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Influence of laser irradiation on deposition characteristics of cold sprayed Stellite-6 coatings

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ABSTRACT

Depositing hard materials such as Stellite-6 solely by cold spray (CS) is challengeable due to limited ability of plastic deformation. In this study, the deposition of Stellite-6 powder was achieved by supersonic laser deposition (SLD) which combines CS with synchronous laser irradiation. The surface morphology, deposition efficiency, track shape of Stellite-6 coatings produced over a range of laser irradiation temperatures were examined so as to reveal the effects of varying laser energy inputting on the deposition process of high strength material. The microstructure, phase composition and wear/corrosion resistant properties of the as-deposited Stellite-6 coatings were also investigated. The experimental results demonstrate that the surface flatness and deposition efficiency increase with laser irradiation temperature due to the softening effect induced by laser heating. The as-deposited Stellite-6 tracks show asymmetric shapes which are influenced by the relative configuration of powder stream and laser beam. The SLD coatings can preserve the original microstructure and phase of the feedstock material due to relatively low laser energy inputting, which result in the superior wear/corrosion resistant properties as compared to the counterpart prepared by laser cladding.

1. Introduction

Cold spray (CS) is a relatively new materials deposition technique discovered in the early 1980s and has been rapidly developing during the past two decades. In this process, metal powders are accelerated to a high velocity ranging from 300 to 1200 m/s by a supersonic gas flow and then impinge onto the substrate or already deposited coating at a temperature well below the melting point of sprayed materials [1]. The high-velocity impact can induce intensive plastic deformation of the spraying particles and the substrate, enabling the formation of a less-oxidized coating. As a result, deleterious effects such as high temperature oxidation, evaporation, melting, residual stresses and other common problems inherent to traditional thermal spraying (such as flame spraying, arc spraying, and plasma spraying) can be minimized or eliminated. These advantages allow CS to be used for depositing a variety of materials including metals, alloys, polymers, composites and nanostructure materials [2–6]. However, CS has limitation in the range of materials possible to deposit since materials deposition by CS is mainly reliant on the plastic deformation of both spraying particles and substrate. It is therefore difficult to deposit brittle or hard materials unless they are co-deposited with a ductile matrix material. In general, particle velocity prior to the impact is an important factor for CS because the successful deposition of spraying particles relies solely on the kinetic energy rather than the combined effects of both kinetic and thermal energies available in conventional thermal spraying. It has been widely accepted that there exists a material-dependent critical velocity above which successful bonding between coating and substrate can be attainable [7–10]. In recent years, several computational and experimental researches have been carried out on the effects of particle and/or substrate temperature on the critical velocity and coating formation. It was found that particle preheating can reduce the critical velocity while substrate preheating can promote the bonding between the particles and substrate [11–16].

As preheating of particle and substrate plays an important role in coating formation during CS, it would be therefore desirable that introducing additional heat source into CS to thermally soften the spraying particles and/or substrate. Laser, as one of the most ideal heat sources for materials process due to its unique advantages such as high energy density, chemically clean and flexible operation, has been coupled with CS for pre-/post-treatment in the past

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few years. Christoulis et al. [17] and Danlos et al. [18] used pulsed Nd-YAG laser to modify the state of the substrate surface before CS process. Morimoto et al. [19] and Marrocco et al. [20] investigated the improved performances of cold sprayed coatings with laser post-treatment. Poza et al. [21,22] evaluated the effect of laser remelting on the mechanical behavior of cold-sprayed Inconel 625 coatings. Recently, a new material deposition technology known as supersonic laser deposition (SLD) has been developed by introducing synchronous laser irradiation into CS process [23–25]. In SLD, the deposition zone of CS is heated simultaneously by laser in order to preheat particles and soften substrate, allowing the spraying particles to deform and build up a coating at impact velocities about half of that in CS. Meanwhile, cold or slightly heated nitrogen or compressed air can be used instead of high temperature helium due to the elimination of the need for high impacting velocities, which would lead to the reduction of operating cost by over an order of magnitude. In addition, the SLD technique can dramatically expand the processable material range of particle and substrate in comparison with CS due to the reduced critical deposition velocity. A wide range of materials including metals, alloys and composites have been deposited by SLD [26–40]. Lupoi et al. [26] presented the deposition of titanium coatings on steel tube substrate using SLD; Jones et al. [27] demonstrated near fully dense tungsten coatings onto molybdenum substrates by SLD; Gorunov et al. [28] studied the microstructure and mechanical properties of stainless austenitic steel coatings obtained by SLD; Yao et al. [34,40] reported microstructure and wear/corrosion-resistant properties of cobalt- and nickel-based alloy coatings deposited by SLD. Furthermore, successful deposition of a series of composite powders comprising hard alloy particle and temperature-sensitive ceramic particle (such as diamond/Ni60, WC/SS316L, WC/Stellite-6) has been achieved by SLD [31,32,35,36].

Although considerable research efforts has concentrated on preparing high quality SLD coatings with excellent properties, the influence of different laser irradiation temperature on the deposition characteristics has not yet been systematically investigated, especially for high strength materials such as Stellite-6, Ni60, and Ti6Al4V. Therefore, the surface morphology, deposition efficiency, track shape of Stellite-6 coatings produced over a range of laser irradiation temperatures were examined in the present study so as to reveal the effects of varying laser energy inputting on the SLD process for building up high strength material coating. The microstructure, phase composition and wear/corrosion resistant properties of the as-deposited Stellite-6 coatings were also studied.

Table 1
Chemical composition of Stellite-6 powder.

Elements	Co	Cr	W	C	Ni	Mo	Fe	Si	Mn	Others
wt.%	Bal.	29.00	4.00	1.2	3.00	1.50	3.00	1.10	1.00	<1.0

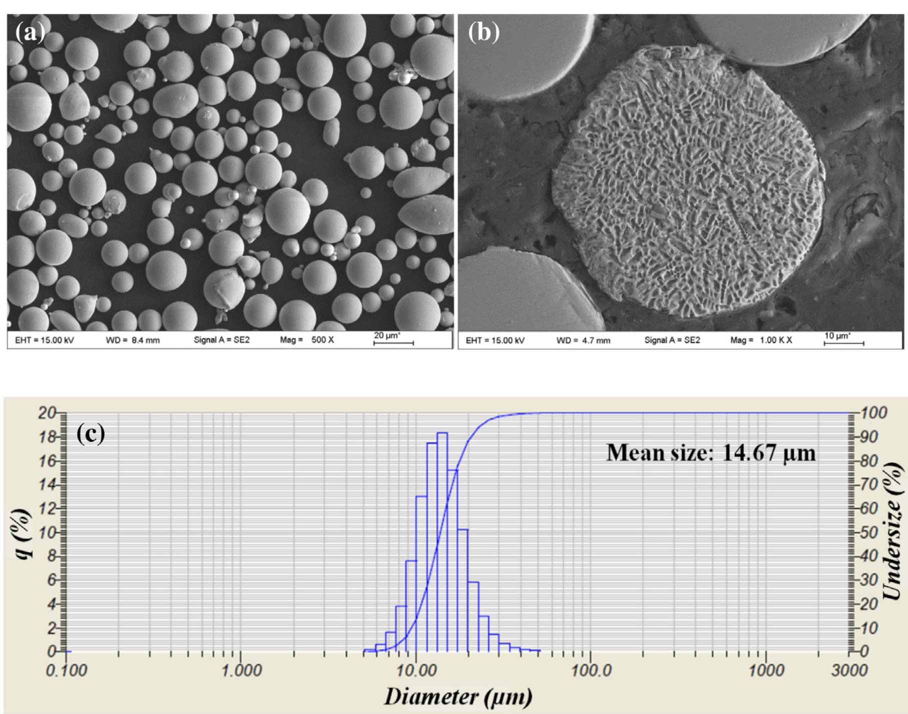

Fig. 1. Morphology (a), interior microstructure (b) and powder size distribution (c) of Stellite-6 powder.

Table 2
Chemical composition of substrate material.

Elements	Fe	C	Si	Mn	P	S
wt.%	Bal.	0.43	0.23	0.66	0.002	0.014