coatings

Editorial

Special Issue: "Coatings for Harsh Environments"

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Abstract: The operation of numerous safety-critical components in industries around the world relies on protective coatings. These coatings often allow process equipment to be purposeful in environments well beyond the operational limit of the uncoated components. Durability, ease of application, repairability, reliability and long-term performance of such coatings are vital to their application. Therefore, this Special Issue of Coatings, "Coatings for Harsh Environments", is devoted to research and review articles on the metallic, non-metallic and composite coatings used in aggressive environments.

Keywords: corrosion; thermal spray; testing; geothermal; high temperature; hot corrosion; oxidation; erosion; wear

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Preface

Humans have taken advantage of materials since prehistorical times, so much so that human civilisation has often been categorised into three archaeological periods: the Stone Age, the Bronze Age and the Iron Age [1]. Throughout much of human history, materials played a part in progressing human civilisation, and coatings developed slowly from artistry to technology. The initial developments in coatings were primarily decorative in nature. However, decorative values, which prevailed well past the Renaissance, gave rise to the protective function of coatings [2].

The technology associated with the development of coatings emerged after the Industrial Revolution. Further advancement was heralded by the need for technological developments during the World Wars, truly following the English saying, "necessity is the mother of invention". Not only did coatings fulfil a decorative function but they also allowed engineering to progress to a new level. Humans were able to use materials in extreme environments never before envisaged to be accessible by developing "engineered" coatings. These extreme environments are often called "harsh" environments.

Harsh environments cover areas such as high- and low-temperature, (bio)-chemical and mechanical disturbances (including extreme stresses and stress cycles), electromagnetic noise, pressure, radiation, or vacuum [3]. These environments by their very nature challenge the ability of materials to function. The complexity of components increasingly used for engineering applications mean that a wide variety of coating materials and methods are required for different coating applications. The purpose of these newly developed coatings is not only to protect the component exposed to the harsh environments but also to provide additional functionality where possible. These engineered coatings are able to decrease the production costs compared to other monolithic components. In addition, some of them are also able to reduce the running cost of plants in harsh environments by allowing component repair.

A high-temperature application offers harsh environments where conventional materials often reach the limit of their operability. In such environments, coatings offer affordability and functionality. A few examples of such environments include the gas turbines and the boilers for power generation. The environments in both systems include high temperatures, but the jet engines experience extreme temperatures, thermal cycles and stresses. The thermal barrier coatings offer thermal protection that allows the turbine blades to operate without excessive creep or melting. The coatings not only need to offer thermal protection but also operate under severe stress without cracking [4]. In addition to ceramic thermal barrier coatings, cermet coatings are also being developed to endure hot corrosion. These coatings when sealed by a high-energy laser offer better corrosion resistance than unsealed coatings [5].

In boiler services, high temperature corrosion and oxidation is a major issue and this is mitigated by using corrosion resistant coatings. Materials such as $MoSi_2$ allow alloys to be used in high-temperature oxidizing environments [6]. Novel coatings of Cr–N and Cr (N,O) are beginning to emerge that allow conventional steels such as 304 to be used in challenging environments [7]. These coatings are also being developed for applications where a high temperature exists in combination with wear and high stresses [8]. The combination of corrosion and wear at high temperatures makes the selection of coatings even more challenging. New concepts involving thermal diffusion coatings are being developed for boilers. Extensive corrosion testing of boronised, aluminised and chromised systems are being carried out to assess their applicability [9].

With the development of new materials such as high-entropy alloys (HEA), nanocrystalline and compositionally complex materials, new test methods need to be developed to assess these materials. If these materials need to be applied as coatings then coating methods need to be adopted to accommodate such materials' chemistries and properties. The phase evolution and deposition parameters need to be assessed. These will govern the performance of such coatings in service. However, prior to their adoption by the industry, testing needs to be carried out. The application of these materials requires corrosion testing, and the correlation between performance and microstructure needs to be established.

Recent developments in the above area have been encouraging. Arc-sprayed Fe-based amorphous/nanocrystalline materials have been developed and tested for cavitation erosion resistance [10]. Electro-spark deposition of CoCrFeNiMo HEA has been developed and the microstructures of the developed coatings have been studied [11]. Other compositionally complex alloys such as CoCrFeMo0.85Ni have been deposited by a high-velocity oxy-fuel (HVOF) spray. Their corrosion resistance in an aqueous chloride environment has also been studied [12]. These developments are in their early stages. Further improvements are required prior to the industrial uptake of these materials.

Harsh environments are also encountered by onshore and offshore structures. The combination of groundwater and vibrations for onshore, and seawater, sunlight, waves and tide for offshore have deleterious effects on structural steels. To mitigate corrosion of steel structures and pipelines, several coating systems are being developed. The application depends to some extent on the location of the part to be protected (or the environment). Broadly, two main coating concepts are adopted for corrosion mitigation. First, the use of dielectric barrier layers in conjunction with cathodic protection. Second, the use of sacrificial coatings which act as uniformly distributed anodes. Enamel coatings fall in the first category. These coatings offer protection in conjunction with cathodic protection. However, when damaged the efficacy might be compromised. Evaluation of these coatings when damaged offers new insights into the behaviour of these coatings [13].

Sacrificial coatings offer protection to steel structures by being preferentially consumed, or in other words by providing cathodic protection. In offshore structures and bridges, the choice of coating material depends on the location or the exposure environment. In the top side of the structure, thermally sprayed zinc (and zinc aluminium) alloy coatings in conjunction with a topcoat have a long history of adequate performance, particularly in the Norwegian bridge sector [14]. However, for the submerged zone and the splash zone, thermally sprayed aluminium (TSA) is often considered beneficial. The performance of TSA is dependent on several factors such as the alloy type, coating production method, surface preparation, coating thickness and sealant selection, among others. A review by Syrek-Gerstenkorn et al. [15] covers the area of TSA in detail.

Much of the work presented in this Special Issue focusses on thermal spray coatings. However, there are several other coating methods which are being explored by researchers around the world [16–23]. One such method is organic surface treatment. These treatments have been traditionally carried out using chromates. However, with the REACH regulation coming into force, there has been a concerted effort in finding alternatives to chrome treatments [24]. Treatment of copper by a non-chromate alternative has been found to offer an environmentally friendly technology for the electronics industry, where copper is indispensable [25].

Research work such as the above offers alternatives where the conventional technologies are unsustainable. Similar studies on coatings and surface modifications are ongoing where the preference to ensure the health and safety of fellow humans and the protection of the natural environment has overtaken the drive for quick financial gains. It is imperative that research continues to ensure improvement in the quality of human lives, but with a compassion for nature.

Conflicts of Interest: The author declares no conflict of interest.

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