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Sliding Wear Behavior of High Velocity Oxy-Fuel Sprayed WC-CO Coatings

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Abstract

The Thermal spraying techniques are coating processes in which melted materials are sprayed onto a surface and the feedstock is heated by electrical or chemical means. High velocity oxy-fuel (HVOF) spraying is seen as the pre-eminent process for deposition of such coatings. The coating that is formed is not homogenous and typically contains a certain degree of porosity, and, in the case of sprayed metals, the coating will contain oxides of the metal. This paper examines the effect of WC–Co coatings on the wear behaviour, WC were thermally sprayed by a high-velocity oxy-fuel (HVOF) system from WC–12% Co powder. Sliding wear resistance of this coating was calculated using pin-on-disk tribometer (ASTM G99-90). The morphologies of WC-Co coating were observed by X-ray diffraction (XRD), Energy dispersive analysis and Scanning electron microscope (SEM). Micro hardness is calculated by using Vickers Hardness test. And it was found that WC-Co coatings show better wear resistant properties.

Keywords: *Thermal spraying, WC-Co coatings, HVOF, Sliding wear, XRD, SEM*

1. Introduction

Coatings can be considered as materials with more resistance to the substantial surface degradation procedure. Coatings offer a way of extending the limits of use of materials at the upper end of their performance abilities, by allowing the mechanical properties of the base materials to be sustained while shielding them against wear or deterioration [27]. Benefit of coatings is that they are relatively inexpensive and they can be applied insitu. There are many coating deposition techniques available, out of them Thermal spray coating offers a way to engineer the surface properties of components [25-29]. Hard metals, such as WC–Co, Cr_3C_2–NiCr, WC–$(W,Cr)_2C$–Ni, WC–NiCrBSi belong to one of the most significant group of materials by thermal spray processes into coatings, which are primarily applied for the protection against wear, such as sliding , abrasion and erosion [1-13]. The coating that is produced is not homogenous and characteristically contains a certain degree of porosity, but in the case of sprayed metals, the coating will contain oxides of the metal. The bond between the base metal and the coating may be mechanical, metallurgical, chemical or a combination of these. The properties of the applied coating are reliant on the feedstock materials.

Since last decade High Velocity Oxygen Fuel (HVOF) sprayed coatings have been applied widely mainly in industrial applications and Power plants as they have low porosity and oxide content, high hardness and high adhesion. High Velocity Oxygen Fuel (HVOF) coating is a deposition process where powder coating material is

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heated rapidly in a hot gaseous medium. At the same time the powder material is sprayed at a high particle velocity onto a prepared substrate surface where it builds up to get the desired coating. HVOF processing did not degrade significantly the composition of the consumable and has been shown to produce coatings with low porosity and oxide content, better density, better coating cohesive strength and bond strength than many thermal spray processes [21] and [19]. Ni based coatings are used in claims when wear resistance combined with oxidation or deterioration resistance is required. The largely engaged Ni based powder belongs to the Ni–B–Si system with the adding of other alloying elements [23] and [20]. Wang *et al.*, [18] and Kulu and Pihl [22] reported that the wear resistance of self-fluxing alloys (NiCrFeSiB) coatings can be greatly increased by adding refractory carbides such as WC, VC, WC-Co, TiC, $B_{13}C_2$ and CrC to the metallic matrix. WC-Co coatings are frequently used in applications that need abrasive wear resistance. Refractory metal strengthener presence is quite necessary for the mechanical properties. By the observation of Kim *et al.*, [24], the coating of 35% WC with NiCrBSiC exemplify the best quality in terms porosity and hardness. The increase of the WC content from 0 to 35% increases the coating hardness. There is a toughening effect and general hardness escalation without significant increase of brittleness. Further rise of the WC content makes the hardness drop.

Most widely used wear resistant coatings in industry was tungsten carbide coatings, in specific in power generative systems, aerospace, and automotive applications. The improved performance was accredited to the lower wear and frictional force and high hardness of WC-Co coating. Hardness, wear resistance, and strength (Tribo mechanical properties) are influenced mainly by the size and distribution of WC grains, the volume fraction and thermo-mechanical properties of the metal matrix, , the porosity and post-treatments of the composite hard metal coating [2, 4, 6,7,10 and 11]. In the coatings the hard WC particles lead to high wear resistance and coating hardness, while the metal binder (Co, Ni, or CoCr) supplies the required coating toughness [30, 31]. Both higher temperature and room temperature investigations have been conducted [14-17]. These coatings are widely used in many industrial applications ranging from transportation, aerospace, off-shore and all engineering disciplines. While spraying of WC–Co powders, significant changes in the chemical and phase compositions can occur [13].

This Present study focused at gaining a better understanding of the micro structural features that governs the mechanical and the tribological behaviour of WC–12 wt% Co coatings under High Velocity Oxygen Fuel (HVOF) spraying technique. Sliding wear resistance of this coating was calculated using pin-on-disk tribometer (ASTM G99-90). The morphologies of WC-Co coating were observed by X-ray diffraction (XRD), Energy dispersive analysis and Scanning electron microscope (SEM). Micro hardness is calculated by using Vickers Hardness test. And it was found that WC-Co coatings show better wear resistant properties.

2. Experimental Procedure

2.1. Materials

All Agglomerated powders of tungsten mono carbide with 12 wt. % β-cobalt was prepared for the present study and coating is applied to the pin. For this work En31 disk is used and the composition is given in Table 1.

Table 1. En-31 Composition

Chemical composition	Percentage (%)
Carbon	0.902-1.20 max
Sulphur	0.1 – 0.35 max
Phosphorus	0.040
Manganese	0.3 to 0.35 max
chromium	1.002-1.60
Silicon	0.10-0.35
Iron	Remaining

2.2. High Velocity Oxygen Fuel (HVOF) Coating

The powders were deposited onto mild steel pins by using a high-velocity oxy-fuel system. A gas mixture of 70% acetylene (C_2H_2), 30% propylene (C_3H_6) was used as the fuel gas. Table 2 shows the spraying parameters. During the spraying, the samples were kept stationary and the surface of the samples was sectioned perpendicular to the axis of the gun, which pass through over the samples with a step of 5 mm after a scan. The coating thickness was approximately 162 µm in the as-sprayed state, followed by grinding and polishing for the micro structure analysis.

Table 2. HVOF Spraying Parameters

HVOF Gun type	DJ2700
Fuel gas	LPG
Spray distance	6 to 7inches
Oxygen flow rate	200-300SLPM
Powder feed	25-36 gm/min
Deposition Efficiency	65-75%
Traverse rate (m/sec).	0.0029-0.0032 m/sec
Compressed air pressure	06.0 Kg/cm2

2.3. Characterisation of Coatings and Worn Surfaces

X-ray diffraction (XRD) used to identify the phases present in powders and coatings. A 0.05° step size was employed with a 2 seconds dwell time per step. SEM was employed to study plan view and cross-sections of samples. The Cross-section was made on a plane through the wear path parallel to the sliding direction at that point. Samples were prepared by cutting with a diamond blade, mounting in cold-mounting epoxy resin, grinding and polishing. Micro hardness measurements of the coatings were made with a Vickers instrument with a 50 kgf load. Ten indents were made along the mid-plane of polished diagonal section and the mean hardness obtained from the separate readings.

2.4. Sliding Wear Tests

The experimentation is carried on with the pin on disc apparatus (Figure.1). The disc used during the experimentation is made of the material EN-31 and the pins used for conducting the work are made of Mild Steel (MS) and Tungsten carbide-Cobalt (WC-Co). The experimentation is done on in two different conditions. a) Dry conditions. b) Wet lubrication. In Dry conditions experimentation is done at room temperature without any lubrication and at atmospheric pressure and is done by setting the various following conditions.

a) Load Applied . 3 KG

b) Diameter of the track . 60 mm

c) Radius of the track . 30 mm

d) Lubrication . Not present

e) Temperature . Room temperature

f) The diameter of the pin used . 10 mm

g) Area of contact between pin and the disc . 78.5 mm2

h) Input Power . 15A

i) Frequency . 50 Hz

j) Voltage . 230V

In Wet lubrication the experimentation is done at a temperature of 350^0C, using servo 4T as the lubricant for experimentation and maintaining the atmospheric pressure and is done by setting the various following conditions.

a) Load Applied . 5 KG.

b) Diameter of the track . 100 mm.

c) Radius of the track . 50 mm.

d) Lubrication . Servo 4T.

e) Temperature . 3500C

f) The diameter of the pin used . 10 mm.

g) Area of contact between pin and the disc . 78.5 mm2

h) Input Power . 15A

i) Frequency . 15Hz

j) Voltage . 230V

Figure 1. Pin on Disc Apparatus

3. Results & Discussions

3.1. SEM Analysis

The cross-sections of the HVOF sprayed coatings observed by SEM (Figure 2 and 3) shows the gas atomized WC-Co particles have an irregular and angular structure. The thickness of the coatings was measured from the micrograph, of about 162 μm and bond well to the substrate. Average grain size is 1.305(μm). Adherence between substrate and coating seems to be good at the interface we observe low presence of either cracks or voids. The properties and performance of tungsten carbide coatings is predicted to a function of carbide size, shape and distribution, matrix hardness and toughness and solution of carbon in the carbon in the cobalt matrix.

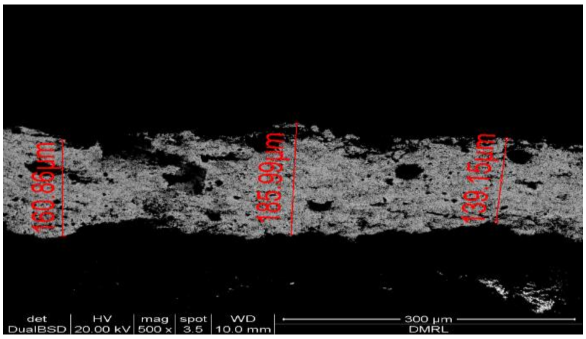

Figure 2. Microstructure of WC-Co Coating

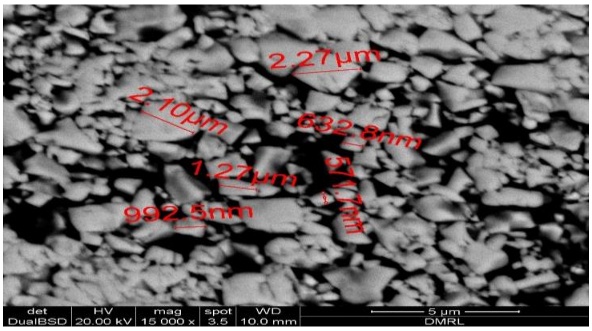

Figure 3. Morphology of WC-Co Sprayed Particles

3.2. Wear and Frictional Force.

The wear and friction experiments were conducted at room temperature and at 350^{0}C. Each test was repeated twice to ensure reliability in the measured quantity. Figure.5 shows the variation of wear with time for the WC-Co coated pin and MS pin under dry condition at 350^{0}c and wet condition at room temperature. Clearly, it is observed in the graph that wear rate & frictional force of coated pin is very, very less as compared to uncoated pin as shown in Figure 4 to 7.

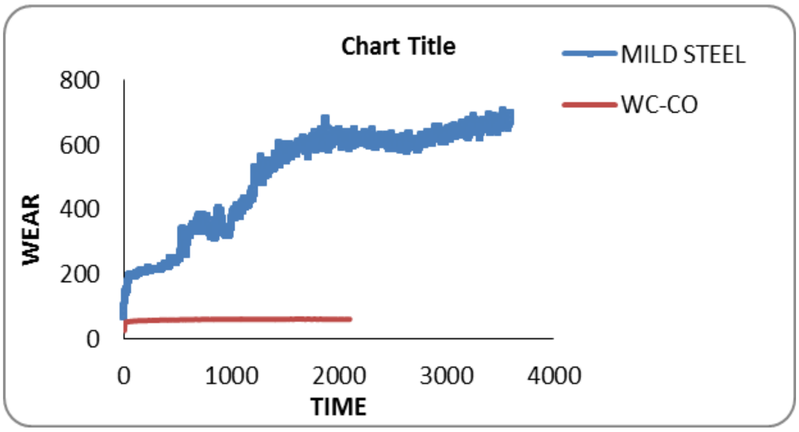

Figure 4. Comparison of TIME VS WEAR for Coated Pins and Uncoated Pins Under Dry Condition and at 350 ^{0}C

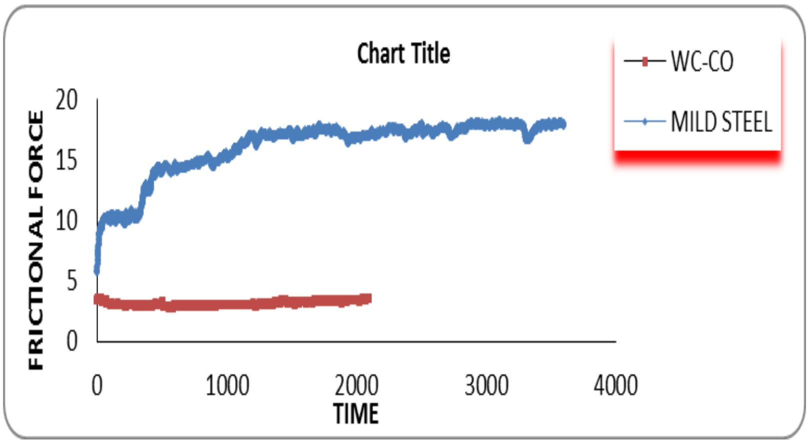

Figure 5. Comparison of TIME VS FRICTNAL FORCE for Coated Pins and Uncoated Pins under Dry Condition and at 350^{0}C

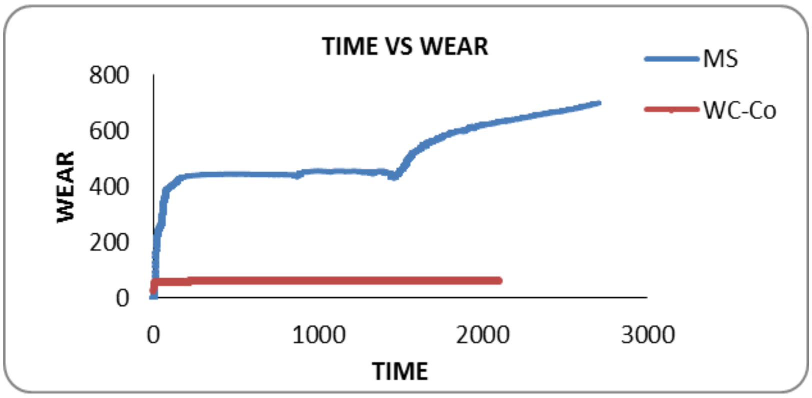

Figure 6. Comparison of TIME VS WEAR for Coated Pins and Uncoated Pins under Lubricating Condition and at Room Temperature

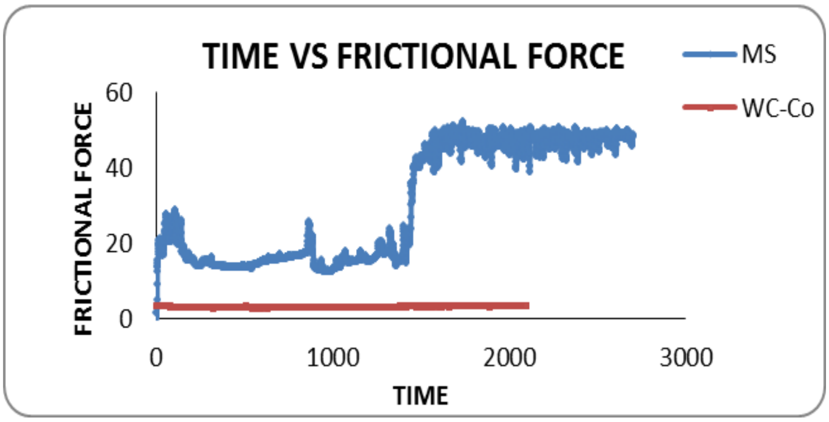

Figure 7. Comparison of Time vs Frictional Force for Coated Pins and Uncoated Pins under Lubricating Condition and at Room Temperature

3.3. EDS Analysis

Coating must cherish a large volume fraction of finely-distributed tungsten mono carbide (WC) to achieve the optimum wear properties. This is dependent on minimization of decarburization of WC which readily occurs at high temperatures associated with the thermal spray process. The coatings contain a much higher concentration of WC, as it is observed by the higher proportion of dark gray phase. The EDS analysis of WC-Co coating in the Figure. Clearly from the EDS data large percentage of WC-CO consists of WC (81%), Co (14%) and small amounts of oxygen, chromium, iron.

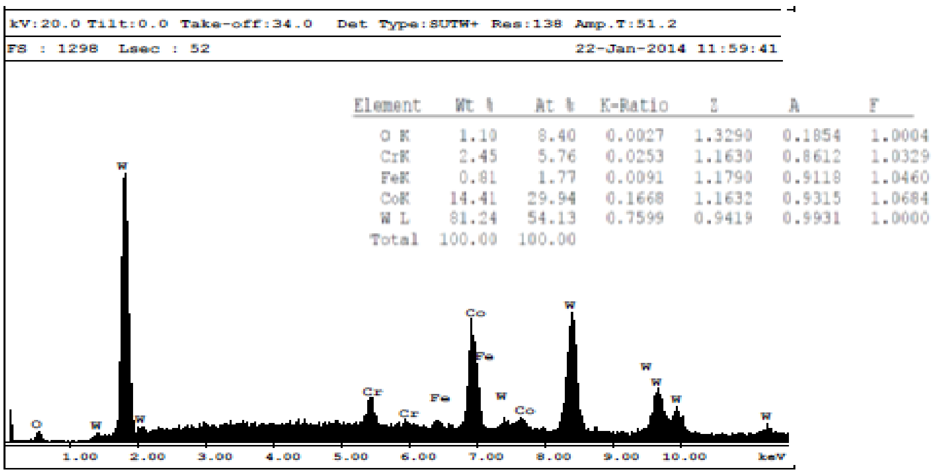

Figure 8. EDX Analysis of WC-Co Coating

3.4. XRD Analysis.

The XRD diffraction range of the conventional WC–12 wt.% Co powder (Figure. 9) shows peaks indexed to WC and Co. A small amount of W_2C phase was also found. The XRD traces of the coatings exhibit WC and W_2C peaks along with broad diffuse peaks between 2θ=11-30° representing amorphous phase . This indicates the XRD analysis confirmed the presence of a larger percentage of WC (Figure 10). This result satisfies the results taken in EDS analysis. This result was expected due to the higher flame velocity & the lower flame temperature of HVOF process, which limit the decomposition process.

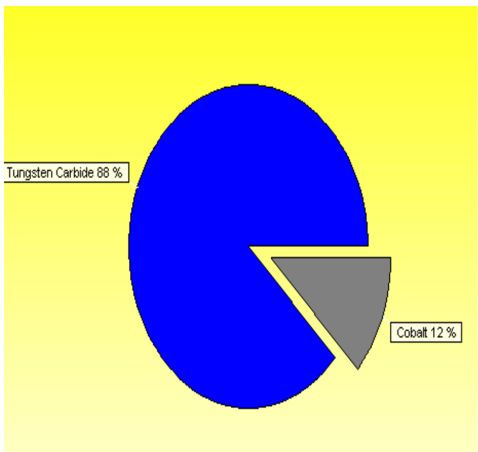

Figure 9. Chemical Composition of WC-Co

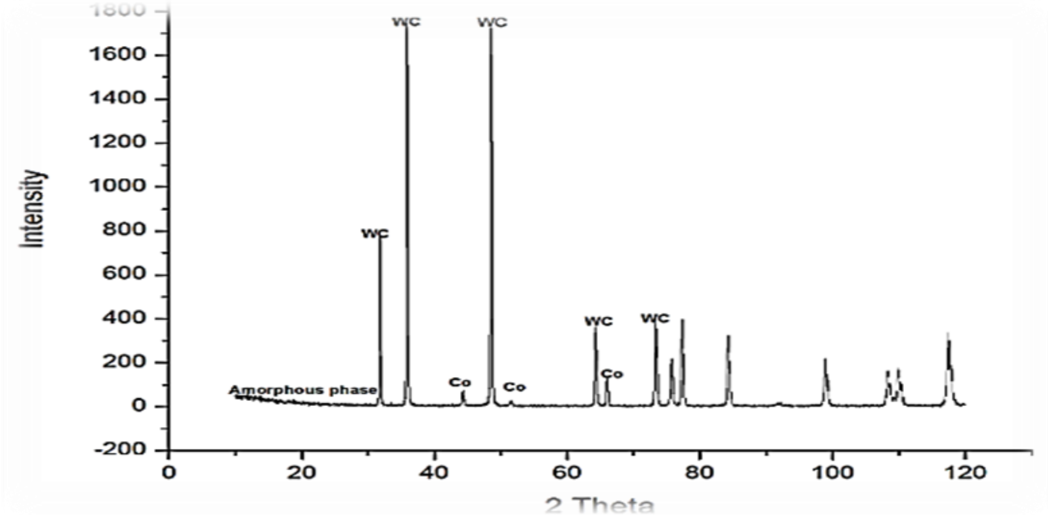

Figure 10. XRD Pattern of the WC-Co Coating

4. Conclusion

The microstructure morphologies of the coatings were analyzed as well by means of Energy dispersive X-ray analysis (EDXA), X-ray diffraction (XRD) and scanning electron microscopy (SEM). It was found that the as-sprayed WC–12%Co coatings were composed of WC as the major phase and W_2C as the minor phases. Because of the W_2C and WC phases hardness and wear resistance of WC-CO coatings were 8 times better than that of base metal and wear resistance of WC-CO coatings were 3 times better than that of base metal. WC-Co coatings exhibit low frictional force & porosity as compared to base metal.

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