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Investigation of NiAl intermetallic compound as bond coat for thermal barrier coatings on Mg alloy

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ABSTRACT

Bond coats play a significant role in manipulating the stability of 8YSZ thermal barrier coatings (TBCs) deposited on Mg alloy. In this study, the metal of Ni-Al mixture was sprayed as bond coat via reaction plasma spraying (RPS). Besides, Intermetallic compound NiAl was prepared by self-propagating high-temperature synthesis (SHS). The pure intermetallic compound NiAl was sprayed as bond coat via atmospheric plasma spraying (APS). The microstructure, composition, bond stability and corrosion resistance of the produced bond coats were investigated to find the optimal bond coat for the TBCs on Mg alloy. Results indicate that the bond coats composed of NiAl show excellent bond stability. High toughness of the RPS Ni-Al bond coat results in high tensile bond strength. The APS NiAl bond coat leads to outstanding thermal shock resistance mainly attributing to its moderate thermal expansion match, good mechanical properties and excellent corrosion resistance.

1. Introduction

Mg alloys are the lightest materials among those metals used for structural or mechanical applications [1]. Besides, Mg alloys have many excellent properties such as high specific tensile strength, good stiffness and vibration absorption [2]. Thus Mg alloys have potential applications in automobiles, electronic products, aerospace, etc [3,4]. Unfortunately, Mg alloys have low melting point, poor wear resistance and high chemical activity, which have limited their widespread applications [5]. Several researches reported that various coatings prepared by thermal spraying could provide desired properties of thermal, corrosion and wear resistance for the Mg alloy substrate [6,7].

Thermal barrier coatings (TBCs), typically consisting of metallic bond coat and 8 wt.% yttria stabilized zirconia (8YSZ) top coat, have low thermal conductivity and excellent surface properties [8–10]. The bond coat and the top coat were successfully deposited on rare earth-magnesium alloy MB26 by atmospheric plasma spraying (APS). The TBCs have an effective protection for Mg alloy [11]. The bond stability of the coatings on Mg alloy is an essential feature to evaluate the quality of the coatings. In order to improve the stability of the sprayed coatings on Mg alloy substrate, one available method is to improve the compatibility between the coatings and the substrate [12]. The effective method is to adopt an appropriate bond coat.

Intermetallic compounds are composed of a variety of metal elements or metalloid elements. They are solid solution with ordered super-lattice structure and certain range chemical components, which are based on the intermediate part of the phase diagram [13]. There are metal bond and covalent bond in intermetallic compounds. The diffusion is slowed down and the creep activation energy is improved due to the stable chemical bonds. The long range order structure of intermetallic compounds can suppress the change of cross slip, leading to reduce the crack initiation during cyclic loading. Owing to the formation of dense oxide film in oxidizing atmosphere, the intermetallic compounds show good oxidation resistance. Besides, intermetallic compounds have many excellent properties such as high melting point, high hardness and excellent creep resistance [14]. Considering the stable chemical, excellent mechanical properties and the good compatibility with metal and ceramic, intermetallic compounds are adopted to prepare as the TBCs' bond coat on Mg alloy through APS. In order to find the optimal bond coat material and develop the TBCs on Mg

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alloy with excellent protective performance, the bond stability and protection of the intermetallic compounds bond coat should be systematically investigated.

NiAl intermetallic compound with B2 structure has attracted considerable attention because of their excellent properties such as low density, high melting points, excellent resistance to environmental degradation, and good mechanical and chemical stabilities at high temperatures [13–15]. It has great potential for structural applications. It can be used as the bond coat material in TBC systems to improve the performance of the coatings [16–19]. Being a promising bond coat material with high strength and moderate thermal expansion coefficient, NiAl intermetallic compound could be exploited as bond coat materials in TBCs on Mg alloy.

Several coating techniques have been employed to process NiAl coatings. Reaction plasma spraying (RPS) and self-propagating high-temperature synthesis (SHS) were adopted to synthesis the NiAl intermetallic compound. Material synthesis and normal plasma spray can be accomplished simultaneously during RPS basing on solid-solid reaction or gas-solid reaction. RPS shows high deposition, simple process, low operation cost, good adherence with substrate and the opportunity to synthesize metastable or transitional phases [20]. Relatively, high purity phases can be synthesized through SHS. The SHS process demonstrates several advantages, such as rapid formation, good controllability and process economic [21]. Subsequently, the SHS synthesized phase can be deposited as coat by APS. In this study, the coatings with NiAl intermetallic compound were prepared as bond coats in TBCs (8YSZ top coat) on MB26 alloy through RPS and SHS plus APS, respectively. The microstructure, composition, bond stability, and corrosion resistance of the produced bond coats were systematically investigated to find the optimal bond coat for the TBCs on Mg alloy. It might provide some useful information for potential application of intermetallic compound as thermal sprayed coat.

2. Experimental

The Ni, Al powders (Beijing General Research Institute of Mining and Metallurgy) with a molar ratio of 1:1 were dry-mixed in a plastic container using zirconia balls at low speed (~35 rpm) for 8 h. The mixed Ni, Al powders were uniaxially pressed into cylindrical compacts with the dimensions of Φ22 mm × 15 mm. The compact was placed on a graphite-flake with a thickness about 2 mm in a stainless steel glove box. The SHS reaction for the compact was ignited under Ar atmosphere by the arc, which was generated by passing a strong current between the tungsten electrode and the graphite-flake. The power was switched off after the SHS reaction was initiated. The fully reacted samples were collected. And then, the obtained SHS block was crushed to small particles with size about 30–100 μm, which were suitable for APS.

The RPS powders of Ni-Al agglomerates were prepared by spray drying. Ni-Al mixture with a molar ratio of 1:1 was ball milled for 8 h with the additions of ethanol, Gum Arabic and Tri-Ammonium Citrate. The weight proportion of the powder mixture, ethanol, Gum Arabic and Tri-Ammonium Citrate is about 120:100:2:1. The milled suspension was then sprayed into a drying tower (GZ-5, Yangguang Ganzao). The obtained powders with a size range of 30–100 μm were collected for RPS.

The candidate APS feedings (SHS NiAl powders, spray dried Ni-Al agglomerates) were sprayed onto MB26 alloy substrate to deposite bond coats via Unicoat Spraying System (F4 gun, Sulzer Metco, Switzerland) with Ar-H_2 as plasma gases. Accordingly, the pure NiAl bond coat and RPS Ni-Al bond coat were obtained. After that, 8YSZ top coat were deposited on the bond coat by APS. The spray distance was 100 mm with a spray current of 600 A. Free-standing coats (thickness about 1 mm) for other tests were deposited on Graphite substrate abraded with fine abrasive paper of 1200 grit.

The dilatometric measurements of MB26 alloy, sprayed bond coats and 8YSZ coat were conducted by a high-temperature dilatometer (Netzsch 402C, Germany). During the dilatometric measurement, a small piece of sample with a length of 25 mm was heated from 50 °C to 450 °C with a heating rate of 5 °C min^{-1} and then held for 10 h, followed by cooling down to room temperature.

Small discs with a size of 10 × 10 mm^2 were coated for tensile bond strength measurement. The bond strength tests were carried out using an Instron (1121 USA) machine with a tensile speed 2 mm min^{-1} based on ISO 4624. The final value was obtained after averaging at least 3 measurements. The thermal shock test was performed to determine the life time of the coatings when subjected to a rapid temperature change. The steps in the thermal shock process were following: the coated sample was constantly heated for 15 min at 400 °C in a furnace followed by sudden quenching into water coolant. The sample was dried by air flow and then re-heated in the furnace. This procedure was repeated until the failure in form of most of coating delamination and the thermal cycling number was the life time of the coating. The final value was obtained after averaging at least 3 measurements.

The corrosion of bond coat was evaluated by electrochemical corrosion test. 3.5 wt.% NaCl solution was used as corrosion medium. Electrochemical corrosion of the sprayed bond coat was evaluated by potentiodynamic polarization. An electrochemical workstation (CHI 660A, CH Instruments) together with a conventional three electrode cell was used to perform polarization curves of the sprayed bond coats in 3.5% NaCl solutions at room temperature. A platinum counter electrode and a glassy carbon reference electrode (GCE) were used. The polarization curves were scanned from a cathodic potential of −1.8 V to an anodic potential of 0 V at a rate of 0.01 V s^{-1}.

The crystal structures of the samples were analyzed by X-ray diffraction (XRD) (Bruker D8 Advance Diffractometer with Cu Kα radiation) using a scanning rate of 10° min^{-1}. Environmental scanning electron microscopy (ESEM, XL-30ESEM FEG, Mico FEI Philips) equipped with energy dispersive X-ray spectrometer (EDS) was applied for the investigation of morphology and composition of the samples.

3. Results and discussion

3.1. Preparation of the samples with different bond coats

The candidate RPS Ni-Al bond coat spraying material is the spray dried Ni-Al agglomerated particles. SHS synthesized material after crushing was prepared to deposit high purity NiAl intermetallic compound bond coat through APS. The microscopic morphologies of the spraying feedings are shown in Fig. 1. As shown in Fig. 1(a) and (b), it can be found that small Ni and Al particles are well agglomerated to form typical globular agglomerated particles with uniform size distribution. As a result, the particles would exhibit excellent mobility. Small Ni and Al particles are uniformly distributed in the agglomerated particle, which are suitable for RPS. The small Ni and Al particles can be fully heated and well reacted in the high temperature flame during RPS. The microscopic morphology of SHS synthesized material after crushing is shown in Fig. 1(c) and (d). The obtained particles have irregular shape. It is mainly related to the fracture process of the synthesized intermetallic compound. Owing to the compact structure and uniform size distribution, these particles exhibit good mobility.

The phase compositions of the spraying powders were detected by XRD. As shown in Fig. 2 “SD (SD is abbreviated from spraying