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Microstructure and corrosion behavior of cold sprayed SiC_p/Al 5056 composite coatings

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A B S T R A C T

Al 5056 composite coatings reinforced with silicon carbide (SiC) particles were deposited by cold spraying. The influence of fraction of ceramic particles on microstructure and corrosion behavior was evaluated. The results show that the addition of SiC particles yields coatings with lower porosity than Al 5056 coating. Quantitative analysis of 3-D optical microscopy images reveals that the maximum size of the embedded pores increases with the fraction of SiC particles. The corrosion performances of coatings were evaluated by open circuit potential measurements and potentiodynamic polarization scans in 0.1 M sodium sulfate solution with pH fixed at 11.5. The OCP values of coatings were much lower compared to pure Al plate. Compared to pure Al plate, the anodic parts of the polarization curves of the coatings show a similar trend; however, the current densities of the coatings evaluated at an overpotential value of +600 mV (I_{overp}) were higher. The addition of SiC particles reduced I_{overp} in comparison with Al 5056 coating. Nevertheless, the volume fraction of SiC in feedstock has no significant effect on the anodic polarization behavior. Since all the coatings are dense with a porosity lower than 2.5% and containing no interconnected porosity, thickness and porosity did not affect the corrosion behavior.

1. Introduction

Metal matrix composites (MMCs) [1] are made by dispersing a reinforcing material into a metal matrix. These materials are nearly always more expensive than the more conventional materials they are replacing. As a result, they are found where improved properties and performance can justify the added cost. Today their applications are found most often in aircraft components, space systems and high-tech sports equipment [2]. Current techniques for fabricating the composites include casting [3], sintering [4], forging [5], hot extrusion [6], physical vapor deposition [7], and thermal spray deposition [8].

Since the bulk properties of many existing materials (e. g., steels, aluminum alloys, magnesium alloys, titanium alloys) are currently suitable for a wide range of applications, surface modification becomes an alternative method to improve specific performance. Moreover, it is a cost-effective solution [9]. Thermal spraying techniques [10] are widely used to deposit on-site thick coatings, which include flame spraying, plasma spraying, arc spraying, and high-velocity oxygen fuel (HVOF) spraying. Because the dynamics of the particles interacting with the spray jet [11] and the spreading conditions of particles on the substrates, all conventional thermal spraying techniques could induce a considerable change in chemical composition from feedstock powders to as-sprayed coatings. In general, deposits always exhibit high levels of interlamellar oxide and porosity, which could be detrimental to corrosion resistance, strength and machinability properties [12]. A number of processes related to the torch have been developed, which could be "in-line" processes and/or post-processes, for example pre-heating treatment, post-cooling treatment, post-heat treatment, HIP, in-situ laser treatment, and post-laser treatment [13]. These processes could improve the thermal sprayed coatings performance, however, they are not always compatible with all applications of thermal spraying, and they will increase the fabrication cost.

Under these conditions, an alternative is to use cold spraying (CS; also known as Cold Gas-Dynamic Spraying, CGDS) which is the latest technical development among all thermal spraying processes [14]. For cold spraying, the operating temperature is much lower. Unlike other thermal spraying techniques, the process temperature of cold spraying is typically way below the melting or softening point of the feedstock powders. That is why the term "cold spraying" is used. A cold sprayed coating is formed from powder particles with high kinetic energies impacting on the surface of the substrate. High velocities of sprayed particles (500–1000 m/s) are achieved using a de Laval nozzle into which pre-heated gas (air, nitrogen or helium) is under expansion. Powder particles upon impact deform strongly and form a dense, non-oxidized and adherent coating. These features solve the common drawbacks of

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conventional thermal spraying techniques. As a consequence, cold spraying is increasingly used in a variety of industries. According to the materials concerned, cold sprayed coatings could be divided into various categories, including pure metals (Al [15], Ti [16], Cu [17], Ni [18], etc.), alloys (Ni–Cr alloys [19], stainless steels [20], etc.), and composite coatings (Al–Al_2O_3 [21], Al–SiC [22], Al–TiN [23], Al–AlN, Al–W, Al-diamond [24], Ni–Al_2O_3 [25], WC–Co [26], etc.). Nowadays, it has become evident that cold spraying is an attractive and versatile technique to apply thick coatings, which can cover more industrial applications for MMCs, even taking cost into consideration.

Among various available matrix materials, aluminum and its alloys are widely used due to their low density, high strength, and good corrosion resistance. These alloys are also cheaper than other low density alloys such as magnesium or titanium. The addition of relatively inexpensive silicon carbide (SiC) particles (as compared with diamond, TiN, AlN and TiB_2, etc.) to an aluminum alloy matrix improves strength, elasticity, and wear resistance. By carefully controlling the relative amount and distribution of the ingredients as well as the processing conditions, these properties could be further improved. As a result, SiC reinforced aluminum alloy composites have various applications in electronics, aerospace and automotive industries (e. g., electronic packages, attachment fittings, mechanism housings, bushings, cylinders [27]).

Corrosion is responsible for the failure of numerous systems and structures. Good corrosion resistance is expected for the requirement of long service life for cold sprayed coatings. The addition of the reinforcing particles could significantly influence the corrosion behavior. Meydanoglu et al. [28] showed that the addition of ceramic particles into the 7075 Al matrix led to increased corrosion current densities when compared to that of unreinforced 7075 Al coating. A. Pardo et al. demonstrated that the corrosion resistance of the aluminum-matrix composite coating AA6061/SiC/20p decreased slightly, and the matrix/SiC interfaces acted as preferential nucleation sites [29]. Composite materials could have lower corrosion resistance than aluminum alloy matrices. The main reasons for this are: (1) formation of galvanic couples between active aluminum and the noble reinforcing particle, and (2) microstructure of interface reinforcement/matrix (chemical composition, porosity). To date, the corrosion behavior of cold sprayed SiC reinforced aluminum composites coatings has not been looked at. This study aims at shedding light on the effects of the content of SiC particles on the microstructure and corrosion behavior of SiC_p/Al 5056 composite coatings deposited by cold spraying technology.

2. Experimental procedure

2.1. Materials

Aluminum was used as the substrate material to limit galvanic coupling with the coating which could modify the electrochemical behavior of coatings. Al plates were cut to 50 × 50 mm. In order to enhance the adhesion between the substrate and coating, the surface of the substrate was sand-blasted using alumina grits prior to spraying (ISO 6344, Grit designation, P100). All the substrates were rinsed in an ultrasonic bath with acetone to remove adsorbed species and residual alumina.

The feedstock powders were composed of spherical gas-atomized Al 5056 powders (Al—5.0 Mg–0.12 Mn–0.12 Cr (wt.%), LERMPS, Belfort, France) as the matrix and commercially available brushed SiC powders (H.C. Starck, USA) as the reinforcement. Al 5056 powders are spherical in shape as shown in Fig. 1(a). The particle size analysis measured by laser diffractometry (Mastersizer 2000, Malvern Instruments Ltd., UK) showed that the size distribution ranged from 8.7 to 39.4 μm in diameter with an average centered on 19.6 μm (Fig. 1(b)). Morphology of SiC powders is angular with sharp edges (Fig. 1(c)), and size distribution ranged from 48.3 to 92.6 μm in diameter with an average centered on 66.9 μm (Fig. 1(d)). SiC powders were mechanically blended with the matrix powders Al 5056, and four fractions in volume (0%, 15%, 30%, and 60%) of SiC powders were used.

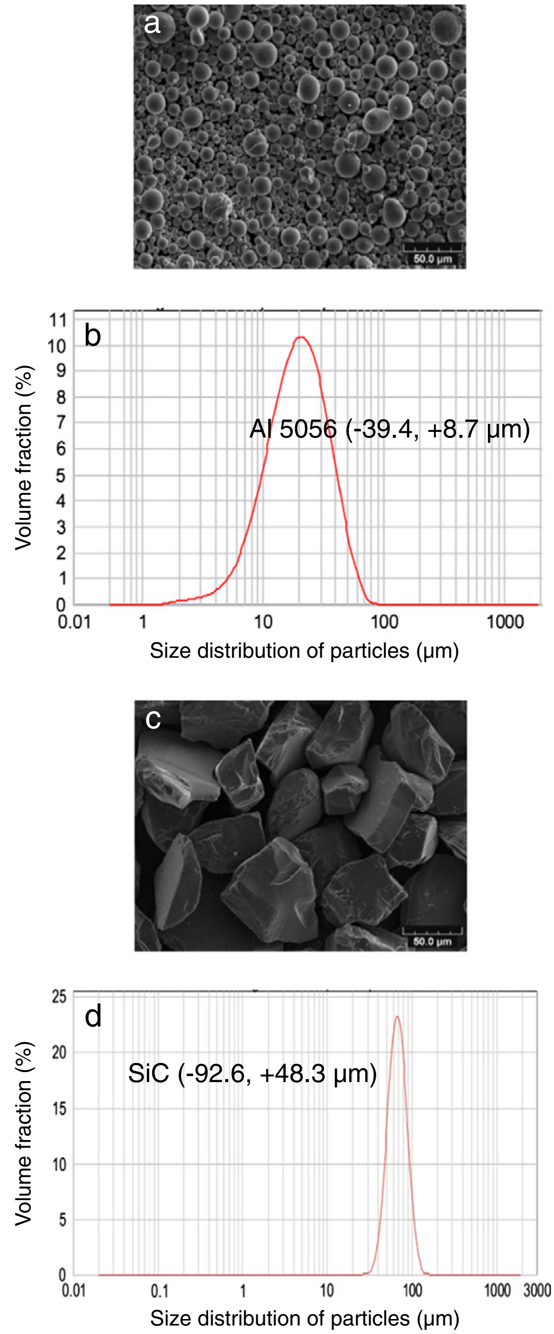

Fig. 1. Morphology of (a) gas-atomized spherical Al 5056 powders and (c) angular SiC powders; Size distribution of (b) Al 5056 powders and (d) SiC powders.

2.2. Cold spraying procedure

A commercial spray gun (Kinetics® 3000, CGT GmbH, Germany) was used to spray coatings, which consists of a converging-diverging nozzle with an outlet diameter of 6.5 mm. The de Laval nozzle had a divergent section length of 170 mm with an area expansion ratio at approximately 4.9. All coatings were deposited by performing two torch cycles using the optimized spray parameters which had been examined in preliminary studies [30]. This study has shown that when the gas temperature reached 600 °C, the