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Performance evaluation of HVOF deposited cermet coatings under dry and slurry erosion

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ABSTRACT

The present work reports on the examination of three High Velocity Oxy Fuel deposited coatings, Tungsten Carbide, Chromium Carbide and Aluminium Oxide, under slurry erosion and dry erosion conditions. The density and hardness of coatings produced in this manner are typically superior to other thermal spray processes, and are therefore suitable for use in corrosive and highly erosive environments. The primary aim of this investigation was to establish the total mass and volume loss from each coating under dry and slurry erosion testing conditions and compare the level of material loss following the respective testing regimes. The scope of the study incorporated the application of cathodic protection to prohibit the effects of corrosion in the case of slurry erosion testing. This approach ensured that any damage to the surface could be attributed to pure erosion, and as such, be assessed against the dry erosion test data. Subsequent examination of the resulting wear scars facilitated assessment of the level of damage caused by the impinging slurry. Results revealed variation in the level of degradation experienced by each coating type under the respective test conditions. Under both dry erosion and slurry erosion, Tungsten Carbide with a Cobalt binder proved an effective protective coating by exhibiting a reduction in material loss over other assessed coatings.

1. Introduction

The deleterious effects of erosion and corrosion are widely observed within flow handling components. These can lead to increased downtime and in severe cases, the complete failure of a part or system [1–3]. This can have serious consequences in terms of operator safety and widespread environmental impact. The application of hard surface coatings is one technique developed to reduce the damaging effects of erosive particulates and extend the service life of components exposed to erosive environments [4]. High Velocity Oxy Fuel (HVOF) is one such technology and is used to deposit a variety of wear resistant coatings onto numerous substrate materials. Powder particles are accelerated to high velocities through a nozzle while simultaneously undergoing a state change from solid to molten or semi-molten, as a result of considerable heat input [5]. The high kinetic energy of particles as they impact the surface causes significant splat deformation [6], consequently producing a dense coating layer that is resistant to wear and corrosion [7–12].

There have been numerous studies on the erosion performance of HVOF coatings, most notably Tungsten carbide (WC) and Chromium carbide (CrC) based cermets [9,13–18]. In a study utilising pot-type slurry erosion, Goyal et al. [15] reported on the wear modes of HVOF sprayed WC-CoCr and Al_2O_3 based coatings. The investigation focused solely on the effects of erosion and incorporated microstructural examination, calculation of volume loss and wear scar analysis to highlight the various wear mechanisms acting on the two coatings. The study [15] demonstrated a correlation between increased coating hardness and reduced volume loss, with Goyal et al. also attributing the increased volume loss of Al_2O_3 to its high melting point and the resulting presence of large, unmelted particles within the coating. Similarly, Ramesh et al. [14] carried out research on the erosion behaviour of HVOF sprayed WC based coatings on SA210 grade steel substrate. In this investigation [14] an erosive environment was achieved using dry silica sand that impinged onto the specimen surface at high velocities. Specifically, the study examined the impact of spraying parameters on the erosion resistance of the surface coating as well as characterising the wear damage on the specimen surface. Their results reported that the WC coatings suffer a higher rate of volume loss when compared with uncoated steel [14]. This is an unexpected result given the existing studies on HVOF coatings [7,9,13] and was attributed, by Ramesh et al., to the increased hardness ratio between the silica erodent and the substrate steel. It was concluded that silica particles could have been embedded in the surface thereby shielding the substrate from impinging particles.

Despite both investigations [14,15] seeking to evaluate the erosion performance of hard cermet coatings, there is little published research

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contrasting the two test regimes, slurry and dry erosion, on analogous surfaces. One such investigation by Thakur and Arora [19] examined the erosion of WC coatings under pot-type slurry impingement and dry jet erosion. The investigation [19] concluded that cermet coatings were highly erosion resistant when compared with the uncoated substrate and that dry jet erosion brought about substantially greater erosion rates over slurry erosion. This was attributed to all impinging particles striking the specimen at 90°, and to increased particle velocity as compared with pot-type slurry erosion. Despite highlighting this outcome, the impact angle between the two test regimes was not consistent [19]. Many researchers have shown the impingement angle to be directly linked to the recorded material loss [20–22], and as such, outcomes from this study [19] could be further refined by maintaining a consistent impact angle between the two testing methods. It would also be informative to evaluate the performance of additional HVOF coatings under analogous test conditions to establish if they demonstrate a similar response.

The present study provides novel insight on the comparative performance of HVOF deposited Tungsten carbide (WC-CoCr), Chromium carbide (Cr_3C_2-NiCr) and Aluminium oxide (Al_2O_3) based coatings under slurry liquid impingement and dry jet erosion at a shallow angle of attack (20°). Through the use of slurry liquid impingement and dry jet erosion apparatus, the results established the material loss of each coating under both testing regimes and allowed conclusions to be drawn concerning the effect of testing conditions on the respective erosion performance of each coating material. The mass loss attributed to pure erosion under slurry impingement testing was isolated through applied cathodic protection, thereby preventing any electrochemical reaction between the slurry and the specimen surface. Micro-hardness examination along with metallographic analysis facilitated evaluation of coating properties and assessment of damage within the impact region. This body of research seeks to develop an enhanced understanding of the erosion performance of HVOF deposited WC-CoCr, Cr_3C_2-NiCr and Al_2O_3 coatings. Two testing regimes commonly used for erosion assessment were employed to determine whether dry jet erosion provides an accurate representation of the wear mechanisms within flowing conditions.

2. Experimental methods

2.1. Materials

Table 1 details the specific composition of WC-CoCr, Cr_3C_2-NiCr and Al_2O_3 feed powders. Each material was deposited on S355 steel substrate, (EN:10025), via HVOF spraying. Prior to spraying, the substrate plates were grit blasted with alumina particles and cleaned with methylated spirit. The specific spray parameters used for each coating can be found in Table 2. Coatings were evaluated in the as-deposited condition, with surface peaks removed using 500 grit SiC paper.

2.2. Coating characterisation

Coating microstructure was characterised by light optical and scanning electron microscopy (SEM), facilitated by an Olympus G51X series light optical microscope and a Hitachi S-3000 N SEM. Energy Dispersive Spectroscopy (EDS) provided the chemical analysis of the coatings through spot analysis of specific regions within the coating layer.

Table 1
Powder properties [23–25].

Coating material	Powder I.D.	Composition (wt.%)	Size distribution (μm)
WC-CoCr	Woka 3652	80.6W-10Co-4Cr-5.2C-0.2Fe	−45 + 15
Cr_3C_2-NiCr	Woka 7202	69.9Cr-20Ni-9.6C-0.5Fe	−45 + 15
Al_2O_3	Al-1110-HP	$100Al_2O_3$	−22 + 5

Table 2
HVOF spray parameters.

Deposition parameter	WC-CoCr	Cr_3C_2-NiCr	Al_2O_3
Spray gun	DJ-2600	Tafa JP5000	UTP Top Gun
Standoff distance (mm)	229	355	178
Spray angle (°)	90	90	90
Vertical traverse speed (mm/s)	1.8	1.8	3
Horizontal traverse speed (mm/s)	1.13	1.33	1.13
No. of passes	40	74	70
Fuel flow rate (l/min)	681.5	0.455	732
Oxygen flow rate (l/min)	229.8	860	262
Carrier gas flow rate (l/min)	369.4	9.911	23.6

Specimens were cross-sectioned and prepared for microstructural evaluation using standard metallographic preparation techniques. A Mitutoyo MVK-G1 micro-hardness indenter with applied load of 200 gf provided hardness values for the deposited coatings. A Mercury Intrusion Porosimeter (Quantachrome Poremaster 60) facilitated the assessment of coating density. In order to isolate porosity in the coating layer, a precision cutting wheel (Accutom–5) was employed to remove the bulk substrate material, with subsequent acid bath to eliminate any remaining traces of S355 steel. Optical porosity measurements recorded in accordance with ASTM E2109–01(2014) [26] validated the porosimetry results.

2.3. Dry erosion testing

A sand blasting gun with inverted particle feeder, shown as a schematic in Fig. 1, was selected to carry out dry erosion testing. Comparable systems have been utilized in previous studies [14,19,27,28].

Erosion testing was carried out at room temperature using a method based on GE E50TF121 specification [29] on the three selected coatings. The test sample was mounted at 20° to the jet stream at a standoff distance of 100 mm. Alumina with an average particle size of 50 μm was accelerated onto the surface at a feed rate of 5.3 g/s, with the test concluded when 300 g of alumina had been passed through the jet nozzle. Samples were weighed in the pre- and post-test conditions to attain the mass loss for each coating with associated volume loss (Figs. 3 and 4).

2.4. Liquid impingement

A closed loop jet impingement rig, shown as a schematic in Fig. 2, was selected to facilitate the slurry erosion experiments as similar systems have been used in existing studies to determine the effects of erosion and corrosion within a flowing environment [22,30–32]. A closed loop system offers the ability to accurately control and alter the flow

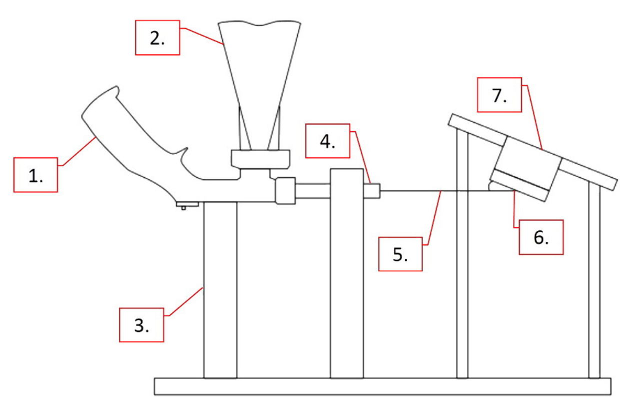

Fig. 1. Schematic diagram of dry erosion test rig (not to scale). (1) Sand blasting gun; (2) Particle hopper; (3) Rig fixture; (4) Jet nozzle; (5) Particle stream; (6) Test specimen; (7) Sample holder.