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CAVITATION EROSION, SLURRY EROSION AND SOLID PARTICLE EROSION PERFORMANCE OF METAL MATRIX COMPOSITE (MMC) COATINGS SPRAYED WITH MODERN HIGH VELOCITY THERMAL SPRAY PROCESSES

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Abstract

Thermally sprayed metal-matrix composite (MMC) coatings are widely used to protect components and surfaces against wear in various applications. Hard and wear resistant coatings increase the component lifetime and allow the refurbishment of the worn components. This produces significant savings and promotes ecological manufacturing. The current state-of-the-art coatings are produced with high velocity oxygen-fuel (HVOF) spray processes, while modern high velocity air-fuel (HVAF) spray process has become increasingly available in production and research. The current study focuses on the performance of tungsten carbide (WC-10Co4Cr) and chromium carbide (Cr_3C_2-25NiCr) based MMC coatings sprayed with gaseous and liquid fuelled HVOF processes and a modern HVAF spray process. Two powder feedstock types, i.e. dense particles with fine carbides and porous particles with coarse carbides, were selected for both compositions. The results show significant improvements especially for WC-10Co4Cr coatings sprayed with HVAF when compared to HVOF sprayed coatings. In addition, Cr_3C_2-25NiCr coatings sprayed from the dense powder resulted in improved wear resistance compared to conventional feedstock powder.

1. Introduction

Thermal spraying is one of the most versatile techniques to produce protective metal-matrix composite (MMC) coatings on component surfaces to improve component performance and lifetime. The most common MMC compositions in thermal spraying are WC-Co(Cr) and Cr_3C_2-NiCr depending on the application environment. High velocity thermal spray processes are generally used as they produce moderate melting degree and high particle velocities. HVAF spray process produces lower particle temperatures compared to HVOF spray processes that use pure oxygen to burn the gaseous or liquid fuel. On the other hand, the particle velocities and spray rates are significantly increased with the HVAF. As a result, finer particle size distributions can be used resulting in dense coatings with controlled melting degree of the metallic binder phase. Such particle conditions have been found to produce coatings with improved performance. Thermally sprayed coatings have been evaluated for cavitation and silt erosion conditions in hydropower applications among with many other techniques (Ref 1). The properties of HVAF sprayed coatings provide potential improvements for such environments. Therefore, this study focuses on HVOF and HVAF sprayed coatings and their performance in the cavitation erosion, slurry erosion and solid particle erosion environments.

2. Materials and Methods

Commercial gaseous-fuel HVOF (DJ2700: Oerlikon Metco, Germany), liquid-fuel HVOF (JP5000: Praxair, USA) and gaseous-fuel HVAF (M3: Uniquecoat Technologies LLC, USA) spray torches were used to spray commercial WC-10Co4Cr (WC) and Cr_3C_2-25NiCr (CC) feedstock powders. WC1 and CC1 designations stand for coatings sprayed from feedstock powders with porous particles and WC2 and CC2 for coatings sprayed from dense powders. Vibratory apparatus was used to study the cavitation erosion resistance of the coatings, following the ASTM G32 parameters and using the alternative in-direct test method described in the standard. Solid particle erosion tests were carried out with centrifugal erosion tester described in (Ref 2). Crushed quartz sand with 0.1-0.6 mm particle size was used as the erodent with an approximate impact velocity of 80 m/s, and impact angle of 30° and 90°. Slurry erosion resistance was evaluated with a high speed slurry-pot equipment described in more detail by Ojala et al. (Ref 3). Quartz particles with nominal size distributions of 2-3 mm were used as abrasives and mixed with water to produce a slurry with 33 wt% solid content.

3. Results and Discussion

3.1 Cavitation Erosion Resistance

The cavitation erosion resistance of the coatings in Figure 1a systematically decreases with the decreasing particle temperature and increasing particle velocity, i.e. moving from HVOF to HP/HVOF and from HP/HVOF to HVAF spray process. The WC coatings demonstrated higher cavitation erosion resistance compared to CC coatings, especially when sprayed with HVAF spray process. Even though the particle velocities between HVAF sprayed WC and CC materials were comparable, approximately 900 m/s, the nominal material density (Cr_3C_2-25NiCr: 7.04 g/cm^3, WC-10Co4Cr: 13.93 g/cm^3) and resulting kinetic energy density was significantly higher for WC-CoCr compositions. The higher cavitation erosion rate of CC2 coatings can be attributed to the plasma densification process, which produced particles with finer carbide size resulting in lower carbide mean free path (Ref 4). This combined with increased carbon dissolution compared to the CC1 coatings reduced the toughness of the coating.

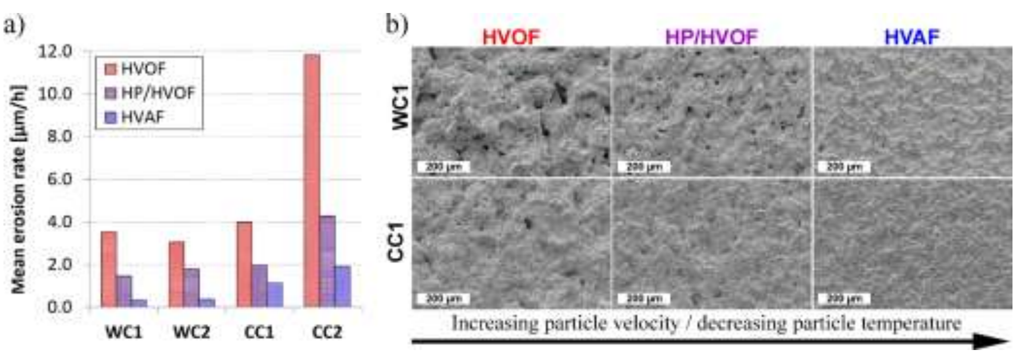

Figure 1. a) Mean erosion rates of the coatings and b) SEM images (SE) of the cavitation erosion surfaces of WC1 and CC1 coatings after 8 hours.

The cavitation erosion surfaces of WC1 and CC1 coatings are presented in Figure 1b, showing the decreasing wear surface roughness with increasing particle velocity. The wear mechanism is fatigue wear produced by continuous stress pulses caused by the collapsing cavitation bubbles near the surface. Cracks nucleate at coating defects and propagate through weak areas such as poor particle-particle interfaces, pores and existing cracks. Removed particles typically consist of several splats and measure 10 to 100 µm depending on the spray process (Ref 5).

3.2 Solid Particle Erosion and Slurry Erosion Resistance

The slurry erosion and solid particle erosion tests produced comparable performance between the material and process combinations, presented in Figure 2a and 2b. HVAF sprayed WC coatings resulted in significant reduction of erosive wear compared to HVOF sprayed coatings, whereas the HVAF sprayed CC1 coating experienced higher wear. The latter is caused by low carbide content resulting from carbide rebounding (Ref 4). In addition, the temperature of the HVAF spray process limits the carbide dissolution, which leaves the metal matrix in softer state allowing easier plastic deformation, ploughing and material removal. The difference between HVAF sprayed WC1 and CC1 can be observed in Figure 2c, where the CC1 coating contains marks of substantial deformation of the coating surface while several carbide rich islands marked with arrows are protruding from the surface.

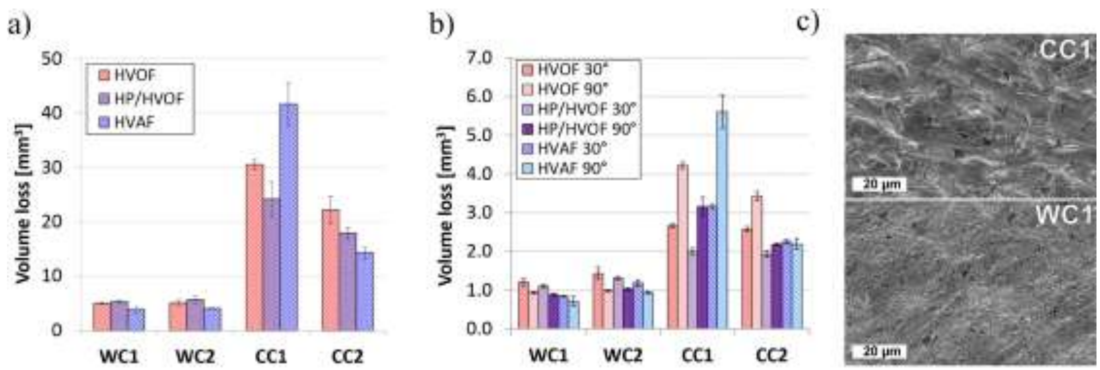

Figure 2. Volume loss of coatings after a) slurry erosion test (2-3 mm) and b) solid particle erosion test (0.1-0.6 mm), and c) slurry erosion wear surfaces of HVAF sprayed CC1 coating and HVAF sprayed WC1 coating.

4. Conclusions

- Significant improvement of cavitation erosion resistance was achieved with HVAF sprayed WC-10Co4Cr and Cr_3C_2-25NiCr coatings compared to conventional HVOF spray processes.
- Compared to HVOF sprayed coatings, the HVAF sprayed coatings demonstrated comparable or improved resistance against slurry erosion and solid particle erosion.
- The HVAF sprayed WC-10Co4Cr coatings provided the overall best performance.

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