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Interface fracture property of PEO ceramic coatings on aluminum alloy

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Abstract

This paper combines the four-point bending test, SEM and finite element method to study the interface fracture property of PEO coatings on aluminum alloy. The interface failure mode of the coating on the compression side is revealed. The ceramic coating crack firstly along the 45° to the interface, then the micro crack in the coating deduces the interface crack. The plastic deformation observed by SEM shows excellent adhesion property between the coating and substrate. The plastic deformation in the substrate is due to the interfacial crack extension, so the interface crack mode of PEO coatings is ductile crack. The results of FEM show that the compression strength is about 600 MPa.

Keywords: PEO coatings; Interface fracture; Four-point bending; Finite element method

1. Introduction

Plasma electrolytic oxidation (PEO) coatings are gaining more and more attention[1]. Combining electrochemistry oxidation with plasma discharge in electrolyte, PEO technique produces ceramic coatings with excellent properties such as high hardness [2–5], wear resistance [6–10], corrosion resistance [11–16] and thermal protection [17,18]. The thickness of PEO coating can be easily controlled, to the maximum of around 200 μm, by adjusting process parameters. Because of all the advantages mentioned above, PEO technique is very promising for a number of industrial applications.

Because of partial consumption of the substrate during the process, PEO coatings should have high resistance to interfacial spallation due to strong bonding at the interface. According to Nie [6], the thin inner layer of the coatings near the interface exhibits a number of sublayers, and the lower portion of the intermediate layer has a nanoscaled polycrystalline microstructure. Gnedenkov [19] used pull tests and scratch tests to study adhesion property of PEO coatings on aluminum alloy. Their results show that the adhesion strength exceeds 82 MPa, which is the adhesive glue tension strength. Despite some early reports about the adhesion of PEO coatings, the interface fracture property of PEO coatings needs further studies.

The present study focuses on the failure analysis of PEO coating deposited on aluminum alloy substrates using four-point bending. The work reveals the mechanism of cohesive cracking and spallation in the coating by cross-sectional SEM analysis. In addition, finite element method is adopted to simulate the deformation and stress in the coating/substrate system.

2. Research routine and experimental details

PEO experimental equipment is shown in Refs. [20,21]. Al–Cu–Mg 2024 aluminum alloy plate was used as the substrate material, and aqueous solution of sodium silicate with concentration of 20 g/L was used as the electrolyte. The coated plate is cut into beams with the size of 50 mm in length, 8 mm in width and 1 mm in height. The as-deposited coatings were polished with SiC paper to remove the outer loose layer. Polished PEO coating exists only on the top side of the beam, with a thickness of about 150 μm.

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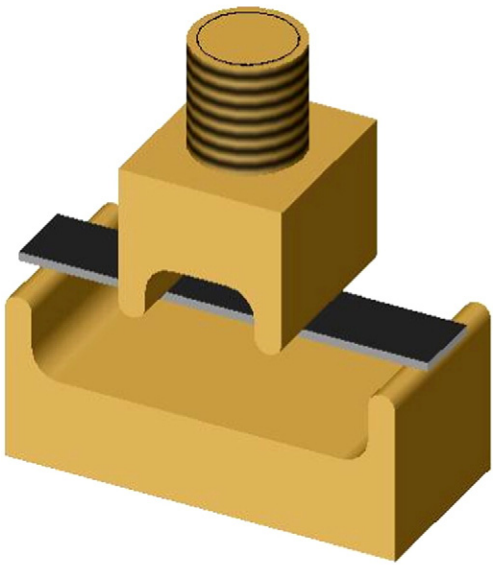

Fig. 1. Sketch map of four-point bending test.

The schematic illustration of test equipment is shown in Fig. 1. During the four-point bending test, PEO coating is in compression stress state to prevent vertical crack in the coating. The distance between the outer pins is 40 mm; the distance between the inner pins is 15 mm. The specimen was loaded in displacement control mode with a constant loading velocity. Load and displacement history is recorded by the micro computer system. The sudden drop in the load curve is used to characterize the initial failure of the coating.

After the failure, SEM is used to study the cross section and interface profiles. The interface crack is so long that the whole interface profile cannot be contained in one SEM picture. Therefore, many SEM pictures are combined to give the whole profile. After the PEO coating is stripped off the substrate, the morphologies of both sides near the interface are characterized by SEM. The element composition of delaminated surfaces of substrate and PEO coating is characterized by EDS.

In the finite element model, substrate is considered as linear strain-hardening elastic-plastic material with elastic module of 73 GPa, yielding stress of 274 MPa and strain-hardening modulus of 1.46 GPa. The local elastic module of PEO coating gained by nano-indentation is 210 GPa. However, according to Ref. [17], the global modulus of PEO coating is less than the local modulus gained by nano-indentation, and the global modulus gained by bi-material beam cooling experiments is about 40 GPa. So in the finite element model, PEO coating is considered as elastic material with elastic modulus of 40 GPa. Interface between coating and substrate is considered as perfect adhesion. The FE model is loaded at the critical level according

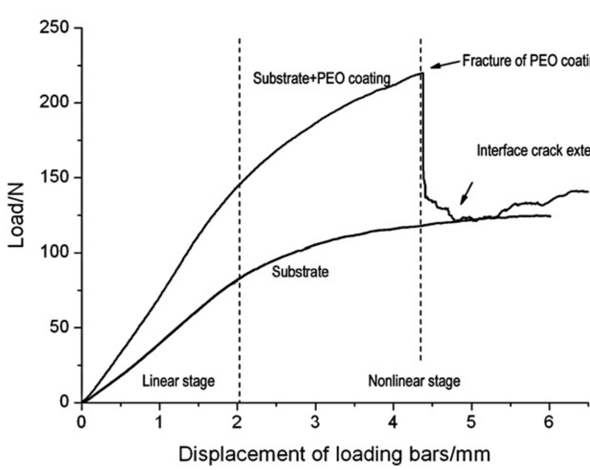

Fig. 2. Load–displacement curves of four-point bending.

Fig. 3. Interface fracture of PEO coating.