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Galvanic corrosion property of contacts between carbon fiber cloth materials and typical metal alloys in an aggressive environment

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ABSTRACT

The demand for the use of carbon-fiber-reinforced materials in automotive industry is increasing worldwide. However, a destructive galvanic corrosion is inevitable when carbon fiber contacts with metals. In present research, the galvanic corrosion between carbon fiber and three kinds of well used metals, steel, A356 aluminum alloy and Ti6Al4V titanium alloy, was studied. By employing the potentiodynamic polarization tests and zero resistance ammeter testing (ZRA) method, the corrosion potential and their difference in values were figured out. The corrosion behavior of the uncoated samples and the coated aluminum alloy was evaluated in a 3.5% NaCl solution. It was found that when coupled with carbon fiber, steel and A356 aluminum alloy were corroded while the titanium alloy remained almost intact. To address this problem for the lightweight aluminum alloys, a plasma electrolytic oxidation (PEO) technique was employed to synthesize an oxide coating on the A356 alloy and Ti6Al4V titanium alloy as well. The results of the experiments showed the rate of the galvanic corrosion current could be decreased significantly when the PEO coatings were applied on the aluminum surfaces. The coatings prepared using duplex unipolar and bipolar treatments had a dense surface and as a result, showed the lowest corrosion current and highest corrosion resistance in the polarization corrosion and ZRA tests. For the Ti–6Al–4V cases, both coated and uncoated samples exhibited excellent galvanic corrosion resistances in the test environment.

1. Introduction

The relationship between a vehicle's mass (weight) and its fuel economy is well known. Materials and techniques for cutting weight from vehicles are a part of routine automotive engineering practice. Large reductions in weight while maintaining size and enhancing vehicle utility, safety, performance, ride and handling are often thought of as requiring radical changes, such as the all-aluminum bodies or carbon-fiber composites sometimes featured in concept vehicles [1,2]. A carbon fiber is a long, thin strand of material about 0.005–0.010 mm diameter composed mostly of carbon atoms. The graphite basal planes oriented parallel to the axis of the fiber make the carbon fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The yarn of fabric is combined with epoxy and wound or molded into shape to form various composite materials. Carbon fiber-reinforced composite materials are used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automotive springs, sailboat masts, and many other components where light weight and high strength are needed [3].

Aluminum and its alloys are widely used in a large number of industrial applications due to their excellent combination of properties, such as relatively good corrosion resistance, excellent thermal conductivity, high strength to weight ratio, easy to deform, and high ductility. Aluminum alloys have generally been used in manufacturing automobile and aircraft components in order to make the moving vehicle lighter, which results in saving fuel consumption [4]. Aluminum is an active metal whose resistance to corrosion depends on the formation of the protective oxide film on its surface. For these reasons, a number of investigations in its electrochemical behavior and corrosion resistance have been carried out in a wide variety of media.

Carbon fibers and aluminum alloys have created considerable interest as structural engineering materials and in many applications, carbon fiber composite materials are connected to aluminum metals. When carbon fibers in a polymer based matrix composite are used as a structural component, it should be noted that carbon fiber is a very efficient cathode and very noble in the galvanic series [5–7]. Therefore, contact between carbon fiber composites and metals with similar properties in an electrolyte such as rain or seawater will be extremely undesirable. If galvanic coupling occurs, galvanic corrosion of the metal may occur. Additional possibilities of corrosion related to raising the galvanic potential, particularly for passive metals such as aluminum alloys, include: initiation of pitting corrosion and extensive crevice corrosion [8,9].

Plasma electrolytic oxidation (PEO) coatings are much harder than anodized coatings and can be used to protect a variety of light metals (Ti, Al and Mg) and their alloys [10,11]. The PEO process typically uses

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Table 1
Potentiodynamic polarization parameters of uncoated/coated A356 and steel in a 3.5% NaCl solution and thickness of alumina coatings.

	Coating thickness (μm)	β_a (mV/dec)	β_c (mV/dec)	E_{corr} (mV)	I_{corr} (μAcm^{-2})	R_p ($k\Omega \cdot cm^2$)
Steel	N/A	190.6	133.3	−770.0	80.0	0.43
A356	N/A	80.4	95.6	−836.5	8.0	2.37
Sample A-bipolar	21.8	342.4	221.1	−942.1	0.8	77.88
Sample B-unipolar/bipolar	17.5	150.0	150.0	−366.9	0.4	81.52
Sample C-bipolar/unipolar	15.9	958.4	164.5	−1145.6	7.0	8.69
Sample D-unipolar	12.2	247.7	215.6	−987.5	1.0	50.12

a dilute alkaline solution, which is not harmful to the environment. The coatings are typically five to a few hundred microns in thickness, with crystalline and amorphous phases containing both metal substrate and electrolyte chemical components [12,13]. As the coating thickness increases, the PEO coating forms a porous and rough out-layer on the top of a dense layer. Depending on the current mode as well as the current pulse timing, the thickness of the outer layer can be reduced. The improved surface performance obtained yields numerous real and potential applications for the PEO technology in the aerospace (fasteners, landing gear, blades, discs and shafts of aircraft engines), the automotive (seat frames, doors, pistons and cylinder liners), the gas and oil (gears and rotary pumps) and the biomedical industries [14,15].

In this study, the galvanic corrosion between metals and a carbon fiber sheet were investigated. PEO oxide coatings on aluminum alloys were prepared under different current modes. In order to investigate the possibility and intensity of galvanic corrosion, not only potentiodynamic polarization but also zero resistance ammeter (ZRA) testing methods were used to evaluate the corrosion properties of a steel and a titanium alloy as well as coated and uncoated Al alloys (A356) in 3.5% NaCl solutions. Effects of the current modes on the coating morphologies and anti-corrosion performances are extensively discussed in this paper. As a result of this study, a better understanding of the galvanic corrosion behavior of the carbon fiber-metal system can be achieved.

2. Experimental details

Circular coupons (20×20×5 mm) cut from steel ASTM A1018 an A356 alloy and a Ti6Al4V alloy were ground and polished before washed in water and then air-dried. The composition of the ASTM A1018 steel is 98.81–99.26 Fe, 0.18 C, 0.6–0.9 Mn, 0.04 max P and 0.05 max S. The composition of the A356 aluminum alloy is 0.25 Cu max, 0.20–0.45 Mg, 0.35 max Mn, 6.5–7.5 Si, 0.6 max Fe, 0.35 max Zn, 0.20 max Ti, 0.05 max others (each), 0.15 max others (total), and bal Al. The composition for Ti6Al4V is 6.0 Al, 4.0 V, 0.25 max Fe, 0.2 max O, and the remainder Ti. A PEO coating preparation system as described in Ref. [16]. was used to produce the oxide ceramic coatings on the aluminum coupon samples. The coatings were prepared in an alkaline electrolyte ($KHPO_4$, 6 g/l) plus sodium silicate powder

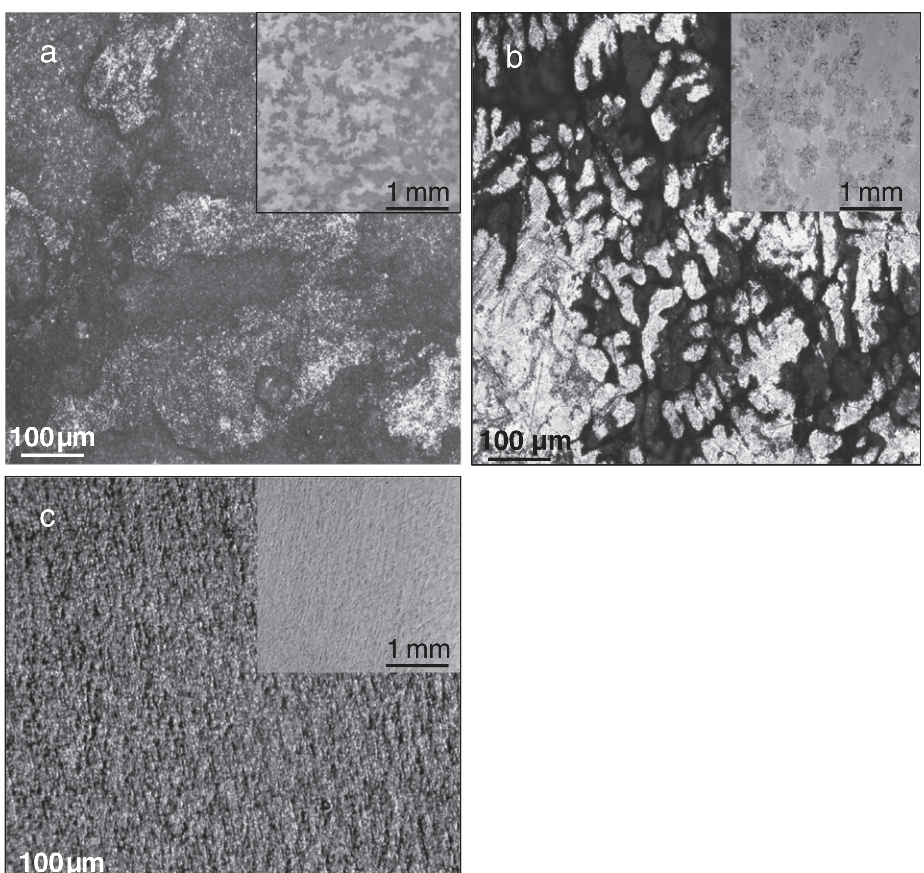

Fig. 1. Optical images of (a) ASTM A1018 steel and (b) aluminum alloy A356 and (c) Ti6Al4V alloys after corrosion tests. Inserts in (a), (b) and (c) showed the corroded areas at a low magnification.