Wear behaviour of Cr3C2-25NiCr, WC-12Co and Al2O3-3TiO2 coatings deposited by Detonation spray process

(Wear)

Gurdip Singh
Research Scholar, (Mechanical Engg. Dept.)
Punjabi University
Patiala, Punjab(India)
Jocabean88@gmail.com, gurdeepgrewalmech@sus.edu.in

Rajan Verma
Research Scholar, (Mechanical Engg. Dept.)
Punjabi University
Patiala, Punjab(India)
Rajan.r.verma@gmail.com

***Abstract*—Wear is very severe problem in industry which leads economic loss to society. In the present research study, three coating powders, Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-$3TiO_2$, were deposited on AISI E52100 Bearing Alloy steel by the D-gun spray technique, in order to enhance its wear resistance. The as-sprayed coatings were characterized by XRD and SEM analyses. The sliding wear behaviours of the uncoated, D-gun sprayed Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-$3TiO_2$ coated AISI E52100 steel were investigated according to ASTM standard G99 on a pin-on disc wear test rig. Cumulative volume loss was calculated for the coated as well as the uncoated specimens for 30, 40, and 50N normal loads at a constant sliding velocity of 1 m/s. It has been observed that D-gun sprayed Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-$3TiO_2$ coatings can be useful in minimizing the wear problem of AISI E52100. These coatings were found to be successful in retaining their surface contact with the substrate after the wear tests. However, the D-gun sprayed Cr_3C_2-25NiCr coating will be recommended as a better choice to reduce the wear of AISI E52100 in comparison with WC-12Co and Al_2O_3-$3TiO_2$ coating.**

***Keywords*— Wear, Cr3C2-25NiCr, WC-12Co, Al2O3-3TiO2, Detonation spray process**

I. Introduction

Wear is a very common problem caused due to degradation of material such as wear of spindles, pulleys, ring, lappet hooks in textile machinery, bearings etc. The case study of ring (E52100) for wear has been selected as topic for research work. Due to abrasive wear, ring requires frequent replacement. Abrasive wear also results in production and economic loss as it increases the idle time of the machine to reposition it. Wear-related problems can be minimized mostly either by using high-cost wear resistant alloys/ metals that are better than the existing low-cost alloys, or by improving the wear resistance of the existing metals and alloys by surface modification. As wear is a surface phenomenon and occurs mostly at outer surfaces, it is more appropriate and economical to use the latter method than the former. Thermal spray techniques have been considered extensively to produce coatings for both performance and life enhancement of the engineering components [1]. Thermal spray coatings are used in a wide range of industries to improve the abrasive, erosive, and sliding wear of machine components. Detonation-gun (D-gun) spray, a variant of thermal spraying, is also a versatile technology, which is capable of achieving very high gas and particle velocities approaching 4–5 times the speed of sound. This process provides the possibility of producing high hardness coatings with significant adherence strength [2–4]. The D-gun process offers highest velocity (800–1200 m s−1) for the sprayed powders that are unattainable by the plasma and HVOF conditions [5–7]. The high active energy makes the powder closely conjoint the surface, and forms a layer with high strength, high hardness and good wear resistance [7-9]. This technology has been widely used in many fields, such as aviation, space flight, petroleum, metallurgy, and machinery industry [7, 10, 11].In the present study, the wear behaviour of Cr3C2-25NiCr, WC-12Co and Al2O3-3TiO2 coatings deposited by D-gun process has been compared. It has been determined from the literature review [12-20] that these coatings provide better resistance to wear. The outcome of the study can be useful to select an appropriate coating for wear applications.

II. EXPERIMENTAL PROCEDURE

A. Substrate Material

AISI E52100 Bearing Alloy steel has been chosen as substrate material in the current study. Composition of the substrate material was analyzed at Patiala Metallurgical Lab, Industrial Focal Point, Patiala, (Punjab). Table 1 shows the chemical composition (wt%) of AISI E52100. Small cylindrical pins of diameter 5mm and length 30mm were prepared from AISI E52100. These pins were required to perform pin-on-disc experiment at room temperature. The faces of the pins were

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ground on cylindrical grinding machine. Grinding was followed by polishing with 1/0, 2/0, 3/0, and 4/0 grades polishing papers.

Table 1 Chemical composition of AISI E52100

Element	C	Si	Mn	Cr	P	S	Ni
wt%	0.96	0.23	0.28	1.32	0.015	0.020	0.107

B. *Coating Formulation*

Three types of coating powders, Cr3C2-25NiCr, WC-12Co, and Al2O3-3TiO2 were chosen for detonation spray deposition on one of the flat surfaces of the pins. The coatings were deposited at Svx Powder M Surface Engineering Pvt. Ltd., Greater Noida, Uttar Pradesh, India, by using their commercial HVOF spray system. The process parameters were kept constant throughout the coating process. The spraying parameters adopted are presented in Table 2. Prior to the deposition of the coatings, the specimens were grit blasted using Al2O3 (mesh size 30) to thinly remove the metal surface layer and to create a rough contour on the surface necessary for the adhesion of the coatings. The blasted surfaces, with the surface roughness of about 8-10µm Ra, were then thermally sprayed with above said powders.

Table 2 Spray parameters employed for the D-gun coating

Parameters	Coatings		
	Cr3C2-25NiCr	WC-12Co	Al2O3-3TiO2
Flow rate of Fuel gas (Oxygen)	2640 LPM	2960 LPM	5040 LPM
Flow rate of Fuel gas (Acetylene)	2320 LPM	2400 LPM	2160 LPM
Flow rate of Carrier gas (Nitrogen)	960 LPM	720 LPM	720 LPM
Stand-off distance (mm)	165	165	175
Coating thickness (microns)	200-250	200-250	200-250

C. *Characterization of as-sprayed Coatings*

Surface morphology of the as-sprayed coatings was studied with the help of a Field Emission Scanning Electron Microscope (JSM 6610LV, JEOL) available at SEM lab, Sophisticated Instrument Centre, Punjabi University Patiala (India).

D. *Wear Test*

Wear tests were conducted on uncoated and detonation gun sprayed specimens using a pin-on-disc machine (Wear and Friction Monitor Tester TR-201) conforming to ASTM G99 standard. Wear tests were performed on the pin specimens that had flat surfaces in the contact regions and rounded corners. The pin was held stationary against the counter face of a rotating disc made of En-31 plain carbon steel of 60mm track diameter. This counter face was case hardened at 62–65 HRC as provided with the pin-on-disc machine. The pins were polished with emery paper while both the disc and pin were cleaned and dried before carrying out the test. The pin was loaded against the disc through a dead weight loading system. The wear tests for coated as well as uncoated specimens were conducted under the normal loads of 30, 40, and 50N and a fixed sliding velocity of 1 m/s. The track radii for the pins were kept at 60mm. The speed of rotation of the disc for all the cases was adjusted so as to keep the linear sliding velocity at a constant value of 1 m/s. A variation of ±5 r/min was observed in the rotation of the disc. Wear tests were carried out for a total sliding distance of 5400m, such that only the top-coated surface was exposed to each D-gun-sprayed sample. After each cycle, the specimen was removed from the holder, cooled to room temperature, brushed lightly to remove lose wear debris, weighed, and fixed again in exactly the same position in the holder for the next cycle, so that the orientation of the sliding surface remains unchanged. Weight losses for pins were measured after each cycle to determine the wear loss. All weight measurements were carried out on a 0.1mg precision balance.

The wear volume loss data for the coated as well as uncoated specimens were reported with respect to cumulative time to establish the wear kinetics. The wear volume loss for the coated and uncoated materials were obtained by

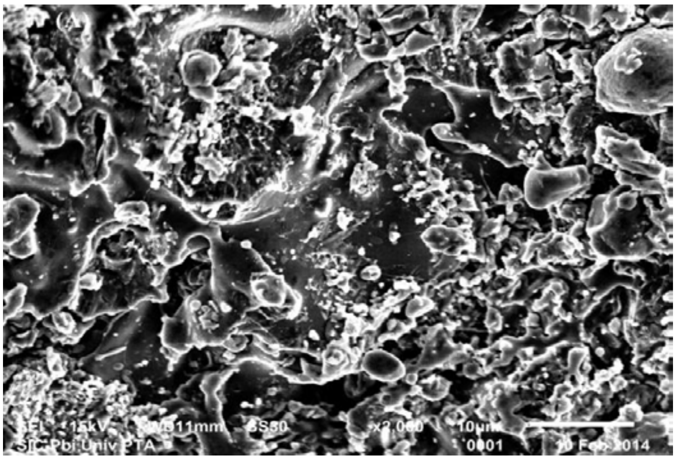
$$W = \frac{\delta w}{\rho}$$

Where W is the Wear Volume Loss, δw is the weight loss in, gm and ρ is the density of material, gm/mm^3.

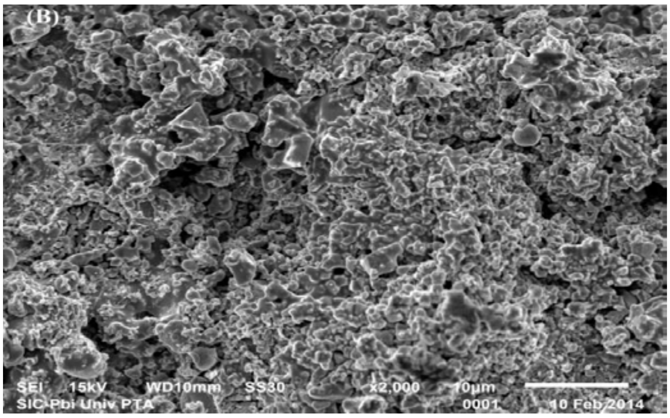
III. RESULT AND DISCUSSION

A. *Characteristics of as-sprayed coatings*

SEM micrographs showing the surface morphology of the as sprayed Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-3TiO_2 coatings on E52100 are shown in Figure 4. The microstructures for all the cases revealed the presence of splats, surrounded by the splat boundaries. The splats are irregular in shape for all the cases. The WC-12Co coating has small size splats whereas the splats are coarse for Cr_3C_2-25NiCr and Al_2O_3-3TiO_2.



(a)



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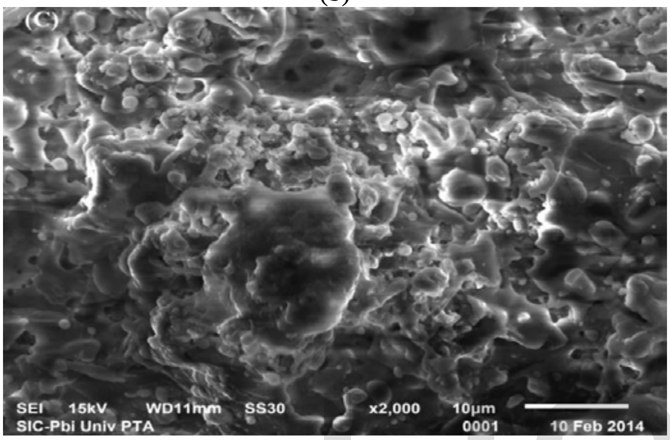


(c)

Figure 4: Surface Morphology on as coated E52100: (a) Cr_3C_2-25NiCr (b) WC- 12Co (c) Al_2O_3-3TiO_2

B. *Comparative Wear Behaviour for three coatings*

The comparison of wear loss for three coatings; Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-3TiO_2 on E52100 at 30N, 40N and 50N is shown in Figure 5, 6 and 7. It is observed from the results in Figures 5, 6 and 7 that the three coatings; Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-3TiO_2 have shown better wear resistance as compared to E52100 substrate material. From the bar chart, it is clear that that Cr_3C_2-25NiCr is showing almost negligible cumulative volume loss as compared to other two coatings. Cr_3C_2-25NiCr coating has minimum effect of load for CVL. In the cycle CVL for all the coating is almost same. But as the duration of cycle increases, the CVL for Al_2O_3-3TiO_2 increases rapidly as compared to Cr_3C_2-25NiCr and WC-12Co. Therefore the wear resistance of Detonation sprayed coatings on E52100 in their decreasing order can be given as Cr_3C_2-25NiCr > WC-12Co > Al_2O_3-3TiO_2 which means that Cr_3C_2-25NiCr coated substrate is most wear resistant among the four substrates

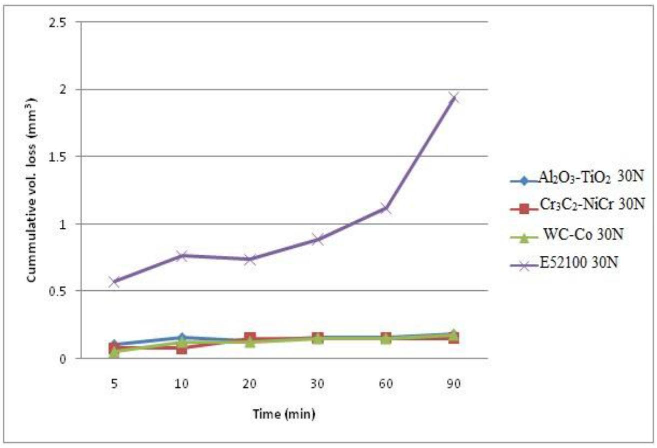


Figure 5: Cumulative Volumetric Wear Loss (mm^3) for three coatings on E-52100 substrate at 30N

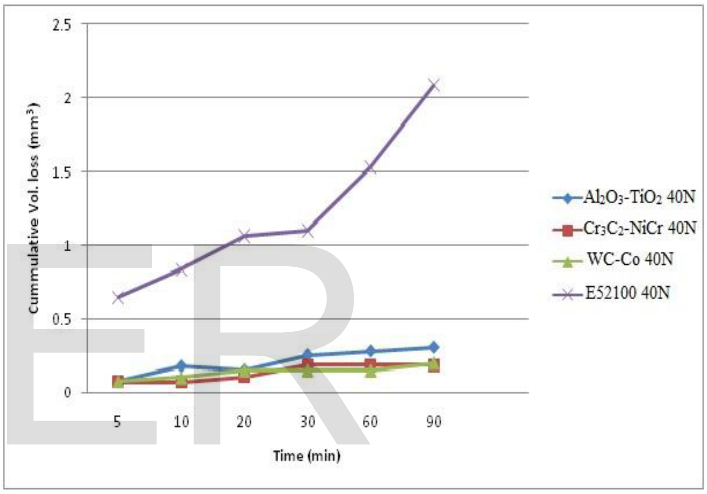


Figure 6: Cumulative Volumetric Wear Loss (mm^3) for three coatings on E-52100 substrate at 40N

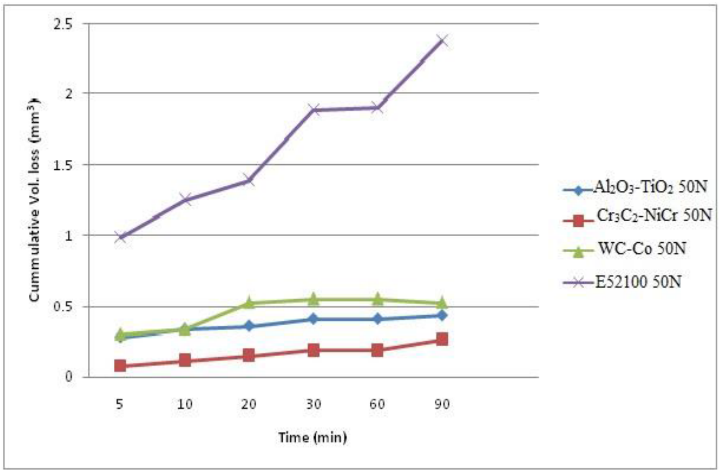


Figure 7: Cumulative Volumetric Wear Loss (mm^3) for three coatings on E-52100 substrate at 50N

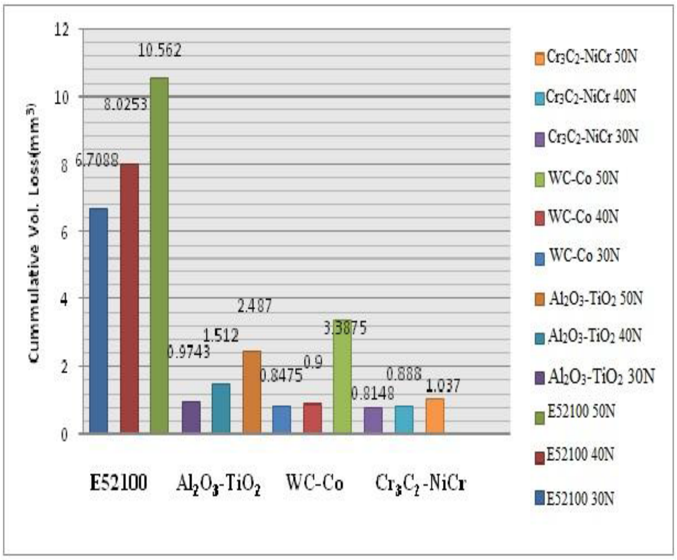
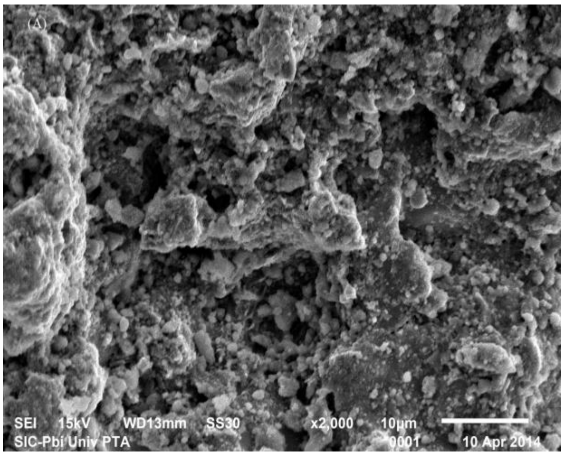


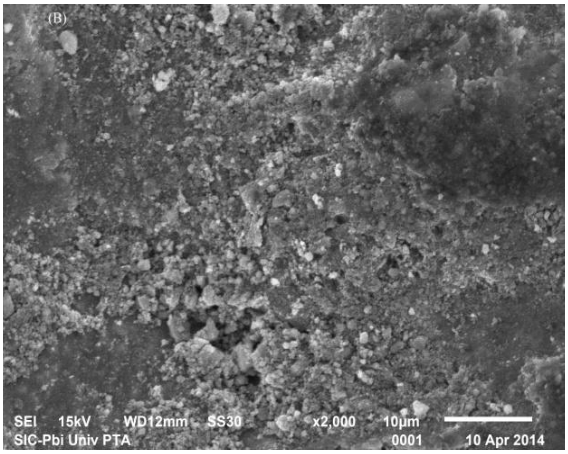
Figure 8: Cumulative Volume loss (mm^3) in one cycle for D-gun sprayed coatings and bare E-52100 at 30N, 40N, and 50N

C. *SEM Analysis after Wear test*

The surface morphology analysis of the worn surfaces for (a) Cr_3C_2-25NiCr (b) WC-12Co (c) Al_2O_3-3TiO_2 coated specimens at a normal load of 50N are shown in Figure 9. After the wear of the material, microstructure figure clearly show the presence of wear tracks on the surfaces. The surfaces have become rougher with unidirectional growth of the structure, probably along the direction of rotation. Further, it looks like the surface has lost the material in the form of microchips, probably due to ploughing of the surface by the wear debris between the contact surface of the pin and the disc.



(a)



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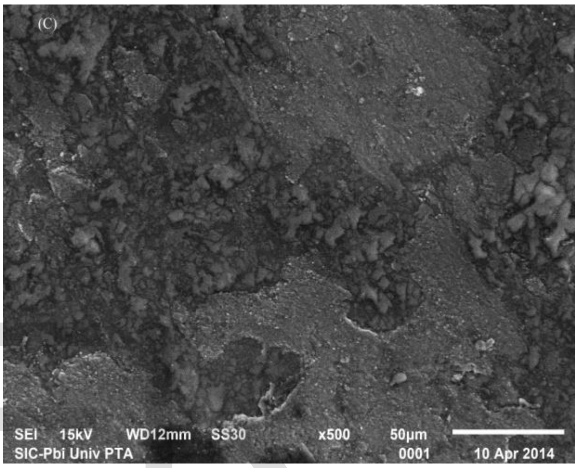

(c)

Figure 9: Surface Morphology on as coated E52100 after wear: (a) Cr_3C_2-25NiCr (b) WC- 12Co (c) Al_2O_3-3TiO_2

IV. *CONCLUSIONS*

1. Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-3TiO_2 coatings have successfully been deposited on E52100 Bearing alloy steel by detonation spray coating.
2. SEM analysis revealed splat morphology with distinct boundaries for the as-sprayed coatings, which is a characteristic feature of thermal sprayed coatings.
3. The coatings were found to be successful in keeping their surface contact with the substrate AISI E52100 when subjected to wear tests.
4. Cumulative volume loss for D-gun sprayed Cr_3C_2-25NiCr, WC-12Co and Al_2O_3-3TiO_2 coated as well as uncoated E52100 specimens increases with increase in load.
5. The Cr_3C_2-NiCr coating has shown minimum cumulative volume loss among all the three coatings. The wear resistance of the coatings in their decreasing order (at 30N, 40N & 50N) is Cr_3C_2-25NiCr > WC-12Co > Al_2O_3-3TiO_2.

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