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Tribological behaviors of plasma sprayed CuAl/Ni-graphite composite coating

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A B S T R A C T

Aluminum bronze (CuAl) coating reinforced by nickel cladded graphite (Ni-graphite) was fabricated by air plasma spraying. Results show that the Ni-graphite had excellent interfacial compatibility with the CuAl matrix. With occurrence of re-graphitization of the graphite and the so-formed lubricating film on its frictional surface, the CuAl/Ni-graphite coating had a wear rate dozens of times lower than those of the other CuAl-based coatings benefited from the greatly alleviated abrasion wear and splats delamination. Additionally, the CuAl/Ni-graphite coating generated slightest damage to the frictional counterpart, showing the promise to be a bearing coating.

1. Introduction

Thermal spraying technologies are coating processes that provide functional surfaces to improve the performance of substrates [1–3]. Among the numerous sprayed techniques, plasma spraying has been most widely used because of its low-cost and diversity of available coating materials. During plasma spraying process, the inert gas – usually argon or argon–hydrogen mixture – is ignited into plasma state with ultrahigh temperature so that the powder feedstock can be heated intensively into molten and semi-molten particles. Then, these molten and semi-molten particles are accelerated towards the preheated substrate, flattening and solidifying to coatings. The ultrahigh temperature of plasma torch ensures the quick melting of the powder feedstock, in combination of protection from the inert gas, generating the low oxidation level in plasma sprayed coatings [4]. Actually, plasma spray technique has significant applications in preparing wear-resistant coating [5,6]. The plasma sprayed cermet and ceramics coatings, with high hardness and wear resistance, are gradually taking over hard chromium electroplating for the purpose of environment protection [7–9]. Besides, soft bearing coatings with self-lubricating ability can also be fabricated by plasma spraying to reduce friction force and protect wear counterpart.

Plasma sprayed aluminum bronze (CuAl) coatings are widely used as bearing surfaces for the combination of good mechanical and anti-friction properties [2,4]. Common CuAl alloy contains 5–12% of Al (mass fraction) that can strengthen the alloy and retain the low shear strength of copper to benefit the friction-reducing performance. However, the inherently limited hardness of copper-based alloys makes them liable to wear damage [10]. This drawback of bronze coatings, fortunately, can be overcome by introduction of wear-resistant reinforcements such as diamond, TiN, and WC [11–14]. Naturally, the interfacial compatibility of the reinforcements and the metal matrix is worth of particular attention, since reinforcing phases with inferior compatibility tend to be pulled out thereby causing third-body abrasion to the frictional pairs and leading to increased friction coefficient. In this respect, it is imperative to pursue reinforcements with good interfacial compatibility and lubricating performance to improve the tribological properties of CuAl alloy coating.

In the present study, nickel cladded graphite (Ni-graphite) was firstly selected as the reinforcement of plasma sprayed CuAl alloy coating to enhance the tribological property. We focused on Ni-graphite for the consideration that graphite has excellent anti-wear and low-friction properties while the cladded nickel on graphite surface is helpful to enhancing its interfacial compatibility with the CuAl matrix. The microstructure, hardness, phase composition and tribological property of the as-received CuAl/Ni-graphite composite coating were investigated. As comparison, pure CuAl coating and two

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other CuAl composite coatings reinforced by alumina (Al_2O_3) and molybdenum (Mo) respectively, were also fabricated and studied.

2. Experimental

2.1. Fabrication of CuAl-based coating

The commercial powder feedstocks used for plasma spraying involves a CuAl alloy powder (KF130, Beijing Research Institute of Mining & Metallurgy Beijing, China), a fused and crushed Al_2O_3 powder (SY121, Sunspraying Ltd., Beijing China), a sintered and crushed Mo powder (Metco 63NS, Sulzer, Switzerland), and a nickel cladded graphite (KF21, Beijing Research Institute of Mining & Metallurgy Beijing, China). Table 1 shows the chemical composition and size ranges of the sprayed powder feedstocks. And Fig. 1 shows the SEM images of the powder feedstock. The CuAl, Mo, and Ni-graphite powders show good sphericity which are beneficial for powder flowability and plasma spraying. While the Al_2O_3 powder particles have irregular morphology resulted from the fusing and crushing process as well as the inherent brittleness of ceramic material.

Austenitic stainless steel discs (1Cr18Ni9Ti; $\Phi 24 \times 7.5$ mm) were used as substrates. Prior to plasma spraying, the substrates were grit blasted with silica sands and degreased in ultrasonic acetone bath. Plasma spraying processes were carried out with an APS-2000A system (Institute of Aeronautical Manufacturing Technology, Beijing, China). Argon and hydrogen were used as primary and secondary plasma gas, respectively. A six-axis robot (IRB 2400, Asea Brown Boveri Ltd., Switzerland) was used to fix the plasma gun so that consistent spraying distance and passes can be obtained. Reinforcements were separately mechanically blended with the CuAl alloy powder at the same mass fraction of 20%. Optimized spraying parameters for preparing pure CuAl and composite coatings are listed in Table 2.

2.2. Characterization of the CuAl-based coatings

The morphologies of sprayed coatings were observed using a JSM-5600LV scanning electron microscope (SEM, JEOL Corporation, Japan) equipped with an energy dispersive spectrometer (EDS). The phase compositions of as-sprayed coatings were characterised with a *D*/max 2400 X-ray diffractometer (XRD, Rigaku, Japan) equipped with a monochromatic Cu-Kα X-ray source (40 kV, 100 mA). The XRD patterns were obtained in the range of $30^\circ \le 2\theta \le 80^\circ$. The bonding states of the graphite in the CuAl/Ni-graphite composite coating were characterised with a Jobin-Yvon HR-800 micro-confocal Raman spectrometer equipped with an argon-ion laser source (power density: 0.3 mW/m^2). Microhardness of the coatings was measured on a Vickers hardness tester at an applied load of 200 g and a dwell time of 10 s.

2.3. Sliding wear tests

Dry sliding friction and wear tests were carried out on a ball-on-disk reciprocating tribometer (CSM, Switzerland). Fig. 2 illustrates the schematic diagram of the reciprocating ball-on-disk system. The counterpart balls are commercially sintered alumina balls with a

Tabel 1
Composition and particle size range of sprayed powder.

Powder	Composition, in mass percentage	Particle size range (μm)
Aluminum bronze	90% Cu and 10% Al	45–105
Alumina	99% Al_2O_3	20–45
Molybdenum	99% Mo	45–75
Nickel coated graphite	20% Graphite and 80% Nickel	50–80

Table 2
Atmosphere plasma spraying parameters.

Coating	Voltage (V)	Current (A)	Distance (mm)	Ar flow rate (L min^{-1})
CuAl	60	500	100	60
CuAl/ Al_2O_3	65	500	80	50
CuAl/Mo	60	500	80	50
CuAl/Ni-graphite	55	500	100	60

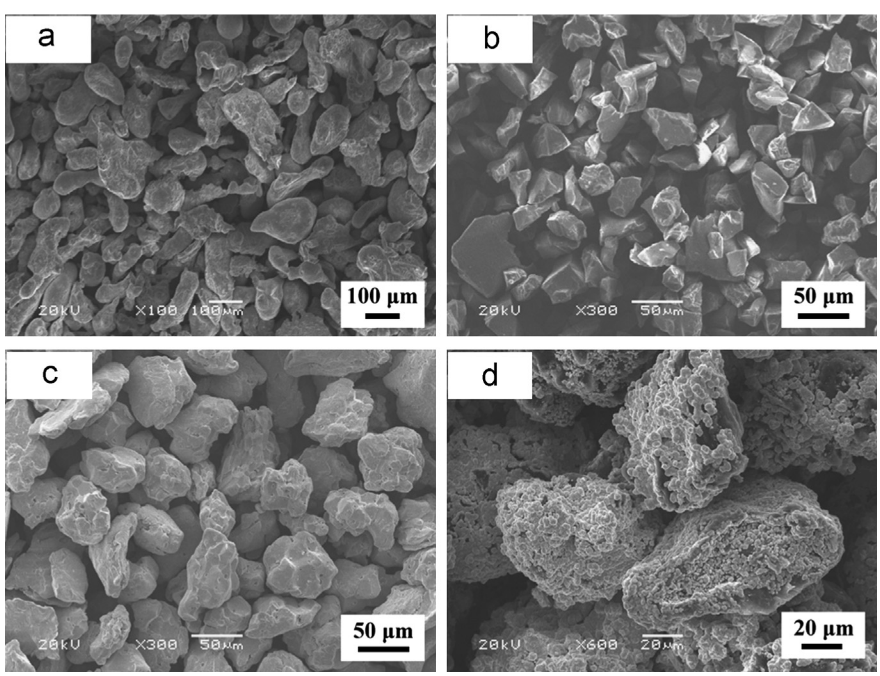

Fig. 1. The SEM images of powder feedstocks for plasma spraying: (a) CuAl, (b) Al_2O_3, (c) Mo, and (d) Ni-graphite.