ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 344–350

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Copper matrix composite coatings produced by cold spraying process for electrical applications

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ARTICLE INFO

Article history:
Received 15 September 2015
Accepted 24 January 2016
Available online 28 February 2016

Keywords:
Cold spray
Copper
Composite
Conductivity
Wear

ABSTRACT

Composite coatings were deposited on commercially pure copper substrates by cold spraying of feedstock consisted of copper and Al_2Cu powders. The amount of the Al_2Cu powder incorporated in the feedstock varied in between 0 and 15 vol.%. Characterisations of the coatings were done by microstructural examinations, hardness and electrical conductivity measurements and wear tests. Composite coatings deposited from the feedstock containing 5 and 10 vol.% Al_2Cu powder exhibited better electrical conductivity and superior wear resistance than the monolithic (Al_2Cu free) copper coating. Presence of 15 vol.% Al_2Cu in the feedstock diminished both the wear resistance and the electrical conductivity of the coating.

1. Introduction

Copper is an attractive material for electrical applications (such as welding electrodes, conductors, etc.) because of its high electrical and thermal conductivities. However, poor mechanical properties, including hardness, strength and wear resistance limit their service life [1,2]. When strengthening without a significant reduction in conductivity is of concern, deformation and dispersion hardening mechanisms appear as attractive engineering solutions for copper. Deformation hardening may not be convenient for the components utilised at high temperatures owing to the softening as the result of recrystallisation. On the other hand, dispersion hardening can provide a good combination of high strength and conductivity at elevated temperatures. In this respect, copper matrix composites become attractive materials for manufacturing of components that require good wear resistance and electrical conductivity at elevated temperatures such as spot welding electrodes, connectors, and other electronic devices [3–5]. However, dispersion hardening has potential to cause a loss in ductility and toughness.

Since surface properties play crucial role on the performance and service life of many engineering components, surface modification by deposition of dispersion hardened copper layer (will be referred as ''composite coating'' hereafter) appears as an attractive technical alternative to bulk copper matrix composites to be utilised in wear related applications where electrical conductivity and toughness are the major concerns.

Being motivated by the facts mentioned above, an attempt has been made in this study to cover the surfaces of a

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http://dx.doi.org/10.1016/j.acme.2016.01.005

commercially pure copper with a copper matrix composite coating by cold spray process, which bases on forwarding ductile metal powders or mixture of metal and ceramic powders at high velocities and low temperatures [6–9]. Earlier studies reported in the open literature have examined the effect of parameters to the properties of the copper based coatings. For instance, Phani et al. [10,11] showed the effect of heat treatment to the hardness and electrical conductivity, Koivuluoto et al. [12] and Sova et al. [13] were discussed the effect of reinforcing particles to the hardness and Seo et al. [14] and Eason et al. [15] were evaluate the effect of heat treatment to the hardness of cold sprayed copper based coatings. In these studies, mostly oxide and carbide type ceramic powders have been used as the reinforcement and generally composite coatings exhibited higher hardness but lower electrical conductivity than monolithic copper coating. Despite increased hardness, reduction in wear resistance due to the pull out of the reinforcement particles during sliding contact has been reported for SiC particle reinforced copper matrix composite coatings [16]. Since adhesion at the particle/matrix interface plays critical role on detachment of reinforcement particles from the matrix, in the present study Al_2Cu powder has been used as the reinforcement to achieve better chemical compatibility and binding with the copper matrix as compared to ceramic powders. Main objective was to form a wear resistant and conductive Al_2Cu reinforced copper matrix composite coating on copper substrate. Since intermetallic compounds may deteriorate the conductivity of copper while enhancing their hardness, copper matrix composite coatings were deposited at different percentages of Al_2Cu particles to get the optimum combination between wear resistance and electrical conductivity at a certain Al_2Cu volume fraction.

2. Materials and methods

Coatings were deposited on commercially pure copper substrates by cold spray process. The feedstock was prepared by mixing of pure copper powder (Alfa-Aesar, %99.9, spherical, APS of 10 μm) and Al_2Cu powder at different ratios (0–15 vol.%). Feedstock was sprayed by using of RUSONIC Model K-201 cold spray equipment with converging–diverging type tubular nozzle having an expansion ratio of 2.3. As the process gas, air at 600 kPa (6 bar) was used, which was heated up about 500 °C during cold spraying. Traverse speed of the nozzle and number of pass were set at 5 mm/s and 4, respectively.

The reinforcing Al_2Cu powder utilised in this study were produced in laboratory scale by mixing pure aluminium (Alfa-Aesar, 99.5%, spherical, APS of 12 μm) and copper powders. The mixture of copper (53 wt.%) and aluminium (47 wt.%) powders, were held at 550 °C for 6 h after compacting. Compacts were then broken into pieces, ball milled and sieved through 325 mesh sieve to collect irregular Al_2Cu powders smaller than 44 μm. The XRD pattern of the Al_2Cu powders utilised as the reinforcement is shown in Fig. 1.

The characteristics of the coatings were determined by microstructural examinations, hardness and electrical conductivity measurements and wear tests. Microstructure of the coatings was evaluated by using an image analyser (Clemex Vision PE 6.0.027) equipped light optical microscope (LOM, Leica^{TM} ICC50 HD) from the cross-sections of the coatings after grinding and polishing in standard manner. During LOM examinations, microstructural constituents were defined by different colours and area percent of the colours were quantified as the volume percent of the relevant phases by utilising the image analyser. Hardness of the coatings was determined under a load of 25 g in HV scale by using a Shimadzu^{TM} HMV microhardness tester. Electrical conductivities of the coatings were measured by utilising a Hocking^{TM} Auto Sigma 3000 electrical conductivity meter which operates according to eddy current principle. Probe of 500 kHz sinewave appropriate for measuring the conductivity of thin sections was used. Measurements were done by placing the probe perpendicular to the coating surface. Prior to measurements, surfaces of the coatings were grinded with 1000 grit SiC paper and polished with diamond slurry.

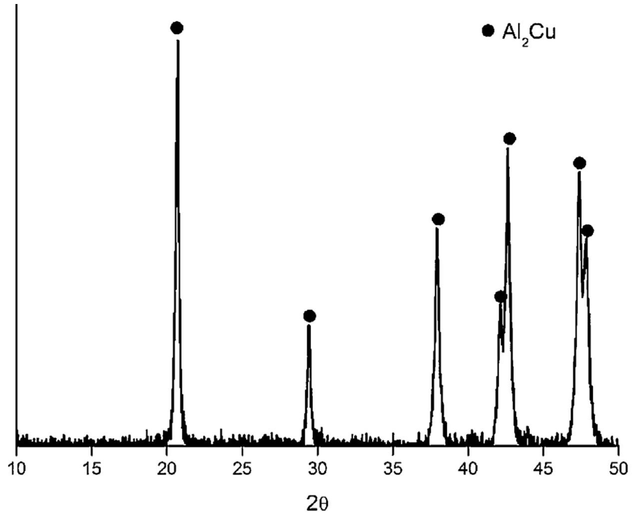

Fig. 1 – XRD pattern of Al_2Cu powders produced for this study.

Dry sliding wear performance of the coatings was tested on a Tribotech^{TM} reciprocating wear tester after grinding their surfaces with 1000 grit SiC paper. Tests were conducted at normal atmospheric conditions under a load of 3 N by rubbing of 100Cr6 steel ball having 6 mm diameter. Sliding stroke, total sliding length and sliding velocity were set as 5 mm, 50 m and 10 mm/s, respectively. After the wear tests, wear tracks were examined by using a Veeco Dektak 6 M surface profilometer and an energy dispersive spectrometer (EDS) equipped scanning electron microscopes (SEM, Hitachi TM1000 and Jeol JCM 6000 NeoScope). Tribological behaviour of the coatings was evaluated in terms of steady state coefficient of friction (CoF) and relative wear rate (RWR). CoF values were determined from the friction curves after they reached a plateau. RWR values calculated by considering the 2D profiles of the wear tracks (width and depth) to determine the cross sectional wear track areas and finding the ratio of the wear track area of any coating to that of the monolithic one. Thus, the RWR of the monolithic coating was taken as 1.0.