Research on the formation and development of micro defects in organic coatings caused by environmental loads

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Abstract In recent years, the rapid advancement of the global aviation industry has increasingly positioned it as a catalyst for economic development worldwide. Consequently, significant attention has been devoted to addressing corrosion issues in aviation equipment. Organic coatings have emerged as the predominant method for corrosion protection in aerospace equipment, owing to their cost-effectiveness, wide applicability, and effective protective properties. However, the complex environmental stresses experienced during flight often result in premature failure of organic coatings. Hence, understanding the failure mechanisms of organic coating protection systems under such intricate conditions is paramount.

As we all know that the primarily function of organic coatings was forming a protective barrier between metal surfaces and corrosive medium. However, the existence of organic coatings cannot completely suppress the occurrence of corrosion. During service, corrosive media can reach the interface between metal and coating through organic coatings through diffusion, causing corrosion of the substrate metal. Additionally, solvent residues during the coating application process can lead to the formation of pores and micro-defects within the coating, providing pathways for accelerated corrosion. These internal micro-defects can be categorized into inherent flaws and those induced by environmental factors. Current research predominantly focuses on artificial defects, facilitating the study of their impact on coating protection and the development of new defect identification methods. However, the characteristics of internal micro-defects in coatings during actual service differ significantly from artificial defects. Therefore, investigating the formation and progression of defects induced by environmental loads in coatings during service is vital for understanding damage mechanisms and enhancing protective coating performance.

This study utilized X-ray tomography to analyze changes in the number, morphology, and distribution of micro-defects in coatings under tensile stress. The results indicate that under the influence of a single corrosion factor, micro-defects are primarily distributed within the organic coating. With increasing soaking time, the number of micro-defects shows a gradual increase, along with observed aggregation at the interface between the organic coating and the metal substrate. Under single alternative load action, a slight increase in the number of micro-defects within the

coating is observed, with more noticeable aggregation at the interface between the organic coating and the substrate. As the number of alternating loads increases, the number of micro-defects within the coating gradually decreases, but the number of defects near the interface position increases significantly. Under the synergistic effect of corrosion and alternating stress, the number of micro-defects within the coating significantly decreases, while a large amount of defect aggregation is observed at the interface between the organic coating and the substrate.

The research results on the morphology of micro-defects indicate that as sphericity increases, there is a gradual decrease in the volume of micropores, and the two are related by an exponential function. According to the morphological characteristics of pores, internal pore defects in coatings can be categorized into three types. The first type of hole is an ellipsoid with a long axis parallel to the Z-axis, the second type is a sphere, and the third type is an ellipsoid with a long axis perpendicular to the Z-axis. From the experimental results, it can be observed that under a single corrosion action, there is a significant increase in the number of first-type pores inside the coating. With the extension of soaking time, the number of second-type pores gradually increases, and the internal pores of the coating are mainly composed of second-type pores. Under a single alternating load, the number of the second and third types of holes gradually decreases, and the percentage of the three types of holes gradually becomes consistent. After 500,000 synergistic effects, the number of first-type pores increased while the number of second-type pores significantly decreased. As the loading frequency increases, a large number of second-type holes inside the coating gradually shift towards third-type holes.