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Crack monitoring method based on Cu coating sensor and electrical potential technique for metal structure

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Structural health monitoring

Abstract Advanced crack monitoring technique is the cornerstone of aircraft structural health monitoring. To achieve real-time crack monitoring of aircraft metal structures in the course of service, a new crack monitoring method is proposed based on Cu coating sensor and electrical potential difference principle. Firstly, insulation treatment process was used to prepare a dielectric layer on structural substrate, such as an anodizing layer on 2A12-T4 aluminum alloy substrate, and then a Cu coating crack monitoring sensor was deposited on the structure fatigue critical parts by pulsed bias arc ion plating technology. Secondly, the damage consistency of the Cu coating sensor and 2A12-T4 aluminum alloy substrate was investigated by static tensile experiment and fatigue test. The results show that strain values of the coating sensor and the 2A12-T4 aluminum alloy substrate measured by strain gauges are highly coincident in static tensile experiment and the sensor has excellent fatigue damage consistency with the substrate. Thirdly, the fatigue performance discrepancy between samples with the coating sensor and original samples was investigated. The result shows that there is no obvious negative influence on the fatigue performance of the 2A12-T4 aluminum alloy after preparing the Cu coating sensor on its surface. Finally, crack monitoring experiment was carried out with the Cu coating sensor. The experimental results indicate that the sensor is sensitive to crack, and crack origination and propagation can be monitored effectively through analyzing the change of electrical potential values of the coating sensor.

1. Introduction

There is a high possibility that aircraft metal structures will be damaged due to fatigue loading, wearing, environment corrosion and other factors during their service.[1,2] Along with damage accumulation, structural load-bearing capacity will decline continuously, which can cause structure failure, or worse, sudden rupture which will lead to the occurrence of

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catastrophic accident and enormous financial loss. The most important approach to ensure the safety and reliability of the aircraft structures is condition assessment and fault early warning for the aircraft structures. And the top priority is fatigue crack detection and real-time monitoring.

At present there are certain types of sensor applied to aircraft structural damage monitoring, including optical fiber sensor,[3] piezoelectric sensor,[4,5] comparative vacuum monitoring sensor,[6] and eddy current sensor,[7,8] acoustic emission sensor,[9], etc. However, when these sensors are applied to aircraft metallic structural crack monitoring, they may have their own limitation such as the difficulty of functional and structural integration with aircraft metal substrate, mediocre capability to withstand severe and complicated working environment, and application limit caused by high cost and high requirement on equipment and technology.[10,11] Therefore, it is essential to develop a simple and reliable structural crack monitoring technique.

In recent years, electrical potential difference method has achieved rapid development and wide application in non-destructive testing field[12–16] due to the following advantages: simple principle,[17] high precision, wide scale, high benefit-cost ratio, strong adaptability,[17,18] etc. However, there are still certain issues in monitoring crack by using electrical potential technique directly. The first issue is that the technique is sensitive to structural shapes,[19,20] so the cracks of structures with complicated shapes are difficult to measure. Besides, it is essential to locate crack positions for the previous probes layout,[21–23] which makes on-line monitoring yet difficult. Moreover, it may be difficult to monitor cracks of structures with low electrical conductivity by using this method.[24]

To solve the drawbacks mentioned above, pulsed bias arc ion plating technology is introduced into this study. The research approach is as follows. A Cu conductive coating with simple certain shape is deposited by pulsed bias arc ion plating technology on the surface of the structure fatigue critical parts which can be confirmed through theoretic analysis. If the coating sensor has excellent damage consistency with the substrate, when cracks appear on the surface of these parts, the corresponding cracks will also initiate at the coating sensor. By using electrical potential difference principle, relevant information about crack can be obtained through analyzing the electrical potential value change of the coating aroused from crack initiation and propagation, thus it is possible to realize structure surface crack monitoring.

This paper mainly presents a crack monitoring method based on Cu coating sensor and electrical potential difference principle. And we also investigate how to prepare a suitable Cu coating sensor integrated with substrate firmly, whether the Cu coating sensor has excellent damage consistency with the 2A12-T4 aluminum alloy substrate, whether preparing the Cu coating sensor would lead to obvious negative influence on fatigue performance of the substrate, and how to monitor structural cracks with Cu coating sensor.

2. Methodology

2.1. Materials

2A12-T4 aluminum alloy sample with center hole was chosen as the research object to verify the feasibility of this method.

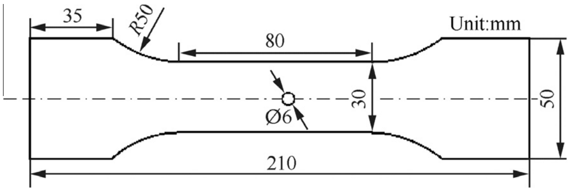

Fig. 1 Shape and dimension of sample.

The composition of 2A12-T4 aluminum alloy is as follows: Cu 3.80wt%–4.90wt%, Mg 1.20wt%–1.80wt%, Si $\leqslant$ 0.50wt%, Fe $\leqslant$ 0.50wt%, Zn $\leqslant$ 0.30wt%, Ni $\leqslant$ 0.10wt%, impurity $\leqslant$ 0.10wt% and Al balance. The sample prepared by the national standard GB/T 228–2002 is shown in Fig. 1, and the thickness of the sample is 2 mm.

2.2. Cu coating sensor

The shape of the Cu coating sensor is shown in Fig. 2. The coating sensor consists of two layers: the dielectric isolated layer and the conductive sensing layer, which are obtained by anodic oxidation technology and pulsed bias arc ion plating technology, respectively. The purpose of the dielectric isolated layer is to separate the conductive sensing layer and the substrate to make sure only the target monitoring area on sample surface is conductive. The Cu conductive sensing layer prepared on the surface of structure fatigue critical parts which can be confirmed as the target monitoring area through theoretical analysis is the function layer. The crack initiation and propagation on coating sensor induced by structural crack will change the electric field of the conductive sensing layer, which is shown as fluctuation of electrical potential values, thereby obtaining the information about structural crack through monitoring the electrical potential values of the coating sensor.

2.3. Damage consistency verification

It is the precondition and basis of monitoring structural crack with the coating sensor, for it has a good bonding strength and an excellent damage consistency with substrate. Two methods were employed to investigate the damage consistency of coating sensor with substrate of 2A12-T4 aluminum alloy in this study. One was the strain contrast of static tension sample. The strain gauges were stuck on the corresponding positions on both sides of the sample, on one side of which the coating sensor was prepared beforehand. The strain data of the coating and the substrate of 2A12-T4 aluminum alloy in the static tension test were collected and analyzed. The other was the phenomena observation in fatigue experiment. The reading microscope (resolution: 0.1 mm) was employed to observe whether the Cu coating sensor was integrated with the

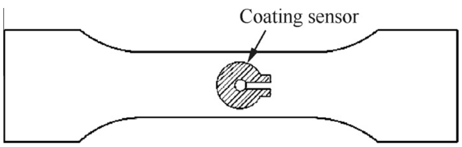

Fig. 2 Schematic illustration of Cu coating sensor.