

Suspension-HVOF spray TiO₂ coatings and their corrosion behaviour

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ABSTRACT

Ceramic coatings are commonly used as barrier coatings to protect the metal surface against corrosion due to possessing better wear, corrosion and heat resistant properties than metals. Titanium dioxide is one of the extensively used ceramic coatings for a broad range of applications including solar cells, self-cleaning, air purification and biomedical applications. Since coating microstructures and properties vary with the deposition method, thermal spray coatings are very promising in terms of corrosion and wear resistance. High-velocity oxy-fuel (HVOF) spray method is a commercially used eco-friendly coating method that provides better control over coating properties than most thermal spray techniques. Here, TiO₂ coatings are deposited on carbon steel substrate using suspension-HVOF spray. Commercial aqueous suspension of TiO₂ nanoparticles was used as a feedstock material, and sprayed at two different flowrates. The morphological analysis of the developed coatings was conducted using scanning electron microscope. To understand the wetting behavior, roughness profile, adhesion and scratch resistance of coatings, drop size analyzer, profilometer, adhesion and scratch tests were performed. Further, samples were immersed into 3.5 wt.% NaCl solution to compare the corrosion behavior of both coatings.

Key words: Suspension HVOF spray; Ceramic coatings; Corrosion resistance.

INTRODUCTION

With the increased pollution and energy demand, industries are shifting towards cleaner and greener power generation source. Geothermal energy, where energy is derived from the sub-surface of earth, is an excellent and continuous source of energy. Despite having the potential of providing cleaner energy, there is a huge gap between the theoretical potential of geothermal power plants and their practical applications. Some of the major reasons are high power generation cost and poor efficiency of the plant. The components of geothermal power plants, especially heat exchangers suffer from poor durability due

to constantly being in an aggressive environment (varied temperature and pH, brine, steam, acids, etc.) of the plant that give rise to corrosion and scaling. Hence, the operational and maintenance cost of the plant increases. Typically, expensive metals or alloys are used to avoid corrosion and scaling, which further contributes into the increased cost of power generation. Therefore, coatings with unique surface geometries are preferred as they protect the metal/alloy surface but also increase their heat transfer. Generally, various active and passive techniques are used to improve the heat transfer between surface and liquid. However, due to the lower energy requirement, passive techniques such as development of unique surface geometries are widely preferred [1]. The optimized surface geometries might improve the heat transfer efficiency as well as reduce the cost of heat exchangers that could be used in a broad range of industries. Surfaces with engineered micro- or nano-scale features are extensively preferred due to their enhanced surface area.

Thermal spray is one of the industrially accepted coating deposition method that give rise to coatings with nano- and micro- features (columns, lamellas, porosity, etc.). In this study, high velocity oxy-fuel (HVOF) thermal spray method was used to deposit TiO_2 coatings on carbon steel. Traditionally, a powder-based feedstock is used in HVOF, but due to the issues like clogging, powder size limitation and tedious powder feedstock preparation methods, researchers are inclined towards liquid-based feedstock materials [2]. A liquid feedstock could be in the form of a suspension or precursor solution. In this study, an aqueous suspension of TiO_2 nanomaterials was used as feedstock. In a typical thermal spray method, the feedstock material is injected into the flame, where after melting down, it is accelerated towards the substrate in the form of a molten/ semi-molten/ re-solidified droplets. After hitting the substrate, splats are formed and a consecutive deposition of splats form coating. Immediately after injection of suspension feedstock droplets into the flame, they go through aerodynamic breakdown (also called atomization), followed by evaporation of suspension medium, agglomeration of suspended particles, sintering of agglomerated particles and melting of sintered material. All of these physico-chemical events depend on the thermal and kinetic energy exchange between feedstock droplet and the flame [2]. There are different spray parameters that significantly influence the coating deposition, and to understand the structure-property relationship, it is essential to understand the role of different spray parameters in coating formation. Therefore, in this study, the effect of feedstock flowrate on coating microstructures and properties was studied.

EXPERIMENTAL PROCEDURE

Method

Substrate: Carbon steel (S275JR, EN 10025-2) with 2.5x2.5x6 mm dimensions was used as a substrate.

Surface pretreatment: Before coating deposition, carbon coupons were grit blasted with #100 alumina with 80 psi pressure at 80 mm standoff distance (SOD).

Coating material: An aqueous suspension of 5 wt.% TiO_2 nanoparticles (<50 nm) was used as a feedstock material, which was commercially obtained from Promethean Particles Ltd., UK. Since nanomaterials tend to make agglomerates, prior to deposition, the suspension was vigorously mixed using a shear mixer at 2400 rpm for 15 min, followed by an ultrasonic mixing using a probe for 10 mins at 40kHz frequency, which help in homogenizing the nanoparticles suspension.

Coating deposition: The coatings were deposited using suspension thermal spray, where a UTP Top Gun torch with a 22 mm long combustion chamber and a 135 mm long expansion nozzle mounted on an OTC All-V20 robot was used. A syringe pump (ISCO 260D) connected to the combustion chamber, was used for axial feeding of the suspension into the flame. Hydrogen (788 L/min) was used as a fuel and the flowrate of oxygen was 280 L/min. The standoff distance and number of passes were 150 mm and 30, respectively. Two different feedstock flowrates, i.e., 10 mL/min and 20 mL/min were used to deposit TiO_2 coatings. Coatings deposited at 10 mL/min flowrate are called as HST-10 while coatings deposited at 20 mL/min flowrate are called as HST-20.

Characterisation

Scanning electron microscope (SEM) analysis was done to characterise both the top-view morphology and cross-section of the coated samples using EVO LS15 SEM (Zeiss) instrument, where acceleration voltage of 20 kV was used at a working distance of 8.5 mm. To understand the effect of different coating microstructures on the wettability of the sample, water and diiodomethane contact angles were measured using a Kruss drop size analyser (DSA). Total nine measurements (three measurements at each of three different locations) were taken for each sample. The coating surface roughness was examined using a non-contact 3D optical profilometer (Alicona InfinteFocus SL). The analysed area was 15 mm x 15 mm for each coating. A tape adhesion test (ASTM D3359; [3]) was done to assess the adhesion of the coatings using an Elcometer 1540 Cross Hatch Cutter, where a 5x5 (at least) grid pattern of 1x1 mm squares was cut into the coated sample surface. The adhesion level was examined based on the Part-B standard 5-point scale, where 5B and 0B represent perfectly smooth lattice cut and >65% area affected, respectively. The tribological performance was assessed using a Sclerometer Hardness Tester (Elcometer 3092), where a tungsten carbide tip was pressed (applied load= 1N, 2N, 5N and 10N) against the surface being tested and dragged a short distance (~10 mm) to form a scratch. The scratched area was analysed using an atomic force microscope (AFM).

RESULTS AND DISCUSSION

Surface morphology of the deposited coatings are shown in Figure 1, where (a & b) and (c & d) represent the HST-10 and HST-20, respectively. It was found that both coatings showed typical columnar or cauliflower-like features on the surface. This happened due to the shadowing effect, where molten, semi-molten or re-solidified droplets of the coating material deposit on the surface asperities due to following the gas trajectories and hitting the substrate at shallow angles [4]. Overall coating morphology for both the coatings look very similar but there was a difference in splat formation was found. Splats formed in HST-10 were smoother, well-melted and thinner (Figure 1(c)), while for HST-20, splats were rougher and insufficiently melted (Figure 1(d)). This can be explained as with the increased feedstock flowrate, the deposition efficiency increases but simultaneously, along with more powder, more liquid in the form of suspension medium is also introduced into the flame. Since water was used as suspension medium here, it slightly cooled down the flame during evaporation, leading to a less thermal energy exchange between droplets and the flame [2]. Consequently, in HST-20, droplets might not melt fully, and rougher and thicker splat formation took place.