Surface & Coatings Technology 261 (2015) 278–288

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

The effects of heat treatment on the mechanical properties of cold-sprayed coatings

Renzhong Huang, Michiyoshi Sone, Wenhua Ma, Hirotaka Fukanuma

Plasma Giken Co. Ltd., Toshima, Tokyo, Japan

ARTICLE INFO

Article history:
Received 7 March 2014
Accepted in revised form 5 November 2014
Available online 14 November 2014

Keywords:
Cold spray
Tensile strength
Elongation
Fracture surface
Heat treatment

ABSTRACT

In the cold spray process, deposition of particles takes place through intensive plastic deformation upon impact in a solid state at temperatures well below their melting point. Therefore, spray particles experience little oxidation or decomposition during this process. As a result, cold-sprayed coatings have excellent mechanical, electrical and thermal properties. In this work, pure Al, Cu, Ti and stainless steel 316 were deposited by cold spray. The tensile strength and elongation of these coatings were also measured. The results showed that the as-sprayed coatings of the four materials have poor ductility and almost no elongation. However, heat treatment can improve the mechanical properties of the cold-sprayed coatings to some extent. Here, the effects of heat treatment conditions on the mechanical properties of the four cold-sprayed materials are discussed.

1. Introduction

Cold spray is an emerging spray coating technology that was first developed in the mid 1980's at the Institute of Theoretical and Applied Mechanics in the former Soviet Union [1]. Compared to the traditional thermal spray processes, the most distinct characteristic of cold spray processing is its lower processing temperature; consequently lower thermal effects to the processed materials. Therefore, cold spray is particularly suitable to prepare coatings that are sensitive to oxidation or applications in the fields in which oxidation and thermal influences during the coating process have to be avoided [2]. So far, cold spray has been used to spray not only ductile materials such as copper [3,4], aluminum [5], nickel [6], nickel-based alloys [7], zinc; [8] but also metal matrix composites [9,10], cermets [11,12] and ceramic materials [13].

The most prominent property of cold-sprayed coatings is its low oxidation. Moreover, cold-sprayed coatings can be extremely dense under suitable spray conditions where the particles experience intensive plastic deformation. Dense coatings with low-oxidation will also mean that they have excellent mechanical, thermal and electrical properties [14,15]. Therefore, the coating deposited by cold spray is a strong candidate to apply as a structural component in the industrial field. However, the temperature history of particles during deposition processing generates some residual tensile stress due to thermal effects [15,16]. Moreover, the severe impact deformation generates some residual compressive stress due to the kinetic effects [16–19]. The intensive plastic deformation of particles also decreases the ductility of cold-sprayed coatings due to work hardening effects. The existence of residual stress and work hardening in cold-sprayed coating decreases its mechanical, thermal and electrical properties. Some researches about the improvement of cold-sprayed coating via heat treatment were reported [14,15,20–24]. Heat treatment can effectively change the microstructure of cold-sprayed Cu [14,15,20], Al [21], stainless steel coatings [22,23] and Inconel 718 [24]. The thermal and electric conductivity of cold-sprayed coatings increased owing to the improved contact of particle-to-particle interface and the micro-hardness decreased owing to the removal of work hardening after heat treatment [14,20]. Moreover, the mechanical properties (tensile strength, elongation and tec.) of cold-sprayed coatings improved via heat treatment [15,23,24] and even demonstrated similar performance as bulk materials [15]. The previous studies paid major attention on the improvement of the mechanical properties via heat treatment. However, the determinants of the coatings' mechanical properties are still undefined up to now.

In the present study, four typical materials of Al, Cu, Ti and stainless steel were deposited by cold spray and their mechanical properties were tested. Moreover, the effects of heat treatment temperature on coating microstructures and mechanical properties were also investigated. The relationship between the porosity of cold-sprayed coatings and their mechanical properties was discussed.

2. Experimental procedures

2.1. Feedstock powder and cold spray process

Commercially available Al (>99.7%), Cu (>99.7%), Ti (Grade 2) and stainless steel 316 powders are used in the study and their morphologies are presented in Fig. 1(a)–(d). The pure Al and Ti powders show

E-mail address: rz_huang@plasma.co.jp (R. Huang).

http://dx.doi.org/10.1016/j.surfcoat.2014.11.017
0257-8972/

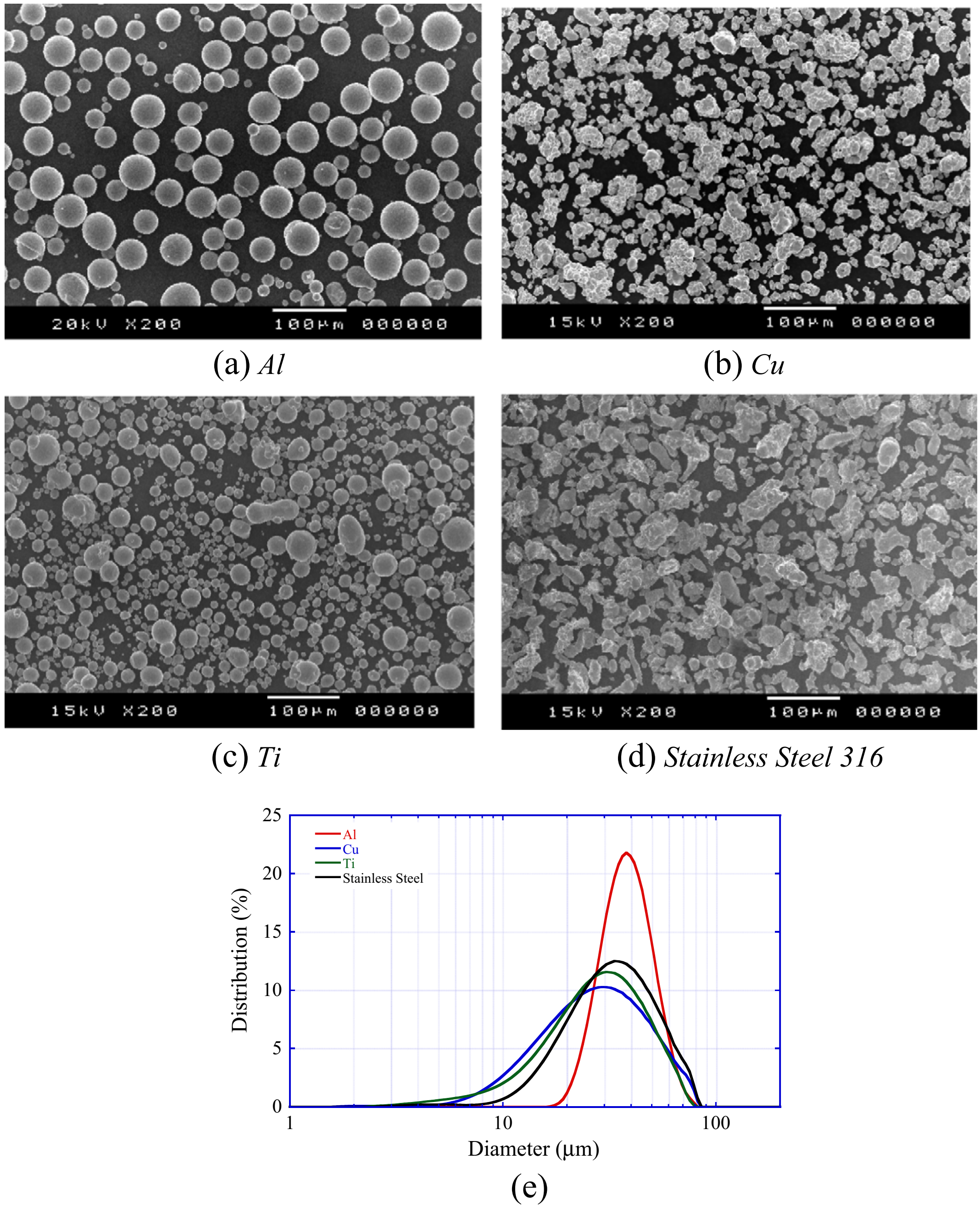

Fig. 1. Morphology of Al (a), Cu (b), Ti (c), stainless steel 316 powder and their diameter distributions (e).

perfect spherical shapes. The pure Cu and stainless steel 316 powders show near spherical shapes. The volume distributions of the particle diameter are shown in Fig. 1(e). Al powder has the narrowest distribution of particle diameter among the four types, with a volume average diameter of about 38 μm. The powder diameter of pure Cu and Ti ranges from 5 to 80 μm, and both of their volume averages are about 30 μm. The powder diameter of stainless steel 316 ranges from 10 to 80 μm, and the volume average of particle diameter is about 35 μm.

A commercial cold spray system, model number PCS-1000 designed by PLASMA GIKEN CO. LTD., was used to prepare the coatings. A convergent–divergent (De-Laval) nozzle was configured to accelerate the working gas to supersonic speed. Nitrogen gas was used as the propellant gas in this test. The spray conditions for cold spray are shown in Table 1. Al alloy cylinder with 100 mm of both outer diameter and length was utilized as the substrate, and more than 5 mm of coatings were deposited in order to satisfy the dimension of tensile specimen. Fig. 2(a) illustrates the coating preparation process. The cold-sprayed coatings were cut from the substrate, and then machined to a tensile specimen as shown in Fig. 2(b). The detailed dimension of tensile specimen is shown in Fig. 3, and it followed the standard of No. 14B according to JIS Z2201.

Table 1
Spray conditions.

Materials	Al	Cu	Ti	SS316
Gas pressure (MPa)	3			
Gas temperature (°C)	380	800	900	800
Powder feed rate (g/min)	25	100	60	100
Spray distance (mm)	30			