

Sticking Phenomena at the Brake Pad – Disc Interface: An Open Call for Electrochemists

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ABSTRACT

The work reports for the first time galvanic current measurements for the friction material - cast iron couple. In particular, three friction materials are investigated with respect to a reference grey cast iron. Measurements are performed using Zero Resistance Ammeter (ZRA) –based techniques and voltammetry methods.

Discussion of the results allows to investigate the interplay existing between galvanic couplings and growth of corrosion products at the interface between braking pad and cast iron disc. The effects of several physico-chemical properties of friction materials, such as their composition and wettability, are discussed as well.

It is demonstrated that the presence of selected elements in the composition of friction materials (e.g. Zn, Fe and Cu) and the pad wettability are strongly modulating the galvanic current trend over time and play a major role on the corrosion scale growth at the pad-disc interface and the associated sticking effect.

Key words: Braking system, Friction material, Cast iron, Galvanic current, ZRA methods

INTRODUCTION

Top-notch disc brake systems are complex multi-material devices. Most typical configurations include at least three elements,^{1,2} namely: a) an anodized aluminum caliper; b) a cast iron brake disc; and c) a couple of composite braking pads (see Figure 1). During car driving, all these components can be exposed to several environments including rain, snow, chloride-rich conditions (e.g. presence of road salt), heavy traffic (SOx, NOx) and face severe corrosive phenomena.³

For these reasons the development of new materials with a lowered corrodibility is a major task for disc brake system manufacturers.^{4,5} Furthermore, the definition of corrosion management strategies is growing in importance due to the continuous development of the electric vehicles (EV), which necessitate of braking systems with a prolonged service life and extended corrosion resistance.^{1,6} Indeed, in the case of electric or hybrid vehicles, the kinetic energy dissipated during braking is converted in electricity used to recharge the battery pack. This mechanism, also known as regenerative braking, can reduce the brake effort of the conventional disc brake system up to 80%. As a consequence, in the case of new EVs comprising a regenerative braking system, the consumption of both discs and braking pads is strongly reduced. It appears thus clear that the development of brakes with a service life comparable to that of the vehicle is growing in importance and requires: 1) the design of components with a prolonged corrosion resistance; and 2) the implementation of control systems to monitor the corrosion resistance of the components over the whole car life.

In this context, corrosion phenomena in braking systems are only barely investigated in the literature and mostly rely on conventional electrochemical methods including linear sweep voltammetry, impedance spectroscopy and on-field corrosion measurements.^{7,8} It appears thus fundamental to extend the range of investigated techniques in order to broaden the comprehension of the corrosion issues which are typical of brake disc systems and contribute to the development of solid corrosion management protocols.



Figure 1: A) Car wheel comprising a disc brake system; B) Disc brake system for high end cars; C) Schematic illustration of disc (C1) and braking pads (C2); the galvanic current (I) between the two and the associated electron flow are represented by the means of black lines. Considering the used experimental setup, oxidation of the disc is associated with positive currents while negative currents are associated with the oxidation of friction material comprised in the braking pads.

Among several corrosion-related topics, the investigation of shear adhesion (also known as sticking effect) between brake disc and brake pad, after exposure to humid and/or chloride-rich environments is

probably one of the most important.^{8,9} In particular, this phenomenon results from the galvanic coupling between friction material and cast iron disc while these are in contact for a long period (e.g. during prolonged parking). In these conditions, the corrosion of both friction material and disc leads to the growth of corrosion scales at the interface between the two with an associated bonding of the components. As of today, the study of the corrosion of coupled friction materials and rotors by the means of investigating the galvanic current between the two is missing in the literature.¹⁰

For these reasons, the manuscript reports about galvanic current measurements of three selected friction materials and a reference grey cast iron. Insights on the interplay between composition, electrochemical performance and growth of corrosion products are provided using several techniques including X-ray diffraction, X-ray fluorescence, contact angle measurements, linear sweep voltammetry and zero resistance ammetry. Results allow for the first time to investigate the galvanic current trends over time and to propose a reasonable corrosion mechanism for the pad-rotor galvanic couple.

It is important to highlight that the proposed galvanic current measurements appear as a promising tool to manage corrosion, enabling: a) the design of friction materials with an intrinsic reduced corrodibility; and b) the development of a protocol to monitor sticking phenomena between pads and discs during prolonged parking, by measuring the current flow between the two. On a broader perspective, the proposed approach can contribute to the definition of design rules based not only on mechanical data but also considering the electrochemical performance of the materials included in a braking system. This point seems fundamental and will allow the corrosion-resistance-oriented design of future braking systems and the development of tools to be specifically used for new electric vehicles.

EXPERIMENTAL PROCEDURE

Materials

The investigated friction materials are obtained by dissection of prototype braking pads. The cast iron specimens used for galvanic current measurements show a 100% pearlitic lamellar structure (carbon content equals to 3.5%_{wt}) and are obtained by dissection of a prototype brake disc.

Corrosion potential (E_{corr}) and corrosion current (I_{corr}) measurements

Linear sweep voltammetry (LSV) with Tafel fitting is used in order to measure the corrosion potential (E_{corr}) and corrosion current (I_{corr}) of friction materials. LSV measurements are performed using a three-electrode configuration and a potentiostat/galvanostat operating at a scan rate equals to 0.167mV/s. The working electrode (WE) refers to a friction material specimen with known area; the counter electrode (CE) is a graphite rod with an area at least 10 times larger than the WE and the reference electrode (RE) is a saturated calomel electrode (SCE). LSV measurements are started after the Open Circuit Potential (OPC) stabilization (variation $\leq 5\text{mV/h}$). The electrolyte is a 5%_{wt} NaCl aqueous solution at $30.0 \pm 0.5^\circ\text{C}$. This concentration value is chosen since it is conventionally used during neutral salt spray tests of braking system materials (see ISO 9227¹¹).

Galvanic current measurements

Galvanic current measurements are performed using a potentiostat/galvanostat as zero resistance ammeter (ZRA). A three-electrode setup is used in which each friction material (FM) and cast iron specimens are used as counter (CE) and working (WE) electrodes respectively, as reported in Figure 2. Both WE and CE have the same area, equals to 20cm^2 , aiming at representing a real brake condition in which the FM and the cast iron disc show the same geometrical contact area (see Figure 1C). The reference electrode is a saturated calomel electrode (KCl) while the electrolyte is a 5%_{wt} NaCl aqueous solution at $30.0 \pm 0.5^\circ\text{C}$. The use of a full immersion configuration can be considered as an accelerated method to investigate the Zn oxidation over the whole friction material thickness. In particular, FMs always comprise a certain Zn amount, which is added in order to behave as sacrificial anode. Zn is homogeneously distributed through the whole pad thickness and becomes progressively exposed to the environment as the pad is consumed (e.g. during repeated braking).