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Enhanced erosion performance of cold spray co-deposited AISI316 MMCs modified by friction stir processing

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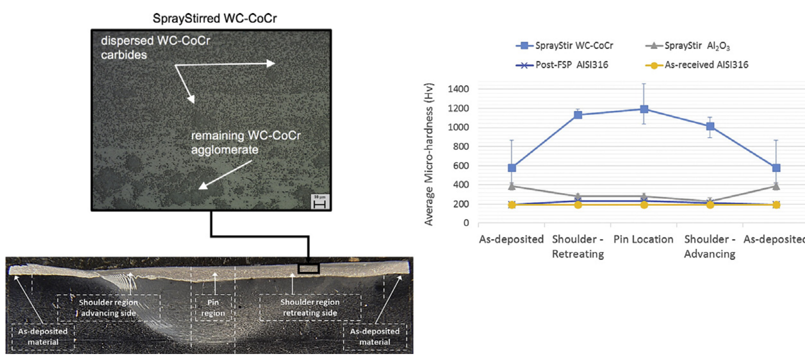
HIGHLIGHTS

- WC-CoCr and Al_2O_3 reinforced MMC coatings were cold sprayed on AISI316 and friction stir processed.
- FSP homogenised the distribution of reinforcements and reduced the interparticle spacing by up to 91% in the WC-CoCr MMC.
- The SprayStirred WC-CoCr demonstrated a hardness increase of 500% over the AISI316.
- As-deposited and SprayStirred coatings were examined under slurry erosion test conditions.
- The SprayStirred WC-CoCr demonstrated a 77% reduction in volume loss over the cold sprayed coating at 90^{O} impingement.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study reports on the erosion properties of a novel surface engineering process combining cold spray and friction stir processing. Tungsten carbide (WC-CoCr) and aluminium oxide (Al_2O_3) powders were cold spray co-deposited with AISI316 using a twin powder feed system. The deposited coatings were subsequently friction stir processed to refine and redistribute the reinforcing particles and remove the coating-to-substrate interface layer, thus generating a new metal matrix composite surface. Microstructural analysis of the SprayStirred (cold sprayed then friction stirred) specimens revealed significant particle refinement and improved particle distribution over the as-deposited coatings. The erosion performance of these SprayStirred surfaces was evaluated using a flowing slurry and demonstrated an 80% decrease in volume loss over the as-received AISI316 at 30° angle of attack. For SprayStirred WC-CoCr, microhardness measurements indicated an increase of approx. 530% over the unaltered AISI316 and 100% over the cold sprayed coating. These findings highlight the considerable increase in erosion performance of the SprayStirred specimens, and thus demonstrate the benefits of this innovative surface engineering process. This outcome is attributed to dispersion strengthening, imparted by the refined tungsten carbides. Furthermore, the SprayStirred WC-CoCr coating exhibited an 85% reduction in volume loss over an HVOF sprayed WC-CoCr coating.

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1. Introduction

Particle reinforced metal matrix composites (MMCs) have been shown to offer enhanced erosion properties over the bulk material. As such, the level of interest in these engineered materials has grown in recent years. Industries engaged in this research include automotive, mineral extraction and oil and gas, owing to the cost saving associated with producing wear resistant surfaces on cheaper substrate alloys. The present study examines a novel surface engineering technology combining cold gas dynamic spraying (cold spray) and friction stir processing, that has been optimised to successfully produce particle reinforced MMCs on the surface of AISI316.

Cold spray is a solid state coating technology that is used to produce coatings that retain the material properties of the feedstock powder. Coating deposition is achieved by accelerating the feedstock material to a supersonic velocity using a compressible carrier gas such as nitrogen or helium. The particles undergo extensive plastic deformation as they impact on the target surface which promotes bonding with the substrate material. The specific details relating to the bonding mechanisms are detailed elsewhere [1–3]. Cold spray offers several distinct advantages over high temperature coating processes including the prevention of oxidation [4], thermally induced phase changes [4,5], and tensile residual stresses [6]. Additionally, the cold spray process is capable of generating compressive residual stresses that enhance the fatigue performance of coatings over traditional thermal spray methods [7]. These key advantages are expanded upon in the published literature [8].

The deposition of erosion resistant feedstock powders such as cermets or oxides, has traditionally been difficult to achieve using the cold spray process. This is a result of the low ductility, and thus, limited plastic deformation of these erosion resistant powders, at the temperatures experienced during cold spray. Several research groups have attempted to overcome this limitation of the cold spray process by premixing ductile and cermet or oxide feedstock material [9] or by making use of agglomerated powders [10]. The drawbacks associated with premixing and using agglomerated powders are reviewed in the published literature [8].

In the present study, the difficulties in depositing erosion resistant coatings has been overcome using a novel co-deposition technique, whereby, the cermet or oxide powder (reinforcement) is co-deposited with a comparably ductile feedstock powder (binder), using a twin powder feed system. In this setup, two separate powder feeders supply the reinforcement and binder powders simultaneously to the cold spray nozzle, thus eliminating the need for premixing.

The strength of MMCs derives from the pinning of matrix dislocations by the reinforcing particles [11], with the amount of strengthening closely linked to the size, distribution and quantity of reinforcements within the matrix [12–15]. Microscale reinforcements impart strength through the load transfer from the soft, ductile matrix to the stiff reinforcements under an applied load [16]. The cold spray process imparts further strength to the binder particles in the form of work hardening [12] and grain refinement [16,17]. Severe plastic deformation of the binder produces an elongated grain structure, accompanied by an associated buildup of dislocations resulting in work hardening [12]. Additionally, binder particles that directly impact the surface of the substrate, and hence experience particularly extensive plastic deformation, exhibit a finer grain structure when compared with the feedstock material. The high pressures that are generated when these particles impact the substrate cause the elongated grains to recrystallize [17,18], thus producing the finer grain structure. Several investigations have evaluated the erosion and sliding wear properties of MMCs [9,19,20] and report a substantial reduction in the erosion rate of particle reinforced MMCs over the uncoated substrate.

The cold spray process does, however, exhibit some notable drawbacks [21]. Often, the cold spray deposition of MMCs produces an inhomogeneous microstructure, with clustered reinforcements yielding areas of unreinforced matrix [22]. Furthermore, delamination can occur between coating and substrate, owing to lower adhesive strength as a result of the particles remaining below the solidus as they impact the surface of the substrate [23].

This investigation incorporates a novel two-stage surface engineering process referred to as SprayStir. The first stage involves the deposition of an MMC coating by cold spray. To mitigate the aforementioned disadvantages of the cold spray process, shallow penetration friction stir processing (FSP) is employed to modify the deposited coating and top surface of the substrate. The FSP process is detailed in prior studies [8,24,25].

Despite the reported improvements to the tribological and microstructural properties of different alloys by FSP [26,27], the use of FSP on cold sprayed steel has not been extensively examined. However, one study by Morisada et al. [28] reported a 65% increase in the hardness of a friction stir processed, HVOF deposited MMC over the as-deposited coating. The authors attributed this to the refinement and improved distribution of the tungsten and chromium carbides. Additionally, defects such as microcracking and porosity were eliminated post-FSP. Existing research concerning cold spray deposited MMCs is limited primarily to aluminium based MMCs [22,29]. Hodder et al. [22] investigated the effects of FSP on a cold spray deposited MMC containing Al_2O_3 particles. While the authors [22] highlighted the increased refinement and improved distribution of the oxides, they failed to examine the impact of these parameters on the erosion performance of the MMC. Huang et al. [29] investigated the effect of FSP on AA5056 reinforced with SiC particles. This group [29] carried out a microstructural examination of the post-FSP coating and reported significant refinement of the SiC

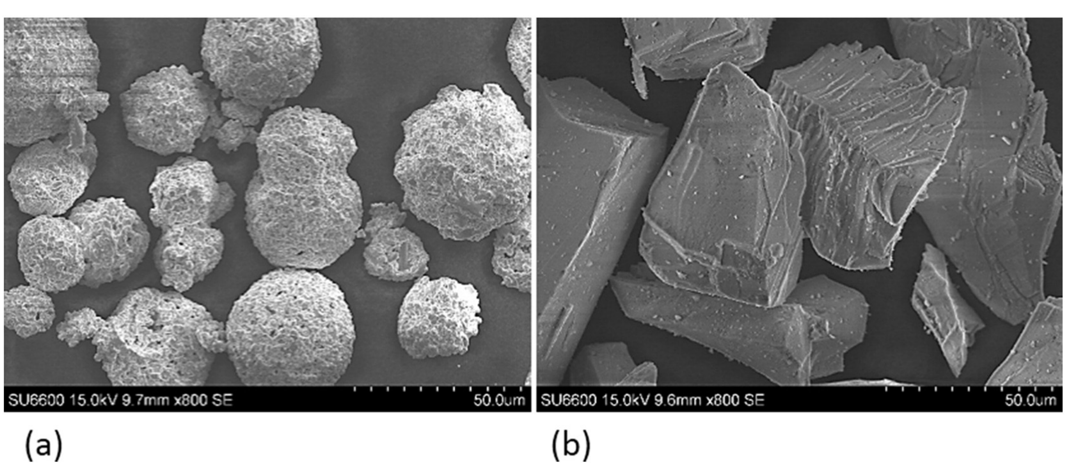

Fig. 1. Scanning electron micrographs of the feedstock powder particles [×800]. a) WC-CoCr; b) Al_2O_3.