

# Assessment of microstructural and mechanical properties of HVOF sprayed WC-based cermet coatings for a roller cylinder

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## Abstract

The present paper concerns an assessment of microstructural and mechanical properties of WC-based cermet coatings for a roller cylinder. With this regard, WC-based coatings were fabricated on NiAl deposited 316 L stainless steel substrates by using HVOF technique. The produced coatings were extensively analyzed with respect to X-ray diffraction (XRD), optical microscopy, image analyzer, scanning electron microscopy (SEM) including energy dispersive spectroscopy (EDS), microhardness and surface roughness. Adhesion strength of the coatings was also measured by using a scratch tester and the scratch was examined with an optical microscope. XRD study revealed that WC, W<sub>2</sub>C, W, C, Co, CoW<sub>9</sub>C, Co<sub>8</sub>W<sub>9</sub>C, Ni, NiAl, Ni<sub>3</sub>Al and FeNi phases are present in the coatings. The metallographical observations showed that all coatings had a similar coating microstructure and good contact to the substrate, highly dense structure, low oxide and porosity contents. In addition to structural and microstructural results, microhardness values of WC–Co, WC–Ni, NiAl coatings and stainless steel were measured to be 1700, 1750, 450 and 220 HV, respectively. It was found that the adhesion force value of WC–Co coating (125.9 MPa) is higher than WC–Ni coating (76.2 MPa). In order to determine wear loss, friction coefficient and wear mechanism, wear tests were performed for the WC–Co and WC–Ni coated NiAl deposited stainless steel substrates at 50 and 100 N loads under dry sliding conditions through a pin-on-plate arrangement against AISI 303 L steel counterbody. Regarding wear mechanism of the coatings, the microstructural analysis of worn surfaces was examined by SEM and EDS. It was found that the friction coefficients of WC–Co coating are higher than WC–Ni coating under 50 and 100 N loads at dry sliding conditions. In addition to this, the total wear loss of the WC–Co coating is more than WC–Ni coating on NiAl deposited stainless steel substrates.

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## 1. Introduction

Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface. This is especially true in wear resistant components, as their surfaces must perform many industrial functions in a variety of complex environments. The surface of industrial component may require

treatment to enhance the surface characteristic. Surface treatments that cause microstructure changes in the bulk material include heating and cooling/quenching through induction, flame, laser and electron beam techniques, or mechanical treatments. Surface treatments that alter the chemistry of a surface include carburizing, nitriding, carbonitriding, boriding, siliconizing, chromizing and aluminizing [1].

In addition, hard facing is another form of surface treatment, where the bulk material's surface is given a protective layer of another material having superior properties than those of the bulk material. An example of this is coating a roller cylinder in fabrication of a copper wire with

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high purity [2]. In this application, steel-based roller cylinder used in the temperature range of 600–800 °C is not regularly working during a wire-drawing process inasmuch as they are subjected to wear, high temperature oxidation and thermal fatigue. For this application, thermally sprayed coatings are used to improve the resistance of roller cylinders to oxidation and surface wear and to increase their heat resistance [3]. The most promising process is HVOF technique for the deposition of the steel-based roller cylinders as it offers an effective and economic method of conferring wear resistance without compromising other attributes of the component. Generally speaking, WC-based powders are deposited on the steel-based substrate by using HVOF technique [4–6].

The principal function of the WC-based coatings is to resist severe wear mechanisms, such as adhesion, abrasion, fretting and particle erosion and high temperature oxidation [7]. The hard WC particles in the coatings lead to high coating hardness and high wear resistance, while the metal binder (Co, Ni, or CoCr) supplies the necessary coating toughness [8]. Taking into consideration these issues, throughout the present investigation, we draw attention to microstructural and mechanical properties of WC–Co and WC–Ni cermet coatings formed on NiAl/stainless steel substrates by HVOF process for the roller cylinder. In this context, WC-based coatings were fabricated on NiAl deposited 316 L stainless steel substrates by using HVOF technique. The produced coatings were characterized by X-ray diffraction (XRD), optical microscope, image analyzer, scanning electron microscope (SEM) including energy dispersive spectroscopy (EDS), microhardness and surface roughness machines. Adhesion strength of the coatings was measured by using the scratch tester. Wear behaviour of WC-based coatings on the NiAl deposited substrate was investigated using the friction and wear tester. The worn surfaces were examined by means of SEM and EDS.

## 2. Experimental procedure

The 316-L stainless steel with 0.030% C, 1% Si, 2% Mn, 0.045% P, 0.030% S, 16–18% Cr, 2–3% Mo and 10–14% Ni composition was used as a substrate because of its industrial applications of rolling, wire-drawing, high temperature moulding component and extrusion. The substrates having dimension of 50 × 25 × 2 mm were grit-blasted on one side to clean and roughen the surface. This process was performed for a period of ~30 s with 35 grit alumina powders using compressed air at a pressure of ~400 kPa. Two types of WC–Co and WC–Ni feedstock powders were used in this work, namely conventional sintered and crushed powders with grain size of approximately 14 µm, such as 13 wt.% cobalt, 87 wt.% WC and 12 wt.% nickel, 88 wt.% WC, respectively. NiAl powder including 95% Ni and 5% Al was also used as a bond coat in order to increase adhesion strength of WC-based cermet coatings to the substrate.

A Metco Diamond Jet (DJ) 2600 HVOF spray system was used to deposit the coatings from WC-based cermet and NiAl metallic powders using the spray parameters listed in Table 1. WC-based cermets and NiAl metallic powders were deposited at different spray parameters providing optimum properties. The ratio of oxygen to hydrogen flow rates was chosen to be approximately 75% of stoichiometry. The substrates were placed on to a turntable and rotated to give an effective horizontal traverse rate of 1 m s<sup>-1</sup> whilst the gun traversed vertically at a rate of 0.005 m s<sup>-1</sup>. The powder carrier gas was nitrogen and the substrates were cooled with compressed air jets during and after spraying. Further details as for the deposition of the coatings can be found in Refs. [9,10].

In order to verify crystallinity of the coatings, X-ray diffraction (XRD) of as-sprayed coatings was performed by the Shimadzu 6000 Model diffractometer with Cu-K<sub>α</sub> radiation (1.5406 Å) using a 0.05° step size and a 2-s dwell time. Prior to microstructural observations, cross-sections of the coatings were obtained by embedding in cold mounting resin followed by grinding and polishing to a 1-µm surface finish and then sputter-coated with gold. Coating cross-sections were cut from the bulk using a spark wire cutter. An optical microscope was used to examine cross-sectional area of the coatings. The coating thickness was measured by the optical microscope. The porosity of layers was measured using an image analyzer (LUCIA 4.21). At least 10 fields were measured at 200× magnification and the porosity values were averaged. The coating structures were examined using a JEOL JJM 6060 scanning electron microscope (SEM) attached with energy dispersive spectroscopy (EDS).

Microhardness tests were performed using a Carl Zeiss microhardness tester with a 80-gf load and a dwell time of 15 s. Hardness quoted is an average of 5 indents (with the quoted range being the standard error in the mean) which were placed in the middle of the coatings on cross-sectioned and polished samples parallel to the coating/substrate interface. Surface roughness measurements were carried out by using Mitutoyo SJ-301 Surface Roughness Tester.

Adhesion force of the coatings was measured by using Shimadzu Scanning Scratch Tester SST-W101 equipped with a standard off-line Zeiss metallographic microscope. In this technique, the load on a Rockwell C diamond with tip

Table 1  
Spray parameters employed during HVOF spraying

| Parameters                                                 | Values |                   |
|------------------------------------------------------------|--------|-------------------|
|                                                            | NiAl   | WC-based coatings |
| Oxygen flow rate (l min <sup>-1</sup> )                    | 130    | 240               |
| Fuel gas (hydrogen) flow rate (l min <sup>-1</sup> )       | 400    | 640               |
| Carrier gas (nitrogen) flow rate (l min <sup>-1</sup> )    | 18     | 16.5              |
| Spray distance (mm)                                        | 250    | 300               |
| Substrate velocity (horizontal plane) (m s <sup>-1</sup> ) | 1      | 1                 |
| Gun traverse speed (vertical plane) (mm s <sup>-1</sup> )  | 5      | 5                 |
| Number of passes                                           | 20–30  | 30                |

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