ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Wear Behaviour of Thermal Spray Coating Process on Carbon Steel

[1]Rakesh Goyal, [2]Kamaljeet Singh, [3]Shivali Singla
[1,2]Chitkara School of Mechanical Engineering, Chitkara University, Rajpura, Punjab, India
[3]Dept. of Mechanical Engineering, B.H.S.B.I.E.T., Lehragaga, India

Abstract
Detonation gun spray coatings have been used to enhance the wear resistance of carbon steels. Alloy powder coatings WC – 10Co -4Cr and Al_2O_3-13TiO_2 have been used as coating powder to deposit on the substrate steel specimens with this process. After wear behaviour was investigated on a Pin –On –Disc Wear Test Rig. The wear performance of WC – 10Co -4Cr was found to be better than the Al_2O_3-13TiO_2 coating. It has been concluded that alloy powders WC – 10Co -4Cr and Al_2O_3-13TiO_2 deposited with the help of detonation spray process have been found very useful to minimize the wear problem of carbon steels.

Keywords
Detonation Gun Spray, Wear, Pin-on-Disc Rig, CWR

I. Introduction
Wear and Friction are responsible for many problems and large costs in a modern civilization and engineers and designers always must take these factors into account when constructing different equipments [1]. The economic losses due to friction and wear amount to about 1 to 2.5% of the gross national product [2]. In year 2002, More than 50 % of all wear-related failures of industrial equipment are caused by abrasive wear. The estimated costs of abrasive wear are between 1 and 4 % of the gross national product of an industrialized nation. [3].
When two surfaces rub against each other, wear occurs. Individuals and industry tend to focus on the wearing surface that has the greatest impact on their own economic situation. Therefore, as the wear is a surface phenomenon and occurs mostly at outer surfaces, therefore it is more appropriate and economical to use latter method of making surface modification i.e. surface engineering than using the former one [4].
Surface engineering is an economic method for the production of materials, tools and machine parts with required surface properties such as wear resistance. The wear process of rollers is integrally affected by various factors such as abrasive wear, oxidation wear, cracking by thermal fatigue, heat impact, fatigue wear and sticking of rolled material onto the roller surface. Wear also involves microscopic and dynamic processes occurring at interfaces between the roller and the rolled material and is almost impossible to observe directly [5].

A. Methods to Reduce Wear Resistance
Although wear cannot be eliminated completely, yet it can be reduced to some extent by different wear prevention methodologies. Few of such methods are stated below [6]:
1. Better Material
2. Lubrication
3. Contact pressure
4. Temperature
5. Environment
6. Maintenance
7. Coatings

Based upon the above said techniques to reduce the wear problem in machinery parts, coating is the preventive method and optimum technique, which is mostly used in practical field of application.

B. Coating Technique
A coating can be defined as a layer of material, formed naturally or synthetically or deposited artificially on the surface of an object made of another material, with an aim of obtaining required technical or decorative properties [7]. If a material is added or deposited onto the surface of another material (or the same material), it is known as a coating. Coatings are frequently applied to the surface of materials to serve one or more of the following purposes [8]:
1. To protect the surface from the environment that may produce corrosion or other deteriorative reactions such as wear.
2. To improve the surface's appearance.

C. Thermal Spray Coatings
Thermal spraying was first discovered and used in the beginning of last century and research in this field progressed ever since. The recognized beginning of Thermal Spraying is believed to be in 1911 in a flame spray process that was developed by Dr. Max Schoop from Switzerland. Other major thermal spray processes include wire spraying detonation gun deposition, plasma spray, and high velocity oxygen Fuel [9].

D. Detonation Gun Spray Coating Process
D-gun spraying is one of the most promising thermal spray techniques and was originally developed and patented by Union Carbide (now Praxair) Since then, the D-gun coating process has been used for wide applications such as in the aircraft industries of the United States, Japan, and the former Soviet Union [9].
A detonation gun consists of a water cooled barrel several feet long and about one inch in diameter with some associated valving for gases and powder, as shown schematically in fig. 1 [10]. A carefully measured mixture of gases, usually oxygen and acetylene, is fed to the barrel along with a charge of powder (usually with a particle size less than 100 microns). A spark is used to ignite the gas and the resulting detonation wave heats and accelerates the powder as it moves down the barrel.

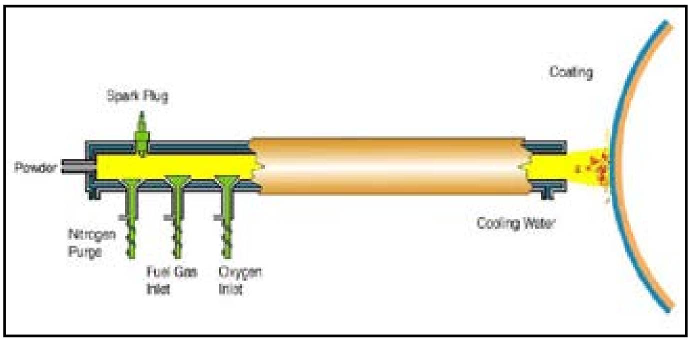


Fig. 1: Schematic Diagram of the D-gun Spray Process [10]

II. Experimental Setup

A. Selection of the Substrate Material

Selection of the substrate material for the present study has been made on the basis of applications for bulldozer rollers. The chosen material is MS. Table 1 shows chemical composition of the MS substrate steel.

Table 1: Chemical Composition (Wt %) of the MS Substrate

	C	Mn	P	S	Si	Ni	Cu	Fe
MS	0.40	1.03	0.027	0.01	0.31	0.13	0.22	Balance

B. Deposition of Coatings

1. Preparation of Substrate Material

Small cylindrical pins having circular cross-section of 8 mm diameter and length 30 mm were prepared from MS material. These pins were required to perform pin-on-disk experiment at room temperature. The faces of the pins were grinded, followed by polishing with emery papers down to 1000 grit. Fig. 2 shows sketch of the pin prepared for the wear study.

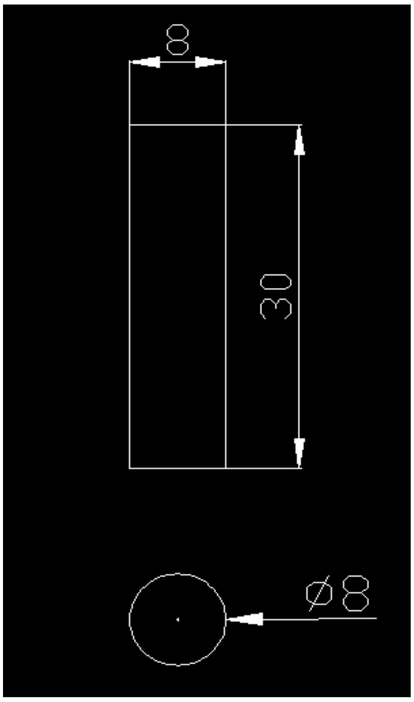


Fig. 2: Sketch of Pin (specimen) used for Pin-on-Disc wear test

2. Thermal Spray Powders for Coatings

Two types of coating powders namely (1) Tungsten Carbide (WC) + (10%) Cobalt (Co) + (4%) Chromium (Cr), (2) Aluminum Oxide (Al_2O_3) + (13%) Titanium Oxide (TiO2) was chosen for detonation spray deposition on the MS substrate specimens. The particle size for both these powders was 25µm ± 10µm.

3. Formulation of the Coatings

The WC – 10Co -4Cr and Al_2O_3-13TiO_2 powders were successfully deposited on MS substrate steel by the detonation spray process. The coatings were deposited at SVX Powder M Surface Engineering Private Limited, Greater Noida, UP, India.

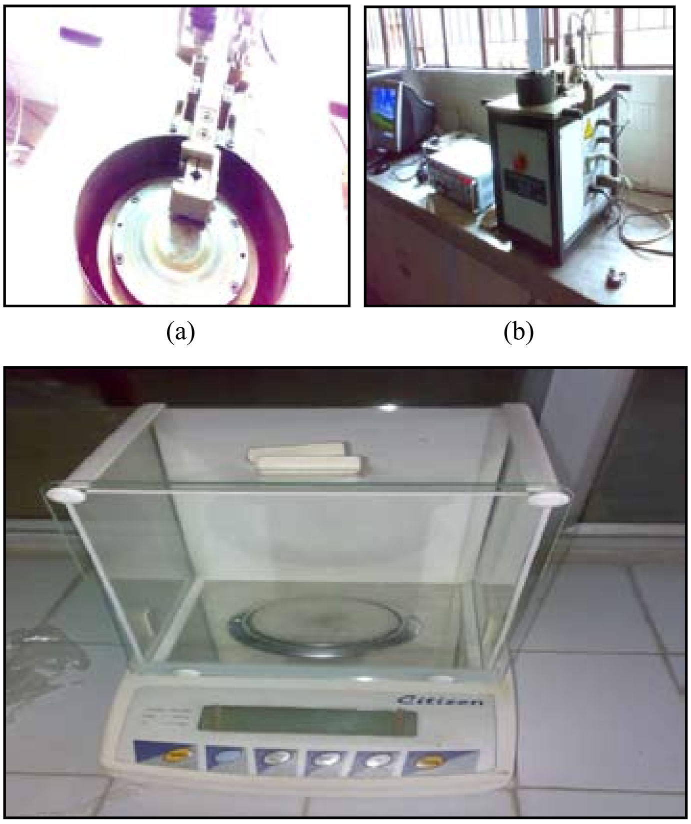
4. Measurement of Coating Thickness

The thickness of coatings was monitored during the processes of detonation spraying with a thickness gauge; Minitest-2000 made in Germany. Efforts were made to obtain coatings of uniform thickness. A uniform thickness coating of 250 µm ± 10 µm was deposited in all the cases of WC – 10Co -4Cr and Al_2O_3-13TiO_2 powders for MS substrate steel.

D. Wear Studies Using Pin- On -Disc Wear Test Rig

1. Experimental Set Up

Dry sliding wear tests for the uncoated and detonation sprayed MS, were conducted using a pin- on –disc machine [Model: Wear and Friction Monitor Tester TR-20].Some photographs of the set up of the machine are shown in fig. 3. The tests were conducted in air having relative humidity in range from 40 to 75 %. Wear tests were performed on the pin specimens that had flat surfaces in the contact regions and the rounded corner.



(a) (b)

(c)

Fig. 3(a): Pin-on-disc Wear Test Machine (b) Control Unit With Computer Interface (c) Weighing Apparatus

The pin was held stationery against the counter face of a rotating disc made of En-32 steel at 40 mm track diameter. En-32 steel is a plain carbon steel; case hardened 62 to 65 HRC as provided with the pin-on-disc machine. The composition of the material of the steel disc is given in Table 2.

Table 2: Chemical Composition (Wt %) of the En-32 steel disc

C	Si	Mn	S	P
0.42 (max)	0.05-0.35	0.40-0.70	0.05 (max)	0.05 (max)

2. Sliding Wear Studies

The pins were polished with emery paper and both disc and the pin were cleaned and dried before carrying out the test. The pin was

ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

loaded against the disc through a dead weight loading system. The wear test for coated as well as uncoated specimens was conducted at constant velocity i.e. at 1 ms-1 and at different loads i.e. 50N, 60N and 70N. The track radii for the pins were kept at 40 mm. The speed of the rotation (478 rpm) of the disc for all the cases was so adjusted to keep the linear sliding velocity at a constant value of 1 m/s. A variation of ± 5 rpm was observed in the rpm of the disc. Wear tests have been carried out for a total sliding distance of 5400 m, so that only top coated surface was exposed for each detonation sprayed sample. Weight losses of each sample were measured after 5, 5, 10, 10, 20, 40 minutes to determine the wear loss. The pin was removed from the holder after each run, cooled to room temperature, brushed lightly to remove lose wear debris, weighed and fixed again in exactly the same position in the holder so that the orientation of the sliding surface remains unchanged. The weight has been measured by a micro balance to an accuracy of 0.001 g.

(i). Wear Kinetics

The wear rate data for the coated as well as uncoated specimens were plotted with respect to sliding distance to establish the wear kinetics. The specific wear rates for the coated and uncoated material were obtained by W = Δw/ LρF, Where W denotes specific wear rates (Bowden) in mm3/N-m, Δw is the weight loss measured in g, L the sliding distance in meters, ρ the density of the worn material in g/ mm^3 and F the applied load in N.

IV. Results and Discussion

The uncoated MS steel as well as detonation spray of Wc–10Co-4Cr, Al_2O_3-13TiO_2 coated specimens were subjected to standard wear testing on a pin-on disk apparatus [11] as per the procedure explained. The wear test was done at load of 50N, 60N and 70N at a constant sliding velocity of 1 m/sec. The variation of cumulative wear rate sliding distance has been discussed in the subsequent sections for the various cases under investigation.

A. Wear Behaviour

(i). Wear Behaviour of Two Coatings (Wc–10Co-4Cr and Al_2O_3-13TiO_2) and uncoated MS Steel

The variation of the cumulative wear rate with the sliding distance for the detonation spray Wc–10Co-4Cr, Al_2O_3-13TiO_2 coated and uncoated MS steel at a normal load of 50N, 60N and 70N has been plotted in fig. 4, whereas the Cumulative Wear Rate (CWR) data has been shown in fig. 5. Plots clearly show that the uncoated MS steel specimen has shown much higher wear rates as compared to its coated counterparts.

Furthermore, the CWR after a total sliding distance of 5400 m for all these cases have been shown in fig. 5. The bar chart also reveals the same that the CWR for uncoated MS steel specimen at 50N, 60N and 70N shows significant wear whereas it has been decreased significantly after the application of different coatings. Therefore it can be concluded that at various loads of 50N, 60N and 70N, the detonation sprayed WC – 10Co -4Cr coating has shown considerable wear resistance as compared to the Al_2O_3-13TiO_2 coated specimens and uncoated MS steel.

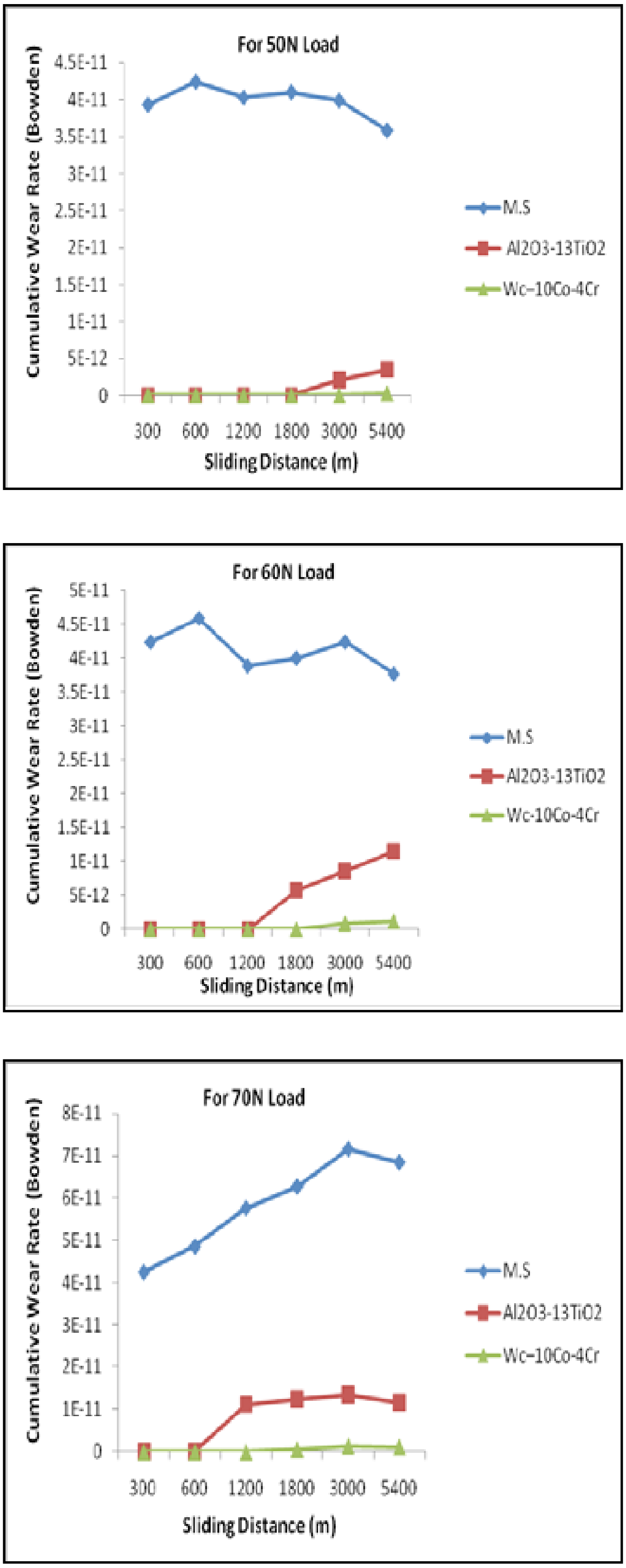
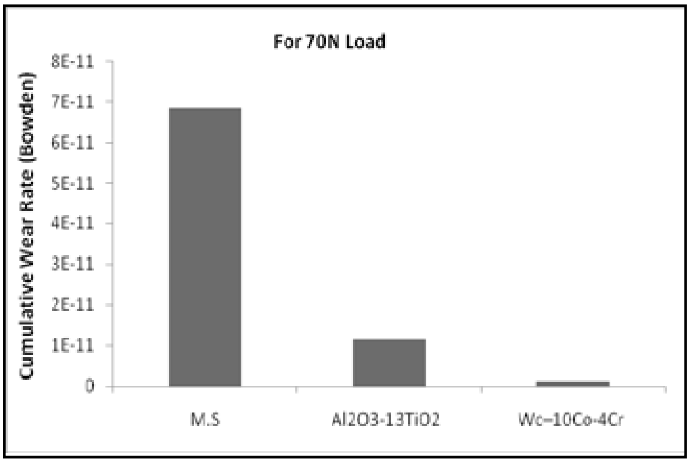
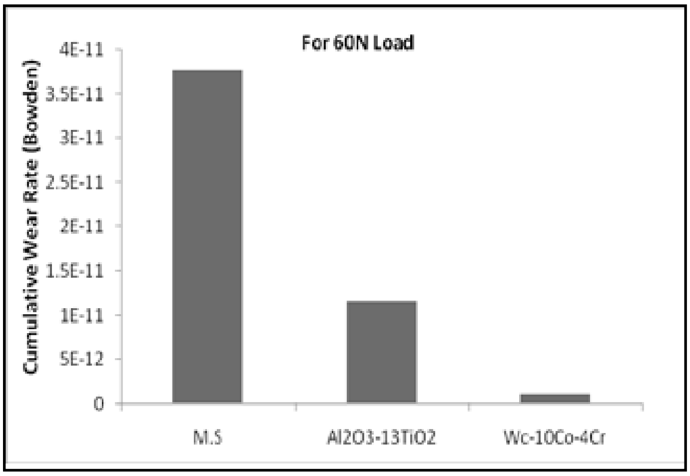


Fig. 4 Variation of Cumulative Wear Rate for uncoated and detonation sprayed coated MS at normal load of 50N, 60N and 70N at sliding velocity of 1m/sec.





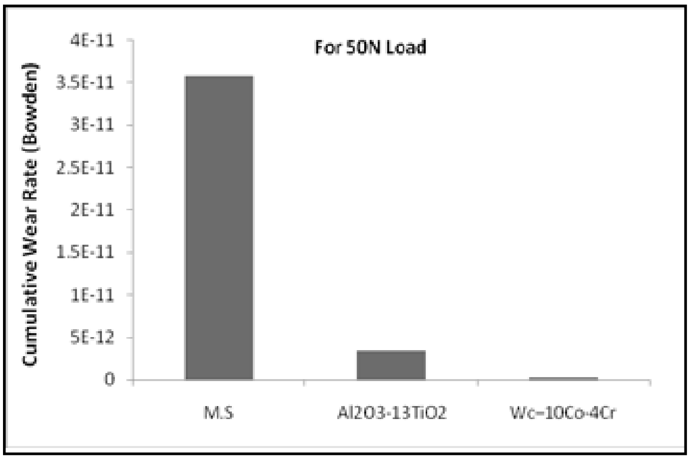


Fig. 5: Bar Chart Shows Cumulative Wear Rate for Uncoated and Detonation Sprayed Coated MS at Normal Load of 50N, 60N and 70N and Sliding Velocity of 1m/sec After Sliding Distance of 5400 Meter

V. Conclusion

1. Improvement in wear resistance of MS was observed after the deposition of detonation sprayed Al_2O_3-13TiO_2 and WC – 10Co -4Cr coatings.
2. WC – 10Co -4Cr coating has better wear resistance than that of Al_2O_3-13TiO_2 coatings.
3. The wear resistance for all the investigated cases at the normal load of 50N and at sliding velocity of 1m/sec followed the trend given below:
   WC – 10Co -4Cr coated MS > Al_2O_3-13TiO_2 coated MS >Bare MS
4. Detonation spray process provides the possibility of deposition of Al_2O_3-13TiO_2, WC – 10Co -4Cr powders on the MS steel. A uniform coating thickness of 250+10 micrometer was achieved.

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