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COMPARATIVE WEAR BEHAVIOR OF DETONATION GUN SPRAYED AL2O3 AND AL2O3-TIO2 COATINGS ON EN-45 STEEL

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Abstract

Surface coating is an important technique in maintenance engineering. Thermally sprayed ceramic coating is the best application that significantly enhances the wear resistance of the engineering components. EN45 is a commercially available alloy that is used in many industrial applications like leaf spring pin, sleeves etc. EN45 is having relatively low wear resistance, and ceramic covered of the wear and eroding zones of such parts is a best pursued practice which exceedingly enhances the regular failures. An efficient method to reduce the wear rate of the metallic surface is thermally sprayed ceramic coatings on softer materials. Ceramics are commercially used and as well technically good because of their mechanical performance, chemical and thermal stability that make it reliable for many engineering applications. Alumina (aluminum oxide) is one of the essential delegates of this class of materials because of its high fracture strength, hardness and thickness, which empower its utilization in the manufacturing of components that are used in extreme conditions. The wear properties of ceramics can be enhanced by controlling its material qualities as well as by controlling the fabrication procedure, which characterizes the material's microstructure. Alumina (Al_2O_3) and alumina-titania (Al_2O_3-TiO_2) powders materials are generally used in thermal spray processes to enhance the abrasion and corrosion resistance. For components in severe tribological applications such as seal rings, valve seats, dies for extrusions, and pump shafts, thick hard coatings can be achieved by detonation spraying, using ceramics such as Al_2O_3, TiO_2 and Al_2O_3-TiO_2 combination. In the present study Detonation Spray process was used to deposit a conventional Al_2O_3-13wt% TiO_2 coatings on EN-45 steel used for leaf springs. Characterization of the powder, coated as well as worn out specimens was performed by XRD and SEM. The coated specimens were tested for wear resistance to study the effect of the coating applied on the various specimens. It was observed that the better coating properties were achieved when Al_2O_3-TiO_2 and Al_2O_3 powders was used in detonation spraying. Both the coatings were found to be successful in enhancing the wear resistance in comparison of bare EN-45 steel.

Keywords: *Thermal Spray, Detonation Gun, Wear resistance, EN45, Alumina, Alumina-Titania.*

I. INTRODUCTION

Several industries face the problem of wear on parts in service. The result of this wear is that the parts should be replaced, which costs and causes downtime on the machine [1,2]. The progressing research of scientists in these fields is to discover, or design, materials that are more wear safe, so as to broaden the life of the parts and lessen the recurrence of part substitution [3], so that huge costs to organizations in the repair or substitution of these wear inclined components. The wear makes many huge amounts of material be lost and profitability that can never be recuperated. Surfacing is a procedure of keeping a material layer over a base metal or substrate either to enhance surface attributes like corrosion, wear resistance, and hardness, and so forth or to get the required size or measurement [4-6].

A variety of bulk materials, (ferrous and non-ferrous metals, or alloy) can be modified by alloying, mixing, compositing, and coating to achieve adequate resistance to wear and corrosion [7, 8]. Surface engineering, including surface treatments and coatings, is a standout amongst the best and effective solutions for tribological issues. Coatings change tribological frameworks by reducing the friction coefficient, enhancing the surface hardness, modifying the surface chemistry and hardness. So they upgrade the wear security of surfaces and extend the lifetime of important parts [9,10]. Amid most recent a very long while, various coatings and thermal spraying techniques have been effectively developed, and used to decrease contact or/and to shield surfaces from harm in mechanical equipments. The expanding utilization of coatings in tribological applications is essentially founded on the accompanying reasons: More and more researchers perceive that the surface is the most critical part in many designing segments, and most disappointments have an association with the properties of the surface region [11-14].

High performance is required for mechanical components and tools, which cannot be realized just by selecting materials or improving structures. The use of Thermal spray coatings gained the attraction of many researchers in this modern era as the substrate remains its original properties, responsible for the strength and toughness [14]. The selection of coatings is a very complex because there is no general rule to help the selection of coatings for various engineering applications. Therefore, for any specific application, we have to select the relevant one from thousands of coatings [15]. The serious wear downside is found in leaf springs of lightweight vehicle trucks. The surface of spring is worn out as a result of abrasive wear, sliding, wear and cracking by surface fatigue. In the present study efforts were made to enhance the wear resistance of leaf spring pin by surface modification technique [16-19]. The surface modification technique should not damage resistance property of forged iron that is utilized in spring of trucks but only to extend the sturdiness and to enhance the wear resistance [20]. Wear resistant coating is deposited in EN-45 steel material. All the oxide ceramics like aluminium oxide (Al_2O_3 traditionally referred to as alumina) is the most established engineering ceramics. Useful properties such as chemical stability, hardness, electrical resistivity and high temperature strength can be achieved by the use of coatings. Alumina (Al_2O_3) and alumina-titania (Al_2O_3-TiO_2) materials are generally in thermal spray coatings to protect against wear and corrosion in variety of engineering applications [21-23]. Alumina is a hard and has less cost material with high hardness, great wear resistance and high melting point. There are a few favorable circumstances of alumina e.g., accessibility, hardness, high melting point, protection from wear etc. Its bond strength with the metallic substrates when connected as a coating is also very good. Some of the applications of alumina are in bearings, valves, pump seals, plungers, engine components, rocket nozzles, shields for guided missiles, vacuum tube envelops, integrated circuits, etc. TiO_2 is a commonly used additive in plasma sprayable alumina power [24-27]. TiO_2 has a relatively low melting point and it effectively binds the alumina grains. However, a success of an Al_2O_3 – TiO_2 coating depends upon a judicious selection of the arc current which can melt the powders effectively. It results in a good coating adhesion along with high wear resistance [28]. Wear behaviour mechanism of coated and bare specimens was studied by employing weight loss on pin on disc test, X-ray diffraction (XRD), scanning electron microscopy/energy-dispersive analysis (SEM/EDAX) and X-Ray mapping techniques.

II. EXPERIMENTATION

2.1. Development of the coatings

2.1.1. Substrate material

Selection of material for coating has been made after studying and reviewing the various research papers. It has found that the EN-45 steel provides better wear resistance than other grades of steels used for manufacturing leaf springs of transport vehicles.

2.1.2 Formation of Pins

Small cylindrical pins with circular cross section with 8 mm diameter and 30 mm length were prepared from EN-45 steel. End faces of pins were grinded and polished using SiC emery papers of 220 to 600 grit sizes & 1/0 to 4/0 grades polishing papers. The specimens were then cleaned and grit blasted with Al_2O_3 before application of coating for better adhesion. All the care was taken to avoid any structural change during the preparation of specimens.

2.1.3. Coating powder

Two types of commercially available Alumina (Al_2O_3) and alumina-titania (Al_2O_3-TiO_2) were selected and were deposited on the base material by using Detonation Gun spray thermal spray process. Coating powder procurement and coating formulation was done at SVX Powder M Surfacing Engineering (Pvt.) Limited, Noida (India). The SEM micrographs of Al_2O_3 and Al_2O_3-13TiO_2 are reported in Figure 1.

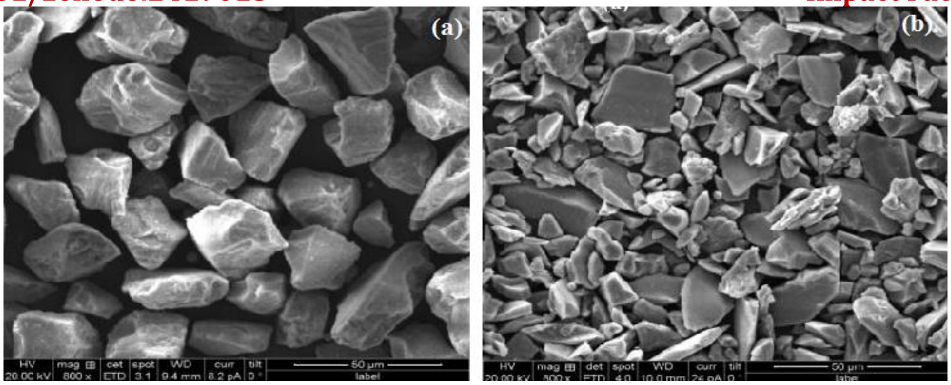

Figure 1: SEM image of a) Al_2O_3 b) Al_2O_3-13TiO_2 powders.

2.1.4. Coating Formulation

The coating powders Alumina (Al_2O_3) and Alumina-titania (Al_2O_3-13TiO_2) were sprayed on EN 45 substrate steel pins with the help of detonation gun spray process. Samples were well polished before application of coating powder material. The coating were deposited at SVX Powder Surface Engineering Pvt. Ltd., Greater Noida, UP. The Detonation spray coating system made by international advanced research centre for powder metallurgy and New Materials, Hyderabad in collaboration with the inventors-IPMS, Kiev, Ukraine. The Detonation spray process parameters used during deposition of coating are presented in Table 1.

2.2. Set up of disc machine

The wear tests were performed in a machine conforming to ASTM G 99 standard. The wear tests for coated as well as uncoated specimens were conducted under three normal loads of 40N, 50N and 60N at a fixed sliding velocity of 1 m/s. A track diameter D=40 mm, sliding speed v =1 m/s is kept. Wear tests have been carried out for a total sliding distance of 5400 m (6 cycles of 5min, 5min, 10min, 10min, 20min, 40min duration). Weight losses for pins were measured after each cycle to determine the wear loss. By using Pin-on-Disc (Wear and friction monitor tester Tr-201 made by M/S DUCOM, Bangalore, INDIA) available at GNE college, Ludhiana, Punjab. The tests were conducted at a room temperature of 34-36 ^{o}C. Against the rotating disc pins was held stationary. Rotating disc made of carbon steel (EN-31) at 40 mm track diameter. Rotating disc is a plain carbon steel, case hardening of 62 to 65 HRC as provided with Pin-on Disc machine. Photograph of set up and carbon disc with pin holder is shown in Fig. 2.

Table 1: Process parameters during Detonating Gun Spray Process

Fuel gas	Acetylene
Carrier Gas	Nitrogen
Pressure of fuel gas (acetylene)	1 - 1.5 bar
Pressure of fuel gas (oxygen)	2 - 3 bar
Pressure of carrier gas (nitrogen)	2 - 4 bar
Flow rate of fuel gas (oxygen)	2800 - 5120 SLMP (standard liters/min.)
Flow rate of fuel gas (acetylene)	2240 - 2420 SLMP
Flow rate of carrier gas (nitrogen)	720-1040
No of shots per second	3
Spraying distance	150-180 mm

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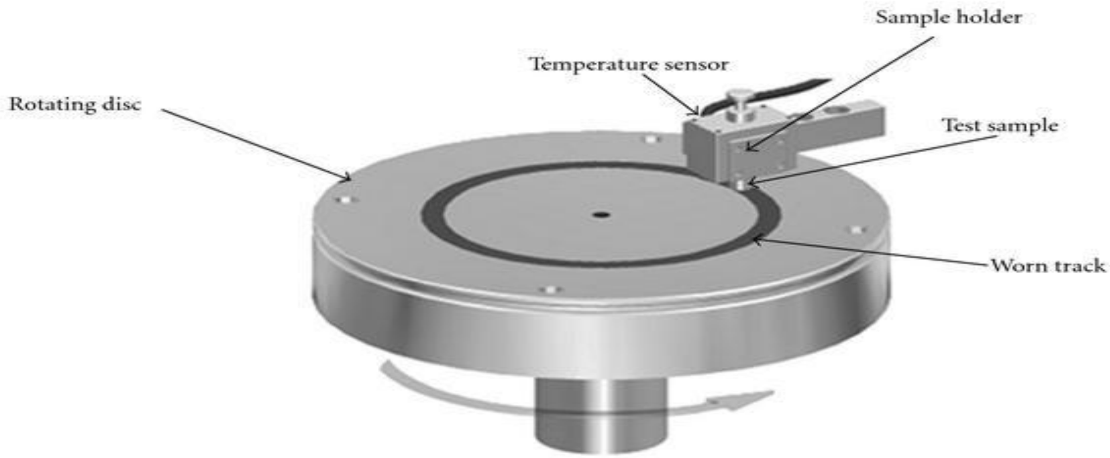

Figure 2: Schematic illustration of the pin-on-disc wear test

2.3. Characterization of as coated and worn out specimen

X-Ray Diffraction analysis was performed on PANalytical diffractrometer (JSM-6510) apparatus at Thapar University, Patiala, Punjab, India. The samples were scanned in 2θ range of 20º to 120º with a scanning speed of 3º/min. To understand the surface morphology of as coated specimens, Scanning Electron Microscope (JEOL6510LV; at Thapar University, Patiala) with EDAX Genesis software was used. Elemental compositions (weight %) at selected point/area was obtained by using EDAX genesis software.

III. RESULTS AND DISCUSSION

3.1. Characterization of the As-Sprayed coating

3.1.1. Visual observations of the as-sprayed coating

All the as coated specimens were visually examined and the optical macrographs were taken and shown in Fig.4.4. It was observed in the visual examination of the micrographic of D-gun sprayed as coated specimen that Al_2O_3-13%TiO_2 coating has dull appearance where Al_2O_3 coating showed shinning grey appearance. The surface of the Al_2O_3 coating appears to rough. No cracks were observed on coating surface during visual inspection.

Figure 3: Macrographs of uncoated and coated pins

3.1.2. Coating Thickness

The FE-SEM micrographs of all the Detonation Gun sprayed as coated specimens, were taken along the cross section and the thickness of coatings was measured. The average coating thickness of Al_2O_3 and Al_2O_3-13%TiO_2

coating were found to be 265um and 275 um which was measured by Mini Test-600B. Each coating thickness mentioned is the average of at least five readings/measurements.

3.1.3 SEM/EDS Analysis of the D-gun sprayed as coated

The scanning electron microscopy determines about microstructure, surface crack, pores and voids of uncoated and coated materials. The microscopy of Al_2O_3 is highly bonded have less cracks, pores and voids. The elements for EN-45 coating for load 40N and 50N. The color of the surface spectrum is dull grey and near this point surface is white which may be due to presence of oxygen and at (spectrum b) the coating is more uniform. The Al_2O_3 and Al_2O_3-13%TiO_2 coatings on EN45 have been analyzed with SEM-EDAX. Surface of the coating is crack free which confirms that the coating has been deposited successfully. EDS analysis also confirms that Al, O, Ti are present in the coating.

3.1.4 Micro-Hardness Measurements

The micro-hardness values for different coating powders are listed in Table 5. From the table it is clear that alumina-titania is having the higher hardness value when compared to alumina coating. The results showed the large variation in the hardness values in case of Al_2O_3-13%TiO_2 coated specimens. This variation in the hardness values may be due to difference in porosity content, presence of unmelted particles, and voids in coatings, which are difficult to control precisely. The results show that Al_2O_3-13%TiO_2 has higher hardness as compared to Al_2O_3. The higher hardness value for Al_2O_3-13%TiO_2, is possibly due to the combination of two difference phases of Al_2O_3 and TiO_2.

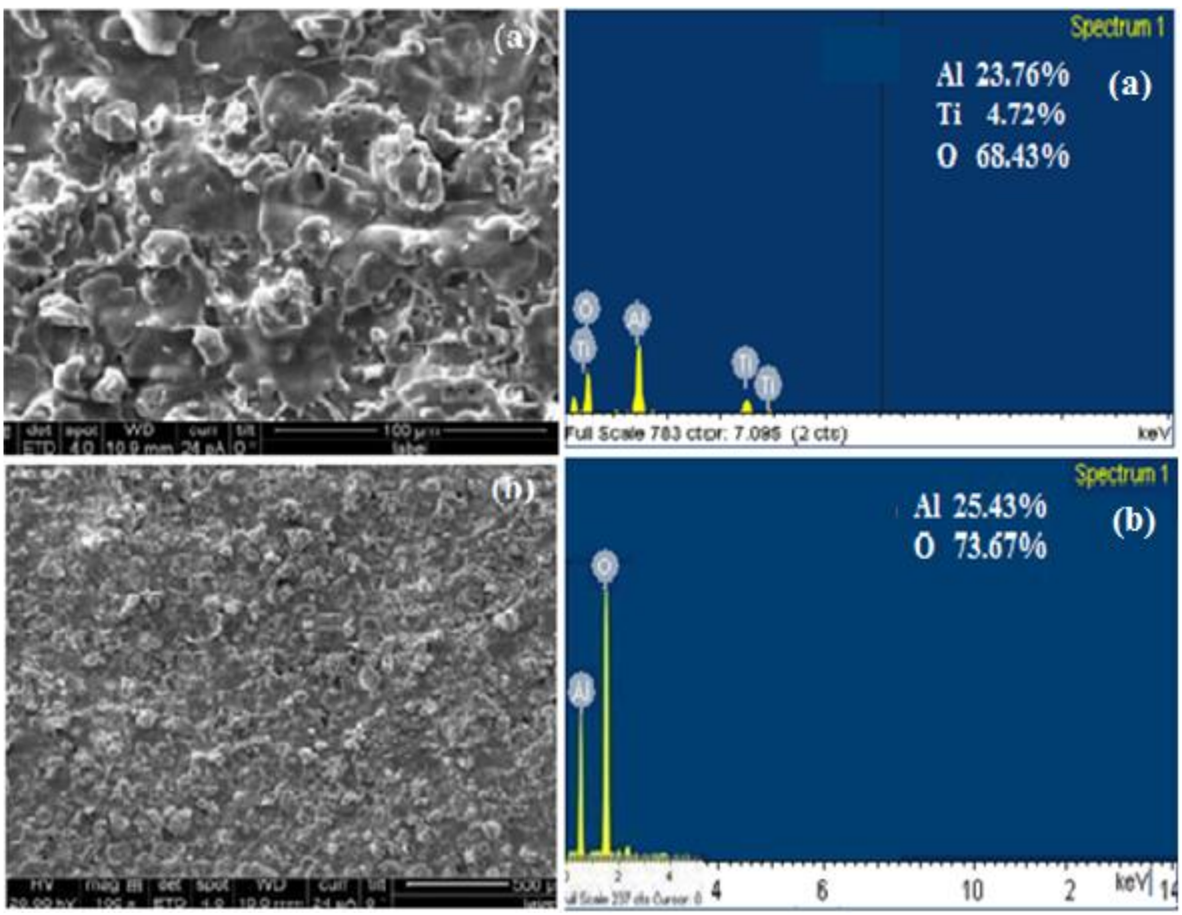

Figure 5.2: SEM image of (a) Al_2O_3 (b) Al_2O_3+13%TiO_2 coated specimens

Table 5.1: Hardness values of specimens

Specimens	Vickers hardness number (HV)
EN 45	114-125
Al_2O_3 Coated	321-376
Al_2O_3 + 13% TiO_2 Coated	356-517

3.1.5. X-Ray Diffraction Analysis

The XRD pattern of the as sprayed Al_2O_3 coating is shown in Fig. 2. XRD of as sprayed Al_2O_3 coating indicates the presence of Al_2O_3 as main phase in both the Alumina and alumina titania coatings. In addition to this presence of Ti_2O as primary phase was also observed in case of alumina titania coating.

3.2 Wear Behaviour

Data generated after the sliding wear test as per ASTM G99 is used for comparison of the wear resistance of different alloying materials. The effect of applied load at 40N, 50N and 60N was also examined. Graphs are plotted between wear rate along y-axis and the time along x-axis, at three different loads i.e. 40 N, 50 N and 60N. The

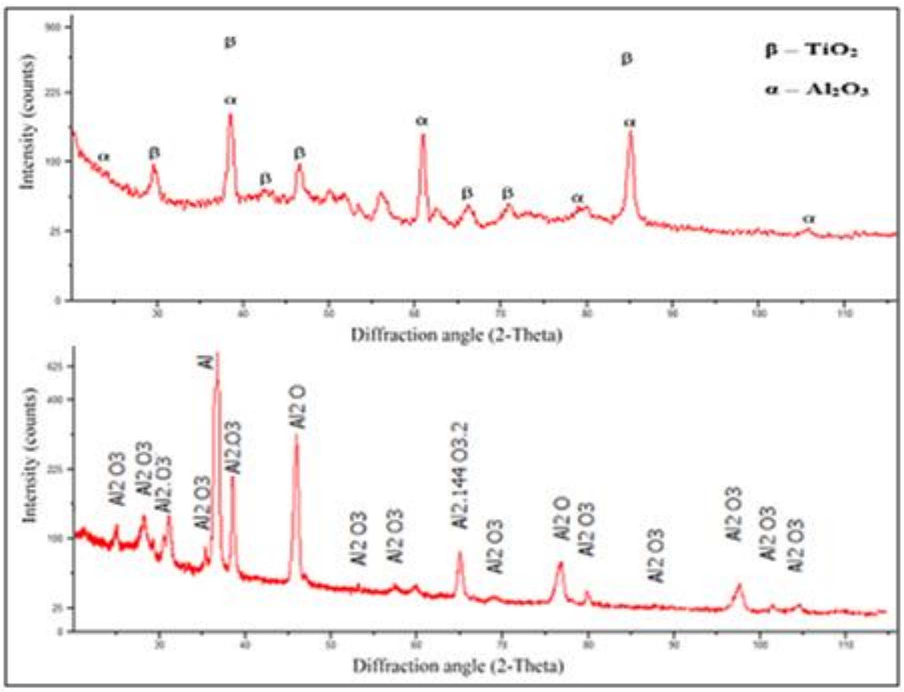

Figure 4.4: XRD pattern of specimens coated with (a) Al_2O_3 (b) Al_2O_3-13TiO_2

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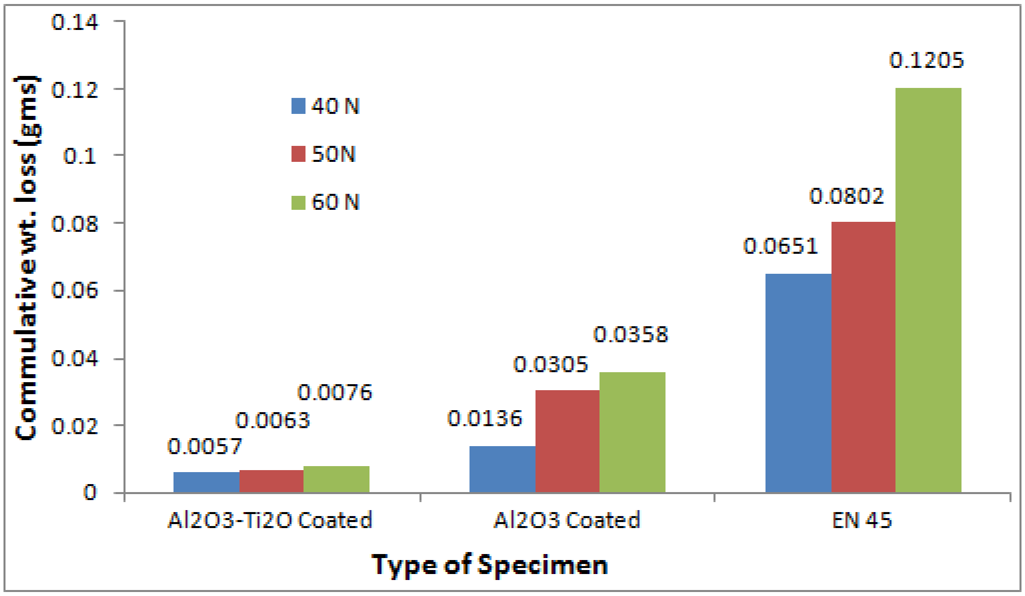

Figure 5.8: Cumulative Volume Loss (gms) in one cycle for D-gun sprayed coatings and EN-45 steel at 40N, 50N and 60N.

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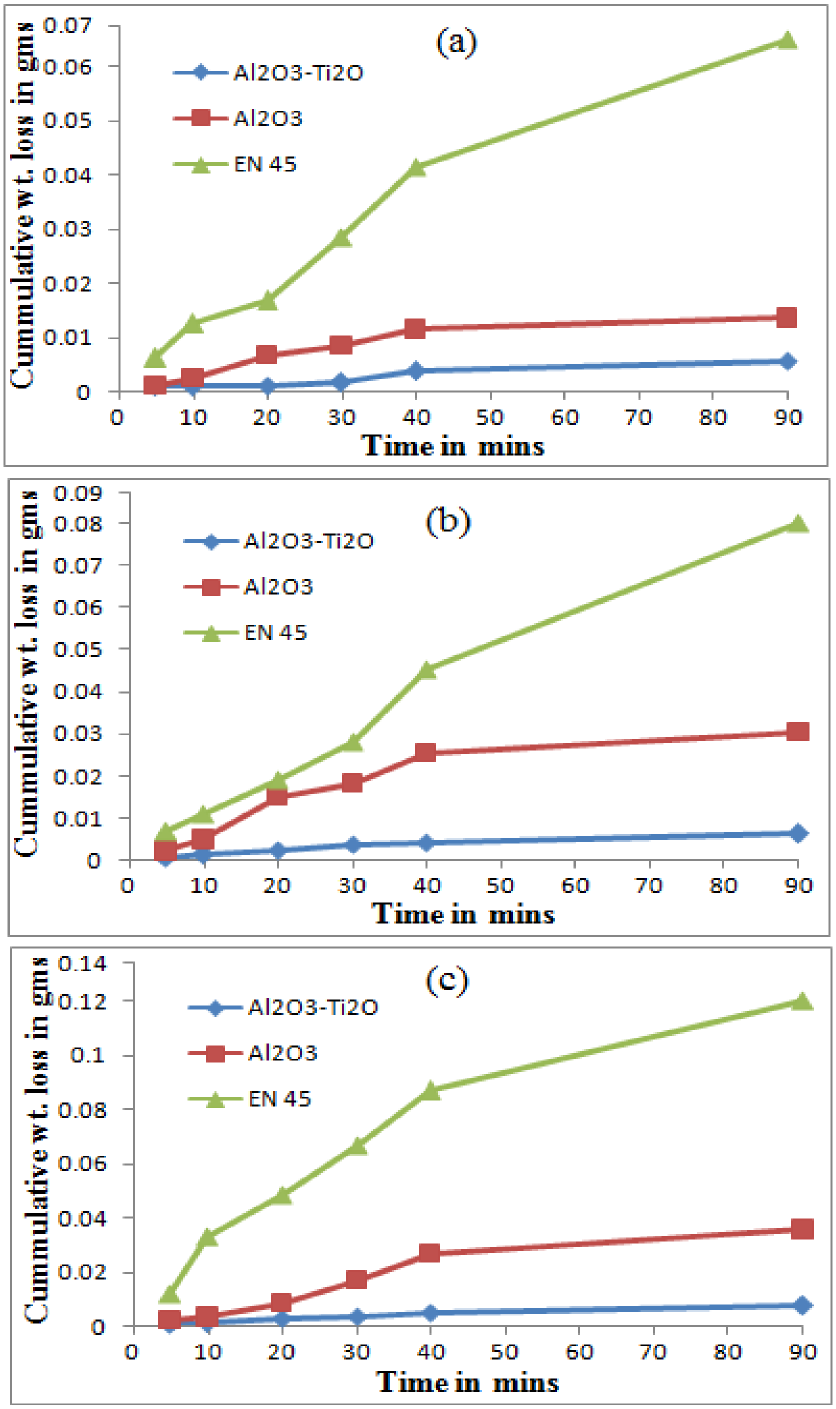

Figure 5.9: Cumulative wt. loss (gms) for Al_2O_3-13%TiO_2, Al_2O_3 coated and Bare EN45 steel at loads(a)40 N (b)50 N (c)60 N

graph in Figure 8 shows the weight losses of the samples as a function of time. It can be noticed that all the samples have linear weight loss, i.e., constant wear rate, throughout the test. For bulk metallic samples, the wear rate curve typically includes an incubation period in the beginning, during which the metal surface is plastically deformed and no weight loss is observed. After this acceleration stage takes place and the wear rate of the metallic sample starts increasing. This, however, is not the case with brittle ceramic coatings. Incubation stage cannot be observed as wear begins immediately by the removal of the poorly adhered particles from the surface. In addition, the acceleration phase of ceramic coatings seems to take place during the very first minute. This difference between sprayed coatings and bulk materials was also noted by Schwetzke and Kreye [28] in their study of thermal spray coatings. The linear wear rates of the samples observed in the graph indicate that the maximum wear rate is reached during the very first minutes. The higher wear resistance was observed in the case of Al_2O_3-TiO_2 coated specimen. The cumulative weight loss in case of Al_2O_3-TiO_2 at 40 N load was found to be 0.0057 gms as compared to 0.0651 gms of bare EN-45 steel at the same load. It indicated that the wear loss is decreased by 91% by Detonation sprayed Al_2O_3-13%TiO_2 coating. Similarly the decrease in wear loss in case of Al_2O_3-13%TiO_2 coating at 50 N and 60 N was found to be decreased by 92 % and 94% respectively. Whereas in case of Al_2O_3 coating the wear loss was decreased at 40N, 50 N and 60 N was found to be 79%, 68% and 70%. From the weight loss analysis it has been found that both the coatings were effective to control the wear as compared to bare EN-45 steel up to a significant level. However it is concluded that alumina-titania provided the better wear resistance than alumina coating. A correlation among the micro constituents, hardness and wear resistance also exists in both the coatings. The very good performance of alumina-titania coating was due to improved coating cohesion by the evenly distributed TiO_2 in the powder and coating.

IV. CONCLUSIONS

The following conclusions have been drawn based on present research study.

1) Both the coatings Al_2O_3 and Al_2O_3-13%TiO_2 were successfully deposited by detonation gun spray on EN-45 steel with dense coating and less porosity. EDX analysis confirms the presence of feedstock materials.
2) It was found that the wear resistance of bare EN-45 steel was decreased by 91%, 92% and 94% by Al_2O_3-13%TiO_2 coating at 40 N, 50 N and 60 N of load respectively. Whereas in case of Al_2O_3 coating the wear loss was decreased at 40N, 50 N and 60 N was found to be 79%, 68% and 70%.
3) From the weight loss analysis it has been found that both the detonation sprayed coatings were successful in reducing the wear rate of bare EN-45 steel. A correlation among the micro constituents, hardness, load and wear resistance also exists in both the coated powders. Wear resistance is a factor which depends on the hardness of the materials. The harder the material, the better is the abrasive wear resistance.
4) The cumulative volume loss for Al_2O_3-13%TiO_2 coating was minimum in the present study. Therefore Al_2O_3-13%TiO_2 is the best coating to deposit on EN-45 Steel material. The wear resistance for coating-substrate was found to be in the order of Al_2O_3-13%TiO_2 > Al_2O_3 > Bare EN-45 steel. Therefore out of this combination Al_2O_3-13%TiO_2 coating substrate combination is the best combination.

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REFERENCES

1. *Bhushan, B. (1999). Principles and applications of tribology. John Wiley & Sons.*
2. *Bolelli, G., Cannillo, V., Lusvarghi, L., & Manfredini, T. (2006). Wear behaviour of thermally sprayed ceramic oxide coatings. Wear, 261(11-12), 1298-1315.*
3. *Braunovic, M., Myshkin, N. K., & Konchits, V. V. (2006). Electrical contacts: fundamentals, applications and technology. CRC press.*
4. *Burwell Jr, J. T. (1957). Survey of possible wear mechanisms. Wear, 1(2), 119-141.*
5. *Burwell, J. T., & Strang, C. D. (1952). On the empirical law of adhesive wear. Journal of Applied Physics, 23(1), 18-28.*
6. *Chapman, B. N., & Anderson, J. C. (1974). Science and technology of surface coating a NATO Advanced Study Institute on the Science and Technology of Surface Coating held at Imperial College, University of London, in April, 1972.*

7. Chatha, S. S., Sidhu, H. S., & Sidhu, B. S. (2012). Characterisation and corrosion-erosion behaviour of carbide based thermal spray coatings. Journal of Minerals and Materials Characterization and Engineering, 11(06), 569.
8. Chen, T. C., Chou, C. C., Yung, T. Y., Tsai, K. C., & Huang, J. Y. (2016). Wear behavior of thermally sprayed Zn/15Al, Al and Inconel 625 coatings on carbon steel. Surface and Coatings Technology, 303, 78-85.
9. Cho, K. T., Lee, Y. K., & Lee, W. B. (2015). Wear behavior of AISI D2 steel by enhanced ion nitriding with atomic attrition. Tribology International, 87, 82-90.
10. Chuanxian, D., Bingtang, H., & Huiling, L. (1984). Plasma-sprayed wear-resistant ceramic and cermet coating materials. Thin Solid Films, 118(4), 485-493.
11. Dehsorkhi, R. N., Sabooni, S., Karimzadeh, F., Rezaeian, A., & Enayati, M. H. (2014). The effect of grain size and martensitic transformation on the wear behavior of AISI 304L stainless steel. Materials & Design, 64, 56-62.
12. Ding, Y., & Rieger, N. F. (2003). Spalling formation mechanism for gears. Wear, 254(12), 1307-1317.
13. Ebrahimi, M., Mahboubi, F., & Naimi-Jamal, M. R. (2015). Wear behavior of DLC film on plasma nitrocarburized AISI 4140 steel by pulsed DC PACVD: effect of nitrocarburizing temperature. Diamond and Related Materials, 52, 32-37.
14. Eyre, T.D., 'Wear characterishcs of metals', Trib. Znt., 9, 203 (1976).
15. Fontanari, V., Benedetti, M., Girardi, C., & Giordanino, L. (2016). Investigation of the lubricated wear behavior of ductile cast iron and quenched and tempered alloy steel for possible use in worm gearing. Wear, 350, 68-73.
16. Fu, Y., Wei, J., & Batchelor, A. W. (2000). Some considerations on the mitigation of fretting damage by the application of surface-modification technologies. Journal of Materials Processing Technology, 99(1-3), 231-245.
17. Gao, C., Kuhlmann-Wilsdorf, D., & Makel, D. D. (1994). The dynamic analysis of stick-slip motion. Wear, 173(1-2), 1-12.
18. Guilmard, Y., Denape, J., & Petit, J. A. (1993). Friction and wear thresholds of alumina-chromium steel pairs sliding at high speeds under dry and wet conditions. Tribology international, 26(1), 29-39.
19. Handbook, A. S. M. (1992). Friction, lubrication and wear technology. ASM International, Materials Park, Ohio, 18, 127-160.
20. Heimann, R. B., Lamy, D., & Sopkow, T. N. (1990). Parameter Optimization of Alumina--Titania Coatings by a Statistical Experimental Design. Thermal Spray Research and Applications, 491-496.
21. Herman, H., & Sampath, S. (1996). Thermal spray coatings. In Metallurgical and ceramic protective coatings (pp. 261-289). Springer, Dordrecht.
22. Holmberg, K., & Matthews, A. (1994). Coating tribology: properties, techniques, and applications in surface engineering. Elsevier.
23. Hong, S., Wu, Y., Wang, B., Zheng, Y., Gao, W., & Li, G. (2014). High-velocity oxygen-fuel spray parameter optimization of nanostructured WC–10Co–4Cr coatings and sliding wear behavior of the optimized coating. Materials & Design, 55, 286-291.
24. Iordanova, I., Surtchev, M., & Forcey, K. S. (2001). Metallographic and SEM investigation of the microstructure of thermally sprayed coatings on steel substrates. Surface and Coatings Technology, 139(2-3), 118-126.
25. Kahraman, N, Gulenc¸ , B, Investigation of the coating thickness effect on the surface roughness and hardness of powder flame spraying coated specimens, Powder Metallurgy Science and Technology, Second International Conference on Powder Metallurgy, Ro PM 2000, Technical University of Cluj, 2000, Romania.
26. Kıvak, T. (2014). Optimization of surface roughness and flank wear using the Taguchi method in milling of Hadfield steel with PVD and CVD coated inserts. Measurement, 50, 19-28.
27. Lian, Y., Deng, J., Li, S., Yan, G., & Lei, S. (2014). Friction and wear behavior of WS 2/Zr self-lubricating soft coatings in dry sliding against 40Cr-hardened steel balls. Tribology Letters, 53(1), 237-246.
28. Liew, W. Y., Protasius, R., Ling, J. L., Siambun, N. J., & Mohd-Lair, N. A. (2016). Reciprocating wear behavior of mild steel carburized using Na2CO3–NaCl. Tribology International, 95, 406-418.

29. *Lindroos, M., Apostol, M., Heino, V., Valtonen, K., Laukkanen, A., Holmberg, K., & Kuokkala, V. T. (2015). The deformation, strain hardening, and wear behavior of chromium-alloyed Hadfield steel in abrasive and impact conditions. Tribology Letters, 57(3), 24.*
30. *Messaadi, M., & Kapsa, P. (2016). Wear behavior of high chromium sintered steel under dynamic impact-sliding: Effect of temperature. Tribology International, 100, 380-387.*
31. *Ming-Chang, J., & Li-Yung, Y. (1993). Environmental effects on wear behaviour of alumina. Wear, 161(1-2), 111-119.*
32. *Mohanty, M., Smith, R. W., De Bonte, M., Celis, J. P., & Lugscheider, E. (1996). Sliding wear behavior of thermally sprayed 75/25 Cr3C2/NiCr wear resistant coatings. Wear, 198(1-2), 251-266.*
33. *Moore, M. A., & King, F. S. (1980). Abrasive wear of brittle solids. Wear, 60(1), 123-140.*
34. *Musikant, S. (1991). What every engineer should know about ceramics (Vol. 28). CRC Press.*
35. *N. P. Suh, The delamination theory of wear, Wear 25 (1973).*