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Cold sprayed metal-ceramic coatings using satellited powders

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ABSTRACT

A new 'satelliting' preparation method was used to create a feedstock of pure Al powder to which a much finer TiC powder was attached. Cold spray (CS) coatings of pure Al, blended Al/TiC and satellited Al/TiC were applied to Al substrates. A seven-fold increase in TiC area fraction was measured in the satellited coating compared to that in the blended coating. Coating thickness also increased as a result of increased ceramic deposition. Cross-sectional analysis revealed that the cohesion achieved between Al and TiC, during satelliting process, survives the CS process, and is hence an effective method of producing ceramic-metal coatings.

1. Introduction

Ceramic-metal composite coatings are widely used to enhance the surface properties and performance of engineering components in abrasive and corrosive environments [1]. There is an industrial need to produce metal-ceramic coatings for aluminium components [2], where the high production cost of these composites is a significant barrier to their exploitation. CS relies upon repeated high plastic deformation of incident particles to form a coating. Additionally, fine reinforcements have a significant effect on enhancing the composite properties [3]. However, low ductility materials are more difficult to deposit since they can rebound when impacting substrate surfaces, thus, brittle materials often need to be combined with more ductile materials for successful cold spraying [4]. It is known that CS coating compositions can be different to that of simply mixed feedstocks because the deposition efficiencies of the constituent powders are not the same at identical processing parameters [5], leading to production of coatings with inhomogeneous composition. To address this, various methods for delivering the soft matrix and hard reinforcing particles have been attempted [6], including mechanical-alloying of the two powders, despite high processing cost, powder work hardening and reinforcement phase heterogeneity in the feedstock [7]. A core-shell structured feedstock has also been prepared by electroless cladding of copper onto diamond, prior to successful CS, however this feedstock preparation is relatively expensive and often requires an additional interlayer material [8].

This study uses satelliting [9] to create a feedstock for CS, performed by attaching fine ceramic onto relatively large metal particles using a polymer binder, without mechanical modification of the feedstock. The efficacy of this process is demonstrated by cold-spraying this feedstock and comparing the coating morphology and TiC fraction with an equivalent blended powder.

2. Experimental methodology

Commercially pure Al with a spherical shape (15–45 μm size range) and angular shape TiC powder (particle size <5 μm) were "satellited" together to create a composite powder feedstock, (Fig. 1-b). The satelliting process involved mixing the two powders (88 wt.% Al & 12 wt.% TiC) in a tubular mixer for 20 min. Simultaneously, a binder with 2.7 wt.% solution of poly-vinyl alcohol (PVA) in water, was applied during the mixing process. The powder mixture was then dried at 100 °C for 12 h, leaving ~0.0007 wt.% solid PVA remaining after drying. Scanning electron microscopy (SEM) was performed using a JEOL-6490LV, using back-scattered electron (BSE) and secondary electron (SE) imaging. Image-processing software (Image-J) was used to measure the difference in TiC crater number by analysis of 1mm^2 of surface SEM images, porosity and TiC deposition from ~1.5 mm^2 cross-sectional images, and coating thickness from 30 measurements across the coating length. Blended powder was also prepared by dry-mixing the same fractions of TiC and Al. Fig. 1c and d compare mixed and satellited

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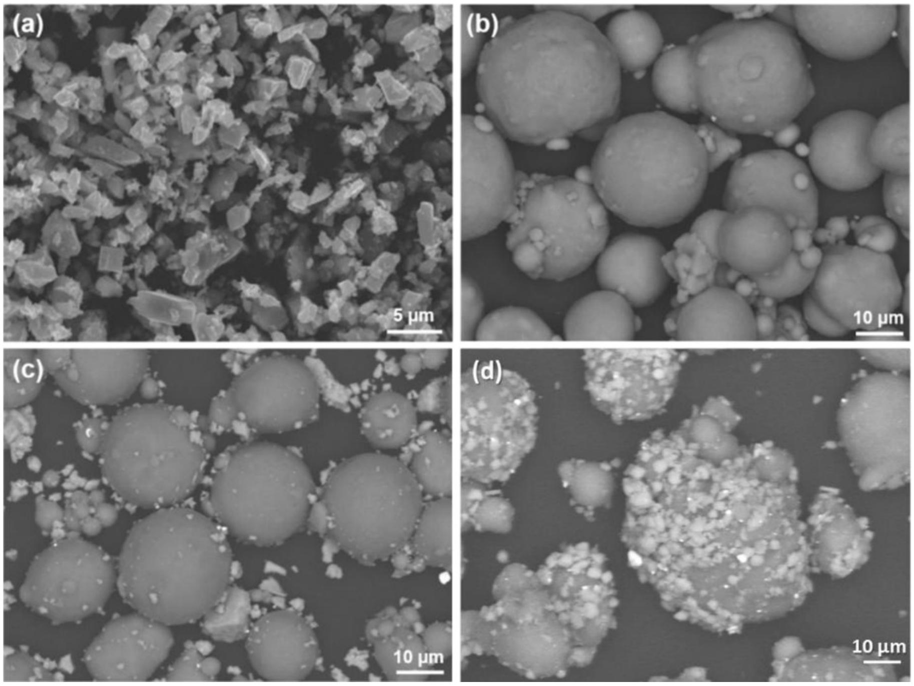

Fig. 1. SEM images showing the morphology of (a) virgin TiC powder, (b) virgin Al powder, (c) simply blended powder (Al/TiC), and (d) satellited powder (Al/TiC) revealing several fully coated particles.

powders. Several Al powder particles are covered extensively with finer TiC particles.

6 × 25 × 50 mm, Al 6068-T6 material was used as a substrate. The full details and set up procedure for the CS apparatus used is described elsewhere [10]. The main parameters used in the CS experiments were kept constant for all material types and were as follows; traverse speed, 60 mm/s, powder mass flow rate 12.4 g/min, stagnation pressure of the main and carrier gas, 28 and 29 bar, respectively. Fast-scanning using a single pass at 800 mm/s was also used to produce individual deposits from pure Al, blended Al – 12 wt.% TiC and satellited Al – 12 wt.% TiC.

3. Results and discussion

Fig. 2 shows cross-sectional BSE SEM images of the coatings as well as surface and cross-sectional images of splats. Top and cross-sectional views of individual deposited particles of the related feedstocks are also presented in the third and fourth rows, respectively. It is apparent that both the level of TiC deposition, as well as interlamellar porosity, are increased for the satellited coating. TiC particles can be clearly seen at splat boundaries. Fig. 3(a) shows the TiC area fraction in both composite coatings, measured from the cross-section, showing a seven-fold increase in mean area fraction for the satellite powder coating compared to the coating made from simply-blended powder.

Fig. 3(b) shows the thickness and porosity measurements for the three coating types. A slight decrease in the coating thickness for the blended powder was measured, in comparison with both the Al and satellited coatings. However, this coating was non-uniform in thickness, reaching a minimum of 50 μm and maximum of 100 μm. The pure Al and satellited coatings had a similar thickness, of just over 100 μm, and also a similar range of thicknesses and hence process repeatability is shown to be improved.

Fig. 3(b) also shows the porosity levels of the deposited coatings. In cold spray, any lack of deformation at any side of a particle will most likely lead to the generation of micro-porosity [11]. Results confirm that the satellited coating has a higher level of porosity (~1.5%), compared with the other coatings. This is likely due to the concentration of ceramic at the splat boundaries, where the hard phase hinders splat deformation from all sides.

From the observation of the TiC area fraction in the coatings, it can be concluded that the use of satellited powder facilitated ceramic deposition. This was achieved by the elimination of non-ductile particles rebounding during cold spraying. To explain the difference in deposition mechanisms for the coating types, individual particle analysis was conducted both planar and perpendicular to the spray direction cross-sections. In Fig. 2(g)–(i), individual, deposited Al particles can be seen on a polished Al substrate. Of note is the substantially reduced cratering and embedding of TiC in areas peripheral to the Al particle in the case of the satellited powder. An average of a 74% reduction in the number of TiC craters on the substrate surface was measured, suggesting that satellited powder constituents remained combined throughout the spraying process. Fig. 2(j)–(l) shows cross-sections of particles deposited from the three feedstocks. In the cross-section of the coating produced from blended feedstock, a deformed, deposited particle can be seen, with loose TiC deposited separately in the vicinity of the particle. For the satellited particle, TiC particles can be seen embedded beneath the deformed particle, and fewer TiC particles can be seen on top of the deposited satellited particles, most likely due to them becoming detached as a result of impact stresses of the satellite particles.

Fig. 4 illustrates the proposed mechanisms for the cold-spray deposition process using blended and satellited powders. In the case of the blended feedstock, the majority of TiC particles arrive separately from the Al particles and predominantly rebound from the substrate surface.

It is suggested that the satelliting is robust enough to survive mechanical agitation during cold spray starting from the powder feeder and through the gun, down to the substrate surface. Accordingly, a high proportion of ceramic which was attached to the satellited powder will be embedded in the coating, which explains the high presence of ceramic in the associated coating. The more evenly distributed TiC in the satellited feedstock, and subsequent