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Sliding Wear Performance of Thermally Sprayed Coatings of Al_2O_3-$13TiO_2$ on MS Substrate using D-Gun

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Abstract-*In this paper, it has been proposed to find out the wear resistance of D-Gun coated MS. The specimens are coated with Al_2O_3-$13TiO_2$ on the steel substrates. The coating was characterized by the SEM/EDS analysis. Subsequently the wear behaviour of the uncoated, Al_2O_3-$13TiO_2$ coated MS was investigated according to ASTM Standard G99-03 on a Pin-on-Disc Wear Test Rig. Cumulative wear rate, cumulative wear volume loss were calculated for the coated, as well as, the uncoated specimens for 30N, 50N and 70N normal loads.*
The as-sprayed coatings exhibited typical splat morphology. It has been concluded that the thermal sprayed Al_2O_3-$13TiO_2$ coating can be very useful to minimize the wear problem of substrate steel plates. The coatings were found to be adherent to the substrate steel after the wear tests.

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 The economic losses due to friction and wear amount to about 1 to2.5% of the gross national product.
Degradation of material by wear cost a very high loss whether it is of reputation or economic loss to all the countries (Steffens & Nassenstein, 1993). Studies on wear failures have shown that the wear of materials costs the U.S. economy about $20 billion per year (in 1978 dollars) (Surface Engineering for corrosion and wear resistance, ASM International). 40% of total US steel production is being utilized for the replacement of wastage due to wear and corroded parts and products used in manufacturing industry.
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. 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 and 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 almost impossible to observe directly (Gu¨lenc & Kahraman, 2003).

1.1 Reduce Wear

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 (Srivastava, 2001):

- Better Material
- Lubrication
- Contact pressure
- Temperature
- Environment
- Maintenance
- Coatings

Based upon the above techniques to reduce the wear problems, coating is best preventive method.

1.3 Coating

A coating can be defined as a layer of material, formed naturally or synthetically or deposited artificially on the surface of an object made oanother material, with an aim of obtaining required technical or decorative properties (Burakowski and Wierzchon, 1999). 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 (Stokes, 2003):

- To protect the surface from the environment that may produce corrosion or other deteriorative reactions such as wear.
- To improve the surface's appearance.

1.4 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 (invented by R.M. Poorman, H.P. Sargent, and H. Lamprey and patented in 1955), plasma spray (invented by R. M . Gage, O. H. Nestor, and D. M. Yenni and high velocity oxygen Fuel (Tucker, 1994).

1.5 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 (Kharlamov, 1987**;** Kadyrov et al., 1995; Ma et al., 1999; Tucker, 1974).

A detonation gun consists of a water cooled barrel several feet long and about one inch in diameter with some associated valuing for gases and powder, as shown schematically in Fig. 1 (Rao et al., 1986). 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.

Detonation gun coatings thus consist of multiple layers of densely packed, thin lenticular particles tightly bonded to the surface. Primarily because of their high density and high bond strength, Praxair Surface Technologies' D-Gun coatings become the standard of excellence for thermal spray coatings.

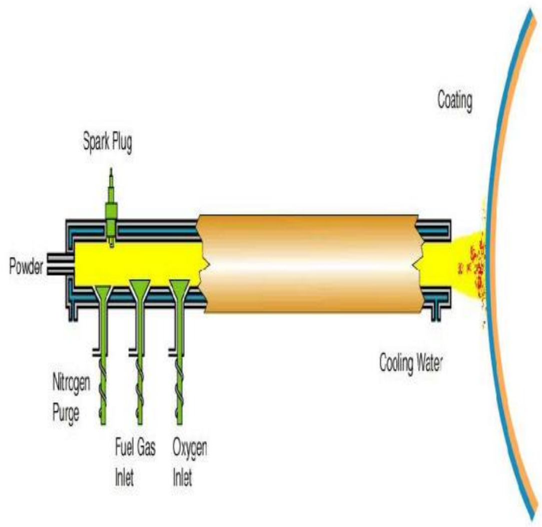


Fig.1 Schematic diagram of the D-gun spray process.

II. EXPERIMENTAL PROCEDURE

2.1 Selection of The Substrate Material

The Selection substrate materials for the present study has been made on the basis of applications in nuts, fasteners. The chosen material is low carbon steels, designated as mild steel MS. Table 1 shows chemical composition of the MS.

Table 1 Chemical composition (Wt %) of the MS

	C	Mn	Si	P	Pb	Cr	Cu	Mo
MS	0.21	0.29	0.092	0.039	0.028	0.081	-	-

2.2 Preparation of Substrate Material

Small cylindrical pins having circular cross-section of 8 mm dia and length 50 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. Figure 2 shows sketch of the pin prepared for the wear study.

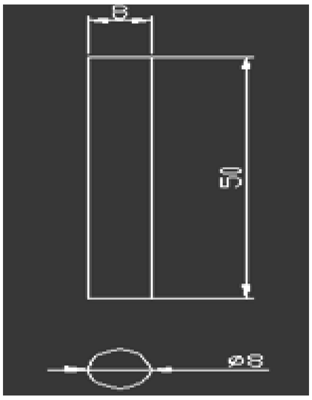


Fig. 2 Sketch of pin (specimen) used for pin-on-disc wear test

2.3 Thermal Spray Powders for Coatings

The coating powder namely Aluminum Oxide (Al_2O_3) + (13%) Titanium Oxide (TiO_2) was chosen for detonation spray deposition on the substrate specimens. The particle size for the powder was 25 µm ± 10µm.

2.4 Formulation of The Coatings

The Al_2O_3-13TiO_2 powders was successfully deposited on MS substrate steels by the detonation spray process. The coatings were deposited at SVX Powder M Surface Engineering Private Limited, Greater Noida, UP, India spray process.

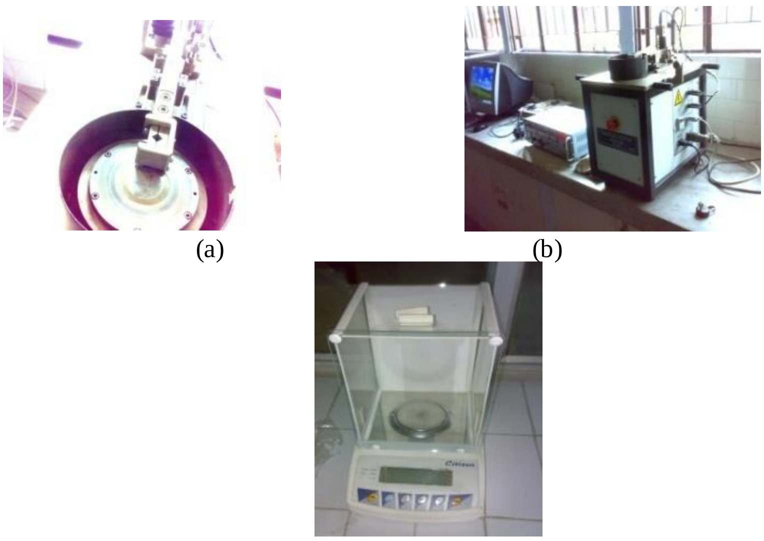
2.5 Measurement of Coating Thickness

The thickness of coatings was monitored during the process 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 Al_2O_3-13TiO_2 powders for all the substrate steel specimens.

III SLIDING WEAR STUDIES USING PIN- ON -DISC WEAR TEST RIG

3.1 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. The pin was held stationery against the counter face of a rotating disc made of En-32 steel at 60 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 .



(a) (b)

(c)

Fig.3 (a) Pin-on-disc wear test machine (b) Control Unit with computer interface
(c) Weighing apparatus. (Courtsey-G.Z.S.C.E.T.,Bathinda).

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)

3.2 Sliding Wear Studies

The uncoated as well as coated specimens were prepared for sliding wear studies as describe in the section . 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 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. The coefficient of friction has been determined from the friction force and the normal loads; only pre-calibrated dead loads were used.

3.3 Analysis for Sliding Wear Study

All the specimens subjected to sliding wear were analyzed for the characterization of wear surfaces. The worn surfaces of the specimen have been examined under the scanning electron microscope using JEOL Scanning Electronic Microscope (Model: JSM-840) at IIT, Ropar (INDIA).

3.4 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

$$W = \Delta w / L\rho F$$

Where W denotes specific wear rates in, mm^3/N-m
Δw is the weight loss measured in, g
L the sliding distance in, m
ρ the density of the worn material in g/ mm^3 and
F the applied load in N.

3.5 Wear Volume

The wear volume loss was also calculated from the weight loss and density of the material for all the investigated cases. These data were reported in the form of plots showing the cumulative wear volume loss v/s sliding distance for all the cases. Bar charts were also drawn to show net wear volume loss for all the cases.

$$\text{Volume} = \text{mass} / \text{density}$$

Wear Volume Loss = $(w/9.81)/\rho$
Where w is the weight loss in, g
and ρ is the density of material, g/mm^3

IV. RESULT AND DISCUSSION

MS steel is deposited by these coating. The usefulness of these coatings with regard to wear protection was investigated with the help of Pin-on-Disk Wear Test Rig according to ASTM Standard G99-03 as has already been stated. The uncoated MS steel showed higher cumulative wear rate, as well as, cumulative wear volume loss in comparison to their detonation sprayed Al_2O_3-13TiO_2 coated MS specimens under the normal load of 50N, 60N and 70N.

V. WEAR BEHAVIOUR

The uncoated MS, as well as, detonation spray Al_2O_3-13TiO_2 coated specimens were subjected to standard wear testing on a pin-on disk apparatus (ASTM standard G99-03) as per the procedure. 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 and cumulative wear volume with sliding distance has been discussed in the subsequent sections for the various cases under investigation.

5.1 Wear Rate

The variation of the cumulative wear rate with the sliding distance for the detonation spray Al_2O_3-13TiO_2 coated and uncoated MS steel at a normal loads of 50N, 60N, 70N have been plotted in Figure 4 whereas the CWR data has been shown in figure 5. It is evident from the plots that the uncoated MS steel has shown much higher wear rates as compared to the coated counterparts. Whereas the wear rates in all other cases are comparatively very lesser at loads for the sliding distance of 5400 m. Al_2O_3-13TiO_2 coated MS specimen has shown negligible wear.

Furthermore, the cumulative wear rates after a total sliding distance of 5400 m for all these cases have been shown in Fig. 5. It is evident from the bar chart that the cumulative wear rate for the MS steel has decreased significantly after the application of Al_2O_3-13TiO_2coatings. Hence, it is clear that Al_2O_3-13TiO_2 have shown better wear resistance on the basis of the overall wear rate for the whole range of sliding distance. Therefore it can be concluded that the detonation sprayed Al_2O_3-13TiO_2 coating is more effective to provide wear resistance to the steel. Overall results indicate clearly the beneficial effect of Al_2O_3-13TiO_2 coatings to control the wear of the steel.

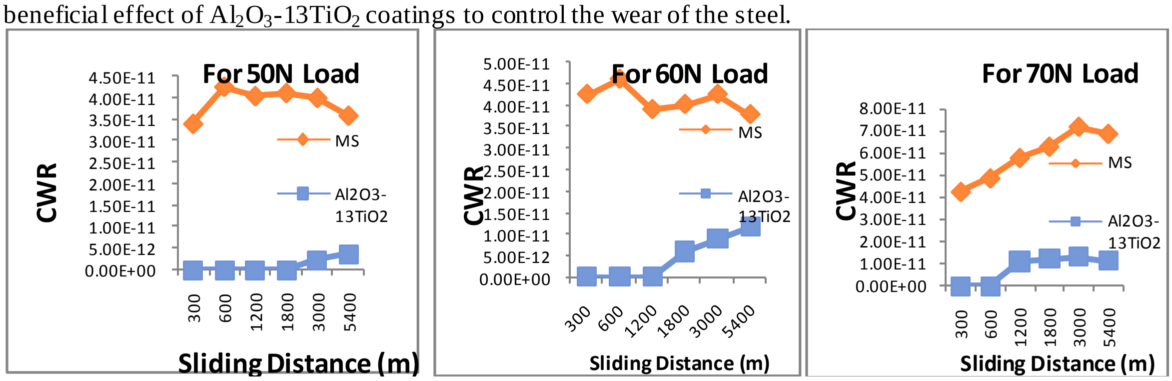


Fig. 4 cumulative wear rate for the uncoated, the detonation sprayed Al_2O_3-13TiO_2 coated MS steel subjected to wear at normal loads of 50N, 60N and 70 N and sliding velocity of 1m/sec

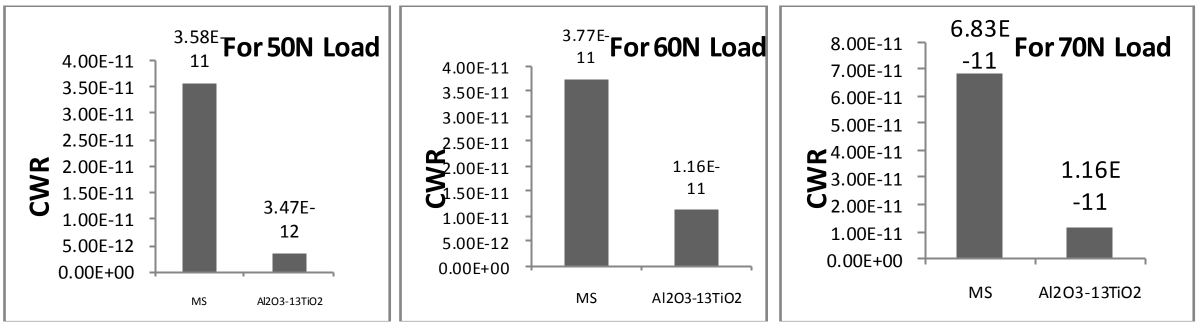


Fig. 5 Cumulative wear rate for the uncoated, the detonation sprayed Al_2O_3-13TiO_2 coated MS steel subjected to wear at normal load of 70 N and sliding velocity of 1 m/sec after a sliding distance of 5400 meters.

5.2 Wear Volume

The variation of the cumulative wear volume with the sliding distance for the detonation sprayed Al_2O_3-13TiO_2 coated and uncoated MS steel at a normal load of 50N has been plotted in Figure 6. whereas the CWV after a total sliding distance of 5400m for all the cases has been shown in figure 7. It is clear from the Fig. 7. that the uncoated MS steel has shown significant higher wear volume losses in comparison with its Al_2O_3-13TiO_2 coated counterparts. For the uncoated MS steel, it has shown increase in volume loss after crossing a sliding distance of 300 m. This specific distance is found to be highest in the case of Al_2O_3-13TiO_2 coated MS steel, whereas, it is lowest for the uncoated MS steel. In this way, it is clear that the wear volume loss has decreased significantly after the application of the coatings.

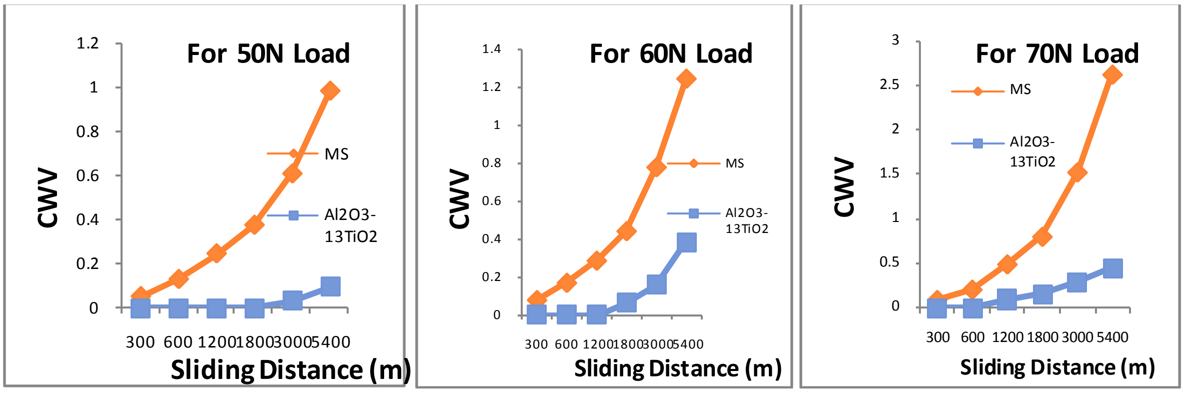


Fig. 5 cumulative wear volume for the uncoated, the detonation sprayed Al_2O_3-13TiO_2 coated MS steel subjected to wear at normal loads of 50N, 60N and 70 N and sliding velocity of 1m/sec.

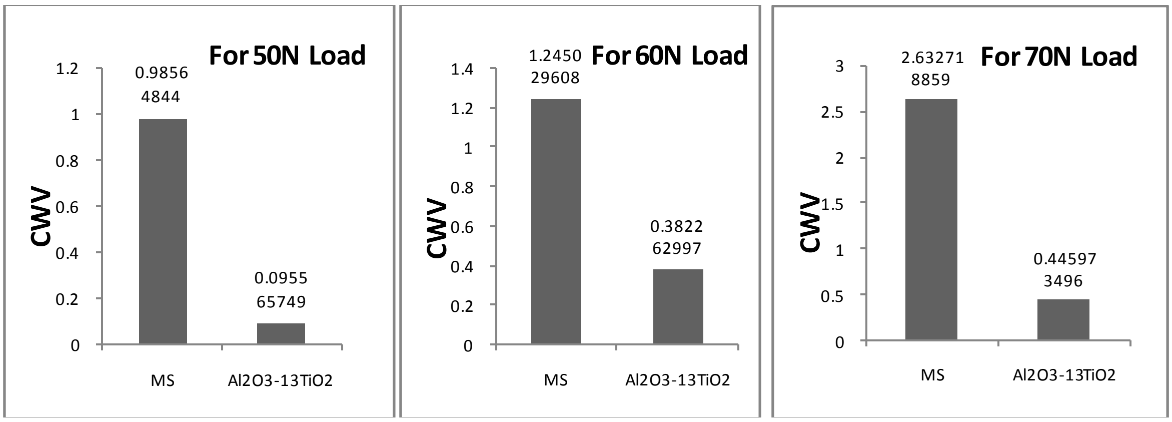


Fig. 7 Cumulative wear rate for the uncoated, the detonation sprayed Al_2O_3-13TiO_2 coated MS steel subjected to wear at normal load of 50N, 60N and 70 N and sliding velocity of 1 m/sec after a sliding distance of 5400 meters.

VI. CONCLUSIONS

- Increase in wear rate was observed with the increase in load.
- Wear volume loss of Uncoated MS was observed comparatively higher than Al_2O_3-13TiO_2 coatings specimen.
- Improvement in wear resistance of MS was observed after the deposition of detonation sprayed Al_2O_3-13TiO_2 coating.
- Detonation spray process provides the possibility of deposition of Al_2O_3-13TiO_2 powder on the MS steels. A uniform coating thickness of 250$\pm$10 micrometer was achieved.
- The coating was found to be successful in retaining their surface contact with the MS substrate steels when subjected to wear tests.

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