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Application of superhydrophobic coatings as a corrosion barrier: A review

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A B S T R A C T

This review provides an overview of recent advances in the application of superhydrophobic surfaces to act as corrosion barriers. The adverse consequences of corrosion are a serious and widespread problem resulting in industrial plant shutdowns, waste of valuable resources, reduction in efficiency, loss or contamination of products, and damage to the environment. Superhydrophobic surfaces, inspired by nature, can be considered as an alternative means for improving the protection of metals against corrosion. Due to the possibility of minimizing the contact area between liquids and a surface, superhydrophobic surfaces can offer great resistance to corrosion. Artificial superhydrophobic surfaces have been developed with the potential of being applied in numerous settings including self-cleaning, anti-icing, oil-water separation, and especially anti-corrosion applications. In this paper, we review the concept of superhydrophobicity through presentation of different theoretical models. The fabrication and application of superhydrophobic surfaces are presented, and we then discuss the use of superhydrophobic coatings as barriers against the corrosion of metals.

1. Introduction

Metals and their alloys are engineered materials that are central to numerous industrial fields. Aluminum (Al), copper (Cu), magnesium (Mg), steel, and their alloys are common metals used in a wide range of industrial, construction, marine, and aeronautical applications. Although many physical characteristics of metals, such as ductility, stiffness, and high strength to weight ratios make these materials very useful, they do have limitations. Corrosion of metals in aggressive environments is one of these [1]. The corrosion of metals can produce a premature failure of metallic components, resulting in financial losses, environmental contamination, as well as injury or death [2,3]. Corrosion is one of the main causes of energy and material loss, accounting for 20% of global energy use. An average of 4.2% of the gross national product (GNP) is lost each year because of corrosion-related issues [4]. The majority of this cost is allocated to the examination of corroded parts of the structures, the repair of the structures using various methods including protective coatings (paints, surface treatments, etc.), and discarding the potentially hazardous waste materials [5].

There are different techniques for preventing the corrosion of metals. One is the coating of a metal surface with an anti-corrosive layer to provide a barrier between the metal surface and the corrosive environment [6–8]. However, contact between the corrosive solution and the metal/coating interface will corrode the metal surface [9,10]. Therefore, reduced interfacial tension or an increased waterproofing of the surface can be a more effective protective coating. Use of good quality corrosion resistant coatings on heavy structures, e.g., bridges and industrial sheds, can help prevent the weakening and collapse of these constructions [3].

Inspired by a vast number of natural phenomena, such as the self-cleaning characteristics of the lotus leaf and the “anti-water” legs of a water strider, artificial superhydrophobic surfaces have been developed [11–15]. Superhydrophobic surfaces with a water contact angle (WCA) > 150° and a water sliding angle (SA) or contact angle hysteresis (CAH) of < 10° have attracted tremendous attention due to their broad applications in scientific and industrial applications, such as self-cleaning [16–20], anti-fouling [21–23], anti-icing [7,24,25] cases, as well as for oil-water separation [26,27], and drag reduction [28,29]. Superhydrophobic coatings have been successfully developed as corrosion protection for many metals and their alloys surfaces, including aluminum [12,30,31], copper [32–34], magnesium [35–37], and steel [38,39].

In this review, we first provide a brief introduction to natural superhydrophobic surfaces and present the fundamental theories related to the wetting and non-wetting behavior of solid surfaces. Then, we discuss the numerous methods for fabricating superhydrophobic surfaces and diverse application of these coatings. Finally, we outline the use of superhydrophobic coatings as corrosion protection for aluminum, copper, magnesium, and steel, and present a brief conclusion.

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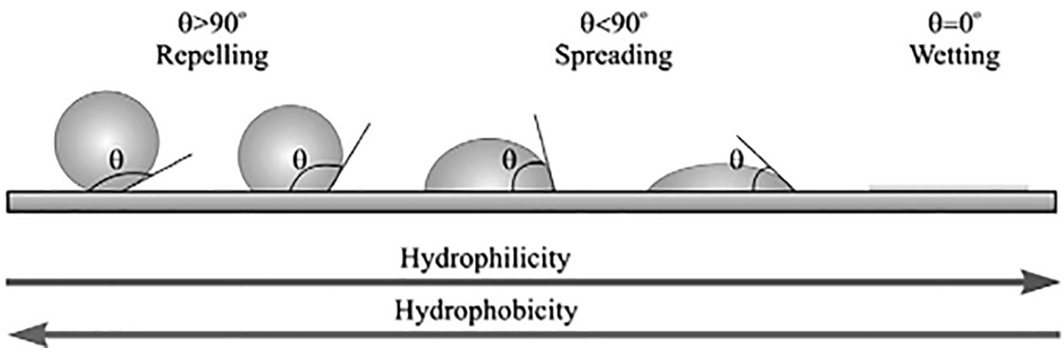

Fig. 1. Schematic of the shape of a water drop and the water contact angle (WCA) for solid surfaces along a hydrophobicity-hydrophilicity gradient [43]

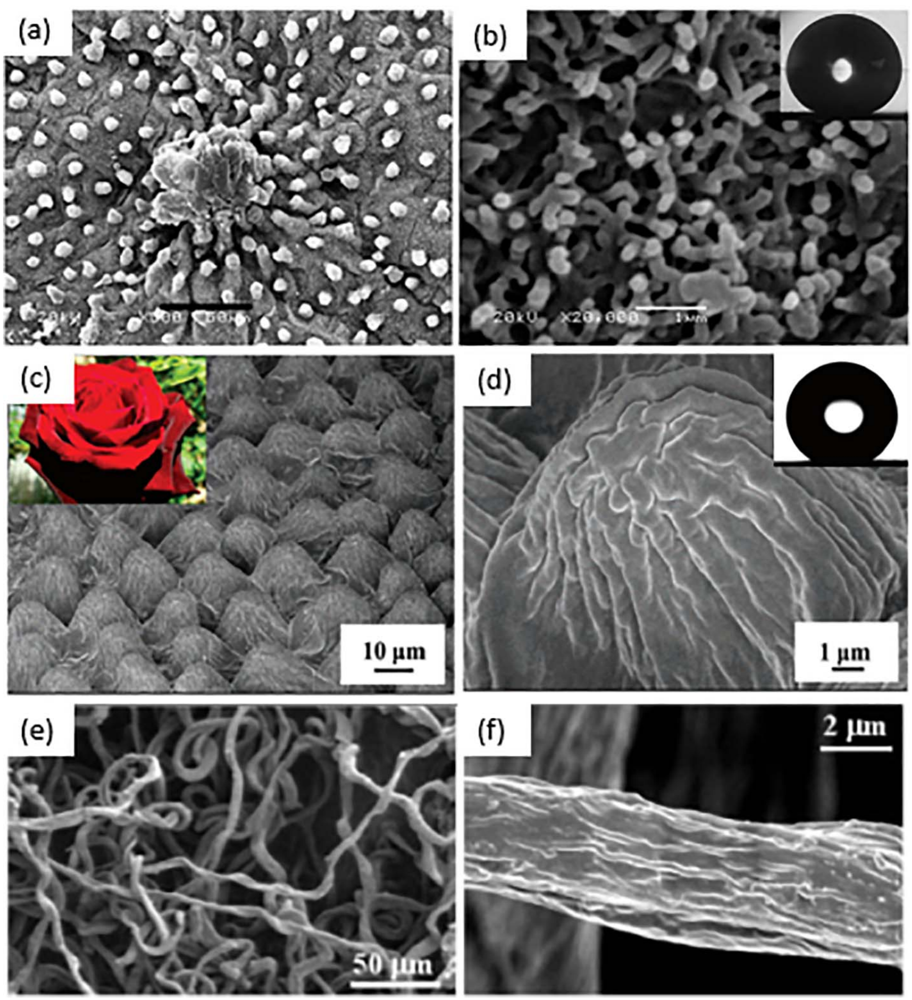

Fig. 2. SEM images of superhydrophobic surfaces at low and high magnification. (a) and (b) lotus leaf with a 162° water contact angle; (c) and (d) rose petal with a 152.4° water contact angle; (e) and (f) silver ragwort leaf with a 147° water contact angle [46,47,61].

2. Superhydrophobicity

Surface wettability is one of the most important properties of solid surfaces and plays a significant role in a wide range of practical applications in daily life, industry, and agriculture [12]. The WCA is defined as the angle where a liquid-vapor interface meets a solid surface. Hydrophilicity and hydrophobicity are the most common terms introduced to describe the relative affinity of water droplets on solid surfaces. As shown in Fig. 1, if the WCA is smaller than 90°, the solid surface is defined as hydrophilic, and greater than 90°, the surface is considered as hydrophobic. On a hydrophilic surface, a water droplet wets as large a surface as possible, likely entering the pores of the material and completely saturating it. On the other hand, a water droplet is repelled by a hydrophobic surface and takes on a near spherical shape. Superhydrophilicity is characterized by a WCA < 10° that describes a complete spreading of water on the substrate. In contrast, superhydrophobicity, defined as a surface having a WCA larger than 150°, describes an almost non-wetting state [40]. Besides static contact angle considerations, CAH and SA are other important criteria for studying the surface behavior of various materials. The water SA is defined as the critical angle at which a water droplet of a certain weight begins a downward slide. CAH represents the difference between advancing and receding contact angles. Both are criteria of dynamic hydrophobicity. Generally, superhydrophobic surfaces are defined as any surface for which the static contact angle is > 150° and the SA or CAH is < 10° [41,42].