Wear 376-377 (2017) 566–577

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Erosive wear behavior of Cold-Sprayed Ni-WC composite coating

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ARTICLE INFO

Article history:
Received 4 October 2016
Received in revised form
11 January 2017
Accepted 12 January 2017

Keywords:
Cold spray
Metal matrix composite
Solid particle erosion
Surface analysis
WC
Subsurface microstructure

ABSTRACT

The effect of WC on cold spray deposition and erosive wear performance of Ni-WC composite coatings was studied. WC and Ni powders were fed to the gun from separate hoppers and a blend of Ni-36 vol% WC was sprayed onto mild steel substrates. By using three different WC powder sizes, the effect of WC size on coating build-up and WC retention were tested. Using smaller size WC particle, higher retention of WC into coating was achieved. Using macro-indentation, a relationship between mechanical properties and content of WC was studied. Detailed microstructural analyses and wear loss measurements were conducted to study mechanism involved in solid particle erosion (SPE) of Ni and Ni-WC coatings. One of the Ni-WC coatings with highest WC retention (10.5 vol% WC) was selected for SPE studies. Both Ni and Ni-WC coatings exhibited ductile erosion. Higher erosion resistance of coatings under normal angle compared to oblique angle was related to the formation of a protective tribolayer. It was found that 10.5 vol% WC content was too low to reinforce Ni against erosion under oblique angle. However, under normal angle, the addition of 10.5 vol% WC deteriorated Ni erosion resistance, by preventing tribolayer formation and brittle fracture.

1. Introduction

Solid particle erosion (SPE) occurs when hard solid particles are entrained in the fluid and strike the surface [1,2]. This type of material removal is a serious problem in many engineering systems, including aircraft engine, steam and jet turbines, and pipelines [1,2]. Erosion of compressor blades in the first stage of the aircraft engine is common, which is due to the sand particles entrained in air [1]. This can deteriorate aerodynamic performance and even structural integrity of blades [1]. Power-generating steam turbines are another example of engineering systems affected by erosive wear, where iron oxide scales from steel heaters are fragmented into approximately 100 μm particles, and cause erosive damage of turbine blades and other components [2]. Many studies have been conducted to understand materials loss mechanisms during SPE and develop protective coatings to increase component lifetimes [1,2]. In SPE, contact stress arises from the kinetic energy of particles, which is controlled by particle velocity, impact angle, and particles size. Particles kinetic energy is partially dissipated by plastic deformation and/or brittle fracture [1,2].

SPE behavior of materials can be classified as ductile or brittle. Material removal by plastic deformation (ploughing or cutting) is the characteristics of ductile erosion; whereas brittle erosion of materials is characterized by crack initiation, propagation and intersection [3,4]. The mechanisms by which materials are eroded depend on operational conditions and surface and erodent particles properties [3,4]. The erosion rate dependence on the impact angle for ductile and brittle behavior is different. Ductile erosion behavior, such as for metals and polymers, presents maximum erosion rate at low angles of incidence, while for brittle materials, such as ceramics, a maximum of material loss is at a normal angle of incidence [3]. In real applications, erodent particles impinge surfaces at a wide range of angles. Therefore, neither metallic materials nor ceramic are the best choice for erosion resistant coatings [1–4]. In order to decrease erosion damage, it is necessary to have a balance of high hardness and adequate fracture toughness. For this reason, more attention has been paid to metal matrix composites (MMCs), which consist of hard particles embedded in a tough metal binder, to control and minimize the wear. In this regard, in order to apply these coatings over components, a variety of techniques have been used in surface engineering including laser cladding and thermal spray processes as most widely employed [5–7]. Ni based coatings are widely applied where wear resistance combined with oxidation or hot corrosion resistance is required [8,9]. Previous studies showed that the wear resistance of Ni coatings can be greatly improved by incorporation of refractory carbides such as WC, WC-Co, TiC, and Cr_2C_3 into the metallic matrix [5,6,10].

Among the different coating deposition techniques, laser cladding has been widely employed to deposit Ni-based composite coating. Using laser cladding, although a very good adhesion of

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http://dx.doi.org/10.1016/j.wear.2017.01.052
0043-1648/

coating to the substrate as well as low porosity can be obtained [11–15], a non-homogenous distribution of reinforcing particles was reported, especially in the case of WC, which tends to precipitate and concentrate at the bottom of the coating [11–13]. Moreover, higher laser power is needed in order to obtain thicker coatings and higher concentration of ceramic particles. This results in unwanted chemical changes, formation of brittle phases and significant residual stress [11–15]. Erosion behavior of Ni-WC coatings has not been widely reported. However, the presence of the brittle phases at interfaces is reported to provide preferential crack paths and increase wear rate [11,12].

Cold spray is a solid state thermal spray process where particles are accelerated in a de Laval nozzle to supersonic velocities (500–1200 m/s) in a gas stream and impact onto a substrate. Gas temperature is often much lower than the melting points of the particles. Besides, particles remain in solid state due to quite short contact time with the high temperature gas. Hence, high-temperature-induced decomposition of carbides and/or other phase transformations that could be detrimental for tribological performance can be avoided [16–18]. Furthermore, impact induced high strains and the heat generated in this process may cause partial or complete recrystallization and evolution of ultra-fine microstructure [16,17].

Several studies were conducted to fabricate hard composite coatings by cold spray. It was found that pretreatment powder processing such as metal cladding on ceramic particles [19] and sintering [20] can help the retention of ceramic particles to the coating. However, achieving high content of ceramic particles using a blend of two powders still remains a challenge, which arises from non-deformability of hard ceramic particles. Little attention has been given in the literature to the mechanisms of hard particles retention to a coating and the effect of the cold spray and powder parameters. In the present study, cold spray deposition was utilized to fabricate Ni-WC composites. The cold spray behaviors of Ni and WC were studied using unmodified powders with no additional processing routes. The effect of WC and its size on coating formation, deposition efficiency, and hardness of Ni were investigated. For the two Ni and Ni-WC coatings, SPE tests were conducted and the role of WC on SPE behavior of coating was studied.

2. Experimental

2.1. Cold spray formation and Coating Characterization

Grit-blasted mild steel plates with thickness of 3 mm and roughness of 7.6 $\pm$ 0.6 μm were used as substrates. Commercially pure water atomized Ni (Novamet, Canada) and plasma spheroidized WC (Tekna, Canada) were used as feedstock powders (Fig. 1). Laser particle size analysis (Horiba, Japan) was used to measure feedstock powder size distribution. Three different particle sizes of WC, $-45+15$ ($d_{50}=40$ μm), $-38+25$ ($d_{50}=30$ μm), and $-25+10$ μm ($d_{50}=15$ μm), were tested. Ni powders had particle size range of 4–10 μm ($d_{50}=7$ μm). Cold spray was conducted using a PCS-1000 system (Plasma Giken, Japan) with nitrogen as the carrier gas. The cold spray unit utilised a de Laval nozzle made of WC-Co. Prior to entering the nozzle, the gas pressure was 4 MPa and temperature was 700 °C. The stand-off distance between the substrate and nozzle exit was set at 40 mm, and the gun traverse speed at 30 mm/s. The particle velocities were measured in a free-jet by a time-of-flight particle diagnostic ColdSprayMeter (Tecnar, Canada). The WC and Ni powders were fed to the gun from separate hoppers. The powder feeder systems was a custom install done by the gun manufacturer, Plasma Giken. By setting feed rates of Ni and WC on 1.25 and 0.5 rpm,

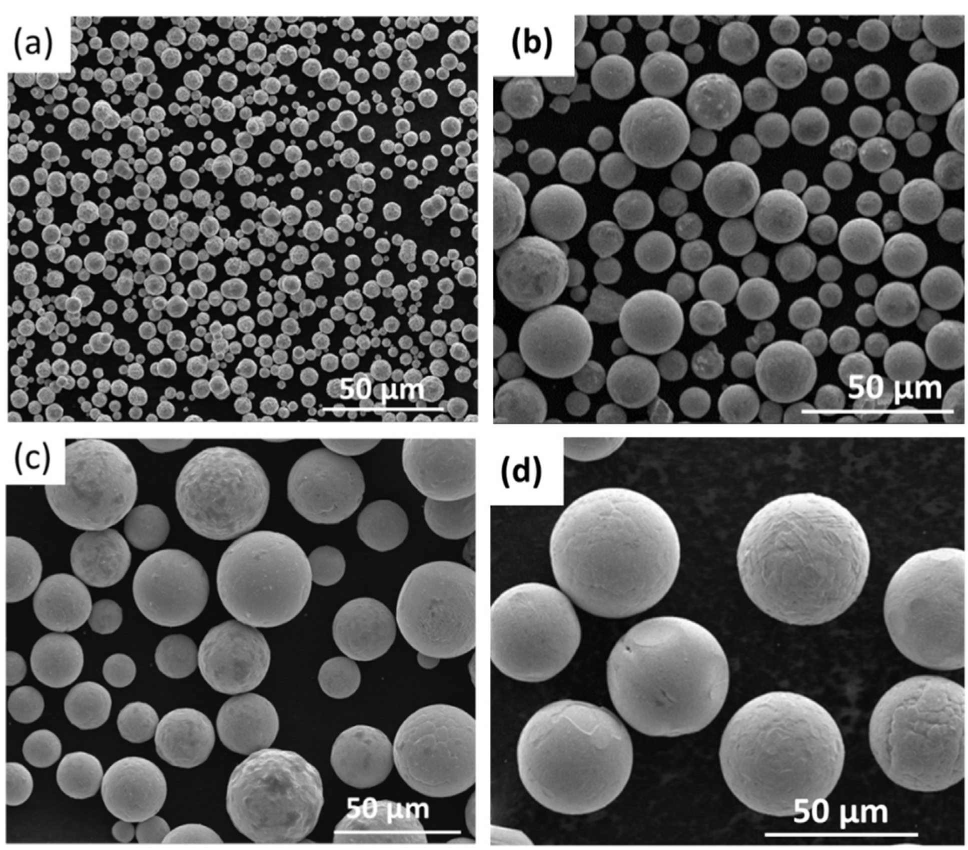

Fig. 1. Morphology and size distribution of the as-received powders: (a) Ni, (b) $-25+10$, (c) $-38+25$, and (d) $-45+15$ μm WC powder.