Applied Surface Science 330 (2015) 300–308

Contents lists available at ScienceDirect

Applied Surface Science

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

Beneficial effects of laser irradiation on the deposition process of diamond/Ni60 composite coating with cold spray

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form
22 December 2014
Accepted 5 January 2015
Available online 12 January 2015

Keywords:
Laser deposition
Diamond/Ni60 composite coating
Cold spray
Graphite
Wear

ABSTRACT

Although cold spray process has many unique advantages over other coating techniques, it has difficulties in depositing hard materials. This article presents a study in the beneficial effects of laser irradiation on the fabrication process of diamond/Ni60 composite coating using cold spray. The focus of this research is on the comparison between the composite coatings produced with laser cladding (LC) and with supersonic laser deposition (SLD), with respect to diamond graphitization and tribological properties, thus to demonstrate the beneficial effects of laser irradiation on the cold spray process. The influence of deposition temperature on the coating characteristics, such as deposition efficiency, diamond volume fraction, microstructure and phase is also investigated. The tribological properties of the diamond/Ni60 composite coating produced with SLD are determined using a pin-on-disc tribometer, along with the diamond/Ni60 coating produced using LC with the optimal process parameters for comparison. The experimental results show that with the assistance of laser irradiation, diamond/Ni60 composite coating can be successfully deposited using cold spray; the obtained coating is superior to that processed with LC, because SLD can suppress the graphitization of the diamond particles. The diamond/Ni60 composite coating fabricated with SLD has much better tribological properties than the LC coating.

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1. Introduction

Diamond is the hardest material and possesses the highest thermal conductivity [1]. Unique properties of diamond make it the best candidate for cutting and wear resistance applications. However, implementation of diamond in tools is a great challenge, which makes diamond tools very expensive, because of deterioration of diamond properties caused by graphitization, oxidation or chemical reactions with the matrix material during cutting process where the temperature of the cutting tool is raised. These problems create many restrictions on manufacturing of diamond tools [1,2]. Currently, the main methods used to produce diamond coatings on polymer or metal substrate include laser cladding, thermal spraying, chemical vapor deposition (CVD) and detonation spray, etc.

Diamond deposition on a molybdenum plate by the combustion flame CVD process has been studied. It was found that the performance of the thin diamond layer was worse under abrasive wear than under sliding wear, since the coating thickness was limited by the high hardness of diamond, which, on the contrary, results in low toughness [3,4]. Detonation spraying provides an effective way to produce diamond grinding tools for the machining of stone, cement, and concrete, it was found that the thermal and mechanical impacts remained low enough to ensure a good reliability of the operating diamonds. However, due to high cost, excessive noise and oxidizing environment of equipment operation, in particular, the diamond crystal structure subjected to graphitization and oxidation during the spraying process, this method is not favorable [5]. In the field of thermal spraying for diamond composite coatings, the exceptional properties of diamond and diamond-based composite coatings, processed with oxy-acetylene (OA) and high velocity oxy fuel (HVOF) thermal spray methods have been investigated [3,6]. It was demonstrated that the heat generated in the thermal spray process can cause graphitization and oxidation of the sprayed material in atmosphere environment, leading to weak bond strength and high porosity of the coating [3,4,6–9]. Laser cladding technology (LC) is also often used to produce the composite coatings of metal matrix diamond, but thermal degradation of diamond is a serious problem, the mixture of diamond and matrix in LC process hardly develops a strong chemical bond and provides enough wetting between diamond particles and the matrix [1,10]. Therefore, effectively controlling the deposition temperature and atmosphere

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http://dx.doi.org/10.1016/j.apsusc.2015.01.029
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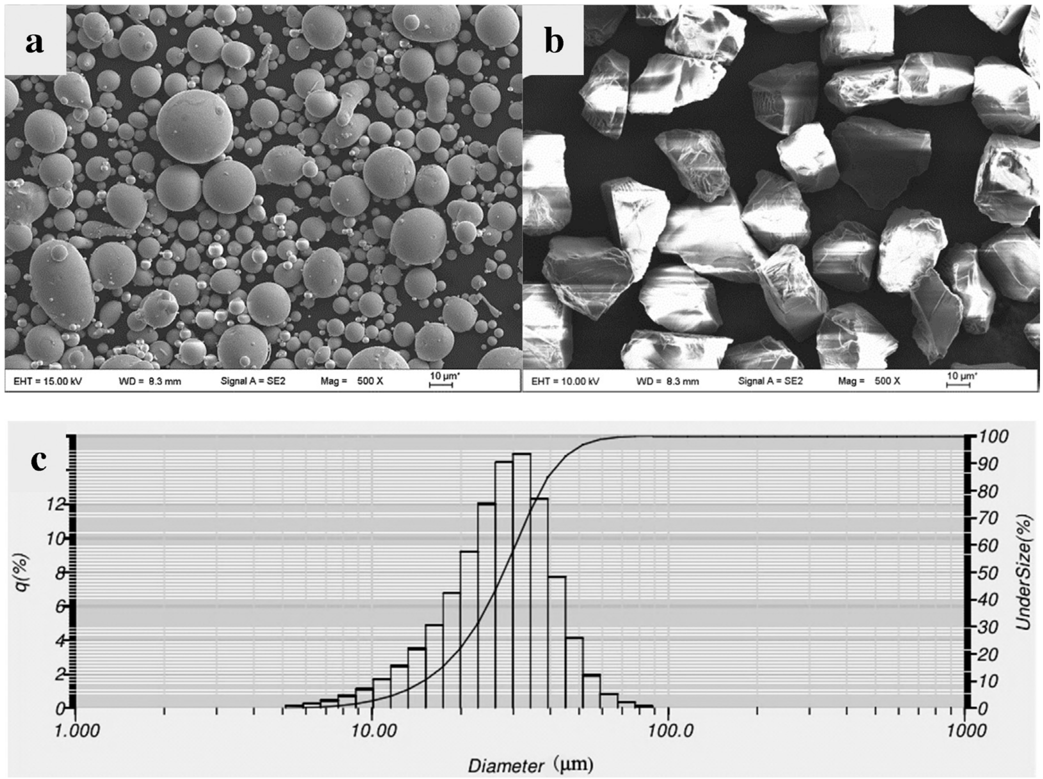

Fig. 1. Morphologies of composite coating powder: (a) Ni60 particles, (b) diamond particles, (c) size distribution of Ni60 powder particles.

in the LC process to achieve good diamond or diamond composite coatings is a potential tendency.

Cold spray (CS) is a process whereby metal powder particles in solid state, accelerated by a low temperature supersonic gas stream, are plastically deformed to form a coating by means of ballistic impingement upon a suitable substrate [11–13]. The metal powders range in particle size from 5 ~ 50 μm and are accelerated by a high-velocity jet stream that is generated through the expansion of a pressurized, preheated nitrogen or air in a vonverging-diverging nozzle to exceed critical plastic deformation velocity [13,14]. Currently, cold spray is mainly employed to deposit relatively soft, heat sensitive and oxidation sensitive materials such as Al, Cu, Ti, 316, Ni25, and amorphous material, WC-Co, Ni-diamond and so on [15–21], but it is difficult to deposit high hardness particles such as Stellite 6, Ni60, diamond, WC and metal ceramic material, etc., by cold spray [22].

CS technique is a potential method for relieving graphitization, oxidation and thermal degradation of diamond particles in the deposition process. Diamond composite coatings are commonly achieved by depositing mixed powder of soft metal and hard diamond particles with CS, Kim et al. reported that SUS304 powder blended with 10 and 20 vol.% Ti-coated diamond particles was used to prepare SUS304/diamond binary composite coatings on Al alloy substrate with CS, the fracture of the diamond particles was found in the composite coating due to the high impact velocity of the diamond particles [23]. Because of chemical inertness of diamond and relatively soft metal matrix, it is difficult to obtain strong chemical bonding and enough wetting between the diamond particles and matrix. In order to improve the interface bonding of diamond composite coatings, Li et al. studied the influence of annealing on the microstructure and wear performance of diamond/NiCrAl composite coating deposited with cold spraying [24]. The poor mechanical properties caused by lower hardness binding phase have restricted industrialized applications of diamond composite coatings. Ni60 is one of the most widely used self-fluxing Ni–Cr–B–Si–C alloy powders for conventional thermal spray. Adding Si, B, Cr elements in a Ni-based alloy can reduce its melting point down to 1050 ~ 1080 °C and enhance the alloy hardness up to 58 ~ 62 HRC [25]. The obtained coating exhibits excellent resistance to wear, corrosion, high temperature oxidation, over a wide range of temperature [26]. Ni-based alloys possess good wettability with diamond and high hardness, which provides diamond with a larger holding force coefficient to avoid shedding from the alloy matrix.

Supersonic laser deposition (SLD) is a new coating and fabrication process that evolved from the cold spray process. In order to expand cold spray technology and improve coatings' performance and quality, SLD technology combines the advantages of cold spray and laser technology and becomes a potential composite coating approach. It was proposed by the team of O'Neill at the University of Cambridge. In the SLD process laser is used to heat the deposition zone in order to soften both substrate and powder particles thus allowing the formation of a coating at a much reduced impact velocity [27,28]. Although SLD technique has been proposed for depositing hard materials, the SLD process has not been well studied, in particular, the influence of high hardness Ni-based alloy as matrix on the performance of the deposited composite coatings.

Since SLD can reduce particle deposition temperature and critical deposition velocity, hard particles, e.g., Ni60 and diamond may be deposit at a lower jet velocity. Meanwhile, the low temperature deposition feature of SLD may beneficially suppress the graphitization and oxidation of diamond particles. In the present research, the attempt of depositing diamond/Ni60 composite on a medium carbon steel substrate at different deposition temperatures was made. Deposition efficiency and the volume fraction of diamond particles of the coatings produced with different process parameters were investigated using scanning electron microscopy (SEM). For the diamond/Ni60 composite coating produced with optimal process parameters, microstructure and graphitization of diamond particle were analyzed with X-ray diffraction (XRD) and Raman spectrum.

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