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Sliding Wear Study of Flame Sprayed Co-Base Powder Coatings

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Abstract: Commercially available Co-base powder was modified with the addition of 10 wt. percentage WC which was further modified with 5 and 10 wt. percentage CrC addition in order to obtain three coatings namely Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC. The coatings were deposited by flame spraying process. The microstructure of these coatings mainly showed eutectic containing Co with almost same amount in three coatings. Other phases such as W dominated and Cr dominated carbides were also observed. The 10 wt. percentage CrC coating showed the highest Vickers hardness and lowest wear rate. The coefficient of friction was also observed low in the 10 wt. percentage CrC coating as compared with other coatings.

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1. INTRODUCTION

The deterioration of equipment parts, such as wear, corrosion, and high-temperature oxidation, usually begins at their surfaces when they work under high temperature, high pressure, and corrosive conditions. Surface engineering is a cost-efficient method for producing materials, tools, and machine parts that must resist severe wear conditions. Improvement of the surface properties by thermal spraying of a hard and wear resistant material is a commonly used industrial practice [1-3].

Various thermal spraying techniques can be used to achieve the best combination of coating and substrate properties for industrial applications. Nowadays, advances in thermal spraying make possible the replacement of bulk components in paper milling [4] or the replacement of chromium plating in aircraft manufacturing [5, 6] and automotive industry [7, 8]. Also the deposition of thermally sprayed coatings on critical parts in petroleum drilling [9] or on components in aero-applications such as fans and high-pressure compressors [10, 11] were successful using flame spraying, detonation gun spraying (D-Gun), high velocity oxygen fuel (HVOF), and atmospheric plasma spraying (APS).

In wear-resistant applications, the coated layer provides the resistance to wear, while the substrate supports the impact to which the system (coating and substrate) is subjected. Coating materials such as cobalt, iron and nickel base alloys with hard carbide particles (WC and CrC) are used to improve the wear resistance in various industrial applications [12-15].

Various researchers [16-18] studied the effect of varying amount of various types of carbides in Ni-base coating. The proportion of carbide particles in the nickel alloy matrix increases the microhardness of the coating, with the nickel matrix providing the desired toughness. The hardness of the alloy coatings also depends on microstructural parameters, such as fraction of soft matrix and type and fraction of carbide particles, size and shape of carbide particles and their stability, etc. Recently many studies [1-3, 12-16, 18-25] have been reported in the literature on the microstructure, microhardness, adhesive strength and adhesive wear behaviour of coatings with and without chromium carbide particles developed by different processes. Mateos *et al*. [20] investigated tribological properties of plasma sprayed and laser remelted 75/25 Cr_3C_2/NiCr coatings and reported that laser remelting improves the microstructure of the coatings, increases the coating microhardness, and improves coating-substrate adherence. Dent *et al*. [23] investigated microstructural aspects of a Ni-23.5Cr- 3.8Cu-0.8Fe-5.9Mo-3.4W-2.8B-4.3C alloy coating produced by high velocity oxy-fuel thermal spraying and found that the splat microstructures consisted of a Ni-rich metallic matrix containing a small fraction of $M_{23}C_6$ particles. Dawei *et al*. [25] studied laser clad coatings of Ni alloys as well as composites containing 50 wt. percentage Cr_3C_2 particles in Ni-Cr alloy and found increased

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Table 1: Chemical Composition (wt. %) of Substrate and Surfacing Powder

Elements (wt. percentage) → / Coating Powder ↓	C	Cr	W	Si	Fe	Co	Mn
Substrate	0.2-0.22	_	_	0.4-0.6	Bal.	_	0.4-0.8
Coating Powder	3.0-3.5	28-30	5-6	0.2-0.5	_	Bal.	0.5-0.7

hardness of the surface layer by 350-400 HV. The presence of undissolved Cr_3C_2 particles, the formation of dense dendrites surrounded by a fine eutectic containing carbide and borides which were found responsible for the strengthening of the composite coating.

Wang *et al.* [26] studied the performance of WC–Co coatings deposited by detonation gun spraying system. The results showed that the use of the separation device resulted in better properties of the D-gun sprayed WC–Co coatings in terms of lower the surface roughness, lower the porosity, higher the microhardness. Also, the tribological performance of the WC–Co coatings was improved. The relationship of surface roughness, microhardness and wear resistance of the WC–Co coatings was discussed.

The aim of the research carried by Sarjas [27] was to study properties of composite powders based on self-fluxing alloys and recycled cermets and to examine the properties of thermally sprayed (HVOF) coatings from composite powders based on iron self-fluxing alloy and recycled cermet powders (Cr_3C_2-Ni and WC-Co). The structure and composition of powders and coatings were estimated by SEM and XRD methods. Abrasive wear performance of coatings was determined and compared with wear resistance of coatings from commercial powders. The wear resistance of thermal sprayed coatings from self-fluxing alloy and recycled cermet powders at abrasion is comparable with wear resistance of coatings from commercial expensive spray powders and may be an alternative in tribological applications in cost-sensitive areas.

The literature did not reveal studies on the effect of WC and CrC addition in Co-base alloy coatings developed by flame spraying process on their microhardness and adhesive wear. Therefore, to fill up this gap, in the present study, attempts have been made to investigate the influence of WC and CrC particle addition on microstructure, microhardness and adhesive wear behavior of Co-base coatings deposited by flame spraying method on low carbon steel substrate.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Methods

The carbon steel substrate was used for coating deposition. The normal composition of substrate is shown in Table **1**. The substrate was degreased and roughened to an average surface roughness of Ra 4.05 μm (Rmax 18.5 μm). Surface roughness was measured by Mahr – Perthometer (M_2 409). The normal composition of the commercially available Co-base powder is shown in Table **1**. This powder was modified by adding 10 wt. percentage WC. The WC containing powder was further modified with 5 wt. percentage CrC and 10 wt. percentage CrC (chromium carbide). In this way three coating powders namely Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage +10 wt. percentage CrC were obtained. These coating powders were deposited by flame spraying process and corresponding coatings in further discussion were designated as Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings.

2.2. Porosity and Hardness of Flame Sprayed Coatings

The porosity was measured by the point counting method [13, 14]. The average of 25 areas of each coating has been used for porosity measurement. Vickers microhardness of the coatings was measured using a load of 100 g and average of ten readings of the coating was used for study purpose [16, 17].

2.3. Wear Test

Friction and wear tests were conducted on a pin-on-disk tribometer. This machine is capable of providing wear data and friction force at different sliding speeds and loads with respect to time and digital display devices are used for monitoring the various parameters. The load on the pin specimen is applied by dead weights supported at the end of a hinged horizontal arm. The wear weight loss was measured by electronic analytical balance [9].

The test pin of size 10x10x100 mm^3 was inserted in a pin holder and cleaned with acetone. The coated discs (cast iron) were ground to obtain a surface roughness, *R*a, between 0.6 and 0.8 μm. The pin holder and disk were then mounted in the machine and the disk was cleaned with acetone. A fresh disk surface was used for each test. After the load was applied, all display devices were balanced and the computer was turned on. Before starting the machine the radius of the pin (wear track radius) was set in order to obtain the desired sliding distance of 3000 m (50 minutes test duration). Next, the machine was turned on to obtain the desired speed and afterwards the load was applied. The constant sliding speed is 1 ms^{-1} and the normal load applied to the disc was 4, 8 and 12 N. The friction coefficient was computer-monitored during the test. Three tests were performed for each condition and the results reported as an average value. The COF was recorded after 10, 25 and 40 minutes during each test and average value is used for study. All tests were performed on pin-on-disc tribometer under dry sliding at room temperature (25 ^{0}C).

3. RESULTS AND DISCUSSIONS

3.1. Microstructure

The microstructure of Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings are shown in Figure **1a-c**. The microstructure of Co+10 wt. percentage WC coating mainly showed eutectic (phase “A”) and various types of carbide particles (phase “B” and “C”). The eutectic (phase “A”) mainly composed of Co, Ni Cr, W, Fe and C. EDAX analysis of eutectic (phase “A”) shows that is contains ≈30% Co, ≈ 24% Ni and ≈15% Fe along with other elements such as 8%Cr, 6%W and 5%C. From the EDAX analysis of various phases “B” and “C”, it was concluded that these phases primarily differ in terms of relative amounts of various elements such as W, Cr and Co etc. The phase “B” is W dominated and analysis of this phase shows 67%W, ~6% Co, ~7% Cr and ~7% Ni and 4%C (%wt). Cr dominated carbides

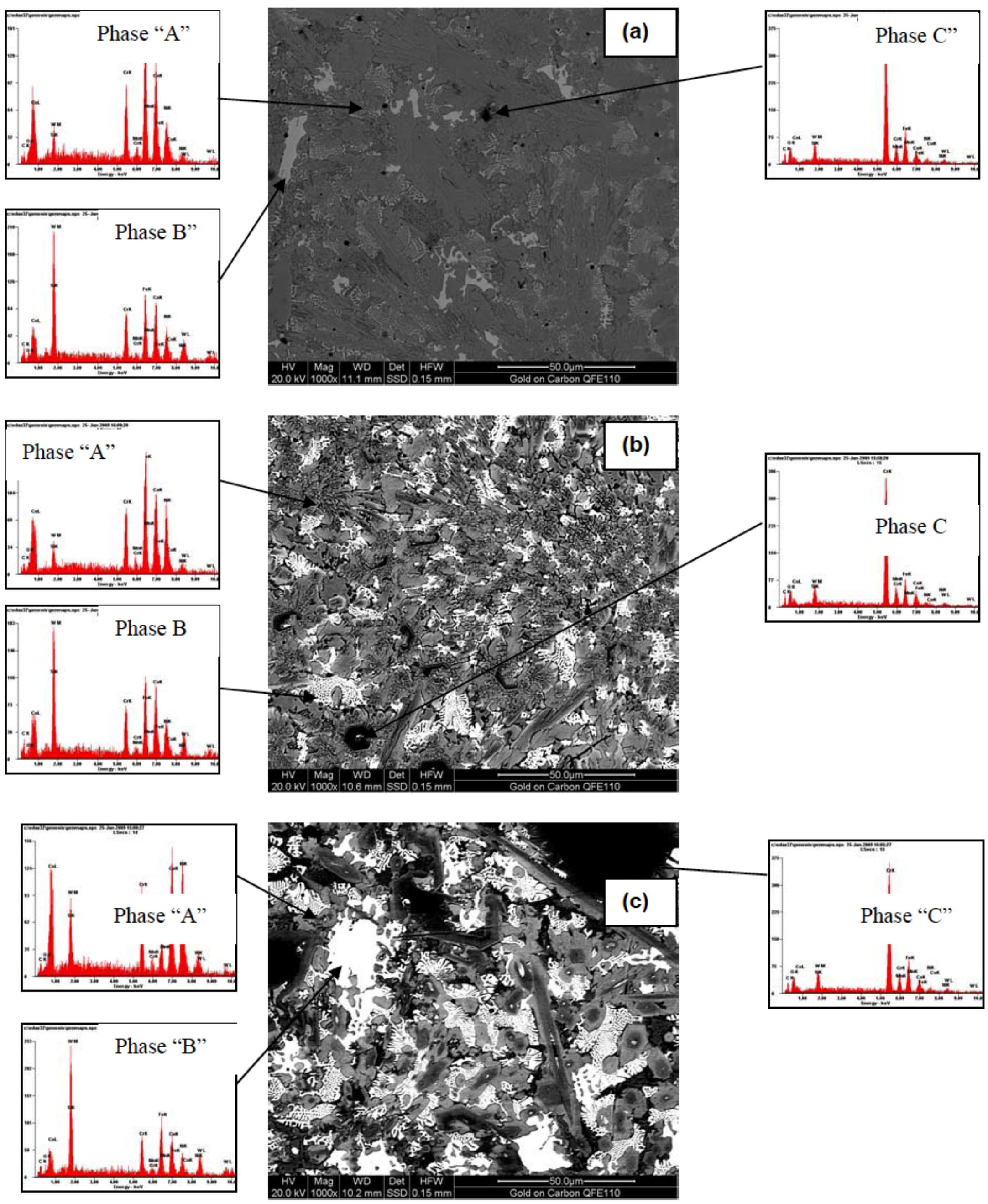

Figure 1: Microstructure and EDAX analysis of (**a**) Co+10%WC (**b**) Co+10%WC +5%CrC and (**c**) Co+10%WC +10%CrC.

(phase "C") are rich in Cr and contains ≈62%Cr, ≈13%W, ≈12%Co, ≈9%C and small amounts of Ni and Fe (<5%).

The wt. percentage of Co (30%) is same in the matrix in all the three coatings and it is uniformly distributed in the matrix. The wt. percentage of Cr increases (from 8-14 wt. percentage) with the increase of CrC addition. The other elements such as Ni, Cr and Fe are also uniformly distributed in the matrix. These results are in agreement with Shetty *et al*. that the matrix is rich in Co containing various types of carbides uniformly distributed in the matrix. Some carbide such as (Cr rich) appears darker in SEM images. This observation is also in line with the Shetty *et al*. [28].

In the Co+10 wt. percentage WC+5 wt. percentage CrC coating both types of carbides (W dominated – phase "B" and Cr dominated – phase "C") contains almost same compositions of various elements. But in Co+10 wt. percentage WC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings the W dominated carbides (phase "B") contains higher wt. percentage of W as compared to phase "C" which is Cr dominated carbides and also contains W. The carbides are not pure phases but also contain Ni, Co and Fe. This is in agreement with Chorcia *et al*. [29].

The alloy in this investigation is hypereutectic alloy and comprises various types of chromium-carbide in which some of the chromium may be replaced by cobalt and/or tungsten with a eutectic matrix containing the other constituents of the alloy. The higher hardness of Co+10 wt. percentage WC+10 wt. percentage CrC coating as compared to other two (Co+10 wt. percentage WC and Co+10 wt. percentage WC+5 wt. percentage CrC) is due to formation of intermetallic compounds [30, 31]. According to Lebaili [32] alloys that present the highest amount of chromium and carbon crystallizes Cr_7C_3 first. The hardness of Cr_7C_3 and carbides is reported as 17.7 and 9.9 GPa respectively.

3.2. Porosity and Hardness of Flame Sprayed Coating

The porosity of Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings were found to be 6.8%, 7.5% and 8.4% respectively. The Vickers hardness (Hv) of Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings was found 636±36, 691±56 and 726±72 respectively (Figure **2**). The average hardness of 10 wt. percentage chromium carbide coating was found higher (726 Hv) as compared to 0 wt. percentage chromium carbide (636 Hv) and 5 wt. percentage chromium carbide (691 Hv) coatings, however, there was more scatter in hardness of 10 wt. percentage chromium carbide coating as compared to 0 wt. percentage chromium carbide and 5 wt. percentage chromium carbide coatings may be due to higher porosity.

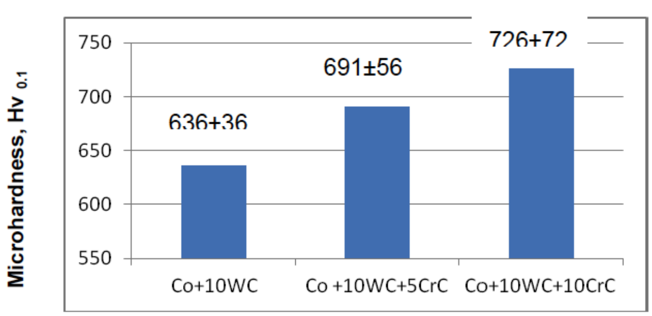

Figure 2: Microhardness of various coatings.

3.3. Friction and Wear Analysis

The wear and friction coefficient of Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings are shown Figure **3a-b**. The wear rate decreases with the addition of CrC in Co+10 wt. percentages WC coatings. The lowest wear rate was observed in 10 wt. percentage CrC coatings. This may be due to high hardness of the coating. The scanning electron microscope (SEM) images of the worn surfaces are shown in Figure **4a-c**. The worn surfaces show a combination of adhesive and abrasive wear mechanisms. The adhesive wear and friction coefficient depends mainly on material composition and counter-body combinations, surface topography and operating conditions (contact mode, normal load and sliding speed, etc.). The rapid initial increase after the start of the wear test may be due to initially high adhesive contact between the counter body and coating material or adsorbed layer. There after there is slight decrease in the adhesive wear which may be due to work hardening of the coating material under compressive stresses [33]. After some time, the wear rate becomes stable and during this stage, the wear debris may be generated. These wear debris may adhere to the coating material or with the counter body which may become loose and transferred as wear debris. If these wear debris are entrapped in between the counter body and coating material may cause abrasive wear also (Figure **4a-c**). This likely causes an increase in frictional force which in turn increases the friction coefficient again. In final stage, the process of newly generation and spallation of wear debris on the surface seems to reach steady-state [34].

For composite coating containing WC particles with high hardness protruding from the worn surface can bear more pressure on surface, thus effectively resist the micro-plowing and micro-cutting brought from counter body. Consequently, the composite coating shows higher wear-resistance. The abrasive nature of the tungsten carbide particles hinders the transfer of material between specimen and counter-body and consequently the severity of the contact is not widely altered. The abrasive properties of the hard tungsten carbide particles produce a large increase in the counter-body wear [35].

4. CONCLUSIONS

The following conclusions can be drawn from the present study:

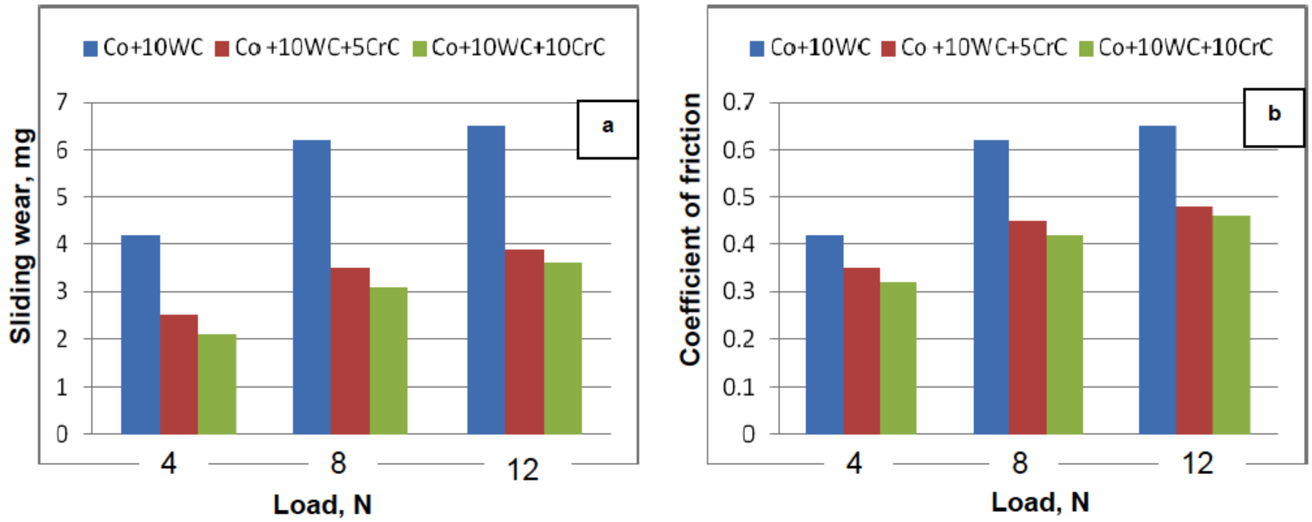

Figure 3: (**a**) Sliding wear as a function of load and (**b**) coefficient of friction as a function of load of various flame sprayed coatings.

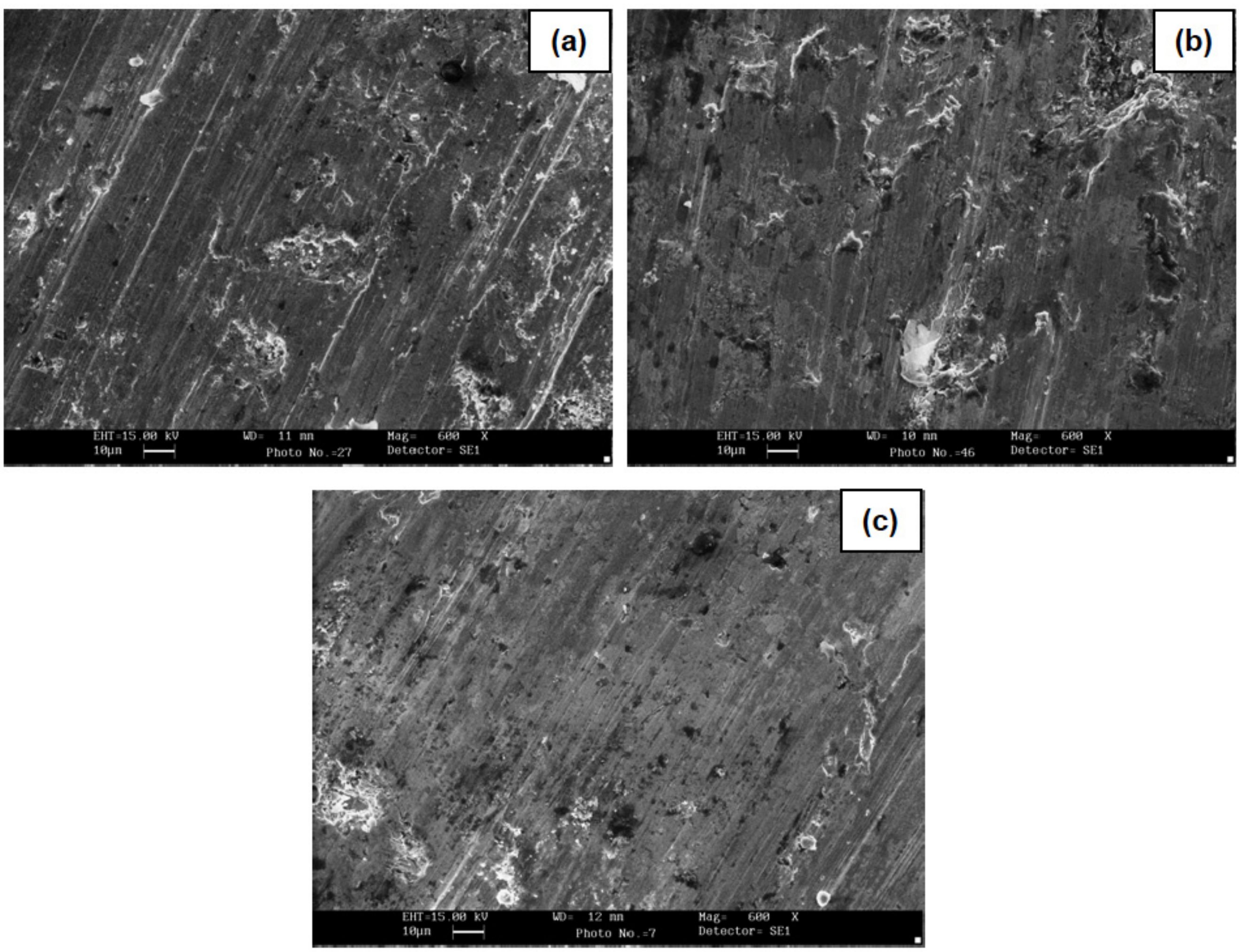

Figure 4: SEM images of worn surfaces of flame sprayed coatings at 8 N load (**a**) Co+10 wt. percentage WC, (**b**) Co+10 wt. percentage WC+5 wt. percentage CrC and (**c**) Co+10 wt. percentage WC+10 wt. percentage CrC coatings respectively.

1. The microstructure of Co+10 wt. percentage WC, Co+10 wt. percentage WC+5 wt. percentage CrC and Co+10 wt. percentage WC+10 wt. percentage CrC coatings mainly showed three different phases namely

eutectic, W dominated and Cr dominated carbides. The amount of Co in the eutectic of all the three coatings is almost same.

2. The Vickers hardness of the coatings increase with the increases in chromium carbide. The 10 wt. percentage CrC addition shows the highest hardness.

3. The 10 wt. percentage CrC coating showed the lowest adhesive wear which may be due to high hardness of this coating and a large increase in the counter-body wear.

4. The coefficient of friction initially increases rapidly but becomes stable after some time. The COF was also low in 10 wt. percentage CrC coating.

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