Chapter 13
Hybrid Sol–Gel Coatings: Erosion–Corrosion Protection

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ABSTRACT
The properties and wide application range of organic-inorganic hybrid (O-IH) sol-gel materials have attracted significant attention over the past decades. The combination of organic polymers and inorganic materials in a single-phase provides exceptional possibilities to tailor electrical, optical and mechanical properties concerning diverse applications. This unlimited design concept has led to the development of diverse coatings for several applications such as glasses, and metals to mitigate mechanical abrasion, erosion and corrosion. This class of materials could be easily obtained by sol-gel method at mild synthesis conditions. Furthermore, the large variety of available chemical precursors allows producing a diversity of coatings with tuned mechanical and thermal properties. This chapter will introduce the fundamentals of the sol-gel method to produce O-IH protective thin coatings and discuss the methodologies used to apply these materials onto different metallic substrates for erosion and corrosion protection.

INTRODUCTION
Corrosion degradation is a major cause of metallic structural deterioration (Figure 1). It severely affects their service life and may result in structural failure, leakage, product loss and environmental pollution, causing large financial outlays for recovery/prevention. The World Corrosion Organization (WCO) estimates that the annual cost of corrosion worldwide is around 3% of the world’s Gross domestic product (Bhandari, Khan, Abbassi, Garaniya, & Ojeda, 2015), not considering the environmental costs due to corrosion. A passive approach to corrosion protection involves depositing a barrier layer that prevents contact of a material with the corrosive environment. Actives approaches reduce the corrosion rate when the protective barrier is damaged and corrosive agents come into contact with the metal substrate. Only the combination of both methodologies can provide reliable protection against corrosion of metallic structures.

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The technological advances require more and more materials with high resistance to aggressive environments. Coatings to protect materials against erosion and corrosion are of extreme importance for both service life and maintenance cost of installations operating in aggressive environments (Szymański, Hernas, Moskal, & Myalska, 2015). The combination of degradation mechanisms, corrosion with erosion, can be several times higher than the effect of each, acting alone. Therefore, materials selection must be considered at every stage of design, construction and operation of equipment and systems. This will minimize premature failures that ultimately lead to severe economic losses and compromise the structure safety.

Sol-gel process has been considered a powerful and versatile strategy to produce functional inorganic and organic-inorganic hybrid (O-IH) materials. The interest in this method started with Ebelman and Graham’s studies in the mid-1880s on silica gels (Hench & West, 1990). However, it was only in the 1980s that this method was adopted by Schmidt (1985) and Wilkes (Wilkes, Orlé, & Huang, 1985) in the synthesis of their O-IH materials. The understanding of the mechanisms underlying the sol–gel methods have been subject of several text books and reviews (Aegerter & Mennig, 2004; Atkinson, 1991; Brinker, Hurd, Schunk, & Frye, 1992; Brinker & Scherer, 1990; Ciriminna et al., 2013; Dimitriev, Ivanova, & Iordanova, 2008; Livage, 1997, 1999; Pierre, 1998; Sanchez et al., 2001, 2010; Sanchez & Ribot, 1994; Clément Sanchez, Belleville, Popall, & Nicole, 2011). Numerous definitions of sol-gel process have also been proposed and discussed (Brinker & Scherer, 1990; Dislich, 1986; Pierre, 1998; Segal, 1984). In this chapter a broader definition, given by Pierre (1998), will be used, in which a sol-gel process is “every process that starts from precursors solutions with intermediate stages including a gel and/or a sol”. Sol-gel method is a low temperature versatile route for the preparation of inorganic and O-IH materials in the form of monoliths, fibres, films or nanoparticles. O-IH materials are extremely interesting once they allow an interface between two worlds of chemistry (organic and inorganic) each with distinctive

Figure 1. Corrosion of a metallic support exposed to marine environment