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RESEARCH ARTICLE

AN INVESTIGATION ON THE PERFORMANCE OF COATINGS UNDER CORROSION-EROSION CONDITIONS: THE MECHANISMS OF EROSION, MICROSTRUCTURES, AND ADHESION

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ABSTRACT

An all-inclusive review related to the recently-conducted researches along with their findings and suggestions on the performance of coatings under wear conditions is represented in this study. Getting a perception of how coatings act under these conditions a crucial knowledge for is predicting the service life of the device, as well as extending it. Accordingly, a multi-aspect performance of coatings is discussed through considering numerous techniques applied by previous researchers. Corrosion-erosion interactions, and models of thermally- and plasma sprayed coatings, multilayered coatings, and a rise of currents resulted from erosion-corrosion are at the center of this study focus. Generally speaking, this review is a contribution to identifying interactions between corrosion and erosion which happen for numerous coating systems. At the end, it is concluded that the common issue among all the considering types of coatings is the need for high-quality coatings in order to eliminate corrosion impacts which, consequently, improves the service life of coatings.

KEYWORDS

Coating, corrosion, erosion, thermal spray, plasma spray

1. INTRODUCTION

The prerequisite of the urgent choosing or designing new surfaces which are fit with the future- made equipment is reaching this perception that the procedures of surface-related degradation must be taken into serious considerations. In this regard, it is necessary to evaluate combined erosion-corrosion mechanisms; namely tribo-corrosion which is a combination of warmth and aqueous medium [1]. That is, an interaction between mechanical erosion and chemical corrosion conditions leading to a loss of material. This process could be briefly explained via this mechanism: erosion-corrosion = mechanical erosion + electrochemical reaction.

Tribological (interactions between tribology and corrosion) issues and corrosion-related degradation are considered as most destructive risks for all-metal arthroplasty [2]. The studies on tribology have today appeared as an active daily-updated field area involving advanced examining methods and techniques in order for a broad perception of the complicated processes existent in tribological correlations. For example, the development of *in situ* electrochemical techniques for examining surface films are now considered as powerful methods capable of being extended in tribological programs. This area, generally, includes corrosion- erosion interactions, models of thermally- and plasma sprayed coatings, multilayered coatings, adhesion, and currents resulted from erosion-corrosion which are taken into deep consideration within the current study.

2. LITERATURE REVIEW

A group researcher believed that in erosion corrosion, the most frequently observed phenomenon is synergism [3]. In this case, both erosion and corrosion are considerably increased by the tribological interactions which, as mentioned earlier, results in more material loss. Therefore, they proposed mechanisms of tribiology as well as a mathematical model incorporating different factors which are influential on erosion-corrosion both in environmental and experimental situations.

Another attempt was made to correlate experimental potential variations observed during tribological in-vitro tests [4]. They simultaneously used a mapping tool for corrosion called *Pourbaix* (or E-pH diagrams). It was finally showed that more researches on the development of suitable mapping tools for tribology are needed.

Tribology is commonly connected with the synergy caused by the coupling of environmental and mechanical impacts. This synergism causes material degradation which is larger or smaller than expected from simply applying environmental-mechanical influences. To explain the positive effects, too, tribological phenomena could be utilized in manufacturing processes (e.g., chemical- mechanical polishing of silicon wafers) [5].

Tribological erosion influences components in various industries including automotive, mining, food, marine, nuclear, and biomedical. Experts in these industries are annually paying millions of dollars to repair the damage resulted from tribological process. The tribology includes the mechanism of corrosion related with the following aspects:

- Fretting
- Abrasion
- Solutions of biological type
- Solid particles' wear
- Tribo-oxidation

A schematic view of the correlation between the above-mentioned factors and tribology is shown in the below image.

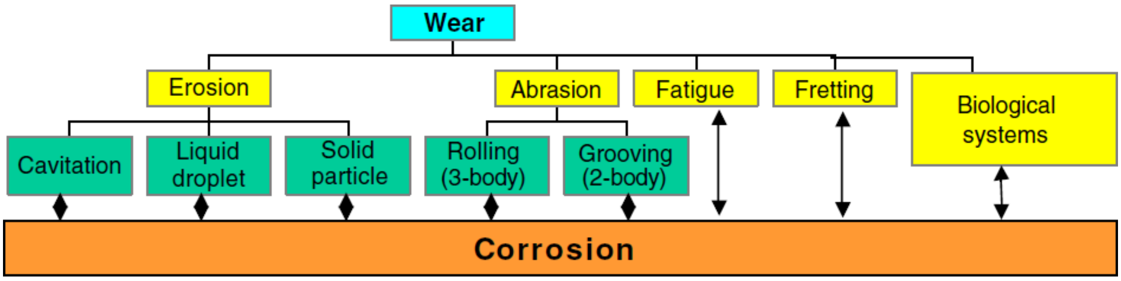

Figure 1: The links between corrosion mechanism and different phenomena

In others study state that for achieving a long-lasting corrosion resistance, it is essential to get to this conception that what the galvanic interaction is between substrates and metallic coatings [6]. The coatings' deposition often involve multiple stages. For example, in the deposition of PVD of Cr_3C_2 films on steel, these stages start with chromium ion etching on the substrate to improve the growth of epitaxial film and the adhesion of the coating. This stage is followed by the deposition of a CrN layer in order to increase adhesion, and finally, it gets to deposition of the top Cr_3C_2 coating.

3. METHODOLOGY

Employing a descriptive method, the present study aims at reviewing researches on the erosion- corrosion issues studied in engineering different coatings and dental coats. Since introducing medical implants in the human body, the issues of erosion and corrosion have been put at the center of attentions [7]. Coating systems were considered and identified along with their application and appropriateness for being used in industrial fields. It also covers and discusses the latest advances in the processes of mechanical erosion. In this regard, some recommended models are reviewed.

4. RESULTS AND DISCUSSIONS

4.1 Wear

Wear damage (e.g., resulted by gas turbine blade roots or the substituted human joints) is always accompanied with erosion-corrosion. Some tribological models have been previously created for passivating metals which explained the impact of normal force and the magnitude of displacement on the anodic current. One of the proposed equations is as follows [8]:

$$I_r = k\left(\frac{1}{\lambda}\right) v_s \left(\frac{F_n}{H}\right) Q_p$$

Where I_r is the current, k is the probability factor, is the length of the sliding direction, F_n is given the normal force, v_s is considered to be the sliding velocity, H is regarded to be the hardness, and Q_p is the charge density of passivation. A brief explanation of almost all the tribological impacts on surface and/or corrosion-related issues is represented in the table below.

Table 1: Brief explanation of tribo-corrosion impacts on surface/corrosion-related issues

Conditions	Reaction
Contact geometry and load	- Contact pressure (subsurface along with surface) - The reaction of a plastic, plastic-elastic, or fully elastic surface/subsurface - Surface deflection
The relative movement in a wear space under load	- Inducing ion release - Influences E_{corr} - Impelling surface phase transformations - Influences kinetics of repassivation - Enhances local mass transport [5]
Changing the imposed load of dynamic contacts	- Free corrosion potential - The recovery time of surface - Change of erosion mechanism - The number of active anodic sites [6]
Tribology	- Affects friction - Local pH of the space - The total loss of mass from the surface [9]

4.2 Medical implications

In terms of the medical implication and importance of tribology, the experts have paid much attention to the erosion and corrosion behavior (or ion release) of the metal joint implants. For example, the corrosion of machined titanium dental implants in inflammatory conditions, erosion and corrosion of titanium observed in the oral space, and tribocorrosion and bio-tribocorrosion in the mouth are all few of many researches performed in this regard [10-12].

4.3 Erosion-corrosion interactions

These interactions are defined as follows:

T = E + C + S

Where the total damage is *T*, the pure erosion loss of materials is *E*, and *C* is named the solids free flow rate of corrosion, and *S* as the synergistic term. Synergy is explained as 'the difference between erosion-corrosion and the total of its two sections' which is described in details as follows:

$S = T - (E+C) = \Delta C_e + \Delta E_c$),

Where C, E, and T are gravimetric elements, ΔE_c stands for corrosion-improved erosion and ΔC_e is defined as the erosion-improved corrosion.

4.4 Models

There have been recently advances in modeling and perceiving the tribological mechanisms. However, there are two major types of models for coatings: thermal spray and plasma spray. Thermal spraying is performed by using cermet coatings to reduce the erosion and corrosion. These cermet-based coatings contain generally WC or Cr_3C_2. Erosion-corrosion examinations indicated that thermally sprayed coatings can severely impact the rate of loss of material under wearing conditions. Additionally, the wear process of carbide coatings was reported to be taken under controlled by a network of carbides.

To compare plasma- and flame-sprayed materials, hard Cr_2O_3 coatings were tested. Because of the large impedance of the coating, the rate of corrosion was reported really low. Finally, reported that environment majorly influences the rate of corrosion. In regards with plasma-sprayed coatings, made the pioneering researches on plasma-sprayed coatings of hydroxylapatite, theoretical aspects of building such coatings, protective coatings in large fans, and thermal-plasma spraying method for the stability of Lanthanum Zirconate, respectively [13-16].

Often during the service, a Mg-based additive is added neutralize the flue gases' pH. However, when lacking such additive, the conditions will be rapidly worsened and become acidic with the ash deposits with more than 70 percent sulfate and a pH equal to 1.9. In this regard, a Nicrome 80/20 which is of kind of plasma-sprayed has been found which so far has showed best resistance against this acidic situation [15].

4.5 Multilayer coatings

PVD coatings are multilayer types with multifunctional features, low residual pressure, and good adhesion to metallic sublayers. Their hardness has been improved by some others researcher [17]. Their recommended multilayer coatings were based on TiC/TiN with improved hardness because of the fine-grained microstructures. Another multilayer, low-cost, and easy coating was posited for carbon-carbon composites, discrete sheets on the sublayer, and cotton fabric [18-20].

5. CONCLUSIONS

This descriptive review identified the main interactions existent among mechanisms of erosion and corrosion. Image 2 is a summary of almost the whole works on coatings published in regards with tribology, some of which have been explained and name in the current study and some have been omitted due to reducing the volume. Generally speaking, not so many researches have been made on tribology of coatings. However, HVOF type of coatings which are thermally sprayed are the most frequently-used coatings for enhancing the erosion-corrosion resistance; and PVD coatings have been popular for sliding erosion-corrosion usages.

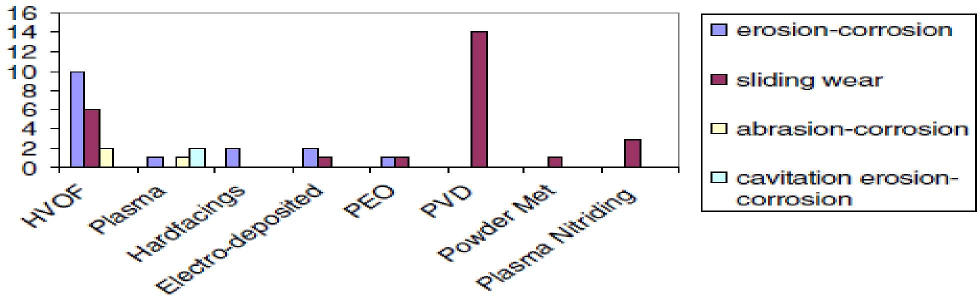

Figure 2: A summary of published works on tribologically examined coatings

Most of the works have considered either erosion resistance or corrosion resistance. Therefore, it is not easy to reach an inclusive view about the general behavior of the considering coatings. However, it is concluded that most of elements used in the coatings resistant to corrosion are not resistant to erosion (and the opposite). This implies an urgent need for designing coatings particularly for erosive-corrosive resistance with coating composition, adhesion, improved sublayer and microstructure features.

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