Corrosion and Protection of High-Strength Aerospace Aluminum Alloys

Published as part of the Virtual Special Issue "Beihang University at 70"

Zhenjiang Zhao, Chao Chen, Chao Han, and Mei Yu*

School of Materials Science and Engineering, Beihang University, Beijing 100191, China

* Corresponding author, E-mail: yumei@buaa.edu.cn

Abstract

Exploring corrosion mechanisms and developing new protective methods are essential to avoid the failure induced by corrosion for aluminum alloys. Methods to improve service stability of aerospace aluminum alloys were discussed.

Key words: Aluminum alloys; Precipitates; Organic-inorganic hybrid coatings; Smart Coatings.

Citation: Zhenjiang Zhao, Chao Chen, Chao Han, Mei Yu. Corrosion and Protection of High-Strength Aerospace Aluminum Alloys. *Materials Lab* 2022, 1, 220043. DOI: 10.54227/mlab.20220043

Main text

With the development of aerospace technology, performance of equipment has been faced with new requirements and challenges. In order to ensure the safety service of aerospace equipment, it is urgent to find out the failure mechanisms and improve the service stability of key structural materials. Aluminum alloys are widely used as structural materials in aerospace field. Corrosion induced failure is one of the most important failure modes of structural aluminum alloys. Studying corrosion mechanisms and developing new protective methods are essential for the safety and long service life of aerospace aluminum alloys.

Generally, corrosion resistance of materials can be improved by modifying the matrix, the coatings, and the bonding force between the substrate and the coatings. For aerospace aluminum alloys, three aspects (Fig.1) could be discussed as follows.

Firstly, local corrosion induced by heterogeneous matrix need to be paid attention. Adding alloying elements is a common method to improve the mechanical properties of aluminum alloys. The elements added in aluminum alloys promote the generation of the precipitates which lead to aluminum alloys matrix showing inhomogeneous chemical activity. For example, during the aging process of aluminum alloys, element enrichment occurs to produce precipitates, such as Al_2CuLi, Al_3Li, Al_2Cu, AlCuMnFe, etc[1].

However, the electrochemical activities of precipitates are different from that of the matrix, and it is prone to form a galvanic corrosion cell in corrosive environments, resulting in preferential dissolution of the precipitates or the surrounding matrix. In addition, the types of precipitates in the aluminum alloy matrix are complex, also the densities and sizes of the precipitates are uneven. The size of precipitates has a significant influence on the transitions from metastable pits to stable pits in aluminum alloys. When investigating the corrosion initiation behaviors of 2297 Al-Li alloy, we found that metastable pits created by the dissolution of large precipitates (or their surrounding matrix) lead to large cavities and severe local acidification. Otherwise, metastable pits that appear around larger particles are more likely to maintain continuous propagation[2]. In addition, the coarse precipitates can also lead to defects in anodic films. For example, we found that the copper-rich AlCuMnFe phase, a typical cathodic phase in Al-Li alloys, will cause defects in the anodic film during anodization process and result in the film failure[3].

Secondly, novel pretreatment methods on aluminum alloy are urgent to be developed. Pretreatment coatings are widely used in protection of aluminum alloys. Commonly used pretreatment methods include anodic oxidation and chromic acid chemical oxidation. However, the above methods sometimes are not suitable due to the limitation of actual circumstances. In this regard, organic-inorganic hybrid coatings have been developed as an alternative method, which can not only improve the bonding force between aluminum alloys and organic coatings, but also provide well corrosion protection for aluminum alloys.

Silanization, a sol-gel method to fabricate an organic-inorganic hybrid coating, is a good candidate for the pretreatment of aluminum alloys[4]. It plays a significant role as a promoter of coatings adhesion and corrosion retarder under various topcoats (such as epoxide, polyester, polyurethane, acrylic resin, etc.). The complex polymer structure is formed due to crosslink reactions between the functional groups of the silane and the resin. Depending on the crosslinking density of the structure, the electrolyte intrusion is further hindered. The

Received 2 June 2022; Accepted 10 July 2022; Published online

DOI: 10.54227/mlab.20220043

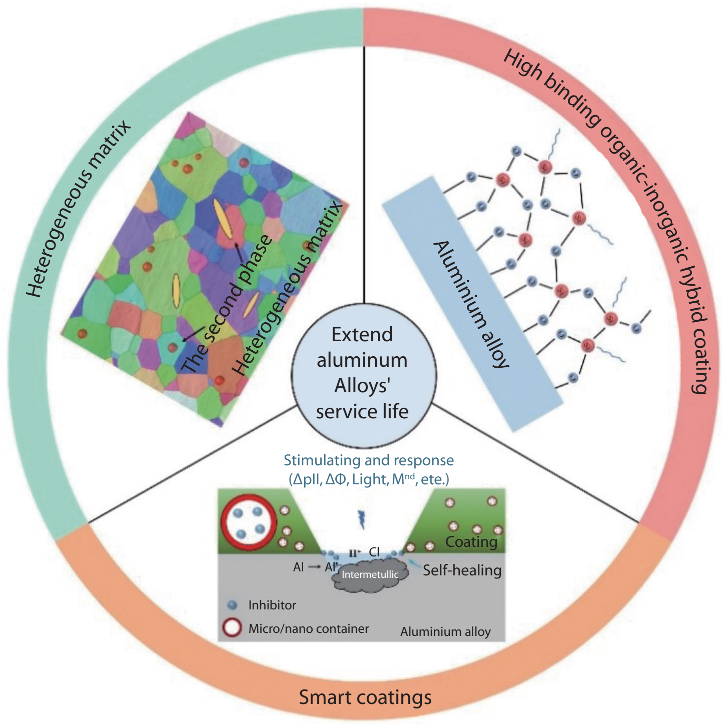


Fig. 1 Overview of issues for corrosion and protection of high-strength aerospace aluminum alloys.

presence of Si-OH groups will promote the adhesion of metal surfaces/coatings because they are easy to form metal siloxane (Si-O-M) covalent bonds[5]. By screening precursor species and adjusting the hydrolysis-polycondensation degree of silane, the precise control of film growth could be realized, and the organic-inorganic hybrid sol-gel coatings with variable phase composition gradient will be constructed.

What's more, smart coatings are emerged to extend the service life of aluminum alloys. When the coatings on aluminum alloys are in service, they will inevitably be damaged and then easy to be penetrated by corrosive media. Thus, it is necessary to modify the coatings with self-healing capability to prolong the service life. Adding corrosion inhibitors to achieve active protection is an effective means to realize the self-healing function of coatings. However, the direct addition of corrosion inhibitors into the coating might induce inhibitors release too fast and premature failure[6].

To overcome this disadvantage, corrosion inhibitors are encapsulated in micro/nano containers with stimuli-responsive release, which is different from ordinary capsules for drug delivery. It is a simple and effective method to develop a self-healing protective coating based on the smart-response release of corrosion inhibitor[7].

Micro/nano containers have a wide range of structures and properties. While loading the inhibitor efficiently, it can respond to the external changes of light, heat, pressure, pH and potential during corrosion, so as to realize the controllable release of the inhibitors[8]. Only when these internal/external stimuli are triggered can the corrosion inhibitors be released from the micro/nano containers, which will prevent the corrosion inhibitors from premature leaking from the coatings and improve the durability of the coatings, so as to enhance the self-healing ability of the coatings and prevent corrosion.

Great breakthroughs in high corrosion resistance of aluminum alloys have been obtained by adjusting the microstructure of aluminum alloys and by using functional coatings. However, the diverse corrosion environments require researchers to deeply analyze the coupling relationships between stress and corrosion medium of aluminum alloys in actual service environment. Exploring the corrosion origin and evolution of aluminum alloys under the action of multi-factor coupling is an important development trend in future. Therefore, it is necessary to conduct in-depth research on the specific corrosion status and potential corrosion mechanisms of aluminum alloys, and adopt new materials and a variety of new technologies, such as organic-inorganic hybrid strengthen methods and smart-response release techniques, for effective control to ensure the safety of aluminum alloys in service.

Acknowledgements:

This work was supported by Beijing Natural Science Foundation (Grant No. 2172032).

Conflict of interest:

The authors declare no conflict of interest.

Author contributions:

Zhenjiang Zhao made the illustrations and the main analytic and writing work. Chao Chen collected the references. Mei Yu contributed to the idea and design of the study, and participated in the revision of the manuscript with Chao Han. All authors contributed to the article and approved the submitted version.

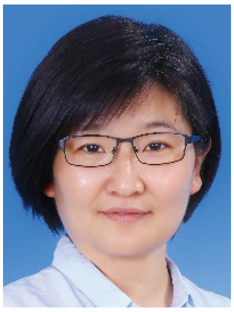
DOI: 10.54227/mlab.20220043

REFERENCES

1. Y. Zhu, J. D. Poplawsky, S. Li, R. R. Unocic, L. G. Bland, C. D. Taylor, J. S. Locke, E. A. Marquis, G. S. Frankel, *Acta Materialia*, 2020, 189, 204
2. J. Liu, K. Zhao, M. Yu, S. Li, *Corrosion Science*, 2018, 138, 75
3. J. Liu, G. Rong, S. Cen, S. Li, H. Shi, K. Zhao, M. Yu, *Journal of The Electrochemical Society*, 2018, 165, C980
4. F. Maia, K. A. Yasakau, J. Carneiro, S. Kallip, J. Tedim, T. Henriques, A. Cabral, J. Venâncio, M. L. Zheludkevich, M. G. S. Ferreira, *Chemical Engineering Journal*, 2016, 283, 1108
5. P. Liu, Q.-H. Zhang, J.-Q. Zhang, J.-M. Hu, F.-H. Cao, *Chemical Engineering Journal*, 2022, 430, 133173
6. L. Ma, C. Ren, J. Wang, T. Liu, H. Yang, Y. Wang, Y. Huang, D. Zhang, *Chemical Engineering Journal*, 2021, 421, 127854
7. F. Zhang, P. Ju, M. Pan, D. Zhang, Y. Huang, G. Li, X. Li, *Corrosion Science*, 2018, 144, 74
8. D. Shchukin, H. Möhwald, *Science*, 2013, 341, 1458

Biographies

Zhenjiang Zhao is currently pursuing his Ph.D. degree at the School of Materials Science and Engineering, Beihang University under the supervision of Prof. Mei Yu. His primary research interests focus on the failure mechanisms of aluminum and steel under electrochemical-stress coupling conditions.



Mei Yu is a professor at the School of Materials Science and Engineering, Beihang University. She received Ph.D. degrees from Beihang University. Her lab focuses on the fundamental corrosion mechanisms, service performance evaluation and protection technology development for aerospace structural materials.