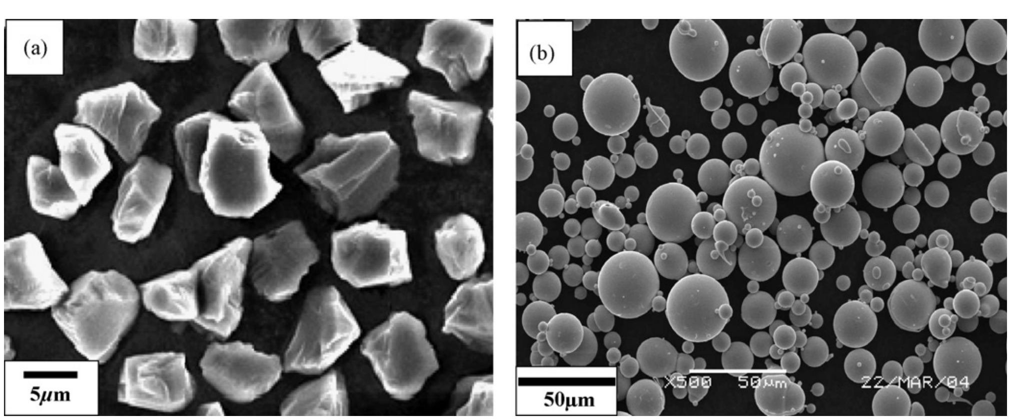

Fig. 1. SEM micrograph of feedstock morphology: (a) diamond and (b) bronze.