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Deposition, characterization and electrochemical properties of silica-phosphate composite coatings formed over A6092/SiC/17.5p aluminum metal matrix composite

Abdel Salam Hamdy[a,*], F. Alfosail[b], Z. Gasem[b]

[a] *Central Metallurgical Research and Development Institute, Cairo, Egypt*
[b] *Center of Research Excellence in Corrosion, King Fahd University of Petroleum & Minerals, Saudi Arabia*

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ABSTRACT

This paper investigates the effect of 2.5 wt.% $(NH_4)_3PO_4$ post-treatment after silica treatment on the formation of silica-phosphate (Si-P) composite coatings over A6092/SiC/17.5p aluminum metal matrix composite (AMMC). In previous studies, the optimum concentration, treatment time and pH of silica treatment have been determined. The aim of the current paper is to determine the optimum conditions under which Si-P composite coatings can provide a maximum localized corrosion protection to AMMC. The surface morphology of Si-P composite coatings and the ability to protect AMMC substrate from localized corrosion in Cl^- media were examined as a function of phosphate treatment time (0, 2, 5 and 10 min). Results showed that phosphate post-treatment after silica coating significantly affects the microstructure and the pitting corrosion resistance of the ultimate coated composites. The coating deposited on AMMC post-treated for 2 min provides better pitting corrosion resistance than that post-treated for 5 and 10 min. It is largely because the morphologies of the coatings are remarkably different under the three post-treatment conditions.

1. Introduction

Aluminum metal matrix composite (AMMC) materials posses outstanding mechanical properties which enable them to be used in military and transportation industry to replace heavy metals. Such replacement can significantly reduce the vehicles weight and save fuel consumption which, in turn, will reduce the emission of carbon dioxide and other toxic gases. However, one of the main drawbacks of such materials is the poor corrosion resistance where the presence of non-metallic phase (reinforcements) inside the alloy matrix enhances the formation of micro-electrochemical cells at the AMMC surface [1].

In 1997, Chen and Mansfeld [2] investigated the corrosion behavior of the same composite material and studied the possibility to use chrome-free Ce-Mo coatings for improving its corrosion protection. Although multi-steps coatings have been used, Ce-Mo coatings failed to provide a significant improvement and the overall protection was not attractive. They stated that “The failure of several common and new environmentally acceptable methods of corrosion protection which have been applied successfully to wrought Al alloys is most likely due to interfaces created during manufacture of the Al 6092/SiC, MMC which are highly susceptible to localized corrosion. Further research should be directed at identifying the nature of such interfaces and their role in determining the corrosion resistance of aluminum MMCs”.

In a previous study [1], we examined the nature of the interface and recognized that several types of corrosion were formed as a function of immersion time in Cl^- solution. Four forms of namely crevice corrosion, galvanic corrosion, pitting corrosion and intergranular corrosion have been identified.

Chromate has been considered as a standard coating for improving the corrosion resistance aluminum based alloys and composites. However, toxic hexavalent chromate has been banned due to its known carcinogenic effect and negative environmental impact [3].

Silica treatment was proposed as a safe alternative to the process involving toxic chromate conversion coatings for the corrosion protection of aluminum alloys and composites [4–25]. In previous work [4,5], we determined the optimum conditions under which silica coating can offer the maximum localized protection for AMMC in chloride media. The silica concentration was determined to be 50 g/l [4] and the silica treatment pH was determined to be 12.9 [5]. The optimum silica treatment time was also measured to be 10 min. When applying such silica coatings over AMMC, the localized corrosion resistance improved about four times. However, few pitting zones are still observed [4,5].

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* Corresponding author.
E-mail address: asalam85@yahoo.com (A.S. Hamdy).

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Several approaches have been reported for improving the pitting corrosion resistance of aluminum alloys and composites [2,5–31]. Among these approaches are surface pre-treatment, surface modification, oxide thickening, alkaline pickling, acidic etching, post-treatment and sealing.

Post-treatment with phosphate has been successfully used by some researchers for enhancing the localized corrosion resistance of several aluminum alloys and composites [28–32]. Most of the reported data used phosphate post-treatment after cerium treatment. Because cerium salts are quite expensive compared with inexpensive silica salts, and silica coating has been studied before by our group and proved to provide a significant improvement to AMMC [4,5], this paper focuses on designing a silica coating post-treated with phosphate for AMMC.

Silica-phosphate (Si-P) coatings prepared in this paper is expecting to be a new attempt toward overcoming the localized corrosion in AMMC. The optimum conditions under which Si-P coatings can provide a maximum localized corrosion protection to AMMC in chloride solution have been determined. The corrosion inhibition characteristics and protection mechanism due to Si-P coating were investigated using cyclic voltammetry techniques, linear polarization, optical microscopy, XRD and SEM-EDS analysis. The surface morphology and kinetics of the Si-P coating were investigated.

2. Experimental

The materials specifications, chemical composition, experimental setting for electrochemical testing, and the surface characterization conditions and instrumentations have been provided in details elsewhere [1,4].

2.1. Silica treatment

All AMMC panels used in this study were treated with 50 g/l silica solution at pH 12.9 for 10 min open to air at room temperature. After silica coating, the samples washed with distilled water and dried with hot air.

2.2. Phosphate post-treatment

The silica coated AMMC panels were subjected to a post-treatment step in 2.5 wt.% $(NH_4)_3PO_4$ solution at 80 °C. The post-treatment times varied from 0, 2, 5 and 10 min. After post-treatment, the samples rinsed in distilled water and dried in hot air. Fig. 1a shows a flow chart for the Si-P coatings preparation under different phosphate post-treatment times. Fig. 1b shows a schematic representation about the coating formation.

3. Results and discussion

The surface morphology and electrochemical characteristics of Si-P composite coatings over AMMC substrate were investigated in views of the optimum phosphate treatment time which can offer the maximum localized corrosion resistance. Four groups of AMMC panels have been examined namely:

Group 1: silica coated without post-treatment.
Group 2: silica coated followed by phosphate post-treatment for 2 min.
Group 3: silica coated followed by phosphate post-treatment for 5 min.
Group 4: silica coated followed by phosphate post-treatment for 10 min.

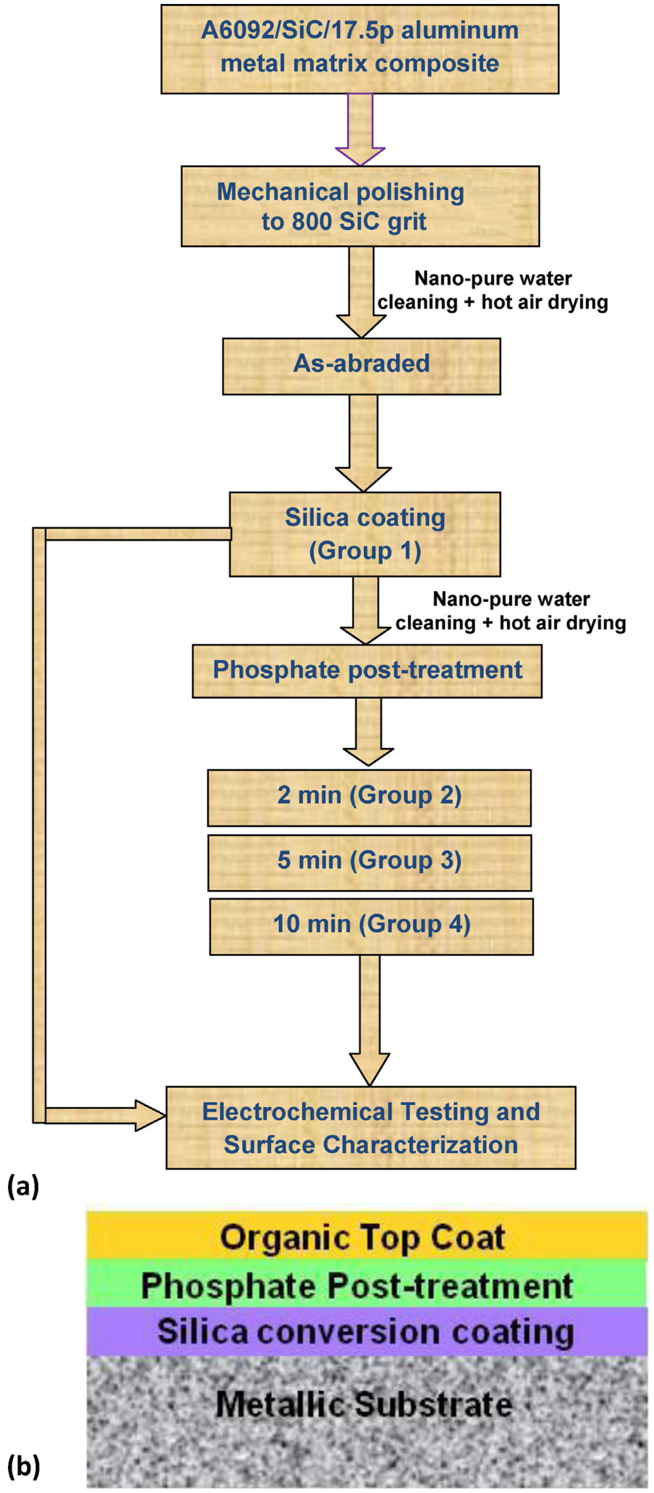

Fig. 1. (a) Flow chart of the four groups of Si-P composite coatings over AMMC panels (b) a schematic representation (not to scale) showing the Si-P composite coating with a possibility of applying a top organic coating (the study focuses only on the Si-P composite coatings.

3.1. Visual inspection and macroscopic examination

The macro-images in Fig. 2 provide overview about the corrosion forms formed at the AMMC after Si-P composite coatings. Generally, Group 2 that coated with silica followed by 2 min phosphate post-treatment showed the best pitting corrosion resistance where the surface examination revealed almost pitting-free